FULFILL

Fundamental decarbonisation
through sufficiency by lifestyle changes

Literature review for analysis of lifestyle changes

FULFILL Deliverable D 2.1

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Fundamental decarbonisation through sufficiency by lifestyle changes

GA#: 101003656

Deliverable number (relative in WP)	**D 2.1**
Deliverable name:	Literature review for analysis of lifestyle changes
WP / WP number:	N° 2
Delivery due date:	30.09.2022
Actual date of submission:	02.11.2022
Place	Milan
Status	Final
Dissemination level:	Public
Lead beneficiary:	Politecnico di Milano
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FULFILL has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003656.

Project Partners

No	Participant name	Short Name	Country code	Partners' logos
1	**Fraunhofer Institute for Systems and Innovation Research ISI**	FH ISI	DE	Fraunhofer ISI
2	**Wuppertal Institut für Klima, Umwelt, Energie GGMBH**	WI	DE	Wuppertal Institut
3	**Accademia Europea di Bolzano**	EURAC	IT	eurac research
4	**Notre Europe - Institut Jacques Delors**	JDI	FR	Notre Europe Jacques Delors Institute
5	**Association négaWatt**	NW	FR	Association négaWatt
6	**Politecnico di Milano**	POLIMI	IT	Politecnico Milano 1863
7	**International Network for Sustainable Energy-Europe**	INFORSE	DK	INFORSE-EUROPE International Network for Sustainable Energy
8	**Zala Briviba Biedriba SA**	ZB	LV	Zaļā brīvība

Acknowledgement

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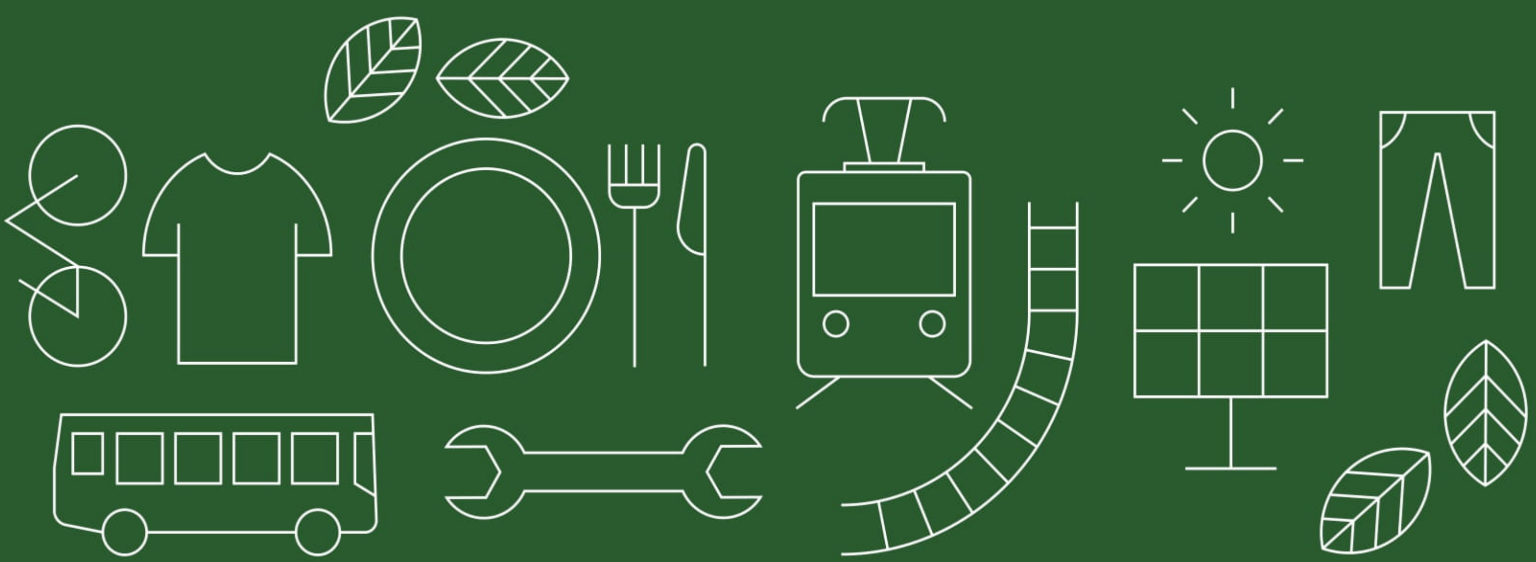

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List of Abbreviations

ASI	Avoid, Shift, Improve framework
CBA	Consumption-based accounting of CO_2 emissions
EEA	European Environment Agency
EREI	Energy Return on Energy Invested
EU	European Union
GDP	Gross Domestic Product
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
NDC	Nationally Determined Contributions
PBA	Production-based accounting of CO_2 emissions
PEDs	Positive Energy Districts
PMV	Predicted Mean Vote (an indicator in comfort assessment)
SER	Sufficiency, Efficiency, Renewable framework
SSH	Social Sciences and Humanities
SUVs	Sport Utility Vehicles
UNEP	United Nations Environment Programme
WHO	World Health Organization

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Abstract / Summary

This report reviews the literature identified by the experts of the Fulfill consortium based on their previous research work and on additional bibliographic research performed during the initial phase of the project.

The review aims at exploring the theoretical and conceptual foundations of climate-oriented lifestyle changes. More specifically, it outlines the current state of knowledge on the role of the sufficiency principle in lifestyle changes as well as a screening of the literature on potential effect of sufficiency-oriented policies.

FULFILL has created a group database, using the (open and freely available) *Zotero* tool, to connect all the partners and allies, systematically organize documents and share existing and future research on the topic of the project. Data sharing encourages more connection and collaboration between researchers, which can result in important findings within the field. It allows researchers to build upon the work of others rather than repeat already existing research.

The results are organized in:

- chapters which would create a basis both for the use within the project and for communication to policymakers, stakeholders, and the public:
    - Why sufficiency is necessary,
    - Why sufficiency is desirable,
    - Why sufficiency is possible
    - International dimension

- and chapters with a more specific aim of supporting the work to be performed in the subsequent work packages:
    - Literature of Relevance for WP3_Micro_Level,
    - Literature of Relevance for WP4_Meso_Level,
    - Literature of Relevance for WP5_Micro_Level,

Based on this review we adopt and use throughout this text the concepts and terms of:

- ***Sufficiency habits***[1] = Sufficiency measures taken by individuals due to permanent lifestyle changes
- ***Sufficiency infrastructures*** = Physical and non-physical infrastructures enabling Sufficiency habits
- ***Sufficiency societal framework*** = institutions, legislation, norms enabling Sufficiency habits

[1] Note that throughout this document, we will highlight terms which have an explicit definition within this text or in the cited bibliography in the following way, i.e. ***bold italic underlined***

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Overview about the FULFILL project

Project Summary

The project FULFILL takes up the concept of sufficiency to study the contribution of lifestyle changes and citizen engagement in decarbonising Europe and fulfilling the goals of the Paris Agreement. FULFILL understands the sufficiency principle as "**creating the social, infrastructural, and regulatory conditions for changing individual and collective lifestyles in a way that reduces energy demand and greenhouse gas emissions to an extent that they are within planetary boundaries, and simultaneously contributes to societal well-being**". The choice of the sufficiency principle is justified by the increasing discussion around it, underlining it as a potentially powerful opportunity to actually achieve progress in climate change mitigation. Furthermore, it enables us to go beyond strategies that focus on single behaviours or certain domains and instead to investigate lifestyles in the socio-technical transition as a whole. The critical and systemic application of the sufficiency principle to lifestyle changes and the assessment of its potential contributions to decarbonisation as well as its further intended or unintended consequences are therefore at the heart of this project. The sufficiency principle and sufficient lifestyles lie at the heart of FULFILL, and thus constitute the guiding principle of all work packages and deliverables.

Project Aim and Objectives

To achieve this overarching project aim, FULFILL has the following objectives:

- Characterise the concept of lifestyle change based on the current literature and extend this characterisation by combining it with the sufficiency concept.
- Develop a measurable and quantifiable definition of sufficiency to make it applicable as a concept to study lifestyle changes in relation to decarbonisation strategies.
- Generate a multidisciplinary systemic research approach that integrates micro-, meso-, and macro-level perspectives on lifestyle changes building on latest achievements from research into social science and humanities (SSH), i.e. psychological, sociological, economic, and political sciences, for the empirical work as well as Prospective Studies, i.e. techno-economic energy and climate research.
- Study lifestyle change mechanisms empirically through SSH research methods on the micro- (individual, household) and the meso-level (community, municipal):
- achieve an in-depth analysis of existing and potential sufficiency lifestyles, their intended and unintended consequences (incl. rebound and spillover effects), enablers and barriers (incl. incentives and existing structures) as well as impacts (incl. on health and gender) on the micro level across diverse cultural, political, and economic conditions in Europe and in comparison to India as a country with a wide range of economic conditions and lifestyles, a history which encompasses simple-living movements, and a large potential growth of emissions.
- assess the dynamics of lifestyle change mechanisms towards sufficiency on the meso-level by looking into current activities of municipalities, selected intentional communities and initiatives as well as analysing their level of success and persisting limitations in contributing to decarbonisation.
- Integrate the findings from the micro and meso-level into a macro, i.e. national and European, level assessment of the systemic implications of sufficiency lifestyles and explore potential pathways for the further diffusion of promising sufficiency lifestyles.
- Implement a qualitative and quantitative assessment of the systemic impact of sufficiency lifestyles which, in addition to a contribution to decarbonisation and economic impacts, includes the analysis of further intended and unintended consequences (incl. rebound and spillover

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effects), enablers and barriers (incl. incentives and existing structures) as well as impacts (incl. on health and gender).

- Combine the research findings with citizen science activities to develop sound and valid policy recommendations contributing to the development of promising pathways towards lifestyle.
- Generate findings that are relevant to the preparation of countries' and the EU's next national determined contributions (NDCs) and NDC updates to be submitted in 2025 and validate and disseminate these findings to the relevant stakeholders and institutions for exploitation.
- Consider the relevance and potential impacts of sufficiency lifestyles beyond the EU.

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1. Introduction and nomenclature about sufficiency

1.1. Sufficiency: comparison of definitions as a "Rosetta Stone" of nomenclature

"Définissez les termes, vous dis-je, ou jamais nous ne nous entendrons."

"Define your terms, you will permit me again to say, or we shall never understand one another. "

(1764) Voltaire. From: Citas, Dictionnaire philosophique

The concept of sufficiency, and the underlying idea of questioning a materialistic orientation of societies, has many ancient roots and more recent ones, from the dichotomy "to be or to have" of (Fromm, 1976) to the discussion about self-sufficiency and conviviality of (Illich, 1973), to sufficiency as a management and social organizing principle in (Princen, 2005).
The sufficiency principle has been a part of the discussion on sustainability and development, notably trough the work of Wolfgang Sachs and his critical analysis of the term development: "The 'efficiency revolution' remains direction-blind if not accompanied by a 'sufficiency revolution'. Nothing is as irrational as rushing with maximum efficiency in the wrong direction." (Sachs, 1993)
But only in recent years and months it has significantly entered in policy analysis and discussion, possibly under the pressure of the concomitant climate and geopolitical crisis. A couple of recent examples:

- ten measures to cut oil use have been presented by IEA at a conference on 18th March 2022 and nine of them were sufficiency measures, only one based on technical improvements. IEA Director Fathi Birol, stated during the conference that the ten measures "are based on analysis of previous real experiences in case of energy shocks, pollution episodes,… they are proven". The analysis of the agency concludes for a potential to reduce oil use of advanced economies by 6% in 4 months.
- EU Commission Vice-President Frans Timmermans at a conference organized by the Swedish representation of the European Commission and We Don't Have Time[2] " on 1st of April 2022 in front of hundreds of youths has expressed a series of ideas connected with the concept of sufficiency: "Just changing a bit our lifestyle can have an enormous effect on climate protection", "use more often bikes and public transport", "we should act for redistribution of the means", "less flights and more trains".

We present in the following an analysis of the development of those concepts by reviewing academic and grey literature and connections among the terminology frameworks used by various authors, a sort of "Rosetta Stone"[3] or translation table. Starting points for the identification of relevant publica-

[2] The Swedish representation of the European Commission and We Don't Have Time organised a Climate Dialogue with Frans Timmermans, the Vice-President of the European Commission on April 1st to discuss EU and climate issues with a special focus on the youth perspective.
[3] "The **Rosetta Stone** is a stele …inscribed with three versions of a decree issued in Memphis, Egypt, in 196 BC… . The top and middle texts are in Ancient Egyptian using hieroglyphic and Demotic scripts respectively, while the bottom is in Ancient Greek…making the Rosetta Stone key to deciphering the Egyptian scripts." Source: https://en.wikipedia.org/wiki/Rosetta_Stone

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tions have been inter alia, the H2020 project SHAPE ENERGY, the bibliography suggested by the Centre for the Understanding of Sustainable Prosperity (CUSP), plus the experience and active research of the FULFILL partners.
Based on this review (see below) and in particular the work of Sahakian and Wilhite (Sahakian & Wilhite, 2014)) we adopt and use throughout this text the concepts and terms of:

- ***Sufficiency habits***[4] = Sufficiency measures taken by individuals due to permanent lifestyle changes
- ***Sufficiency infrastructures*** = Physical and non-physical infrastructures enabling Sufficiency habits
- ***Sufficiency societal framework*** = institutions, legislation, norms enabling Sufficiency habits

The concept of "sufficiency" was introduced by a number of researchers both from the energy and the sociology fields, following the energy crises of the 1970s and 1980s (Goldemberg et al., 1985; Illich, 1978); in the 1990s it was brought into the sustainability debate by W. Sachs: "A society in balance with nature can in fact only be approximated through a twin-track approach: through both intelligent rationalization of means and prudent moderation of ends" (Sachs, 1993) and condensed in his aphorism: "**While efficiency is about doing things right, sufficiency is about doing the right things**" (Sachs, 1999).
Since then, the concept has seen a slowly growing research interest in academic research (Toulouse et al., 2019), even though considerably lower than those devoted to technical means for addressing the climate crisis. Different terminology frameworks are used in the literature and we discuss them in the following. A recent review of concepts and terminology is offered in (van den Berg et al., 2019), who summarize: " . . . (Samadi et al., 2017) make a distinction between efficiency, consistency and sufficiency, defined as follows:
"***efficiency*** is an option in which the input-output relation is improved . . . ***consistency*** aims at fundamental changes in production and consumption by substituting non-renewable resources with renewable resources . . . [and] ***sufficiency*** is linked to the level of demand for goods and services".

This distinction can be compared with the distinctions established in the ***avoid-shift-improve*** **(ASI) framework, which is also widely used in the lifestyle and sufficiency literature (**see e.g. (Creutzig et al., 2018)) : ***improve*** matches with efficiency and technological substitution (i.e., ***consistency***), while ***shift*** and ***avoid*** correspond to lifestyle change (i.e., ***sufficiency***)" (see Table 1).

Table 1 Schematic comparison of two different terminology frameworks. The efficiency, consistency, sufficiency framework by Samadi et al. (Samadi et al., 2017) and the avoid-shift-improve framework by Creutzig et al. (Creutzig et al., 2018). Adapted from: Van den Berg et al. (van den Berg et al., 2019), page 3

Integrated Assessment Models (IAM) Distinction	Efficiency	(Technological) Substitution	Lifestyle Change	
	EFFICIENCY	CONSISTENCY	SUFFICIENCY	
Transport	Fuel-efficient vehicles	Vehicles powered from RES	Public transport	Teleconferencing, walking, cycling
Residential	Energy-efficient appliances (high level in energy labeling)	On-site generation by RES	Thermostat adjustment	Smaller apartments, reduced number and size of appliances
Consumer goods and services	Efficient supply chain	Purchase sustainable goods	Sustainable use of goods	Sharing goods
	Improve		Shift	Avoid

[4] Note that throughout this document, we will highlight terms which have an explicit definition within this text or in the cited bibliography in the following way, i.e. ***bold italic underlined***

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The ***avoid, shift, improve (ASI)*** framework helps examine the role of service-related mitigation options, originally arising from the need to assess the staging and combinations of interrelated mitigation options in the provision of transportation services. In the context of transportation services, ASI seeks to mitigate emissions through **avoidance** of as much transport service demand as possible (e.g., telework to eliminate commutes, mixed-use urban zoning to shorten commute distances), **shifting** remaining demand to more energy efficient modes (e.g., bus rapid transit replacing passenger vehicles), and by **improving** the carbon intensity of modes utilised (e.g., electric buses powered by renewable electricity) (Creutzig et al., 2018).

Saheb (Saheb, 2021) proposes a nomenclature probably easier to connect with the EU legislation and Directives, the ***SER (Sufficiency, Efficiency, Renewable)*** framework (see Figure 1). She proposes a definition of sufficiency as:
"a set of policies and daily practices which avoid the demand for **energy, materials, land water, and other natural resources**, while delivering wellbeing for all within planetary boundaries. Sufficiency closes the inequality gap by setting clear consumption limits to ensure fair access to space and resources"

Also *(Erba & Pagliano, 2021)* include in the sufficiency concept energy, water and land, by e.g. recalling that the EU institutions have taken a commitment to …"no net land take by 2050"… and "On … 2021 the European Parliament approved with a majority of 605/660 a resolution asking the EU Commission to draft a new directive for the protection of soil with the objectives of "no land degradation" by 2030 and "no net land take" by 2050 at the latest." They analyse with a bottom up approach applied to a real case study (a sub-urban district of Milano) the feasibility of achieving a positive energy balance with no or minimal occupation of land, limiting the installation of photovoltaic panels on roofs and already built/paved surfaces and conclude that "the problem of **land requirement** might be greatly reduced when applying efficiency and sufficiency measures, which would drastically reduce energy needs and increase flexibility. Similarly for meeting the challenge to provide storage at various time scales, from the daily to the interseasonal, … efficiency techniques and **physical and regulatory frameworks** that enable low-energy lifestyles (**sufficiency**) … would reduce the size of required storage and the connected embedded energy and energy losses" (see Figure 2).

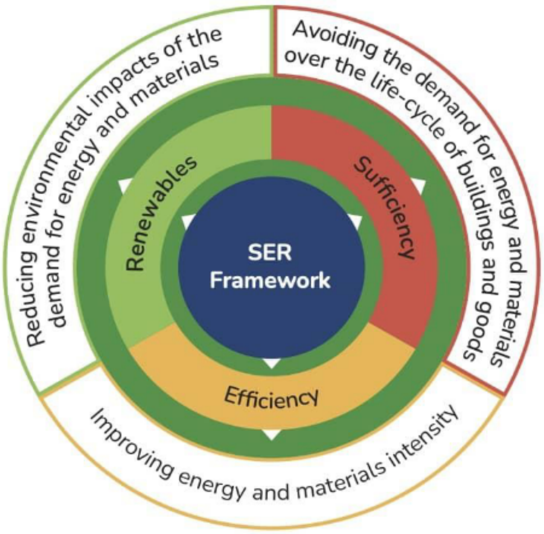

Figure 1 Graphical presentation of the SER (sufficiency, efficiency and renewable) framework proposed by (Saheb, 2021)

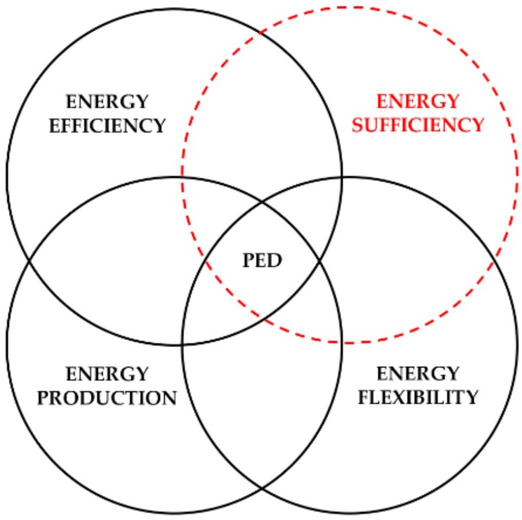

Figure 2 Energy sufficiency as a necessary element of Positive Energy Districts (PEDs) and their flexibility of demand, along with efficiency and renewable generation, according to (Erba & Pagliano, 2021)

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The sufficiency concept has been included, under the French term "***sobrietè***", in energy scenarios by a group of experts in France (negaWatt scenario 2003, https://negawatt.org/Scenario-2003-et-2006) quantifying its relevance in meeting the Climate goals.

It has been included into the French Law for Energy Transition (Loi n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte) on equal footing with energy efficiency. The law states at art. L. 100-1: "La politique énergétique : « 1° Favorise l'émergence d'une économie compétitive et riche en emplois grâce à la mobilisation de toutes les filières industrielles, notamment celles de la croissance verte qui se définit comme un mode de développement économique respectueux de l'environnement, **à la fois sobre et efficace en énergie et en consommation de ressources et de carbone**,… And at art. L. 100-2. "Pour atteindre les objectifs définis à l'article L. 100-1, l'Etat, en cohérence avec les collectivités territoriales et leurs groupements et en mobilisant les entreprises, les associations et les citoyens, veille, en particulier, à : 1° **Maîtriser la demande d'énergie et favoriser l'efficacité et la sobriété énergétiques** ; …"

Even if not at a level of a law, the sufficiency concept has been incorporated as a key element into the Energy Plan 2020–2030 of the State of Genève in Switzerland (*Plan Directeur de l'Énergie 2020-2030*, 2020).

The World Energy Outlook 2020 by the International Energy Agency (IEA, www.iea.org) introduces explicitly sufficiency actions, described there with the term "***behaviour changes***", and their effect on energy use between 2020 and 2030 (International Energy Agency, 2020). The International Energy Agency included in its list various types of behaviour changes, which we will call in this text ***sufficiency habits***, e.g., changing the thermostat settings for summer and winter, line drying clothes, walking and cycling, working from home, car-sharing, etc.

The 6th Advancement Report (AR6) by the Intergovernmental Panel on Climate Change (IPCC) covers demand-side solutions in a new chapter (Chapter 5 of the WGIII: Demand, services, and social aspects of mitigation) where "demand refers to ***end-use demand for services,*** such as nutrition, mobility, thermal comfort and lighting. It emphasises services rather than consumption as an essential dimension to guarantee constituents of wellbeing" (Creutzig et al., 2018, 2021).
The concept of sufficiency is included explicitly for the first time in an IPCC report (*Summary for Policymakers. In: Climate Change 2022. Mitigation of Climate Change Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 2022), and it is defined as:
"*Sufficiency* policies are a set of **measures** and **daily practices** that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries".[5] It should be noted that the concept of sufficiency is here, as in (Saheb, 2021) and (Erba & Pagliano, 2021):

- not limited to the issue of energy use, but is extended also to materials, land and water
- referred to "measures and daily practices", hence involving both what we name here "***sufficiency habits***" and the collective undertakings towards sufficiency, via ***"sufficiency infrastructures***" and "***societal framework***", which are summarised here under the concept of "measures".

This is also in line with the approach taken in a UNEP (United Nations Environment Programme https://www.unep.org) report on "***sustainable lifestyles***" (UNEP et al., 2016): where the following definition is given: "A 'sustainable lifestyle' is a cluster of **habits** and patterns of behaviour embedded in a society and facilitated by **institutions, norms and infrastructures** that frame individual choice, in order to minimise the use of natural resources and generation of wastes, while supporting

[5] 6th Advancement Report (AR6) footnote 60 on page 41 of the Summary for policymakers.

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fairness and prosperity for all". And: "Lifestyles occur within – and are enabled and constrained by – social norms and the physical environment. It is important to differentiate between the factors that can be addressed at the individual or the household level, and those that are beyond individual control…"

1.2. The definitions and nomenclature adopted in this report

From the references discussed in the previous section it can be noted that change in the end-use demand for services via sufficiency is not simply an issue of **personal investment choices and behavioral changes at the individual level**: sociological research indicates the need for **enabling infrastructures and social frameworks** (Axon, 2017; Sahakian & Wilhite, 2014) to support permanent behavior changes (habits).

Sahakian and Wilhite (Sahakian & Wilhite, 2014) conclude: "A theoretical approach with its roots in the mid-20th century has recently been revived and brought to bear on the study of consumption and sustainability: **social practice theory**. This approach shifts the analytical focus away from atomized products, technologies and individuals, towards an understanding of everyday practices, many of which include routinized activities. The contours of social practice theory today build on work by Bourdieu …, Giddens … and Schatzki, among others". And: (Wilhite, 2010) "drawing on these same practice theorists, has proposed that the formation of practices draws on knowledge that is distributed between **people** (bodies and minds), **things** and culturally grounded **social structures**." From the analysis of the literature presented above, which reflects a prevailing tendency to consider the likelihood of life-style changes as strictly connected to the existence of enabling conditions, in this report, we adopt the three-fold formulation of Sahakian and Wilhite (Sahakian & Wilhite, 2014) and for easier communication we rename the three elements in their analysis as:

- ***Sufficiency habits*** = Sufficiency measures taken by individuals due to permanent lifestyle changes (people)
- ***Sufficiency infrastructures*** = Physical and non-physical infrastructures enabling ***Sufficiency habits*** (things)
- ***Sufficiency societal framework*** = institutions, legislation, norms enabling ***Sufficiency habits*** (social structures)

2. Why sufficiency is necessary

The analysed literature provides a number of conclusions about the necessity of limiting use of energy and materials not only via technological improvements but also via the development of ***sufficiency habits*** and their enabling ***infrastructures*** and ***societal framework***.
The analysis of the use of energy and materials shows for example that we are currently not actually substituting fossil fuels with renewables, but rather adding both use of energy from renewable sources and large quantities from fossil sources on the global level. It looks obviously different in various regions, but climate is affected by global emissions.

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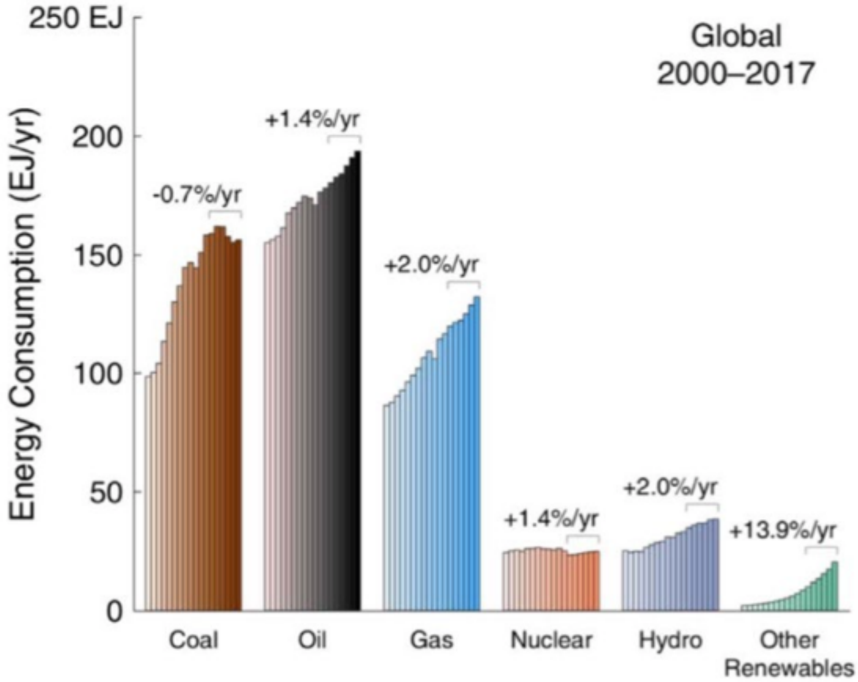

Figure 3 Energy consumption at world level 2000-2017. Source: Jackson, R B, et Al. "Global Energy Growth Is Outpacing Decarbonization." Environmental Research Letters13, no. 12 (December 5, 2018)

Based on IEA data, the International Renewable Energy Agency (IRENA, www.irena.org) in its Renewables 2021 Global Status Report[6] shows that the share of renewables has not increased over the last decade: it has remained blocked to the level of 20%, in spite of large reduction in the cost of energy produced by renewables and high investments in these technologies. Also according to IEA data, in the last 50 years, the share of fossil energies has only been reduced from 86 to 80%.

[6] https://www.ren21.net/reports/global-status-report/

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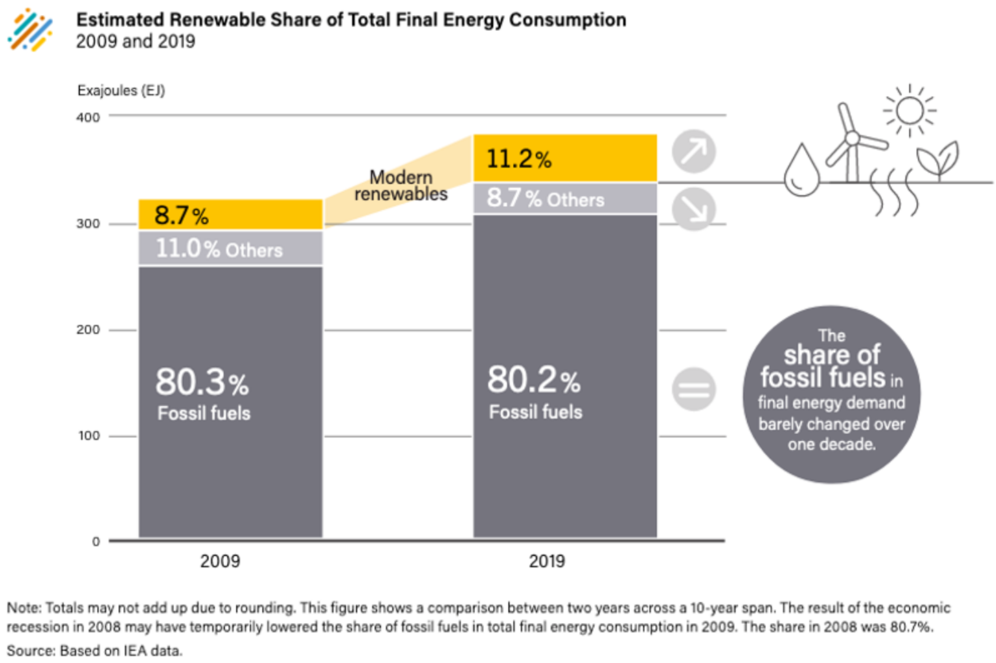

Figure 4 The share of renewables on total final energy consumption at world level has remained stable at 20% in the years 2009 to 2019. Source: https://www.ren21.net/reports/global-status-report/

The above data give evidence that reduction of emissions depends on two variables: deployment of renewables and total energy use; since total energy use continues to grow, on global level decarbonisation is not progressing.
One way often discussed for the reduction of total energy (and materials use) is the so called "decoupling" of economic growth, as measured e.g. by Gross Domestic Product (GDP), from physical inputs. A number of recent analysis, as e.g. (Kuhnhenn et al., 2020), however conclude : "Mainstream climate policy relies on a sufficient decoupling of economic growth and emissions, that is a decoupling that leads to the emission reductions needed to achieve a certain climate goa**l** – i.e. to stay below a 1.5°C increase in global mean temperature. According to available knowledge and empirical evidence, such a decoupling appears impossible, or at least very unlikely**.**" In this chapter we review papers and reports about the issues of degree of decoupling and rebound effect.

Under the critical difficulties concerning decoupling and rebound effect experienced by approaches based mainly or exclusively on technological measures, the limitation of energy and materials use via the inclusion of ***sufficiency infrastructures*** and ***sufficiency social frameworks*** into the policy options appears as a necessity, as recognized recently in the analysis of several institutional bodies.

2.1. The limits of eco-decoupling and their role in making Sufficiency necessary

In recent years, a growing body of scientific literature has pointed to the limits of decoupling economic activity and environmental impacts. A recent briefing (*Growth without economic growth*, 2021) by the European Environment Agency (EEA) asks the question: "As global decoupling of economic growth and resource consumption is not happening, real creativity is called for: how can society develop and grow in quality (e.g. purpose, solidarity, empathy), rather than in quantity (e.g. material standards of living), in a more equitable way?"

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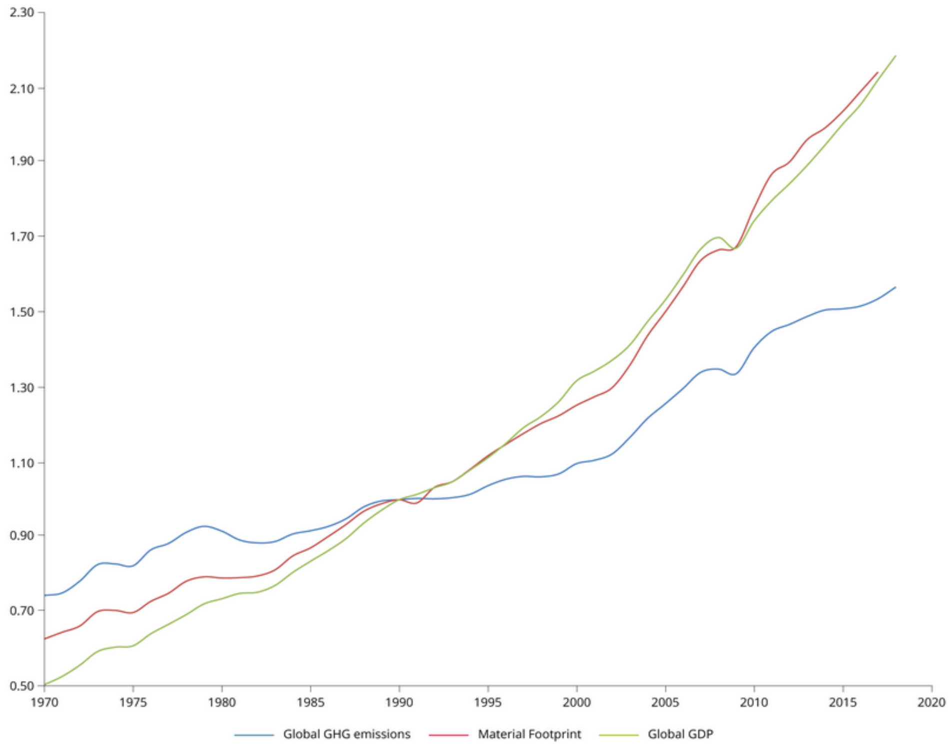

Sources: Modified from Wiedmann et al. (2020). Reproduced under the terms and conditions of the Creative Commons CC BY 4.0 licence (https://creativecommons.org/licenses/by/4.0/).
Data from Olivier and Peters (2020) for greenhouse gas (GHG) emissions; UNEP and IRP (2018) for material footprint; and World Bank (2020a) for GDP.

Figure 5 Relative change of main global economic and environmental indicators from 1970 to 2018. Source : (Growth without economic growth, 2021) - European Environment Agency

In a chapter titled “100 % circularity is impossible” the briefing of EEA states: “Moreover, high throughput and low rates of recycling appear to be conditions for high productivity (Hall and Klitgaard, 2012). Advanced societies require high throughputs of energy and materials to maintain their organisational complexity (Tainter and Patzek, 2012). What these insights point to is the need to rethink and reframe societal notions of progress in broader terms than consumption.”

Most recently (2022), the IPCC Sixth Assessment Report (in its *Sub-section 2.3.3: Decoupling of emissions from economic growth*) also includes a critique of green growth. In this chapter, we offer a review of the main scientific studies that in recent years have shown limits and concluded for unfeasibility of absolute and sufficiently rapid decoupling.
Ward et al. (Ward et al., 2016) argue that “growth in GDP ultimately cannot be decoupled from growth in material and energy use” and that “it is therefore misleading to develop growth-oriented policy around the expectation that decoupling is possible.” They claim that their “model demonstrates that growth in GDP ultimately cannot plausibly be decoupled from growth in material and energy use, demonstrating categorically that GDP growth cannot be sustained indefinitely.” This leads them to conclude that “it is ultimately necessary for nations and the world to transition to a steady or declining GDP scenario.”
After reviewing 179 articles on decoupling, (Vadén et al., 2020) conclude that even though some papers present evidence of absolute impact decoupling (mainly between CO_2 and GDP), there is “no evidence of economy-wide, national/international absolute resource decoupling” and “no evidence of the kind of decoupling needed for ecological sustainability.” Hence their conclusion: “in the absence of robust evidence, the goal of decoupling rests partly on faith.”
Similarly, (Haberl et al., 2020) synthesize the evidence emerging from 835 peer-reviewed articles and find that — while relative decoupling is frequent for material use as well as greenhouse gas emissions— large, rapid, absolute reductions of resource use and greenhouse gas emissions cannot be achieved through observed decoupling rates. Their findings point to an important aspect of the

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debate surrounding 'green growth': while relative decoupling refers to a decline in the resource/energy intensity per unit of economic output, absolute decoupling refers to a decline in resource/energy use in absolute terms while economic output rises.
All the findings contained in the aforementioned studies lead Hickel and Kallis (Hickel & Kallis, 2019) to conclude that "there is no empirical evidence that absolute decoupling from resource use can be achieved on a global scale against a background of continued economic growth" and that "absolute decoupling from carbon emissions is highly unlikely to be achieved at a rate rapid enough to prevent global heating over 1.5 or 2 °C degrees, even under optimistic policy conditions."
According to an analysis presented by Ulrich Hoffman (Hoffmann, 2016) the combination of economic and population growth, the rebound effect which limits total or absolute energy/resource/material efficiency bring to disproof the hypothesis of decoupling GHG emissions from economic growth as currently intended. The author substantiates his assessment of the extreme unlikeliness of 'absolute' decoupling by illustrating the unsurmountable rate of 'relative' decoupling that would be required under a 'growth' oriented global economic paradigm.
Similarly, Tim Jackson's analysis (Jackson, 2017), summarised in Figure 6 depicts that carbon intensity of production fell by 23 per cent in the 28 years between 1980 and 2008 (a drop of about 0.7 per cent per annum).

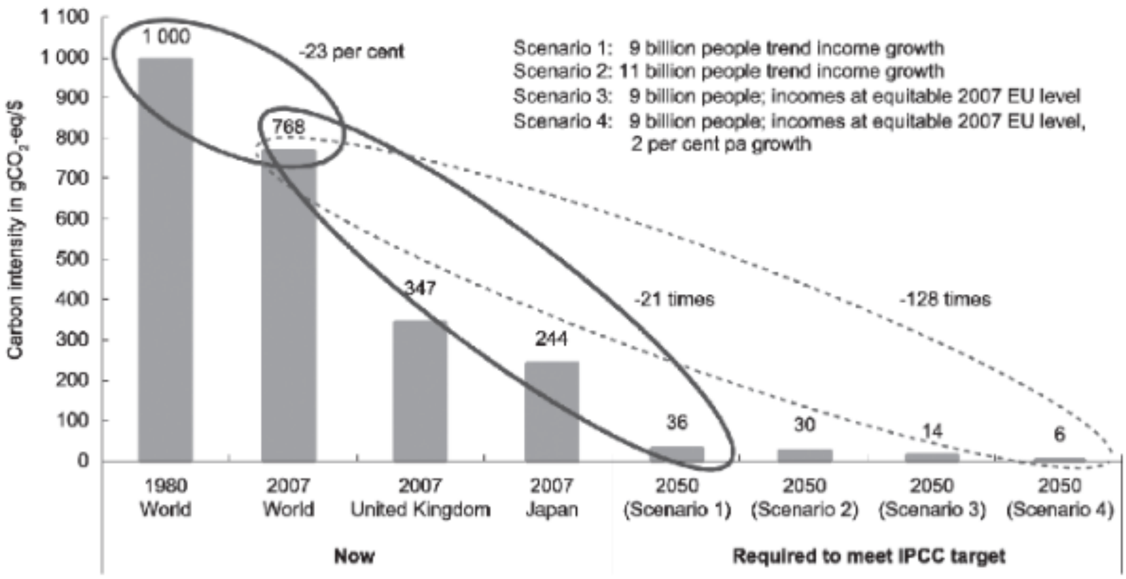

Figure 6 Carbon intensity of the economy in gCO_2-eq/$ in 2007 compared to the intensity required to meet IPCC targets. Source: (Jackson, 2017)

Extrapolating the global population to 2050, the analysis reported by Jackson indicates that carbon intensity would have to be reduced 21-fold (i.e. to about 5 percent of the current level) to limit global warming to 2 degrees. In a global economic equity scenario (i.e. developing countries at par with present level of GDP per capita in developed nations) it would even require a roughly 130-fold drop by 2050. The above scenarios thus call for a year-on-year relative decoupling of 2.3% for 43 years.
Hoffman (Hoffmann, 2011) remarks that the Russian Federation "is the only large economy that has reduced emissions substantially since 1990, mostly caused by a breakdown of its heavy industry (an example of degrowth)" when its emissions fell 3 per cent annually in 1990–2005. In essence, the entire world would have to double the 'achievement' of the Russian Federation. A recurrent theme of the historical analysis is that historically drastic rates of decarbonization have only been possible during phases of economic stagnation or contraction.
The book "Green Growth: Ideology, Political Economy and the Alternatives" (Dale et al., 2016) offers an historical perspective on the roots and evolution of the concept of Green Growth, presents a number of critical analyses on its feasibility, and an overview of alternatives being practiced at regional level.

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There are also numerous studies that instead of discussing the issue of decoupling at the global level, focus on the evidence at the national level. For instance, Le Quéré et al. (Le Quéré et al., 2019) analyse 18 developed economies (Sweden, Romania, France, Ireland, Spain, UK, Bulgaria, The Netherlands, Italy, United States, Germany, Denmark, Portugal, Austria, Hungary, Belgium, Finland, and Croatia) between 2005 and 2015, finding that emissions decreased by a median of 2.4% per year during that decade. Take, for example, the UK that is often cited as one of the most successful decoupling countries. In the Le Quéré study, its consumption-based emissions decreased by 2.1% per year between 2005 and 2015 with positive GDP rates of around 1.1%. But the country has pledged to reduce emissions by twice than that (5.1% per year). And to comply with the Paris Agreement, the UK would need to achieve a steady 13% cut in emissions every year. Part of the decoupling reached by the countries mentioned in the study is explained by a slowing down of rates of GDP growth (hence, closer to a sufficiency strategy than to green growth). Le Quéré et al. (Le Quéré et al., 2019) acknowledge that the studied period is nothing extraordinary: "These reductions in the energy intensity of GDP in 2005-2015 do not stand out compared to similar reductions observed since the 1970s, indicating that decreases in energy use in the peak-and-decline group could be explained at least in part by the lower growth in GDP." Using simulations, the authors estimate that "if GDP returns to strong growth in the peak-and-decline group, reductions in energy use may weaken or be reversed unless strong climate and energy policies are implemented." The authors conclude that: "as significant as they have been, the emissions reductions observed [...] fall a long way short of the deep and rapid global decarbonization of the energy system implied by the Paris Agreement temperature goals, especially given the increases in global CO_2 emissions in 2017 and 2018, and the slowdown of decarbonization in Europe since 2014."
But even in case some areas of the world move towards absolute decoupling this might be happening at too high level of consumption to ensure achieving the climate goals. Still focusing at the national level, Hubacek et al. (Hubacek et al., 2021) look at 116 countries from 1990 to 2018 applying a structural decomposition analysis to understand the drivers behind changes in emissions. "During the most recent three-year period from 2015 to 2018, 23 countries (or 20% of the 116 sample countries) have achieved absolute decoupling of **consumption-based** emissions and GDP, while 32 countries (or 28%) achieved absolute decoupling of **production-based** emissions and GDP. 14 of them (e.g., the UK, Japan, and the Netherlands) also decoupled production-based emissions and GDP. Countries with absolute decoupling of consumption-based emissions tend to achieve decoupling at relatively high levels of economic development and high per capita emissions. Most of EU and North American countries are in this group." From their analysis they conclude that in many countries emissions are semi-stabilising at a too-high level, which brings the authors to write that these countries "cannot serve as role models for the rest of the world" given that their decoupling "was only achieved at very high levels of per capita emissions." They go even further in the last paragraph of the conclusion: "Even though some countries have achieved absolute decoupling, they are still adding emissions to the atmosphere thus showing the limits of 'green growth' and the growth paradigm. Even if all countries decouple in absolute terms, this might still not be sufficient to avert dangerous climate change. Therefore, decoupling can only serve as one of the indicators and steps toward fully decarbonizing the economy and society".
Furthermore, Roinoti and Koroneos (Roinioti & Koroneos, 2017) look at Greece from 2003 and 2013 and only find an absolute decoupling for three years (2005, 2007, and 2008). Simbi et al. (Habimana Simbi et al., 2021) examine 20 African countries between 1984 and 2014 and find that CO_2 emissions increased by 2.11% over the period, and that "the industrial structure and emission efficiency contributed to the reduction of CO_2 emissions but were inadequate to offset the positive contribution of population and economic growth."
Shan et al. (Shan et al., 2021) study the link between economic growth and CO_2 emissions in 294 Chinese cities for the years 2005, 2010, and 2015, finding "varying degrees of decoupling": 11% achieved absolute decoupling and 65% relative decoupling. In the end, the authors write that "although there was slow emission growth or even an emission decline in decoupled cities, they kept adding CO_2 to the atmosphere and increasing CO_2 concentration."
Stoknes and Rockström (Stoknes & Rockström, 2018) argue that Sweden, Finland and Denmark have achieved what the authors call "genuine green growth" (a requirement of a yearly 5% improvement in carbon productivity). However, a recent study by Tilsted et al. (Tilsted et al., 2021) revisited their

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results showing that Denmark had only achieved the 5% threshold a couple of years between 2000 et 2017, and that all the other Nordic countries remained far under the 5% threshold when their imported emissions were accounted for.

A key phenomenological explanation for the impossibility of achieving actual 'de-coupling' is that "technological progress in reducing GHG intensity and concomitant structural change has been outpaced by the scale effect of growth". As a typical illustration of this scale effect, Hoffman (Hoffmann, 2016) describes the evolution of the fuel consumption patterns of the private car population in the European Union in the last 20 years. Based on data from the European Environmental Agency (EEA) he reports that "savings through more fuel-efficient cars were outweighed by the strong increase in the car population and the total mileage travelled. Whereas fuel consumption per privately owned car decreased by about 15 per cent in the period 1990–2007, car population and total mileage travelled increased by over 40 per cent. Consequently, total fuel consumption of privately owned cars rose by more than a quarter".

Further data on how the increase in vehicle size and weight, in particular the increase in sales of Sport Utility Vehicles (SUVs) has completely offset the savings due to increased technical efficiency in motors, can be found in a series of recent reports by the International Energy Agency, as e.g.: "Global SUVs sales set another record in 2011 setting back efforts to reduce emissions"[7]. IEA reports that "If SUVs were an individual country, they would rank **sixth in the world for absolute emissions in 2021**, emitting over 900 million tonnes of CO_2" and " SUVs are … heavier and consume around 20% more energy than a medium-sized car. The global fleet of SUVs has increased rapidly, from less than 50 million in 2010 to around 320 million in 2021 – equivalent to the total car fleet of Europe. As such, **SUVs rank among the top causes of energy-related carbon dioxide (CO_2) emissions growth over the last decade**." Figure 7 from the IEA report shows that SUVs are the **second source of growth of CO_2 emissions** in the decade 2010-2021, even higher than the growth due to heavy industry.

[7] IEA reports on Sport Utility Vehicles (SUVs) can be found at the following webpages:
https://www.iea.org/commentaries/growing-preference-for-suvs-challenges-emissions-reductions-in-passenger-car-market
https://www.iea.org/commentaries/carbon-emissions-fell-across-all-sectors-in-2020-except-for-one-suvs
https://www.iea.org/commentaries/global-suv-sales-set-another-record-in-2021-setting-back-efforts-to-reduce-emissions

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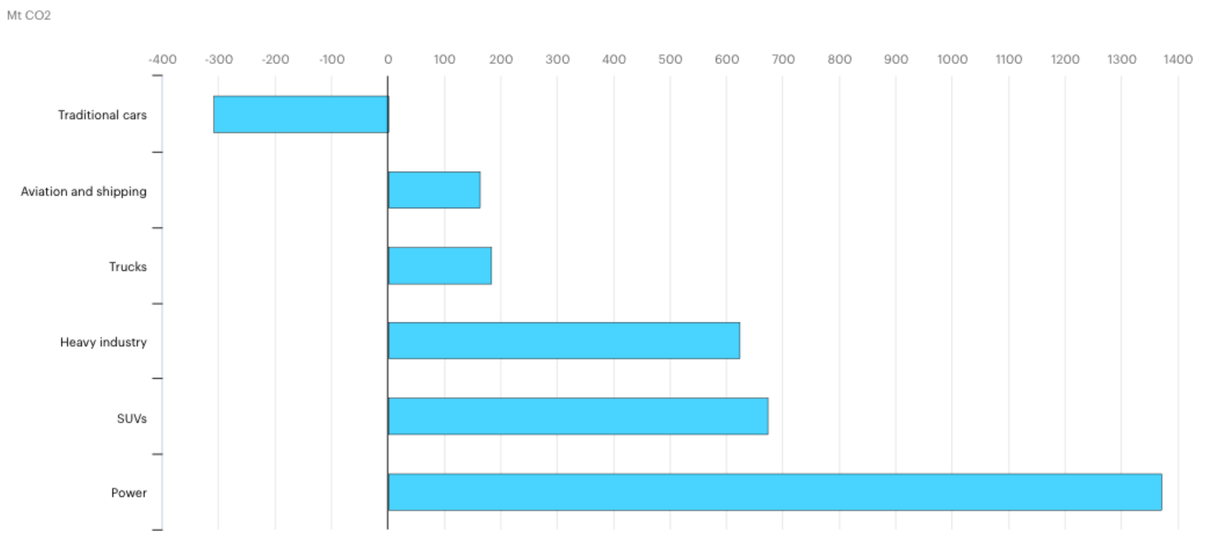

Figure 7 IEA, Growth in CO_2 emissions by energy sub-sector from 2010 to 2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/growth-in-CO2-emissions-by-energy-sub-sector-from-2010-to-2021

In order to GHG/GDP de-coupling to deliver required results through economic restructuring, Hoffman (cited) states that "GHG-intensive sectors and activities would have to shrink faster than the expansion of GHG-efficient ones"". This, according to Hoffman, has actually not happened. What makes this de-coupling through switching to clean-production technologies and other green-growth approaches even more elusive is that finance capital plays a pivotal role in ecological restructuring; the additional capital required for restructuring can only 'emerge' through accelerating the pressure on already existing productive capital to generate surplus value (i.e. profit for paying interest or revenues on shares) and this provides the inevitable impetus for the current scale of production to expand on an absolute level.

The relatively modest impact of renewable energy in achieving significant de-coupling of net energy and material use is explained by Hoffman when he states, quoting (Sarkar, 2009; Rundgren, 2013), that "renewable energy is usually only available in non-concentrated form; it has to be 'compacted' to generate sufficient power. This 'compaction' or, in technical terms, the reduction of entropy of a system, can only be achieved by increasing the entropy in other parts. In practical terms of renewable energy, this means that one can only compact wind, solar, bio or hydro energy by increasing the use of conventional fuel or raw materials. As a result, EREI (Energy Return on Energy Invested) is low and sometimes even negative"

Even more worrying is the fact that decoupling has not only been a failing strategy so far, but also that it is highly unlikely to succeed in the future. According to Parrique et al. (Parrique et al., 2019), there are seven reasons to be skeptical of achieving sufficient decoupling between GDP and resource/energy use, which we report below with their sources, given their relevance in the argument.
1) When a natural resource is extracted, the cheapest sources are generally used first. The extraction from the remaining sources then becomes more impactful in terms of environmental degradation per unit of extracted resource (Bonaiuti, 2018).
2) Efficiency increases are often partially or completely offset by a new allocation of resources and money saved either towards an increase in the same type of consumption, (Alcott, 2008) or other impactful consumptions, the so-called 'rebound effect'.
3) Technological solutions to an environmental problem can create new ones and/or worsen others (van den Bergh et al., 2015). For example, the production of private electric cars puts pressure on the resources of lithium, copper, and cobalt.

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4) The service economy can exist only in addition to the material economy, not in its place. Services have an ecological footprint that often adds to that of goods, rather than replacing them (Özpolat, 2021).
5) Recycling rates are currently low and only slowly increasing, and recycling processes generally still require a significant amount of energy and raw materials. But above all, recycling is strictly limited in its possibilities of providing the resources for an expanding material economy (Hobson, 2021).
6) Technological progress is not oriented to those factors of production that are relevant to ecological sustainability and does not lead to the type of innovation that reduces environmental impacts (Arne Heyen et al., 2017).
7) What has been observed and called decoupling in some local cases has generally been only an apparent decoupling, mainly due to the externalization of the environmental impact from high-consumption countries to low-consumption countries through international trade (Martínez-Alier, 2012).

In the next chapter we review literature on the rebound effect and its role in making sufficiency necessary.

2.2. The Rebound Effect and its role in making Sufficiency necessary

The above observation of Parrique et al. (Parrique et al., 2019) that "Efficiency increases are often partially or completely offset by a new allocation of resources and money saved either towards an increase in the same type of consumption or other impactful consumptions, the so-called 'rebound effect'" deserves a further discussion, since by showing a specific limit of a purely technological approach, it supports the need for a high relevance of inclusion of improvements in ***sufficiency infrastructures*** and ***sufficiency societal framework*** in the policy mix.

According to (Santarius, 2012): "A rebound effect describes the increased demand that is caused or at least enabled by one or a number of productivity increases".
Literature analyses various forms of rebound effect and areas where it has impact. We refer here mostly to the classification proposed by Santarius (Santarius, 2012) in, respectively, financial, material, psychological, and cross-sectoral rebound effect.
Financial rebound effect materializes since generally a physical gain of efficiency is also a prouctiviy increase in economic terms and hence it reduces the cost of certain manufactured goods or energy itself. According to Hoffman (Hoffmann, 2011), "enhanced energy (and related material and resource) efficiency and ample availability of cheap renewable energy will encourage a 'rebound effect', i.e. physical consumption is likely to increase as a result of productivity increases, which leads to lower costs and prices and the shifting of thus saved consumer money or investment funds".
Santarius defined **material** rebound when "Investment in efficiency measures can increase the demand for energy or materials for the production of the associated goods", e.g. the embedded energy in insulation materials (the energy needed to manufacture and transport them) reduces the savings in operational energy. This might seem in fact a questionable definition, at least in the many cases in which the saved energy repays in few years the embedded energy. But under the tight time constraints due to the climate crisis, even if energy is recovered over a long life time of the device or building, the fact that an additional energy expenditure is needed initially might bring to overshooting our CO_2 budget limits.
(Dale et al., 2016) also discuss the rebound effect "caused by higher Energy Material and Resource (EMR) consumption resulting from the need to change fixed capital and infrastructure for increasing EMR efficiency"
The **psychological** rebound effect described by Santarius regards the outcome of higher EMR consumption, "because the user of more efficient technologies is under the impression that he/she has economised on EMR use and that there is thus no harm in using the concerned device a bit more (e.g.

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the user of a more fuel efficient or electrical vehicle increases the mileage)" (Dale et al., 2016; Dütschke et al., 2018; Galvin et al., 2021; Schleich et al., 2014).
The **cross-factor** rebound effect described by Santarius exerts a dynamic force on de-coupling trajectories through the pathway of enhanced labour productivity (and its effect of replacing labour by mechanization and motorization), accelerating energy, material and resource consumption: "an increase in energy efficiency is frequently accompanied by an increase in the productivity of labour and capital, even if this increase was not the primary aim. The overall increase in the productivity of the economy then boosts growth, with further implications for the demand for energy".

Finally, Foster, Clark and York observe that "an economic system devoted to profits, accumulation, and economic expansion without end will tend to use any efficiency gains or cost reductions to expand the overall scale of production … Conservation in the aggregate is impossible for capitalism, however much the output/input ratio may be increased in the engineering of a given product. This is because all savings tend to spur further capital formation" (Foster et al., 2010).

Another phenomenon might also be classified as a rebound, a sort of **geographically displaced rebound** effect. According to (Bleischwitz et al., 2012), "the upswing for eco-industries in the North may have a dark side in the South: resource-rich countries being moved into rapid extraction paths exceeding the eco-systems and socio-economic institutions of those regions and fuelling civil wars with resource rents". An exhaustive assessment of this 'emissions leakage' that 'produces' the deceptive 'illusion' of growth decoupled from amplifying GHG emissions underpins the conclusion that "considerable proportion of GHG intensity drops in developed countries has been achieved not by 'real physical savings', but by 'outsourcing' very EMR-intensive production to developing countries (almost a quarter of GHG emissions related to goods consumed in developed countries has been outsourced)……EMR and carbon-efficiency gains in developed countries need to be scrutinized with care and are often far less impressive than they appear at first sight, according to (Aichele & Felbermayr, 2015).

3. Why sufficiency is desirable

The previous chapter brings evidence to the necessity of reduction of total use of energy and resources, which in turn might necessarily require a sufficiency approach. This chapter concentrates on "societal" benefits, or benefits to individual health and wellbeing but seen from the societal point of view, which sufficiency policies might achieve.
Year after year, the wealth of scientific literature reviewed and assessed by IPCC and other organisations warn us of the dangers of going beyond the planetary boundaries and of the advantages of measures able to flourish within limits.
The existing economic and institutional architecture with its pressure to ever-growing consumption in the global north and its imitation in the global south is constantly increasing the impact on natural resources and biodiversity (*IPBES (2019): Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.*, 2019). Many authors conclude that there is an urgent need to make radical changes in our consumption patterns, redistribution of resources to areas and groups deprived of sufficient resources also for a dignified life and a recalibration of values and ways of life for physical and mental wellbeing.
For example Jackson (Jackson, 2005), reviewing a large body of literature in 2005, including the needs-based theory of development of the Chilean economist Max Neef (Max-Neef et al., 1991) concluded: "Environmental imperatives—the demand to reduce the material impact of human activities—are often portrayed and often perceived as constraining human welfare and threatening our quality of life. In contrast, the eco-humanistic critique suggests that existing patterns of consumption already threaten our quality of life, not just because of their impact on the environment, but also because of their failure to satisfy our needs. Reducing the material profligacy of our lives, according to this view, will help the environment. It also offers the possibility of improving the quality of our lives."

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In the preface to the book ‘Development Dictionary’, its editor (Sachs, 2007) recalls Gandhi’s warning against the dangers of imitating the western model of economic development in a newspaper column written in 1926, “God forbid that India should ever take to industrialisation after the manner of the West. The economic imperialism of a single tiny island kingdom (England) is today keeping the world in chains. If an entire nation of 300 million took to similar economic exploitation, it would strip the world bare like locusts (pXIV).” 96 years later, the impending ecological crisis is indicative of the dangers of the imitation of the global north by 1300 million people of India, or the rest of the global south. If developing countries were to follow the same path to achieve the consumption level of developed countries, then by 2050 we would have seven times resource consumption based on the current projections of population growth (Gerd Scholl et al., 2010).

A similar concern was expressed by Schumacher (Schumacher, 1974) in his book *Small is Beautiful* with reference to the third world economy that should not imitate the west and instead reject “breakneck urbanization, heavy capital investments, mass production, centralized development planning, and advanced technology”, if it were to save its people and environment from destruction.

In order for the world to become sufficient to avoid climate catastrophes “societies as a whole are to be downsized by reducing production, trade, travelling and consumption. Life is to become more local and less mobile, as well as more equitable and ecologically benign, while remaining democratic” (Arias-Maldonado, 2021).

The important point here is that a downsizing of material and energy-intensive activities in order to mitigate climate change is also desirable from many other individual and societal points of view. The conclusion of an analysis of 406 papers and expert judgement by a team of 2-4 researchers for each sector performed by (Creutzig et al., 2022) is that “Demand-side mitigation strategies have positive impacts on human wellbeing (high confidence). Our study shows that among all demand-side option effects on wellbeing 76% (246 out of 324) are positive; 21.6% (70 out of 324) are neutral (or not relevant/specify); only 2.4% (8 out of 324) are negative. Active mobility (cycling and walking), efficient buildings and prosumer choices of renewable technologies have the most encompassing beneficial effects on wellbeing with no negative outcome detected…”

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Legend:
- High positive impact (+3)
- Medium positive impact (+2)
- Low positive impact (+1)
- Overall neutral
- No impact
- Low negative impact (−1)
- Medium negative impact (−2)
- * Confidence level

Sectors	Mitigation strategies/well-being dimensions	Food	Water	Air	Health	Sanitation	Energy	Shelter	Mobility	Education	Communication	Social protection	Participation	Personal security	Social cohesion	Political stability	Economic stability	Material provision	Supply side/incumbents
	SDGs	2	6	7, 11	3	6	7	11	11	4		1, 2, 8,10	5, 10, 16	5, 16	10, 16	11, 16	8	9, 12	8,12
Building	Sufficiency	(+1) ***	(+2) ****	(+2) *****	(+3) *****	(+1) *	(+3) ****	(+1) *	(+1) **	(+1) **	(+2) ***	(+1) **	(+1) **		(+2) *****		(+2) ****	(+2) ****	(−2) ***
Building	Efficiency	(+2) *	(+2) ****	(+3/−1) ****	(+3/−1) *****	(+1) *	(+3) ****	(+2) ****		(+1) ***	(+1) ***		(+1) ****	(+1) ***	(+2/−1) ****		(+2) *****	(+2/−1) ****	(+2/−2) ***
Building	Lower carbon and renewable energy	(+2/−1) ***	(+2/−1) ****	(+3) *****	(+3) *****		(+3) ****	(+1) ***	(+1) ***	(+1) ***	(+2) ***		(+1) ***	(+1) ***	(+2/−1) ****		(+2/−1) *****	(+2) ****	(+2/−2) ***
Food	Food waste	(+1) ***	(+2) ****	(+2) ****	(+2) ***	(+1) **	(+1) ****				(+1) **	(−1/+1) ***	(+1) ***			(+1) *	(+1) **		(−1) ***
Food	Overconsumption	(+1) *	(+1/−1) *	(+1/−1) *	(+3) ****		(+1/−1) *						(+2) ****			(+1) *			(+1/−2) *
Food	Animal-free protein	(+2) ***	(+2) ****	(+3) *****	(+3) ***						(−1) ***	(+3) *****	(+1) ****		(−1) *	(+2) *			(−1) ***
Transport	Teleworking and online education system	(+1) **		(+3) ****	(+2) ****		(+2) ****	(+1) **	(+2) ****	(−1) ***	(+2) ****	(+1) ****	(+2) ****	(+1/−1) ****	(+2) ****	(+2) ***	(+2) ***		(+1) ****
Transport	Non-motorized transport	(+2) **	(+1) **	(+1) *****	(+3) *****		(+2) ****		(+3) *****	(+1) ****	(+3) ***	(+1) ***	(+1) **	(+2) ****	(+2) ***	(+2) **	(+2) ***		(+1) ***
Transport	Shared mobility	(+1) **		(+3) ***	(+2) ****		(+1) ***		(+2) ****		(+1) ***	(+2) ***	(+1) ***	(+1/−1) ***	(+1/−1) ****	(−1) ****	(+2) ****	(+2) ****	(−1) **
Transport	BEVs	(+1) ***		(+2) ****	(+1) ****	(+1) ****	(+3 ****		(+2) ****			(+3) *****	(+2) ***				(+2) ****	(−1) **	(+1) ***
Urban	Compact city	(+2/−1) ***	(+1) **	(+2/−1) ***	(+3/−1) ****	(+1) **	(+3/−1) *****	(−1) *****	(+3) *****	(+1) *****	(+1/−1) ***	(+2) **	(+1) **	(+1) ****	(+1/−1) *****		(+1) ****	(+1) **	(+1/−2) ***
Urban	Circular and shared economy	(+2) ****	(+1) ***	(+2) ***	(+2) ***		(+3) ***	(+2/−1) ***	(+3) *****	(+1) ****	(+1) ****	(+1) ***	(+1) ***	(+2) ****	(+1) **	(+1) **	(+2) **	(+3) ***	(−1) ****
Urban	Systems approach in urban policy and practice	(+1) ***	(+2) ***	(+2) ***	(+3) ***	(+1) ***	(+3) ***	(+2) ***	(+3) ***		(+1) **	(−1) **	(+1) ***	(+2) *	(+1) *		(+1) **	(+3) *****	(+2/−2) **
Urban	Nature-based solutions	(+2) ***	(+1/−1) *****	(+3/−1) ****	(+3) *****	(+1) ***	(+3) ***	(+1/−1) ***	(+1) ***	(+2) ****		(+2) **	(+3) **	(+1) ***	(+2/−2) ***		(+3) ****	(+1) **	(+1) **
Industry	Using less material by design	(+2) **	(+2) ***	(+3) ***	(+2) **	(+2) ***	(+3) ****	(+2) ****	(+2) ****	(+1) **	(+2) ***	(+1) **	(+1) ***	(+1) **	(+1) **	(+1) **	(+2) ***	(+3) **	(−2) **
Industry	Product life extension	(+2) **	(+2) ***	(+3) ***	(+2) **	(+2) ***	(+3) ****	(+2) ****	(+2) ****	(+1) **	(+2) ***	(+1) **	(−1) ****	(+1) **	(+1) **	(+1) **	(+2) ***	(+3) **	(−2) **
Industry	Energy efficiency	(+2) **	(+2) ***	(+3) ***	(+1) **	(+2) ***	(+3) ****	(+2) ****	(+2) ****	(+1) **	(+2) ***	(+2) ****	(+2) ***	(+1) **		(+1) **	(+2) ***	(+2) **	(−2) **
Industry	Circular economy	(+2) ***	(+2) ***	(+3) ***	(+1) **	(+2) ***	(+3) ****	(+2) ****	(+2) ****	(+1) **	(+2) ***	(+1) **	(+1) ***	(+2) **	(+1) **		(+2) ***	(+3) **	(−2) **

Figure 8 Effects of demand-side options on wellbeing in 19 different categories. Magnitude and direction of wellbeing effect. Source (Creutzig et al., 2022)

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3.1. Quantitative assessments of the benefits of sufficiency

Even if a number of analysis conclude for a strong need to reduce the flows of materials and energy created by the human economy, a drastic reduction in material goods and services should not be confused with reduced levels of welfare. In this chapter we review the growing body of research that has quantified the "saturation" of wellbeing indicators in high income countries. A number of analysis reach the conclusion that excess use of energy and reliance on materials has reached a level of dysfunction for individual and collective welfare. For example, the large reliance on private cars is connected to "physical inactivity, obesity, death and injury from crashes, cardio- respiratory disease from air pollution, noise, community severance and climate change" (Burke, 2020).
Actions by individuals towards ***sufficiency habits*** in rich and poor countries have shown positive changes in their wellbeing as it often works as a positive reinforcement and gives a sense of empowerment of "doing something positive" as Capstick et al. (Capstick et al., 2022) demonstrate in their ambitious cross-national study on pro-environmental behaviour and subjective wellbeing. The results are based on a survey of 7 000 people from seven countries: Brazil, China, Denmark, India, Poland, South Africa and the UK. It is interesting to note that regardless of the country (from Denmark ranked 11th on the UN Human Development Index to India, ranked 130th), pro-environmental behaviours such as reducing food waste, buying greener products, donating money to environmental campaigns, or getting involved in conservation work directly contributed to subjective wellbeing.
Beyond voluntary measures, sufficient-based changes on a systemic level (***sufficiency infrastructures*** and ***sufficiency societal frameworks***) are needed according to much of the literature reviewed. Such measures will reduce energy intensive uses, contribute to improved public health and free up public space for non-motorised modes of transport and interaction as the literature quoted below shows.
E.g. Douglas et al. (Douglas et al., 2011) demonstrate the dangers caused to health and safety due to private cars and advocate for reduction of car use. A study based on the cost-effectiveness of bike lanes in New York city when considering public health benefits conclude that investments in bike lanes address multiple health and safety concerns (Gu et al., 2017). Cities across the world are investing in bike projects, with the aim reducing the dependence on cars. A recent paper (Chen et al., 2022) which delivers "the first global dataset for bicycle ownership and use by country from 1962 to 2015", concludes that "A worldwide pro-bicycle policy and infrastructure development enabled modal shift like the Netherlands and Denmark can lead to significant untapped climate and health benefits" and quantifies those benefits.

In Copenhagen, of all the trips to work and education in 2018, 49 % were done by bicycle, just one percentage shy from their target of 50% for 2025. City-wide investment in bicycle infrastructure ensures that the majority, including the most vulnerable citizens, have access to cheap and effective modes of transport and reduces the risks of transport accidents and fatalities, particularly for children and the elderly. People-friendly cycling and walking infrastructure help link neighbourhoods in the city and encourage people to 'meet and mix'. Increased bicycle traffic also means reduced car congestion on roads and subsequent reduction in emissions. For instance, a 10 % increase in the cycling share in the capital region of Copenhagen resulted in 6% reduction in total congestion and the 'equivalent of an annual cost-benefit gain of DKK 184 million' (City of Copenhagen, 2019).

A recent analysis (Barban et al., 2022) about the health benefits of a transition to active commuting (by walking, cycling and e-bike) in France found that this "would prevent 9 797 annual premature deaths in 2045 and translate into a 3-month increase in life expectancy in the general population. These health gains would generate €34 billion of economic benefits from 2045 onwards".

Freeing up of public space from motorised transport and the repurposing of those spaces for environmental resilient projects has multidimensional benefits particularly from a planetary health perspective. Some of the benefits include reduction of $C0_2$ emissions and protection from heat island

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effects. The ten case studies presented in (Valdés Cano, 2022) are examples of reclaiming and repurposing of spaces for the public and the environment from across the major global metropolitan cities like Brussels, Barcelona, Medellin, Montreal and Seoul. These projects were aimed at reducing risks associated with climate emergencies and to create climate resilient cities and regions. Some of the strategies of these projects aimed at "reducing space for motorised traffic, encouraging active mobility and the use of public transportation, reclaiming urban spaces for the people, implementing greening strategies and enhancing water and waste management strategies".

Using the Urban and Transport Planning Health Impact Assessment (UTOPHIA) tool and exposure estimates and morbidity data for 1 357 361 Barcelona residents 20 years age or older (as of 2012) (Mueller et al., 2017) concluded that "Not complying with recommended levels for physical activity, air pollution, noise, heat and access to green spaces was estimated to generate a large morbidity burden and resulted in 52 001 DALYs (disability adjusted life-years) in Barcelona each year". Dons et al. (Dons et al., 2018) show a direct correlation between cycling habits (as cycling to work or school) and healthy values of body-mass index.

(Lawrance et al., 2021) have analysed the relation between climate change and its impact on mental health and emotional wellbeing. Mental health issues impact a billion people globally, and result in economic losses (the authors estimate $2.5 trillion in direct and indirect losses). People directly impacted by the effects of climate change (e.g. high temperatures, extreme weather events, food and water insecurity can disproportionately affect women due to the need to manage menstrual hygiene) and the subsequent socio-economic disruption - experience severe crisis. Those in-directly affected by it due to heightened awareness of the impact of climate change, may experience impact on their mental health, particularly the "young people are the generation growing up with full awareness of the climate crisis and with the largest burden to shoulder to adapt and respond to its effects throughout their lives".

There is an urgent need to address the mental health crisis to protect people from its adverse effects. According to a research lead by World Health Organisation (WHO) in collaboration with various research bodies (Chisholm et al., 2016), published on The Lancet Psychiatry, every dollar invested in mental health will have a return of four dollars in better health and ability to work. From a wellbeing perspective, sufficiency becomes desirable as evidence (documented in the previously cited literature) suggests that individual and collective action on climate change can be beneficial for mental health and reduce climate-induced stress and anxiety. Similarly, investing in spaces with vegetation and water can not only help us cope with extreme climate events, but access to such spaces can improve quality of life and contribute to collective wellbeing.

New research is exploring the relationship between wellbeing and economic activity. While Gross Domestic Product (GDP) continues to be used as a metric for measuring the state of the economy and often equating it to development and wellbeing, scholars are challenging GDP as a benchmark and also calling for new ways of measuring development and wellbeing that accounts for the environmental sustainability and social indicators of progress. (Giannetti et al., 2015) present a critical review of indicators proposed as a substitute of Gross Domestic Product GDP, and identify two main approaches:

- one that uses Gross Domestic Product as foundation to build a complete index and includes proposals to greening Gross Domestic Product, socializing the indices and including it in a more comprehensive index.

- a second approach relates to efforts to redefine the indicators, with the use of environmentally oriented indicators and socially oriented measures.

(Giannetti et al., 2015) conclude that "progress indicators measured only in monetary or social terms are limited and restricted to the weak or the medium sustainability model and must be complemented by biophysical indicators." And "Indicators under the strong sustainability perspective make im-

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plicit that the natural capital and built assets are complements (as opposed to substitutes). Only by maintaining both stocks intact can guarantee long-term economic welfare."

The Commission on the Measurement of Economic Performance and Social Progress, convened by the French President, concluded in 2009: "Choices between promoting GDP and protecting the environment may be false choices, once environmental degradation is appropriately included in our measurement of economic performance." (Stiglitz et al., 2009).

In conclusion, ***sufficiency infrastructures*** and ***sufficiency social frameworks*** are desirable as by promoting ***sufficiency habits*** they:

- directly reduce our environmental impact and thereby reduce adverse health effects,
- helps us find meaning in pro-environmental and people-oriented positive actions that contribute to our subjective wellbeing,
- contribute to public health
- and free up public spaces.

4. Why sufficiency is possible

(Millward-Hopkins et al., 2020), based on Rao and Min's (Rao & Baer, 2012) living standards framework, conclude via energy modelling that through the widespread application of strong 'demand-side-reduction' i.e. sufficiency measures and energy efficiency measures, the global energy consumption in 2050 could be reduced to the levels of 1960s, despite a population three times larger. This section reviews a series of studies which similarly have analyzed the potential role of sufficiency in climate protection efforts and plans.
We report in the following a review of reports which aim at estimating scenarios for demand reduction with a relevant role of ***sufficiency habits***, ***infrastructures*** and ***societal frameworks***. One difficulty in this analysis is connected to the use of different nomenclatures, when classifying the actions in the various studies. Not always the distinction between efficiency, sufficiency and effects of local renewable generation is clear-cut in the reports and papers analyzed. For a discussion on nomenclature, see the chapter "Introduction and nomenclature about sufficiency" at the beginning of this report

4.1. A low energy demand scenario for meeting the 1.5 °C target

The paper (Grubler et al., 2018) states, in the abstract: "We project that global final energy demand by 2050 reduces to 245 EJ, around 40% lower than **today,** despite rises in population, income and activity" It is the scenario which leads to the lowest final energy use, among many.
The report introduces the term "use-efficiency", which in the paper is used as a synonym of "sufficiency", for example in the sentence: "Energy-service efficiency is the product of energy-conversion efficiency and **'use efficiency**'."
The authors point out that: "Enormous scope remains to improve **conversion efficiencie**s through technological change and public policy, particularly envelope-pushing standards for buildings and appliances. ***Use efficiency*** is a more complex outcome of the organisational, institutional and infrastructural forms of energy-service provision. These effects are not commonly resolved in global scenario and modelling analysis."

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One sufficiency measure which is made explicit is a convergence of both Global South and Global North to an average floor space /capita of 30 m^2/capita, hence implying a reduction in the space /capita in the North.

Figure 9 shows the potential total final energy demand reductions through a combination of efficiency and sufficiency measures as estimated in the Low Emission Development Pathways by (Grubler et al., 2018) (Table 2, pp 520. It must be also noted that the absolute reduction percentages are different for the 'Global North' and 'Global South' regions; total reductions projected for the 'Global South' are in general lower than the reductions in the 'Global North' between 2020 and 2050. This can be attributed to the much higher projections for increase in activity levels in the 'Global South' relative to the 'Global North', which dampen the net reductions achieved through efficiency gains etc. It is noteworthy that the analysis indicates that activity levels (i.e. the 'quantity' of activity) are anticipated to increase significantly across all categories of economic and social activity except for industrial production.

		Region	% change in activity levels (2020–2050)	% change in energy demand (2020–2050)	Activity levels in 2050	Energy demand in 2050 (EJ)	Total energy demand in 2050 (EJ) (GJ capita^{-1})
End-use services	Thermal comfort	North	6	−74	47×10^9 m^2	8	16 (1.8)
		South	63	−79	218×10^9 m^2	8	
	Consumer goods	North	79	−25	67×10^9 units	13	41 (4.5)
		South	175	54	186×10^9 units	28	
	Mobility	North	29	−60	25×10^{12} passenger km	16	27 (3.0)
		South	122	−59	73×10^{12} passenger km	12	
	Contingency reserve						8
Upstream	Public and commercial buildings	North	49	−64	35×10^9 m^2	5	8 (0.9)
		South	77	−82	68×10^9 m^2	3	
	Industry	North	−42	−57	1.0×10^9 t	26	107 (11.7)
		South	−12	−23	5.4×10^9 t	82	
	Freight transport	North	109	−28	31×10^{12} tkm	11	27 (3.0)
		South	75	−12	51×10^{12} tkm	17	
	International aviation and shipping (bunker fuels)						10
Total		North[a]		−53		82	245
		South[a]		−32		153	

All sub-totals and totals are rounded (lower integer at numerical values <0.5, to upper integer ≥0.5). [a]Contingency reserve of 8 EJ is allocated equally to the global North and global South. Bunker fuels are reported at the global level only, consistent with current energy balances and emission accounting frameworks.

Figure 9 Projected changes in activity levels and final energy demand in the Low Energy Demand (LED) scenario at 2050 by (Grubler et al., 2018), respectively in the Global North and Global South

4.2. Decent Living with minimum energy by Hopkins-Steinberger at al.

Various analysis have established that, after a certain "saturation level" a further increase in energy use or increase in consumption or GDP/capita has no correlation or benefit for human wellbeing (e.g. on life expectancy), individually and collectively.

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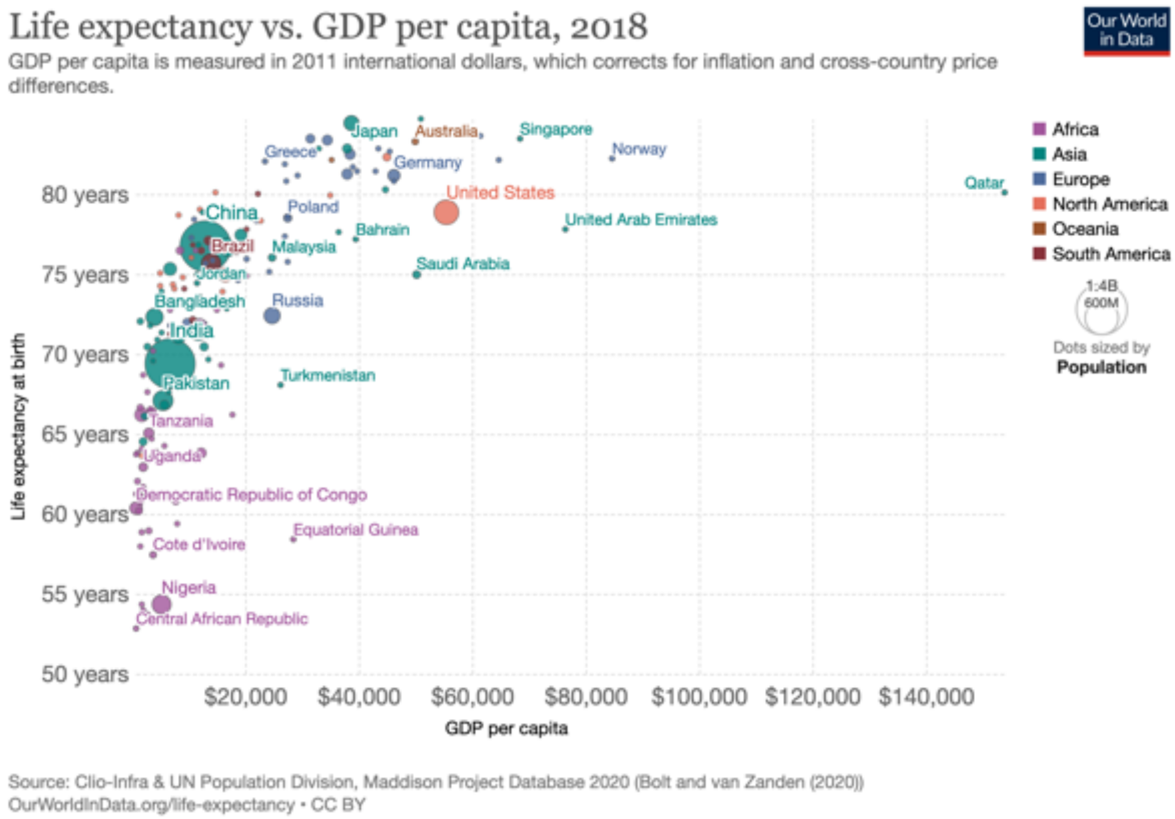

Figure 10 Life expectancy versus GDP/capita, in various countries, in 2018. Source: OurWorldinData.org

Estimating the requirements in energy and materials for human wellbeing is a challenging, but crucial task, for the benefit of the environment.
(Millward-Hopkins et al., 2020) built an energy model upon the existing framework of 'Decent living activities' developed by Rao and Min (Rao & Baer, 2012). This framework primarily attempts at creating an inventory of universal material requirements for fulfilling basic human needs to live a decent life – fulfilling the right[8] to a basic living standard. The framework then further links 'decent living activities' to energy services and then to emissions. Ten major categories of consumption are selected in the study in order to define basic needs: food, shelter, safe water and sanitation, health care, education, transportation, clothing, refrigeration, television and mobile phones. There are two approaches that are identified for estimation of energy requirements: Top-down and bottom-up approach. Top-down approach largely considers empirical data and relationships between social wellbeing (life expectancy, satisfaction, Human Development Index (HDI), SDGs) and environmental impacts. The bottom-up approach compiles consumption inventories of the essential activities and needs of humans, contextualized to the regions and modelled further with energy intensities for each activity. The energy intensities considered in the framework have already assumed certain sufficiency measures such as combination of non-motorized transport, public transport and limited private vehicle use and air travel, the amount of floor space per person as per thermal comfort, etc. Figure 11 shows the energy requirements of decent life activities.

[8] *'Basic rights are the morality of the depths. They specify the line beneath which no one is allowed to sink.'* - Henry Shue (1980), Basic Rights

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DLS dimensions & services	Activity levels		Energy Intensities		
	Default levels	HD	Default (direct)	Default (indirect)	LAT
Nutrition					
Food	2000–2150 kcal/cap/day	15%	–	3 KJ/kilocalorie	30%
Cooking appliances	1 cooker/household	–	0.8 KJ/kilocalorie	1 GJ/app+	50%
Cold Storage	1 fridge-freezer/household	–	0.44 GJ/app+/yr	4 GJ/app+	–
Shelter & living conditions					
Household size	4 persons/household	−25%	–	–	–
Sufficient space	15 meters^2 floor-space/cap*	80%	–	2–4 GJ/m^2	100%
Thermal comfort	15 meters^2 floor-space/cap*	80%	20–60 MJ/m^2/yr	–	300%
Illumination	2500 lm/house; 6 hrs/day	100%	150 lm/W	14 MJ/house/yr	–
Hygiene					
Water supply	50 Litres/cap/day	100%	–	5–17 KJ/L	–
Water heating	20 Litres/cap/day	100%	96–220 KJ/L	–	50%
Waste management	*Provided to all households***	–	–	180 MJ/cap/yr	200%
Clothing					
Clothes	4 kg of new clothing/year	33%	–	100 MJ/kg	–
W ashing facilities	80 kg of washing/year	33%	2.4 MJ/kg	2 GJ/app+	–
Healthcare Hospitals	200 meters^2 floor-space/bed	50%	410–560 MJ/m^2/yr	14–23 GJ/m^2	130%
Education Schools	10 meters^2 floor-space/pupil	50%	100–130 MJ/m^2/yr	4.5–7.5 GJ/m^2	150%
Communication & information					
Phones	1 phone/person over 10yrs old	–	28 MJ/phone/yr	110 MJ/phone	30%
Computers	1 laptop/household	–	220 MJ/laptop/yr	3 GJ/laptop	30%
Networks & data	*High***	100%	–	~0.4 GJ/cap/yr	–
Mobility					
Vehicle production	*Consistent with pkm travelled***	–	–	0.1–0.3 MJ/pkm	50%
Vehicle propulsion	5000–15,000 pkm/cap/year	3–10%	0.2–1.9 MJ/pkm++	–	100%
Infrastructure	*Consistent with pkm travelled***	–	–	0.1–0.3 MJ/pkm	–

* Assuming 10 m^2 of living space/capita plus 20 m^2 of communal space/house; with the latter divided by four, we get 15 m^2/capita overall.
** Activity levels here are not straightforward to define.
\+ 'App' refers to 'appliance'.
\+\+ Large range as this covers different modes (public transport to passenger flights).

Figure 11 Inventory of the prerequisites for Decent Living Standards (DLS) (Rao and Min, 2018a) alongside activity levels and direct and indirect energy intensities of products, supply chains and infrastructure. Numbers are rounded and presented as ranges where there are variations between countries or sub-activities (e.g. different transport modes). Approximate percentage increases for Higher Demand (HD) and Less Advanced Technology (LAT) scenarios are included where possible, but these cannot always be summarised in this high-level format.

According to the energy modelling, the final energy consumption in 2050 would increase to 13-18.4 GJ (3611-5111 kWh)/cap/year across all 119 countries. The current energy consumption considering the energy deficit and surplus consumption due to inequalities ranges from 5 GJ/cap/year to 200 GJ/cap/year - a level of inequality in energy use that mirrors environmental pressures.

One of the findings of the study reveals that the vast majority of countries (as high as 100 countries) are living in energy surplus. "In the Global North, the trends towards sufficiency-levels of consumption that exist – such as Transition Towns and the minimalism movement – are notoriously middle class and white, and are the exception rather than the norm. In the Global South, consumption of the upper-classes has leapt well beyond sufficiency levels, while hundreds of millions remain left in poverty.*" (Millward-Hopkins et al., 2020)

Considering a lower level of ambition, the energy modelling has considered other three situations besides the Decent Living Energy (DLE) scenario: 'Higher Demand (HD)', 'Less Advanced Technologies (LAT)' and a combination HD-LAT, and Figure 12 shows the energy consumption in the four scenarios modelled for 3 countries India, Brazil and South Africa.

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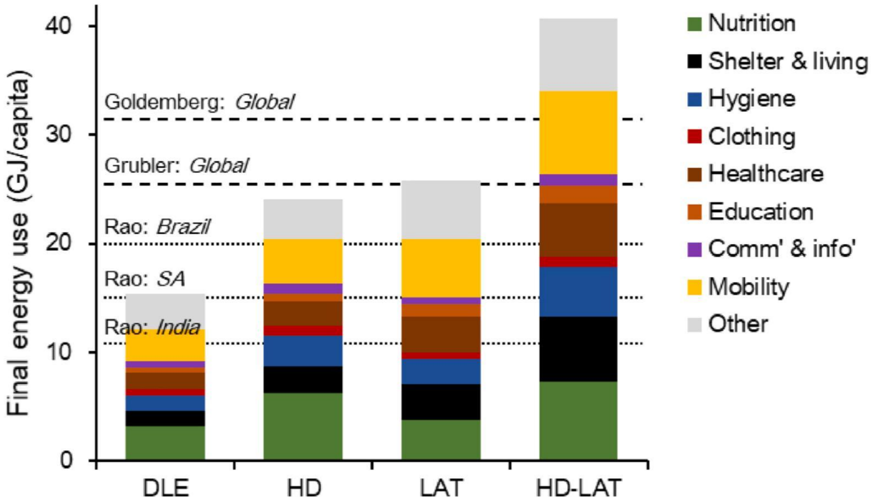

Figure 12 Globally averaged Decent Living Energy (DLE) per capita in 2050 and three scenarios with rolled-back ambition, i.e. higher demand (HD), less advanced technologies (LAT), and higher demand and less advanced technologies together (HD-LAT). Thresholds for energy use from scenarios by other authors are also shown, as described in the text. Note, SA = South Africa.

(Millward-Hopkins et al., 2020) compare the final energy use of the scenario they developed to scenarios of other authors. E.g. they state "An early bottom-up estimate was made by (Goldemberg et al., 1985). They compiled an inventory of activities across residential (cooking, food storage, etc.), commercial (floor space), transportation (private, public and freight), manufacturing (steel, cement, etc.) and agricultural (food) sectors. Together these were suggested to provide 'basic needs and much more', for only 30 GJ/cap/yr of final energy consumption annually. Most recently, Rao et al. (2019) estimated that 12–24 GJ/cap of final energy consumption annually would be required to provide decent material living standards in India, Brazil and South Africa. They used a similar inventory to Goldemberg et al., but included modern communication and information technologies, education, healthcare and water provision (among other things) and, in addition, made robust estimates of indirect energy use."
The above values, and in particular those of the Decent living standards framework (DLS), provide potential benchmarks for the design or evaluation of ***sufficiency infrastructures*** and ***sufficiency societal frameworks.***

4.3. World Energy Outlook 2020 by the International Energy Agency

The World Energy Outlook 2020 (Cozzi & Gould, 2020) provides details and stipulations in sectors such as energy, air pollution, GHG emissions and how behavioural changes impact them in attaining net-zero emissions by 2050.
This report is probably the first attempt by the International Energy Agency (IEA) to introduce into its scenarios "behaviour changes" and estimate quantitatively their potential impact. Considering the list of actions analyzed by IEA, it is apparent that they coincide with what we defined in this report as ***sufficiency habits.***

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Behaviour change		Emissions savings ($Mt\ CO_2$)			Cumulative savings ($Mt\ CO_2$)	Share in 2030
		2021	2025	2030	2021-30	
Space heating	Reduce space heating temperature by 3 °C.	460	400	300	4 340	11% of residential emissions.
		33%	23%	15%	23%	% of total savings.
Space cooling	Raise air conditioning temperature by 3 °C.	95	95	45	860	2% of residential emissions.
		7%	5%	2%	5%	% of total savings.
Line-drying	Line-drying instead of tumble-drying during summer months.	65	55	30	550	1% of residential emissions.
		5%	3%	1%	3%	% of total savings.
Laundry temperature	Wash on average 10 °C colder.	30	25	15	270	1% of residential emissions.
		2%	1%	1%	1%	% of total savings.
Driving more slowly	Reduce driving speed by 7 km/h.	420	400	340	4 280	7% of road transport emissions.
		30%	23%	17%	23%	% of total savings.
Eco-driving	Avoid sudden acceleration, stops or idling; early upshifting.	30	160	290	1 670	6% of road transport emissions.
		2%	9%	14%	9%	% of total savings.
Ride-sharing	Share all urban car trips.	20	100	190	1 100	9% of passenger car emissions.
		2%	6%	10%	6%	% of total savings.
Cycling and walking	Cycle or walk all car trips that would take less than ten minutes to cycle.	15	75	140	820	7% of passenger car emissions.
		1%	4%	7%	4%	% of total savings.
Mobile air conditioning	Raise air conditioning temperature in cars by 3 °C.	120	110	90	1 160	4% of passenger car emissions.
		9%	6%	4%	6%	% of total savings.
Working from home	20% of global workforce works from home 3 days of the week.[7]	80	75	55	800	3% of passenger car emissions.
		6%	4%	3%	4%	% of total savings.
Passenger aviation	Total passenger aviation.	50	260	520	2 850	60% of aviation emissions.
		4%	15%	26%	15%	% of total savings.
	Replace all flights less than 1 hour.	10	50	100	550	11% of aviation emissions.
	Replace three-quarters of all business flights.	25	120	240	1 340	28% of aviation emissions.
	Replace three-quarters of long-haul flights.	35	170	350	1 910	40% of aviation emissions.
Total		**1 390**	**1 750**	**2 010**	**18 700**	

Figure 13 Energy savings in various sectors via « behaviour changes » estimated by IEA. Source: (International Energy Agency, 2020)

Behaviour changes play a major role in the Sustainable Development Scenario (SDS) and Net Zero Emissions scenario (NZE) 2050. Behavior changes account for around 9% of the difference in CO_2 emissions between the Stated Policy Scenario (STEPS) and the SDS in 2030.

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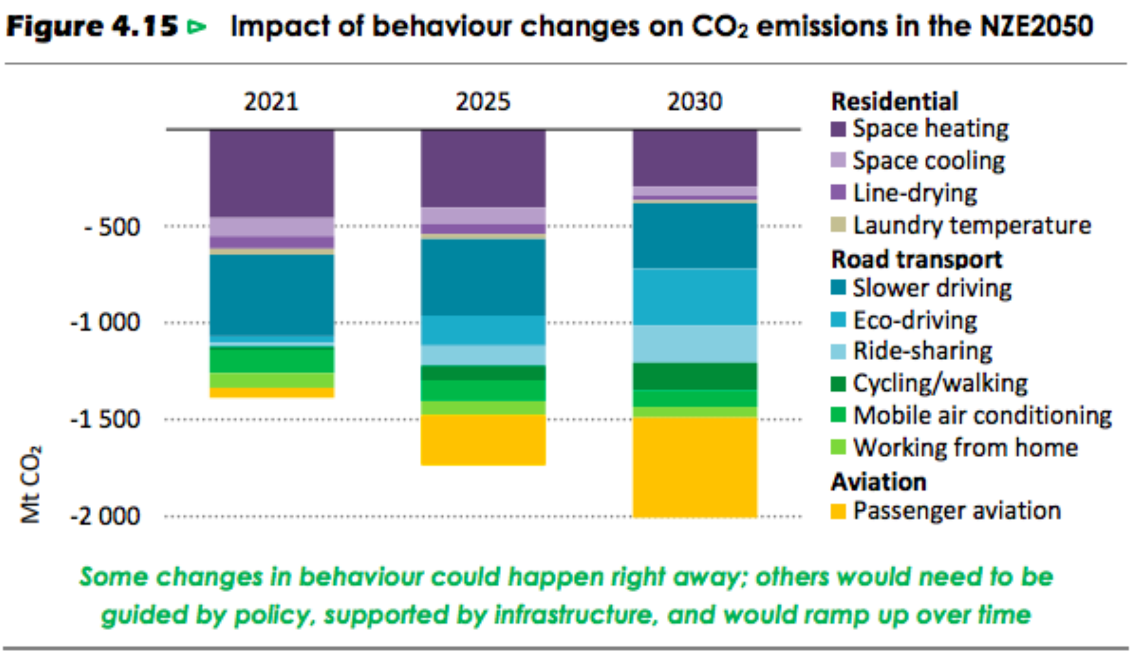

Figure 14 Energy savings in various sectors via « behaviour changes » estimated by IEA. Source: (International Energy Agency, 2020)

Over half the emissions savings for NZE2050 that can be achieved via behaviour changes are in road transport. A quarter of emission savings stems from reduced passenger aviation. The remaining percentage of emissions savings comes from behavioural changes at home.
The report analyses private mobility and notes that, on average, people make short distance drives more frequently than long distances. It is estimated that 60 % of car journeys worldwide are less than 10 km, whereas around 5 % are farther than 50 km. Hence, if half of all the car trips that fall under less than 5 km distance were to shift to bicycles or a less energy intensive method, more than 130 Mt CO_2 can be saved. If eco-driving were to be adopted by half of the drivers globally, it would reduce emissions by more than 330 Mt CO_2. If temperature on average were to be increased by 3°C, emissions related to mobile air conditioning in cars would be reduced by 4 %.
Driving slowly is one of the areas with the highest potential to reduce fuel consumption and, thereby, emissions. Driving in the lowest practical speed at the highest gear helps achieve maximum reductions, which corresponds to around 65-80 km/h for most cars. If there were to be an average 7 km/h reduction in speed for all road traffic, this would reduce emissions today by about 400 Mt CO_2. Another behaviour change is carpooling. If half of all urban trips were to be shared, it would save nearly 100 Mt CO_2 in 2030.
In mobility, given the change in energy mix and taking into consideration the difference in types of vehicles in different regions, it is estimated that around 18 Mt CO_2 can be saved globally if everyone who is able to, is to work from home. If working from home rather than travelling to work can cut emissions by a significant margin, it goes without saying that air travel provides another high potential area. Based on the efficiency of the aircrafts currently, halving business trips that fall under 6 hours of travel time would save around 50 Mt CO_2.
In the residential sector, depending on the region of residence, heating and cooling of spaces has a large potential for reducing emissions. Lowering the heating temperature by 1 °C can reduce energy demand by 6-9%, if all buildings were to reduce their indoor temperatures by 3 °C in the cold season, 450 Mt CO_2 could be saved every year globally.
For cooling demands, emissions would decrease by 7 % for each 1°C increase in target temperature, saving more than 30 Mt CO_2. Drying clothes takes up 8 % of global energy consumption for domestic appliances. If this was replaced by line drying in the six sunny months of the year, we would save around 30 Mt CO_2 in 2030.
A number of demand reductions analysed by the IEA report are based on the availability of strong public transport infrastructure, e.g. high speed trains to substitute part of the air travels.
Savings in energy use by car are considered via reduction in speed limits, which can deliver impressive savings. Quite likely additional relevant savings might come by investments in small range train

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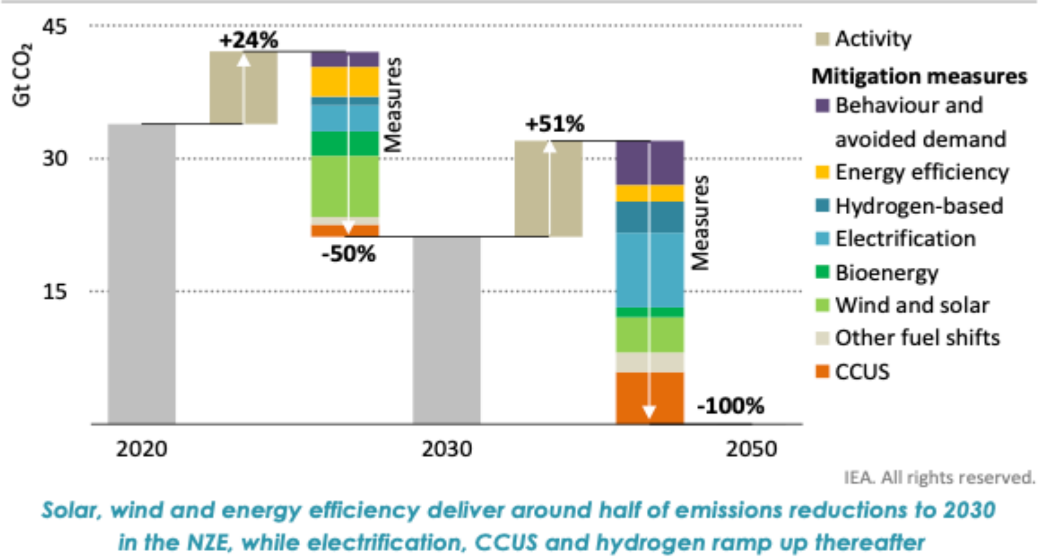
and public transport networks, to further reduce use of individual vehicles, and by setting limits to their weight. Overall most of the measures analysed by IEA require enabling ***sufficiency infrastructures*** and a ***sufficiency societal framework.***

4.4. IEA report « net Zero by 2050 » and comfort assumptions

The report (*Net Zero by 2050 - A Roadmap for the Global Energy Sector*, 2021) was prepared for the 26th Conference of the Parties (COP26) of the United Nations Framework Convention on Climate Change in Glasgow.
This IEA analysis confirms the quantitative relevance of ***sufficiency habits*** and the need of ***sufficiency infrastructures*** and of a favourable ***sufficiency societal framework*** to activate them.



Notes: Activity = energy service demand changes from economic and population growth. Behaviour = energy service demand changes from user decisions, e.g. changing heating temperatures. Avoided demand = energy service demand changes from technology developments, e.g. digitalisation. Other fuel shifts = switching from coal and oil to natural gas, nuclear, hydropower, geothermal, concentrating solar power or marine.

Figure 15 Emission reductions by type of mitigation measures in the NZE 2020-2050 scenario. Source: (Net Zero by 2050 - A Roadmap for the Global Energy Sector, 2021)

The report states: "Many [behaviour changes] would also require new infrastructure, such as cycle lanes and high-speed rail networks, clear policy support and high-quality urban planning" and: "**Three-quarters of the emissions reductions from behavioural changes in the NZE are achieved through targeted government policies supported by infrastructure development**, e.g. a shift to rail travel supported by high-speed railways. The remainder come from adopting voluntary changes in energy saving habits, mainly in homes. Even in this case, **public awareness campaigns can help shape day-to-day choices** about how consumers use energy."

We analyse in the following an area where the IEA analysis possibly underestimates the potential of changes in sufficiency habits: the provision of summer comfort. This service will be in the next decades under upward pressure due to the combination of (expected) income increase in the global south and the increasing temperatures at global and local level.
Figure 16 shows some of the assumptions in the study; we notice that even under the behaviour change scenario it is assumed to adopt set points in summer of 24-25 °C. These values are compatible with a very restrictive application of the Fanger model, with relatively heavy clothing (clo=1)

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for summer and no air movement and a target of Predicted Mean Vote (PMV)[9] = 0,5.

Figure 16 IEA states the need of behavioral changes and provides estimates of their effect. Source: (Net Zero by 2050 - A Roadmap for the Global Energy Sector, 2021)

On the other hand, recent developments in comfort studies, based on the Global Comfort Database II and summarised in the revision of standard ASHRAE 55:2020, show the importance of air velocity in the provision of comfort in summer. The same level of comfort (PMV = 0,5) can be achieved with lighter clothing level (clo = 0,5) air velocity between 0,4 and 1,4 m/s, with temperatures between 28 and 30 °C. Those air velocities in some weather conditions may be achieved with natural ventilation produced with a correct geometry of the building openings or artificially with e.g. large ceiling fans, an old appliance now significantly improved in efficiency, silent operation, remote controls that allow integration in building energy management systems if desired.

Box : how the appropriate choice of comfort variables and their values can provide comfort with low energy use

Erba and Pagliano (Erba & Pagliano, 2021) offer a synthesis of how recent advances in comfort models are now embedded in comfort standards and allow via the use of updated indicators (*"here and now"* indicators such as PMV, SET, adaptive comfort, and *long term* indicators based on the previous ones, to <u>design (spaces and legislation) for sufficiency.</u> The choice of the "comfort scenario" to be reached has a strong influence on the energy needs.

Comfort Scenarios, including Air Velocity and Ceiling Fans

A tendency to develop an architecture fully detached from the external environment and to aim at maintaining internal spaces strictly controlled in terms of temperature and humidity and with essentially zero air movement has dominated the second part of the XX century and the start of the XXI. This was paralleled by a rather narrow interpretation, by the construction and systems industry, of the then predominant comfort model, developed by Fanger (Fanger, 1970), proposed for application in mechanically controlled environments. In reality, the model allows for a rather large range of temperatures, also depending on clothing and chair insulation and activity levels, and does not mandate a narrow range of humidity.

Fanger states that "the influence of humidity [on comfort] is small" and presents calculations and graphs showing that a change of 1% R.H. produces changes of 1/100 to 1/1000 of a unit of PMV, while the comfort range spans from −1 to +1 in terms of PMV.

[9] PMV is one of the available indicators of comfort sensation by occupants in buildings

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At the same time, the adaptive comfort model has been developed based on a large body of data in real buildings and was included in standards (EN 16798 and ASHRAE 55) for non-mechanically conditioned spaces and for conditioned spaces when systems are turned off. The necessity for an extension of the PMV model was acknowledged also by Fanger. The adaptive comfort model, which proposes a linear positive correlation of summer indoor comfort temperature with the average outdoor temperature in the previous week, allows for lower ***energy needs*** when compared to a restrictive interpretation and application of the Fanger-PMV model, while providing adequate comfort, based on a very large database of measurements and surveys.
Finally, **the role of air velocity in providing comfort** in the warm season at temperatures higher than calculated with the PMV formula has been confirmed in a long series of experiments and included in both EN 16798:2017 and ASHRAE 55:2020. By adopting higher air temperatures during warm seasons, building operators may reduce HVAC energy use by approximately 7–10 percent per degree Celsius of temperature increase.

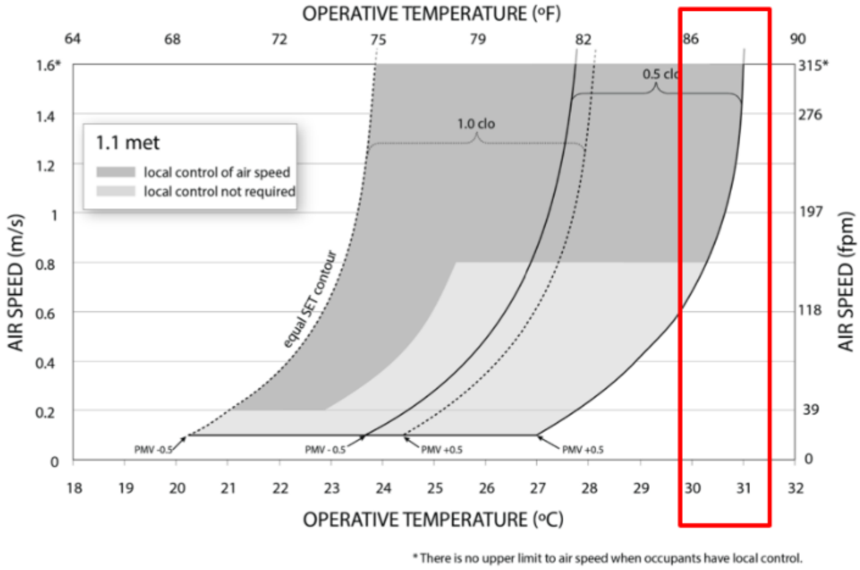

Figure 17 Elevated air speed comfort method. The same level of comfort (e.g. PMV = 0,5) can be achive at low temperature with no air movement and at higher temperatures with air movement. Source: (ANSI/ASHRAE Standard 55-2020. Thermal Environmental Conditions for Human Occupancy, 2020, p. 2020)

However, in spite of the fact that results from over 35 000 occupant surveys contained in the ASHRAE Global Thermal Comfort Database show that occupants prefer more air movement than they are currently experiencing in buildings, designers still have little guidance for designing rooms with ceiling fans (spacing, sizing and cooling effect) and rarely ceiling fans are considered in the energy concept at the design stage and actually installed and coordinated with the lighting design. A new design and sizing tool has been created and made available by the Berkeley group, which also provided results and analysis from the largest study to date of air speeds generated by ceiling fans. **The possibility to apply** (as a user of a building as much as a designer of a building) **efficiency/sufficiency measures such as night ventilation in summer nights and use ceiling fans during the day instead of (or to reduce use of) air-conditioning** depends on explicit recognition at the regulation level of the following issues:
(1) In summer, the same level of thermal comfort, as measured, e.g., via the index predicted mean vote (PMV), can be achieved via various combinations of the physical parameters (operative temperature, relative humidity and air velocity), each scenario leading to different values of energy needed for cooling and energy needed for dehumidification (if any).
(2) **The choice of the comfort category** (I, II or III according to EN 16798-1 (EN 16798-1:2019-Indoor environmental input parameters for design and assessment of energy performance of buildings add, 2019), formerly known as EN 15251 (EN 15251:2007 - Indoor environmental input pa-

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rameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, 2007), or A, B and C according to ASHRAE 55 (ANSI/ASHRAE Standard 55 - 2017. Thermal Environmental Conditions for Human Occupancy, 2017, p. 55)), which is aimed at the building design and/or controls that strongly affect energy needs.
(3) A number of research works show that comfort category I (A), which is the more energy demanding, cannot be perceived subjectively and it is below the accuracy of measurements. In the EU standard (EN 16798-1 (EN 16798-1:2019-Indoor environmental input parameters for design and assessment of energy performance of buildings add, 2019)), category I (A) is reserved to buildings occupied by people with special needs (children, elderly, persons with disabilities, etc.), but it may nevertheless be perceived by designers and presented to clients/operators as the “best” condition.
(4) An important parameter affecting comfort in the warm season is the **insulation level of clothing and of furniture,** as e.g., office chairs (both measured in the unit clo and with indicative values reported e.g., in ISO 7730 (ISO 7730:2005. Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, 2005)). Regulation and cultural norms may actively and explicitly promote the adoption of dressing codes where **light clothing in summer is the norm rather than the exception** (see e.g., the Cool Biz program in Japan) **and office furniture is chosen with low thermal insulation**.

4.5. 1.5-Degree Lifestyles: Targets and options for reducing lifestyle carbon footprints

The study by Lewis et al. (Lewis Akenji, Magnus Bengtsson, Viivi Toivio, et al., 2021) estimates that for meeting the 1,5 °C target we need to aim for lifestyle-related carbon footprints of 2.5 (tCO_2e/cap/y) in 2030, 1.4 by 2040, and 0.7 by 2050.
The study identifies “hotspots: focusing efforts to change lifestyles in relation to these areas would yield the most benefits: meat and dairy consumption, fossil-fuel based energy, car use and air travel. The three domains these footprints occur in – **nutrition, housing, and mobility** – tend to have **the largest impact (approximately 75%) on total lifestyle carbon footprints.**
Based on the domain-specific gap analysis with the targets, **the required footprint reductions in the case of developed countries** are at least 47% in nutrition, 68% in housing, and 72% in mobility by 2030 and over 75% in nutrition, 93% in housing, and 96% in mobility by 2050.”

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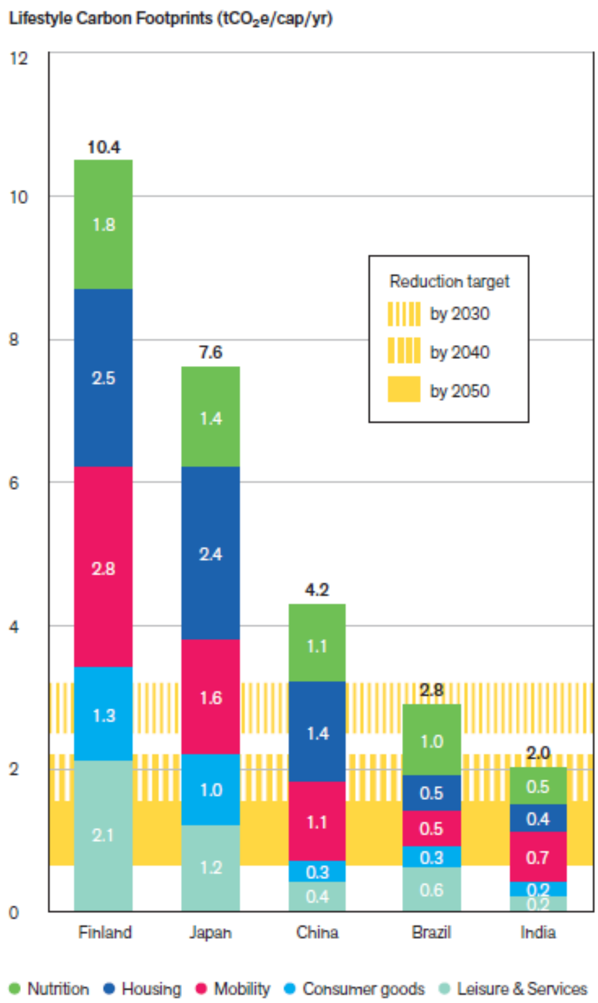

Figure 18 Average per capita life-style carbon footprint per country estimated as of 2017. The lower and upper limits of horizontal lins indicate 1,5D (1,5 °C without/less use of CCS) and 2S (2 °C with CCS) targets, respectively

"The common options in both countries [Finland and Japan] with the **largest reduction potential** of 500 to over 1,500 kg per option on average, are **car-free private travel**, use of renewable energy from the grid, **vegetarian diets**, renewable off-grid energy, hybrid cars, and vehicle fuel efficiency improvement. For Finland they also include **vegan diets** and heat pumps for temperature control. Options with the next largest reduction potentials of 250 to 500 kg per option on average are **ride-sharing, living closer to workplace**, heat pumps for temperature control, **car-free commuting**, alternative dairy products, **low-carbon protein instead of red meat**, and **smaller living spaces**" (pp 27-29).

This scenario uses ***sufficiency habits*** (which we indicated in **bold** in the previous quote), but also efficiency and renewable options. Hence for the purpose of the Fulfill project, we would need to extract from this report the potential of the sufficiency actions only, to the extent possible.

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*Figure 19 Carbon footprint reductions due to various **sufficiency habits**, and technical efficiency measures, as a function of adoption rates, for Finland.*

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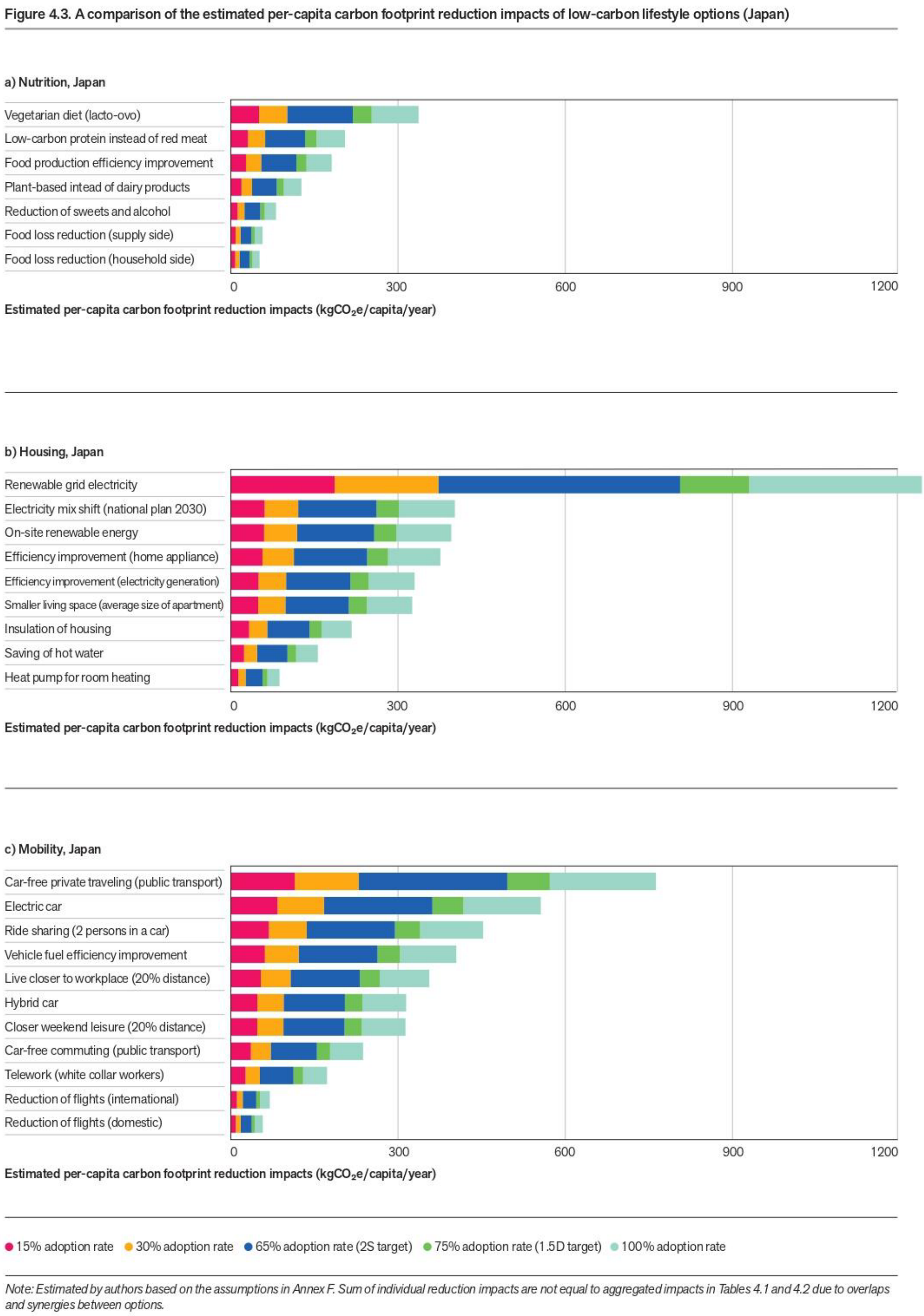

Figure 20 Carbon footprint reductions due to various ***sufficiency habits****, and technical efficiency measures, as a function of adoption rates, for Japan.*

The authors perform a 'what if evaluation' to assess the impact of various levels of adoption rate. "The percentage of the population who will change their behaviours and the extent each individual goes to are critical when estimating impact, thus we show different adoption rates in this study. "Full implementation", as it suggests, means individuals fully implement the low-carbon option and generate maximum reduction potentials. "Partial-adoption" means the options are partially adopted,

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either by individuals or at the society level." (p 27). Analysis of this type might prove very useful for designing public policiesand setting priorities for the deployment of ***sufficiency infrastructures*** and for the creation of an overall ***sufficiency social framework.***

4.6. A 10-Point Plan to Cut Oil Use, by the IEA

In the study (*A 10-Point Plan to Cut Oil Use*, 2022) the distinction between sufficiency and efficiency is clear-cut. The document is very important since it shows ***how quickly some sufficiency measures can be deployed***. It concludes that with a series of sufficiency measures the oil consumption in Europe might be cut by 6 % in just four months. Out of the 10 points proposed 9 are about ***sufficiency habits*** and only one about increasing technical efficiency.

The actions proposed by the IEA in the field of mobility	**Savings in thousands of barrels of oil per day (kb/d)**
Car-free Sundays in cities	Every Sunday: savings of 380 kb/d, only 1 Sunday per month: 95 kb/d
Working from home up to three days a week where possible	1 day: saving 170 kb/d, 3 days: 500 kb/d
Making the use of public transport more economical (even to the point of free travel) and encouraging micro-mobility, walking and cycling	Savings of: 330 kb/d, alternating access by private car to roads in large cities: 210 kb/d
Reduce speed limits on highways by at least 10 km/h	Savings of: 290 kb/d of oil consumption from cars and others 140 kb/d from trucks
Increase car sharing and adopt practices to reduce fuel consumption	Savings of: 470 kb/d
Promoting efficient driving for goods trucks and goods delivery	Savings of: 320 kb/d
Using high-speed and night trains instead of planes where possible	Savings of: 40 kb/d
Avoiding business air travel where alternative options exist	Savings of: 260 kb/d
Alternate private car access to roads in large cities (odd/even license plate policy for weekday access)	Saves around 210 kb/d.
Reinforce the adoption of electric and more efficient vehicles **(efficiency)**	Savings of: 100 kb/d

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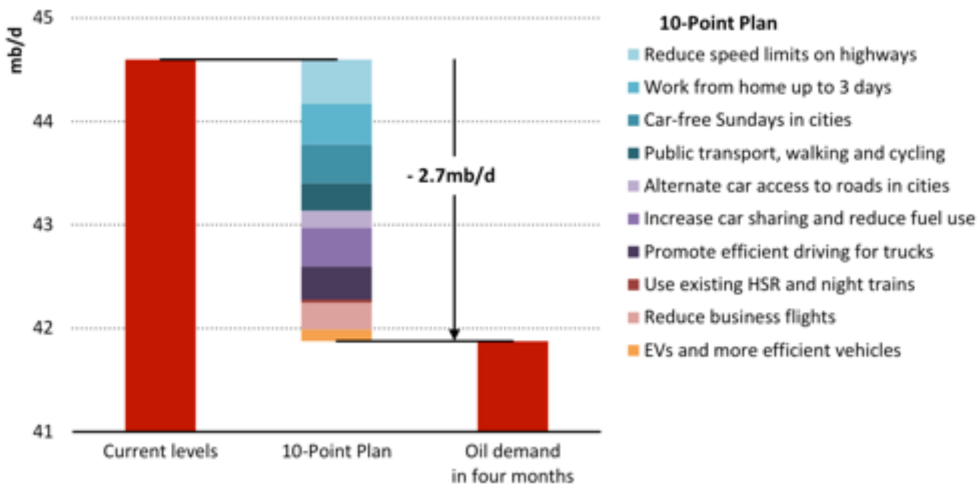

Figure 21 Oil demand reduction in advanced economies within four months in the 10-Point Plan by IEA

5. Literature of Relevance for WP3 Micro Level

The world is witnessing extreme ecological crises in the form of droughts, floods, heat waves, biodiversity loss, among others. There is a growing public discourse on the ways *single citizens* can contribute to mitigate the impending climate catastrophe. As we have seen in the previous chapters most analysts agree that the action of individuals towards sufficiency needs enabling ***infrastructures*** and ***social frameworks***. Not only academic research reaches this conclusion but also the analysis of intergovernmental institutions as e.g. the International Energy Agency.

In spite of the awareness of the interconnection among the various level of action, methodologically it is useful to perform, to the extent possible, an analysis of literature separately for the micro, meso and macro level.

This section focuses on the micro level, analyzing specific lifestyles or ***sufficiency habits*** by individuals and their role in mitigating the climate crisis.
It should be noted that the discourse does not negate the long existing individual practices that have long informed sustainable ways of life. Instead, it is an attempt to bring together information on specific lifestyle practices that have a significant impact on the environment as a whole and how the reduction of energy intensive lifestyle practices can make significant changes. Therefore, individual practices are not seen as disconnected from the larger social context.

The two ambitious reports “1.5-Degree Lifestyles: Towards A Fair Consumption Space for All” (Lewis Akenji, Magnus Bengtsson, Viivi Toivio, et al., 2021) and “The Future of Urban Consumption in a 1.5°C World” (C40 Cities Climate Leadership Group et al., 2019) are impressive in their scope and instrumental in recognizing which particular lifestyles cause the most damage to the environment. Subsequently, the indicators identified in the report can be focus areas for reduction of energy consumption practices. The reports define lifestyle ‘clusters of habits and patterns of behaviour embedded in a society and facilitated by institutions, norms and infrastructures that frame individual choice’ (Akenji and Chen 2016).
The four broad high energy consumption identified domains are: **food, personal transport, housing, and consumer goods.** According to the report, “eating meat, using fossil fuel cars, flying, and large and high energy-consuming houses are especially problematic.” (Lewis Akenji, Magnus Bengtsson, Viivi Toivio, et al., 2021).

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The study concludes " If C40 cities are to cut their consumption-based emissions in half by 2030 and reduce them by 80% over the period up to 2050, **it is critical** that largescale behavioural changes occur as soon as possible, and **that governments and businesses support a swift transition to more sustainable consumption through policy incentives and new business models**." Also this reports hence recognizes the need for individual change in habits and the need for a supportive ***sufficiency social framework.***

Since the emphasis is on micro-level efforts by individual practices, there are many changes that can be made at an individual level that can lead to a cumulative reduction on a systemic level. For instance, housing can determine a lot of factors like the heating/cooling requirements, water, appliances and transport. The Darwin Project in Bordeaux sets a great example of these changes implemented in practice. It comprises a set of eco-renovated buildings with sufficiency principles like no air conditioning, low-tech techniques among others where residents are empowered to "live' sufficiency behaviours (Toulouse et al., 2017) and https://darwin.camp/projet-darwin/un-eco-systeme-ecolo/
High meat and dairy consumption are a large source of emissions, particularly in high income countries. There are examples of initiatives to encourage a practice of reduction in the amount of meat, as a (mandatory) weekly vegetarian day in schools, as discussed in France. This activity has roots in religious/cultural practices and may have a greater acceptance rate as a collective activity (Toulouse et al., 2017).
A number of significant energy consumption activities like laundry, dishwashing, fridge-freezer units, dishwashers, drying units, electric ovens, etc. are also connected to the size of housing. The increase in single family homes means an increase in purchase of appliances. As shown by Darby (2007) & Calwell (2010) (from (Brischke, L.-A., F. Lehmann, L. Leuser, S. Thomas, and C. Baedeker., 2015)), energy efficient appliances did not result in absolute reduction of energy demand of households. Therefore, the use of energy efficient appliances has to be coupled with sufficiency lifestyle practices. For example individuals in the same building or set of buildings may start sharing laundry and other related appliances, as demonstrated for example by the case of Pumpipumpe in Switzerland. This initiative supports sharing of consumer goods aimed at reducing buying of new products and promoting sufficiency-based lifestyle and in-person community interaction (https://pumpipumpe.ch/en/home-en/).
In the following we review some pieces of literature which deal with individual motivations for change and (supposed) motivations for delay, resistance to change.
Some authors, such as (McLoughlin et al., 2019) try to analyse the role of values as "the 'bedrock' on which specific attitudes are founded." They state that: "people who favour so-called 'self transcending' values (which go beyond self-interest, such as altruism or forgiveness) tend to be more likely to be concerned about climate change and support low-carbon policies. People who lean towards 'self-enhancing' values (i.e. self-focused values such as power, ambition and materialism) tend to be less engaged."
Lamb et al. (Lamb et al., 2020) analyse typologies for delaying action which might be use useful for analysing individual behaviour and designing social frameworks and communication to counteract those tendencies to delay : "In contemporary discussions on what actions should be taken, by whom and how fast, proponents of climate delay would argue for minimal action or action taken by others. They focus attention on the negative social effects of climate policies and raise doubt that mitigation is possible. Here, we outline the common features of climate delay discourses and provide a guide to identifying them…. Delay discourses can be grouped into those that: (1) redirect responsibility; (2) push non-transformative solutions; (3) emphasize the downsides of climate policies; or (4) surrender to climate change."
On the other side, there are positive signs about attitudes coming from a series of surveys. For example a number of recent surveys show a high level of awareness about climate change and attitude to change, such as a survey by ADEME on attitudes about use of energy (*Représentations sociales du changement climatique*, 2019) and by the Pew Research Center on support to climate mitigation policies and lifestyle changes (Stokes et al., 2015).

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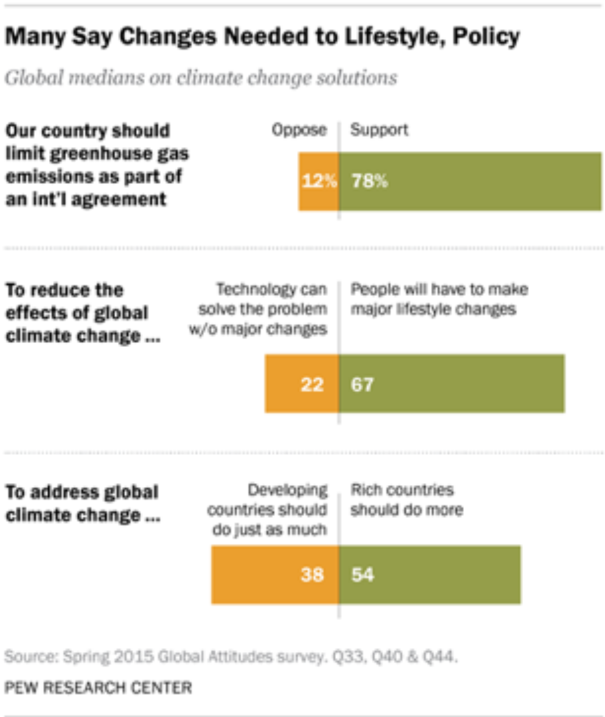

Figure 22 Some results of 2015 Global Attitudes survey by PEW research center

A representative sample of the Austrian population (14 years and older) was asked in August 2020 about their attitudes currently and in the future. The survey found that 70% of the respondents would like to at least partially reduce personal consumption in the future (Riefler, 2020), quoted in (Zell-Ziegler et al., 2021).
A survey by McKinsey (*Why micromobility is here to stay | McKinsey*, 2021) in mid-2021 has found a large availability to commute to work by bike, light motorcycle or other micromobility devices (see Figure 23)

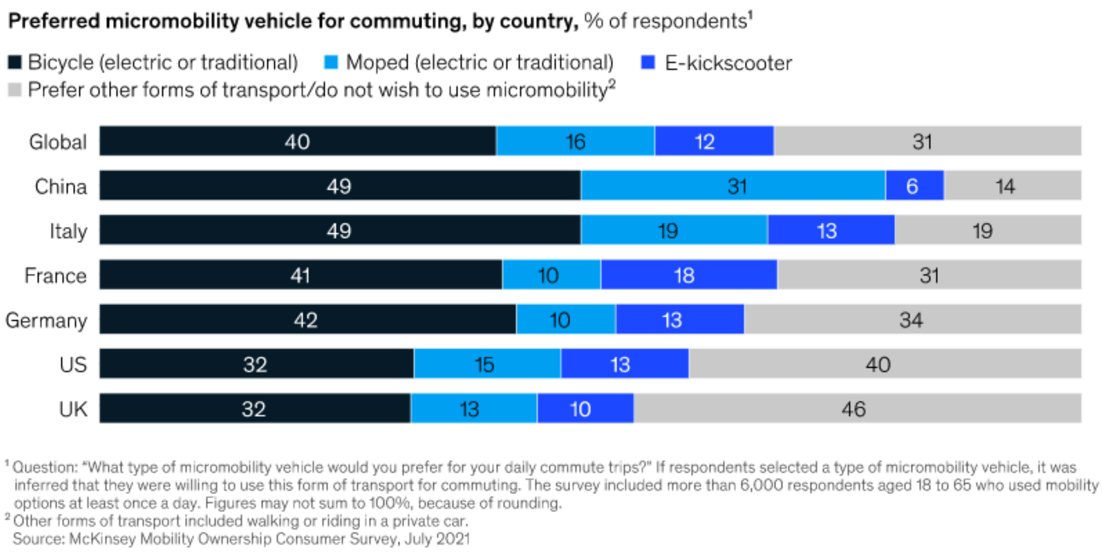

Figure 23 Attitudes towards micromobility, in a survey by McKinsey&Company in 2021. Almost 70% of respondents stated that they are willing to use micromobility for their daily commute.

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6. Literature of Relevance for WP4 - Meso Level

The existing framework of discourse on sustainability does not just point out the environmental impacts of certain actions by individuals, but also emphasises the importance of community engagement and municipal level actions that can catalyse the road to sustainability. In this section we review and summarise some pieces of literature about this "meso" level.

One such example is the Copenhagen bicycle strategy. The urban planning of Copenhagen has been revisited in order to make the city an Environmental Capital. The city council is trying to approach carbon neutrality by 2050 in innovative ways. They are approaching this by actively getting Copenhageners to cycle, making space for bikers by expanding the cycle track networks and providing other infrastructural support to get the citizens to adopt biking. The bicycle share of trips to work and education situated within the city limit rose from an already remarkable 41% in 2016 to 49% in 2018. The city is now only one percentage point away from reaching its target of a 50% bicycle share in 2025 (City of Copenhagen, 2019). This is a change at both personal and communal level, but the council is making changes at a policy level to achieve their targets.

Those achievements in Copenhagen did not come overnight. Denmark along with Germany and the Netherlands has been working towards motor free roads in their cities for decades. The way that these countries have achieved cycling to the numbers that they have now, seems to be by the act of cycling being complemented with extensive bike parking spaces, full integration with public transport, along with a wide range of promotional events to generate enthusiasm and support to opt for cycling. Along with policies that support and encourage pro cycling, they also make driving expensive through taxes and restrictions on ownership of cars (Pucher & Buehler, 2008).

According to the 'case studies on transport policy' published by the Lund University Centre for Sustainability Studies more than 75 % of the urban innovations that successfully reduced car use have been led by a local city government. What seems to have been the most effective are specifically those that drive these conditions along with an ancillary policy to support it, much like the example in Germany, Denmark and the Netherlands. The supporting policies include congestion charge, parking and traffic controls, and increase in car taxation (Nicholas & Kuss, 2022).

Why is it that certain cities have picked the option of biking while other not? (Pucher & Buehler, 2008) argue that this is not just a cultural phenomenon. In 1950 to 1975 cycling was not always the first transportation option in Germany, Denmark and the Netherlands. However, through perseverance and a massive change in public policies related to urban planning and transport, these changes came about. The motive behind these changes in policy was driven due to a need to reduce air and noise pollution, and reduce fatality due to road accidents.

In particular in the Netherlands a shift from car-oriented urban planning to speed moderation and urban and road planning towards a safe and efficient cycling infrastructure and space for pedestrians started in the 70s, largely triggered by a movement of mothers who called itself "**stop the children's murders**" (and entailed large demonstrations, sit-ins blocking roads and squares,...) https://ejatlas.org/conflict/stop-de-kindermoord-stop-the-child-murder-protest-for-children-deaths-caused-by-motor-vehicles.

The case of Germany is particularly interesting as it has a higher level of car ownership than the UK, but the rate of bike share of trips is ten times higher than that of the UK. This is because the access to safe and easier biking made true by infrastructural support as well as other amenities such as public transport helps these country's citizens to adapt to biking.

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Figure 24 A die-in demonstration outside Amsterdam's Rijksmuseum in the mid-1970s, from documentary: How the Dutch got their cycle paths. Source: https://www.youtube.com/watch?v=XuBdf9jYj7o

Apart from local and national government interventions, major stakeholders in the road to sustainability are business owners. Niessen and Bocken (Niessen & Bocken, 2021) look into the possibility of whether businesses can drive sufficiency. The paper aims to provide a framework for building businesses based on the sufficiency principle. This goes beyond just buying less and producing less, but gives strategies and takes a closer look at sufficiency. They argue that while businesses are drivers of consumption, they have been largely overlooked as potential drivers of a sufficiency based economy.
As an example, a company constructing and selling bike trailers for use in the wealthy cities of the North, (under the slogan "every ride with a bike trailer is one less car trip") can distribute for free the plans for constructing a strong and effective bike trailer for transport of goods with local materials, like bamboo, and very simple tools and skills, observing that those places/communities that most need a trailer are also less able to buy one.
ISO 26000, an international standard, defines the scope of corporate social responsibility (CSR) around seven core issues: - governance of the organisation; - human rights; - labour relations and conditions; - environment; - fair practices; - consumer issues; - communities and local development.
In many case solutions based on sufficiency are considered as a task for individuals, but, as noted also in previous chapters " individual efforts supposed to contribute to environmental protection cannot replace collective efforts" (Spengler, 2018). While Spengler agrees that individual efforts are important for sufficiency, he notes that there are quite a few limitations. One such instance is that "around 10% of per capita carbon dioxide emission in Germany are caused by the construction of public infrastructure" leaving no scope for individual efforts in this scenario. He argues that due to a lack of internalisation of external costs, pricing of products that are resource intensive can be much lower than that of labour intensive products. This leads to a hike in consumption of resource intensive products. This along with the existing system of taxes and subsidies, creates conducive conditions to consume more. Hence individual efforts of sufficiency are overpowered by systemic efforts.
Concrete examples of communities embracing the concept of physical limits, rather than simply of "doing more with less" via technical efficiency, are, e.g., the cities of Amsterdam and Brussels, which have adopted the "doughnut" concept proposed by ecological economist Kate Raworth (Raworth, 2017) (in which the outer ring of the diagram represents Earth's environmental ceiling, a place where the collective use of resources has an adverse impact on the planet) as an overarching planning tool. The concept being developed and applied in Bruxelles is reported at: https://doughnuteconomics.org/stories/83, and concrete examples of the application of sufficiency principles are listed at: https://donut.brussels/situations/.

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A series of initiatives aiming at local development via a **low tech approach** are described and analysed by (Lopez & Soulard, 2020). "By low-tech, we mean an evolutionary approach that encourages sobriety in consumption and production thanks to easy-to-use technologies. It does not mean a refusal of technology, but its fair and sufficient use to reduce environmental impact."
Professional training must also follow in order to be in line with this vision of innovation and to be able to introduce an eco-design and techno-discernment pedagogy within the company. Low-tech campus projects are emerging in this respect, particularly in Brittany and the Île-de-France region. Finally, by relying on and developing local public facilities, such as repair cafés, shared workshops, urban farms and networks of third places, local authorities could also promote the low-tech approach in free access, in conjunction with resource banks on techniques and know-how.
In 2009, a few organic market gardeners and technicians from the Association des producteurs biologiques du nord-est rhônalpin (Adabio) decided to make new tools themselves to improve their farming practices. They created L'Atelier paysan, a cooperative that supports farmers in the design and manufacture of machines and buildings adapted to a peasant agro-ecology. All the plans can be found in open source on the Internet and training courses are given throughout France, see www.latelierpaysan.org .
The Manifesto for a happy & creative frugality www.frugalite.org/fr/le-manifeste.html is issued by a collective which promotes low-cost approaches in housing through the rediscovery of traditional materials and the development of innovative building systems. Biobased materials (wood, straw, hemp, miscanthus, flax, etc.) and geobased materials (raw earth, dry stone) are at the heart of its approaches, as their manufacturing process requires little energy. The techniques are open source. The Collect'IF Paille offers training in self-construction.
A general discussion and analysis about the low tech approach is contained in the book of Bihouix Philippe, L'Âge des low-tech. Vers une civilisation techniquement soutenable, Paris, Seuil, 2014 (also available in English).
A network of initiatives in Italy geared to self-sufficiency, focus on local development and climate and soil protection is documenting its initiatives at the website: https://comune-info.net/tag/autogestione/
Local initiatives towards sufficiency may be promoted by groups of citizens and associations as the ones described above, or be created by the decisions of elected assemblies, e.g. at municipal or regional level. (Johansson et al., 2022) present e.g. an analysis of parking policies and a few case studies where it has been decided a strong limitation of parking spaces for cars both on surface and underground. E.g. the City of Paris is planning to cut in half the car parking places.
"Current European parking policies do not seem to steer towards a future where urban transport meets the climate goals. Prominent in current housing and parking policies are the so-called *minimum parking standards*. Recent research has shown that they contribute to increased car use and consequently to higher CO_2 emissions. This is because they contribute to urban sprawl, extensive land use, increased housing and infrastructure construction costs, and that they restrict the number of flats per urban land unit. Other recent research shows that the construction of underground garages causes considerable CO_2 emissions".
"Through a future study approach with Stockholm as a case example, this paper illustrates a policy shift in parking policies considered to be in line with national climate targets. The article presents concrete indicators to quantify the scope of change needed (e.g., removing 60,000 residential parking spaces and providing vehicle sharing with 7,500 cars and at least 7,500 bikes). The focus shift goes from providing physical parking spaces to providing satisfactory **mobility** and **accessibility**. We outline a pathway towards a future scenario of parking and mobility in Stockholm, with a combination of mobility services, parking restrictions (e.g., cap on parking spaces, removal of minimum parking standards), and citizen participation. The pathway is also analysed regarding equity, feasibility, and acceptance."
A cartoon by Andy Singer https://en.wikipedia.org/wiki/Andy_Singer illustrates the possibility of shifting city policies from "car parking requirement" to "affordable housing requirement" and the effects of such a change. People being able to afford a house within the city would not need to do commuting with their cars, hence reducing congestion, pollution, noise.
One might add that if cities allow for good quality urban spaces (pedestrian areas, public parks, ...) living in a small flat while having access to such quality spaces and not being forced to spend a part of life in tiring commutes might be a desirable situation. From a point of view of sufficiency, such a

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configuration would be doubly favourable: low floor area per capita and low use of individual cars thanks to proximity and accessibility.

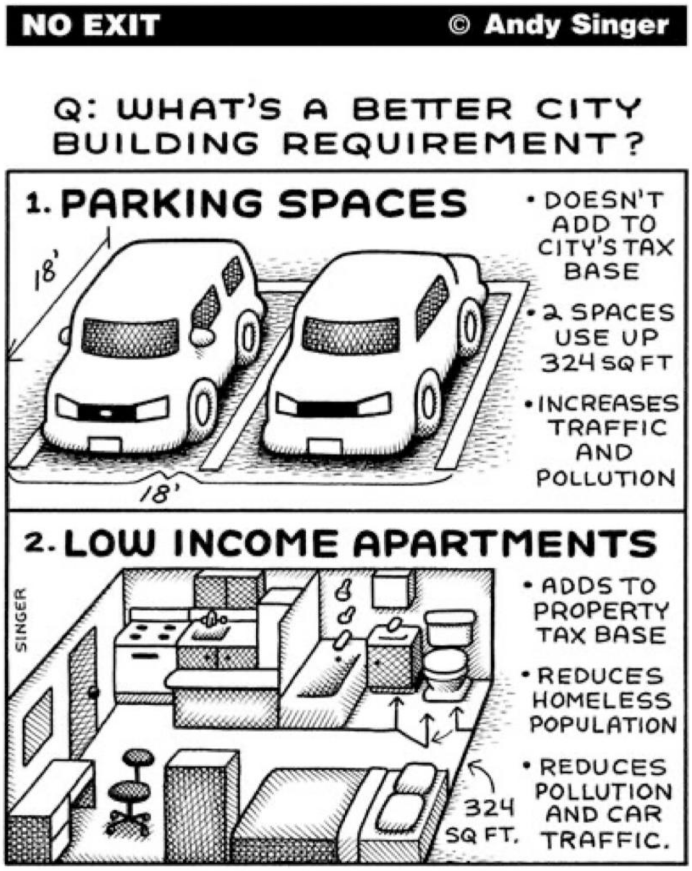

Figure 25 Minimum parrking standards in fact restrict the number of flats per urban land unit, according to (Johansson et al., 2022). A graphical representation by Andy Singer

7. Literature of Relevance for WP5 – Macro Level

We review in this chapter literature which analyses the role of sufficiency at macro level (e.g. in national legislation and regulations). In general the concept of sufficiency has had a minor role in the public debate and policy making compared with policies addressing technical efficiency and decarbonization of energy generation.

But in recent years and months it has significantly entered in policy analysis and discussion, possibly under the pressure of the concomitant climate and geopolitical crisis. A couple of recent examples:

- ten measures to cut oil use have been presented by IEA at a conference on 18th March 2022 and nine of them were sufficiency measures, only one based on technical improvements. IEA Director Fathi Birol, stated “they are based on analysis of previous real experiences in case of energy shocks, pollution episodes,… they are proven”. The analysis of the agency concludes for a potential to reduce oil use of advanced economies by 6% in 4 months.

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- EU Commission Vice-President Frans Timmermans at a conference organized by The Swedish representation of the European Commission and We Don't Have Time[10]" on 1st of April 2022 in front of hundreds of youths has expressed a series of ideas connected with the concept of sufficiency: "Just changing a bit our lifestyle can have an enormous effect on climate protection", "use more often bikes and public transport", "we should act for redistribution of the means", "less flights and more trains".
- During his speech on July 14 2022 («Afin de " se passer du gaz russe ", Emmanuel Macron prépare les esprits à la sobriété énergétique», 2022), the French president Macron announced the preparation of a "energy sufficiency plan", calling for the first time to an "evolution of behaviour" and to "responsibility and example" by companies and public bodies. On September 5 Macron («Appel à la sobriété énergétique et aides financières ciblées : les principales annonces d'Emmanuel Macron», 2022) made a new call to French citizens to "meet the call to sufficiency" ("être au rendez-vous de la sobriété") and insisted "Everyone has a role to play", asserting that "the best energy [was] that which we do not consume", and recalling the objective of achieving "10% energy savings within 2024". The Minister Agnès Pannier-Runacher announced measures as the mandate for shops to keep doors closed when heating or cooling is active, and turning off display light between 1 and 6 at night. Paris, Marseille and Lille took initiatives as turning off lights of monuments and lowering heating set-points in public buildings and swimming pools. A large debate on media followed, with frequent reference to the "sufficiency elements proposed in the NegaWatt scenarios.

Whether these calls to sufficiency are actually transformed in explicit and effective policies and investments in ***sufficiency infrastructures*** is obviously to be seen.

A systemic analysis was conducted in 2020 by (Zell-Ziegler et al., 2021) on the role of sufficiency in the Long-Term Strategies (LTS, being visions at 2050) and National Energy and Climate Plans (NECPs, implementation maps at 2030) defined by EU member States. They find that "The keyword sufficiency is only mentioned in the NECPs of two countries: France (four times) and Germany (once) as well as in the LTSs of two countries: Again France (18 times) and Austria (once)". And conclude that "the term sufficiency is – in most countries – not used in the official communication on climate mitigation might result from the lack of this term within the political and societal debate on sustainability strategies and its lack in the provided reporting templates."

One of the merits of the analysis by (Zell-Ziegler et al., 2021) is that it defines explicitly and clearly what is considered "sufficiency" from other types of actions/policies: the authors "identified sufficiency measures aimed at **reducing** energy service levels (and sometimes explicitly termed as such), measures aimed at reducing certain demands but at the cost of **shifting** (part of the) demand to other still energy-based means/services, and others that improve the **general framework** supporting any energy savings irrespective of their nature, either in a specific sector or across sectors". And "measures aimed at improving transport efficiency or shifting from internal combustion engines to alternative fuels (electricity, gas, other) or at promoting car sharing are not aimed at reducing individual motorised transport and are thus not considered in this analysis as sufficiency measures but as efficiency measure…" They find a prevalence of sufficiency measures aimed at transport with a predominance of "**substitution**" measures and a minor fraction of measures aimed at **reducing** energy service levels (see Figure 26).

[10] The Swedish representation of the European Commission and We Don't Have Time organised a Climate Dialogue with Frans Timmermans, the Vice-President of the European Commission on April 1st 2022 to discuss EU and climate issues with a special focus on the youth perspective.

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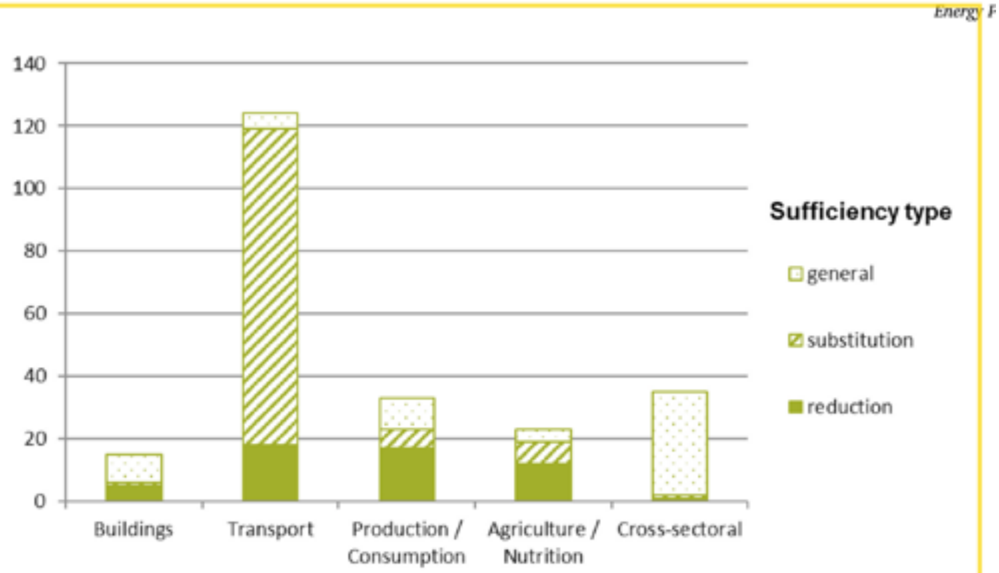

Fig. 2. Number of sufficiency measures by sector and sufficiency type.

Figure 26 Number of sufficiency measures by sector and sufficiency type in EU member States. Source: (Zell-Ziegler et al., 2021)

Two countries hold a special place and interest in energy sufficiency policies according to the analysis of (Zell-Ziegler et al., 2021): France and Austria.

In France, sufficiency has been a discourse and a popular concept since the 2000s, and the publication of a sufficiency based scenario by a network of experts (*négaWatt, 2020. Energy Sufficiency: towards a More Sustainable and Fair Society.*, 2020). The term *sobrieté* (sufficiency) entered French legislation for the first time in 2015 with an Energy Transition Bill (Loi n° 2015-992 du 17 août 2015 *relative à la transition énergétique pour la croissance verte*) highlighting "energy efficiency and sufficiency", although no specific sufficiency policy measures were defined. In a text coproduced by the Ministry of Environment, sufficiency is highlighted as one of the 21 main themes and mentioned again 50 times (*Conseil national de la transition ´ecologique, 2020. Vision de la France neutre en carbone et respectueuse du vivant en 2050. Ministère de la Transition Ecologique.*, 2020). Actual sufficiency measures have been taken only recently, partly triggered by the Citizen's convention on climate change (*Convention Citoyenne, 2020. Site officiel de la Convention Citoyenne pour le Climat.*, 2020) which proposed 149 policy measures, including sufficiency ones (such as 'restrictions of advertisement for highly pollution goods (such as SUVs), ban of short distance flights, ban of office and shop lighting after 1 am, reduction of meat consumption. However, according to (*Haut Conseil pour le Climat, 2021. Avis portant sur le projet de loi climat et résilience.*, 2021). The governmental and legislative process to implement them "often led to a reduction in scope, ambition, and pace compared to the original proposals". For example: "the restriction of advertisement for highly-polluting goods, which was supposed to cover a wide-range of products (such as SUVs), has been limited to fossil fuel suppliers; the ban of short distance flights will only be implemented when trains can make it in less than 2.5 h, instead of 4 h originally (thus concerning a small share of domestic flights)" (Zell-Ziegler et al., 2021).

On the other hand, in Austria, Various Austrian ministries organised a series of four major conferences between 2010 and 2018 entitled "Growth in Transition", where topic of "sufficiency" played an important role in the discourse between civil servants and scientists, but the term "sufficiency" has not entered explicitly in public documents. Ziegler et al., 2021) report that "The LTS does not mention sufficiency by name, but lists numerous ambitious measures: more durable products, fewer flights, higher car occupancy, less meat consumption and flexible community buildings and housing

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for young and old people". In 2019 a Ministerial document on a "bioeconomy strategy, names sufficiency as a strategy element".

8. International Dimension

When discussing the possibilities for a shift towards ***sufficiency habits*** both in the Global North and the Global South, the dimension of environmental inequalities among countries and within countries emerges in literature as an extremely relevant framework in terms of environmental justice and as an element for the design of policies.

8.1. Carbon inequalities among countries

In 2020 the share of production-based global GHG yearly emissions generated by China amounted to 25.8%, while the USA was responsible for 12.8%, the EU-27 for 7.8%, India for 6.7%, Russia for 5.3%, Japan for 2.7%, Brazil for 2.3%, with all other countries having a share of emissions <2%. This list reveals that China, the world's top emitter, is responsible for a share of yearly production-based global GHG emissions almost double the share of the second country in the list, i.e. the USA.

However, climate change is the result of the total amount of GHG emissions in the atmosphere (i.e. a stock) rather than of the level of emissions generated during a given year (i.e. a flow). Consequently, responsibility in causing the climate crisis should be assessed based on a country's contribution to cumulative emissions. If one considers cumulative production-based global GHG emissions for the period 1850-2011 the picture changes considerably: the USA becomes the world's top emitter with a share amounting to 27%, followed by the EU-27 with 25%, China with 11%, Russia with 8%, Japan with 4%, India with 3 and Canada with 2% (Ge & Friedrich, 2014). In this list, China recedes to the third position with a share of cumulative production-based global GHG emissions less than half the size than both the USA and the European Union. These numbers already point to the fact that when longer time frames are considered, the carbon debt of the Global North appears evident as compared to the Global South. In this regard, we can talk of carbon debt as a facet of the wider issue of ecological debt.

The social movement Accion Ecologica (Acción Ecológica, 1999) defines ecological debt as "the debt accumulated by northern industrial countries towards third world countries on account of resource plundering and use of environmental space to deposit wastes." In line with such considerations, (Hickel, 2020b) calculates every country's responsibility in generating excessive emissions, namely the emissions that exceed the safe planetary boundary of 350 ppm atmospheric CO_2. By this approach, the USA is responsible for 40% of 'overshoot emissions', the EU-27 for 29%, Russia for 8%, the UK for 7%, and Japan for 5% (Hickel, 2020b). These figures are significantly higher than earlier estimates and suggest a greater degree of responsibility among high-income nations than previously thought. Overall, the Global North has exceeded its fair-share of the atmosphere by 121%, while overall the Global South is still below its fair-share by 12%. Even China is still within its boundary fair-share (by 3%), although emissions rates are expected to exceed it significantly in the coming years (Hickel, 2020b).

Calculating the difference between Production Based Accounting (PBA) and Consumption Based Accounting (CBA) reveals CO_2 emissions embedded in trade and, consequently, the degree to which the climate record of each nation is altered by the off-shoring of factories that commenced in the 1990s. About 25% of emissions are currently offshored at the global level (Malm, 2020). Most countries in the Global North register higher levels of emissions under CBA rather than under PBA, while the reverse is observed in Global South countries. By way of illustration, according to data compiled by (Friedlingstein et al., 2019), CBA is 3% higher than PBA in the case of Turkey, 6% in the case of

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the US, and 15% in the case of Japan. Whereas CBA is 2% lower than PBA in the case of Egypt, 10% in the case of China, and 30% in the case of South Africa. If we zero in on the EU, we discover that its climate record is 28% higher under CBA than under PBA (Steininger et al., 2018). Such data cast a shadow on the triumphalist narrative of the EU with regard to the supposedly successful dematerialization of its economy in recent years: the truth is that while the EU reduced its territorial emissions of 21% from 1990 to 2017, if emissions embedded in trade are taken in consideration the reduction is limited to just 5%. However, the difference between CBA and PBA differs markedly among EU member states: for instance while the gap for the Netherlands amounts to just 5%, it amounts to 46% for Italy, and to 70% for Belgium (Steininger et al., 2018). In the light of these data, since the 90s the EU has delocalized its carbon footprint to a higher degree than it has reduced it.

8.2. Global environmental inequalities among countries

Looking beyond GHG emission, we observe that the ecological debt that the Global North owes to the Global South extends to also other dimensions of biophysical throughput.

In the period between 1990 and 2015, countries of the Global North appropriated 200 billion tons of raw materials, 550 exajoules of energy, and 30 billion hectares of agricultural land through trade flows from the Global South (Dorninger et al., 2021). Overall, high-income countries are responsible for the majority of excess global resource use, with an average material footprint of 28 tons per capita per year—four times over the sustainable level (Bringezu, 2015). Global trade, therefore, allows countries of the Global North to ensure to their citizens a lifestyle that would be unsustainable for their national ecosystems. For this reason, instead of speaking of the 'Western lifestyle', Brand and Wissen (2013) suggest that we speak of 'imperial lifestyle'. The lifestyle of the majority of citizens of the global North depends on the hoarding of resources that belong to other peoples. In other words, economic growth in the North relies on patterns of colonisation: the appropriation of atmospheric commons, and the appropriation of Southern resources and labour. In terms of both emissions and resource use, the global ecological crisis is playing out along colonial lines. Continued growth in the North means rising final energy demand, which will in turn require rising levels of extractivism. Complicating matters further, decarbonization cannot be accomplished fast enough to respect Paris targets as long as energy use in the global North remains at today's level (Hickel & Kallis, 2019). Sufficiency requires rich nations to scale down throughput to sustainable levels, reducing aggregate energy use to enable a sufficiently rapid transition to renewables, and reducing aggregate resource use to reverse ecological breakdown. This demand is not just about ecology; rather, it is rooted in anti-colonial principles. Southern countries should be free to organise their resources and labour around meeting human needs rather than around servicing Northern growth (Hickel, 2021).

Rethinking development entails also challenging the rankings of countries (such as underpinned by the Human Development Index) according to which presently most countries of the Global North outperform the ones in the Global South. A macroeconomic indicator that presents another snapshot of social progress from the perspective of sufficiency is the Sustainable Development Index (SDI) (Hickel, 2020a). This indicator measures the ecological efficiency of a country's economic development by recognizing that this is sustainable only if it does not imply an excessive appropriation of the biosphere with respect to the criteria of fair distribution among countries.

The SDI uses the indicators (life expectancy, literacy, and per capita income) of the Human Development Index and then divides them by the ecological footprint of the respective country. By doing so, best performing countries are those that ensure their citizens a quality of life above the global average while maintaining a limited ecological footprint. So instead of having Scandinavian countries topping the ranking, we discover that the best performing countries according to the SDI are countries such as Costa Rica, Cuba, Albania, and Georgia. Hence, from a sufficiency perspective, they could be seen as 'appropriately developed' instead of being described and generally perceived as 'underdeveloped'.

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8.3. Carbon inequalities among social classes

While discussing environmental inequalities at the level of nations has merits given the dynamics of ecologically unequal exchange (Hornborg & Martinez-Alier, 2016), national statistics conceal differences among social classes. Focusing on carbon inequalities, (Chancel, 2022) finds that inequality between countries has decreased over the last three decades, meaning that the average carbon footprint of developing countries grew faster than in rich countries since 1990. This is the direct consequence of the rise of a middle class in BRICS countries. However, in the same period, carbon inequalities among social classes have increased, meaning that the gap in the average carbon footprint of a citizen in the top 10 % and one in the bottom 10 % of the global distribution of wealth has widened. In the period 1990-2015, the richest 10 % at the global level (i.e. circa 600 million individuals) cumulatively generated 52 % of emissions, the middle 40 % was responsible for 41 %, and the poorest 50 % (i.e. circa 3 billion individuals) for just 7 % (Gore, 2020). Currently, the average carbon footprint of an individual belonging to the richest 1 % at the global level can be up to 175 times bigger than the one of an individual belonging to the poorest 10 % (Otto et al., 2019). But even more striking from an environmental justice perspective is the fact that in recent decades the rich have increased their emissions more than the poor have. In the period 1990-2015, the richest 10 % posted emissions growth of 46 %, while the poorest 50 % of just 6 % (Gore, 2020). The dynamics of unequal appropriation of the remaining carbon budget for 1.5 °C previously discussed at the level of nations can be observed also at the level of social classes at the global level. In the period 1990-2015, the richest 10 % appropriated 31 % of the remaining carbon budget, while the middle 40 % appropriated 25 %, and the poorest 50 % only 4 % (Gore, 2020). The exorbitant emission levels of the rich make it also difficult for them to achieve the 2030 climate target proposed by the IPCC (2018) amounting to 2.1 tCO_2/year. The average per capita carbon footprint of the richest 1 % is currently around 35 times higher than the target for 2030 and the one of the richest 10 % is 10 times higher (Gore, 2020). To add insult to injury, the carbon footprint of the global poorest 50% is already today below the 2.1 tCO_2/year target. Thus, when policy makers and commentators state that humanity is far from achieving the necessary carbon emission reductions, it would be wise to specify *which* social class they are referring to.

While wealthy individuals (i.e. the richest 10 % at the global level) make up a higher share of the population of countries in the Global North than of countries in the Global South, it should be borne in mind that a sizable number of them live in the latter. It is estimated (Milanovic, 2016) that half of the richest 10% at the global level live in Europe and North America, while 20 % of them live in India and China. However, if we analyse the richest 1 % at the global level, we discover that 1/3 of them live respectively in North America, China, and in the MENA region (Milanovic, 2016). Hence, there are more super-rich individuals in China than there are in Europe.

This consideration makes us better understand that the problem of the carbon footprint of the rich and super-rich is transnational: the data form the above literature show that it is not European citizens *as a whole* who must reduce their emissions, just as it is not Indian citizens *as a whole* who must increase their emissions to achieve a decent lifestyle. Rather, it is the rich and the super-rich in every country who appear to be responsible for excessive emissions. (Chakravarty & Ramana, 2011) conclude therefore that it is time for the rich and super-rich in the Global South to stop "hiding behind their poor". In the pursuit of fair climate policy making, it would make more sense to overcome the dichotomy between Global North and South—that has often led to an impasse in international climate negotiations—and focus instead on citizens and companies who have a high carbon footprint regardless of the country they live or operate in.

In conclusion, a growing literature and data availability suggest that sufficiency strategies must be premised upon the principles of environmental justice and, in doing so, they must take into consideration the various dimensions of environmental inequalities (both among countries and social classes) in order to ensure the social acceptability of the green transition.

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9. Conclusions

This report reviews the literature identified by the experts of the Fulfill consortium based on their previous research work and on additional bibliographic research performed during the initial phase of the project.

The review explores the theoretical and conceptual foundations of climate-oriented lifestyle changes. More specifically, it outlines the current state of knowledge on the role of the sufficiency principle in lifestyle changes as well as a screening of the literature on potential effect of sufficiency-oriented policies.

It compares the various conceptual frameworks and nomenclature proposed in literature and finds that there is a large consensus on the view that a sufficiency-oriented lifestyle is based on changes of the habits of people, companies and institutions which can happen at the needed scale and pace only in the presence of adequate enabling conditions, both at the physical and the regulatory level.

We propose to make explicit those findings also in the nomenclature used to describe sufficiency oriented lifestyle changes, by adopting the definitions:

- ***Sufficiency habits*** = Sufficiency measures taken by individuals due to permanent lifestyle changes
- ***Sufficiency infrastructures*** = Physical and non-physical infrastructures enabling ***Sufficiency habits***
- ***Sufficiency societal framework*** = institutions, legislation, norms enabling ***Sufficiency habits***.

The report analysed relevant literature on the potential reduction of final energy use as a result of the adoption of policies which support the uptake of ***sufficiency habits***. We found a large number of analysis published in peer reviewed journals or as reports by institutions (such as International Energy Agency, UNEP,...) or research bodies, which converge on the large reduction potential offered by sufficiency policies, on their positive side benefits, and on the rapidity by which those policies can produce measurable results.

In many analysis the creation of ***sufficiency infrastructures*** and the establishment of a ***sufficiency societal framework*** emerge as necessary and relevant ingredients of any policy mix aimed at rapidly addressing the climate, biodiversity, health protection, land preservation and security of supply objectives. The above conclusion seems also supported by the evidence of too slow, insufficient, or missing decoupling of energy, resource and land use from economic growth as measured by GDP.

We also find analysis about the large inequalities in carbon and material footprints inter countries and intra-countries and a potential role for sufficiency policies to be part of a necessary reduction of those inequalities and of a higher and fairer accessibility to safe environments and health.

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10. Glossary

Sufficiency habits[11] = Sufficiency measures taken by individuals due to permanent life-style changes

Sufficiency infrastructures = Physical and non physical infrastructures enabling Sufficiency habits

Sufficiency societal framework = institutions, legislation, norms enabling Sufficiency habits

Energy needs for heating and cooling: heat to be delivered to or extracted from a thermally conditioned space to maintain the intended space temperature conditions during a given period of time This indicator is useful for quantifying energy losses through the envelope and via air infiltration and ventilation (e.g. in winter it accounts for transmission losses plus ventilation losses minus free energy gains from appliances, people, and solar radiation entering via the transparent elements).

T*otal primary energy* use: *energy [used] from both renewable and non-renewable sources, energy that has not been subjected to any conversion or transformation process* This indicator is useful for quantifying the inefficiencies in the systems - e.g. avoid burning biomass in an inefficient burner

N*on-renewable primary energy* use: *energy taken [and used] from a source which is depleted by extraction, (e.g. fossil fuels).* It can be considered with or without compensation between energy carriers and with or without compensation for sales of renewable energy from the building to the grid. This indicator allows to quantify the non-renewable fraction within total primary energy use.

N*umerical indicator of non-renewable energy use with compensation*. Only at this stage can compensation between different energy carriers or times be taken into account (or not, depending on national choices). For example cross-compensation between natural gas use and on-site production or the accounting of exported energy at a certain time as a compensation of energy use at another time (on an hourly, monthly, or yearly basis).

GDP growth coinciding with absolute reductions in emissions or resource use is denoted as '***absolute de-coupling***', as opposed to *'relative decoupling*', where resource use or emissions increase less so than does GDP[12].

Eco-anxiety/ Eco-distress: Defined by the American Psychological Association in 2017 as: "the chronic fear of environmental doom"81. May include a range of anxiety, worry, stress, hopelessness, sleep disturbance, irritability, despair, bodily symptoms of anxiety (e.g. awareness of heartbeat, butterflies in stomach, sweaty palms, perceived shortness of breath) and other similar responses.

Climate grief/ Ecological grief/ Eco-grief: The grief felt in relation to experienced or anticipated ecological losses, including the loss of species, ecosystems and meaningful landscapes due to acute or chronic environmental change.

Solastalgia: The distress experienced when someone's home environment is changing in ways perceived to be profoundly negative, either by events related to climate change but also scenarios such as establishment of a mine or a volcanic eruption. Changes that attack someone's sense of home, even without dislocation, can create a deep homesickness.

[11] Note that throughout this document, we use the convention that terms which have a specific definition within this text and/or in the cited bibliography are presented in ***bold italic underlined***

[12] Haberl, H., …, Creutzig, F., 2020. A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesising the insights. Environmental Research Letters 15, 065003. https://doi.org/10.1088/1748-9326/ab842a

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