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1.5 Degree Lifestyles

Targets and options for reducing lifestyle carbon footprints

Annexes to the Technical Report

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1.5-DEGREE LIFESTYLES:

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Annexes to the Technical Report

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Institute for Global Environmental Strategies
Aalto University and D-mat ltd.

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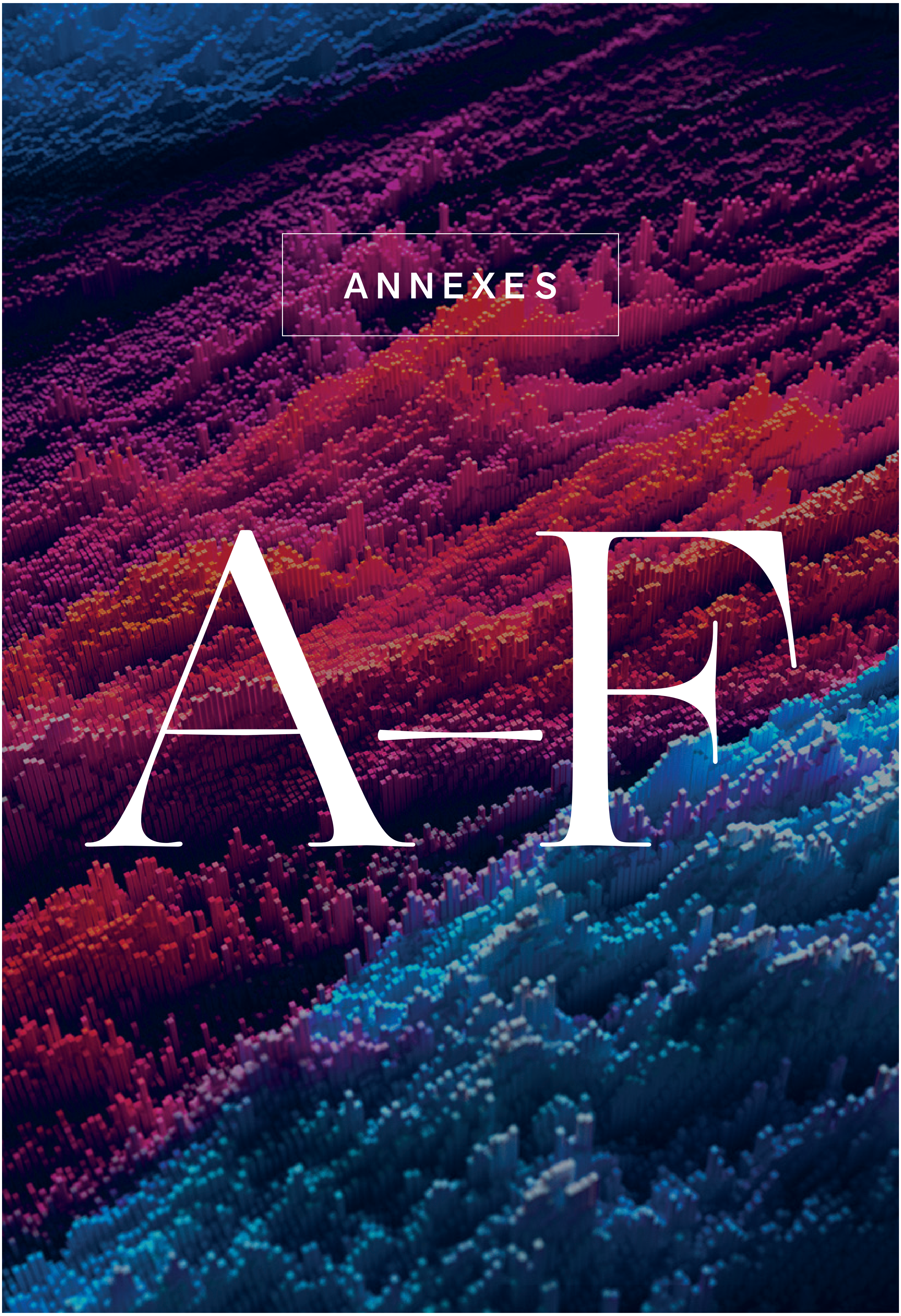
Abbreviations

3EID	Embodied Energy and Emission Intensity Data for Japan Using Input–Output Tables
AR5	IPCC Fifth Assessment Report
BECCS	Bioenergy with carbon capture and storage
CCS	Carbon capture and storage
CO_2	Carbon dioxide
COICOP	Classification of individual consumption according to purpose
COP	Conference of the Parties
GHG	Greenhouse gas
GTAP	Global Trade Analysis Project
GLIO	Global link input-output
HFCs	Hydrofluorocarbons
IAMs	Integrated assessment models
INDC	Intended Nationally Determined Contributions
I/O	Input-output tables
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
LED	Light emitting diode
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LULUCF	Land use, land use change and forestry
MRIO	Multi-regional input-output tables
N_2O	Nitrous oxide
NGO	Non-governmental organisation
NSFIE	National Survey of Family Income and Expenditure
PFCs	Perfluorocarbons
RoW	Rest of the world
SF_6	Sulphur hexafluoride
UNEP	United Nations Environment Programme

ANNEXES

A–F



Annex A. Methodology of Lifestyle Carbon Footprint Target Proposal

A.1 Review of emission scenarios

Scenarios developed by integrated assessment models used for climate projections estimate GHG emissions and concentrations using sets of assumptions, such as the types and costs of technologies used, timing and level of technology penetration, utilisation of fossil fuels and renewable energies, global climate policy, and carbon pricing.

Modelling incurs inherent estimation uncertainties described by likelihood, and likelihood describes the uncertainty of a modelling projection estimate. The terms used herein are defined as follows (Mastrandrea et al. 2010):

Virtually certain: 99–100% probability
Very likely: 90–100% probability
Likely: 66–100% probability
About as likely as not: 33 to 66% probability
Unlikely: 0–33% probability
Very unlikely: 0–10% probability
Exceptionally unlikely: 0–1% probability

IPCC AR5 concluded that the global average temperature increase can be likely kept below 2 °C if the CO_2 concentration in year 2100 is kept at around 450 ppm, and cumulative CO_2 emissions (2011–2100) are limited to around 950 billion tonnes CO_2, and be likely kept below 1.5 °C at below 430 ppm CO_2e. This upper limit was set based on a handful of pathway scenarios, therefore involves higher uncertainty.

We shortlisted the available scenarios using the criteria described in Chapter 2 to derive both 2 °C and 1.5 °C targets based on the emissions targets provided in the reviewed papers. Most of the papers state characteristics such as CO_2 concentrations and climate targets, emissions for 2050 or 2100, when global emissions must peak to meet the Paris target, and use of negative emissions technologies. However, some reports did not provide key characteristics such as probability of meeting the target and cumulative CO_2 emissions, and few contained actual 'ideal' scenarios.

1) IPCC Fifth Assessment Report (AR5) scenarios

We explored the AR5 Scenario Database[1] published in 2014. From the open call for submissions, 1,184 scenarios (including baseline and mitigation pathways) applied to 31 models and reported by 64 publications were collected. The IPCC reviewed scenarios that had passed a peer-review process, contained a determined set of variables, provided information on the model and documentation used, represented a full energy system, and provided data to at least year 2030, as presented in the IPCC AR5 Scenario Database (IIASA Energy Program 2004).

Most of the scenarios in the AR5 Scenario Database are aligned with a 2 °C target and only a few individual scenarios and publications provide detailed information on carbon budgets up to year 2100. We found that 114 scenarios in the Database projected pathways towards 430–480 ppm CO_2eq emissions (IPCC AR5's climate forcing category 1), 55 of which limit cumulative emissions to under 950 $GtCO_2$ (IPCC AR5's 2100 emissions category 1). Of these 55 scenarios, 31 used negative emissions/carbon dioxide removal technologies without limitations, 16 used them with some limitations, 1 used no negative emissions technologies, and 7 used no negative emissions technologies and limited the use of other technologies. None of the scenarios projected target CO_2e levels below 430 ppm, therefore none of them are projected to meet the 1.5 °C target with adequate probability.

2) UNEP Emissions Gap Report scenarios

The UNEP Emissions Gap Report 2016 and 2017 (UNEP 2016, 2017) referred to scenarios in the AR5 Database that limit the global average temperature increase to 2 °C with at least 66% likelihood (10 scenarios) and scenarios published after the AR5 that limit global average temperature increase to 1.5 °C with 50% likelihood, that are not available in the Database (6 scenarios, collected from Rogelj et al. 2015). The Emission Gap Report 2016 also provides a timescale-breakdown of carbon budget. Compared to AR5, the Emission Gap Report 2016 suggested a stricter cumulative budget of 553 billion tCO_2 (2015–2100). Furthermore, UNEP suggested a cumulative carbon budget of 217 billion tCO_2 (2015–2100) to achieve the 1.5 °C target. We reviewed the individual papers used by the Emission Gap Report 2016 and applied the criteria described in Chapter 2.

3) Individual research papers scenarios

Considering the timing of IPCC AR5 Scenario Database publication and the limitation of UNEP Emission Gap Report 2016 and 2017, we also reviewed individual research papers that are not within the scope of those resources. We particularly looked at papers published after the IPCC AR5 and papers with scenarios that aim for achieving the 1.5 °C target (1.5 °C scenarios) as well as 2 °C scenarios that rely less on the use of human sink technologies compared with other scenarios. We reviewed the individual papers from academic journals and applied the criteria described in Chapter 2.

A.2 List of shortlisted mitigation pathways

The carbon budgets proposed by the four shortlisted scenarios are summarised in Table A.1. Among the four 1.5 °C scenarios, the one with human sink technologies (*1.5S*: 38 Gt in 2030, 19 Gt in 2050) has a higher budget compared to the others without (1.5D (a): 27 Gt in 2030, 12 Gt in 2050; 1.5D (b): 32 Gt in 2030, 7 Gt in 2050; 1.5D (c): 9 Gt in 2050). The emission budget in the 1.5 °C scenario with human sink technologies (1.5S) is not much lower than the 2 °C scenario with human sink technologies (2S),

1 According to the International Institute of Applied System Analysis (IIASA), administrator of the AR5 Database, scenarios were submitted using a data template that was made publicly available. At the time of review, the IPCC SR1.5 Scenario Database was not yet available to the public and the Special Report was not available for citation.

Table A.1. Annual GHG emission budgets for the shortlisted mitigation pathways

Scenario	Annual GHG emission budget ($GtCO_2e/yr$)					
	2015	2020	2030	2040	2050	2100
1.5S	51	52	38	28	19	13
2S	45	44	36	28	20	11
1.5D (a)	49	40	27	18	12	2
1.5D (b)	45	44	32	18	7	6
1.5D (c)	-	-	-	-	9	5

Note: 1.5S scenario adopted from Rockström et al. (2017), 2S Scenario from Rogelj et al. (2011), 1.5D (a) Scenario from "A2" scenario in Ranger et al. (2012), 1.5D (b) and 1.5D (c) from "Low Non-CO_2" and "All Options" scenarios in van Vuuren et al. (2018).

or even higher. The budget in 1.5D is much lower than in 1.5S. These differences imply that the future availability and reliance on human sink/negative emission technologies is a more critical determinant of emission budget than the difference between pathways toward the 1.5 or 2.0 °C target .

As a limitation of this screening study, it should be noted that the following scenarios are not directly comparable owing to differences in timespan of the simulation and probability of achieving the global temperature targets. This is due to the limited availability of recently published scenarios that satisfy our selection criteria, which shows compatibility with the 1.5 °C target and limited dependency on negative emission technologies. Also, each pathway is drawn from different models, which may be based on various assumptions. These factors explain why the 2S Scenario has a lower annual emission budget in the near future than the 1.5S Scenario.

1) Mitigation pathway towards 1.5 °C in 2100: Rockström et al. 2017

Rockström et al. (2017) provided an update and a narrative for a roadmap for rapid decarbonisation that leads towards meeting the 1.5 °C target, based on a deep decarbonisation scenario put forward in Rogelj et al. (2015). Rogelj et al. analysed the emissions characteristics of more than 200 emissions scenarios from the MESSAGE and REMIND IAMs (Rogelj et al. 2015). Comparisons between scenarios grouped into '1.5 °C scenarios', 'likely 2 °C scenarios', and 'medium 2 °C scenarios' were made. The impact of those emissions scenarios on the global average temperature change, based on carbon cycle and climate models, was estimated using the MAGICC6 model (Meinshausen, Raper, and Wigley 2011).

All assessed scenarios include net negative cumulative GHG emissions until 2100. The scenarios that do not include negative emission technologies lead to higher mitigation costs. Almost all additional emissions reductions needed to move the target from 2 °C to 1.5 °C are estimated to be achieved through reduction of CO_2 emissions from consumption of fossil fuels and removing CO_2 using BECCS as well as land-use sinks. The scenarios also require significantly higher reductions from transportation, residential and commercial buildings, and industry before 2050. Before 2050, demand-side reductions from building and transportation sectors are more significant than supply-side reductions from the electricity sector and the use of negative emission technologies.

Based on those assessments, Rockström et al. (2017) drew transformation pathways towards rapid decarbonisation. The main characteristics of this scenario are:

- The global average temperature increase is limited to meet the 2 °C target with 75% probability and the 1.5 °C target by 2100 with 50% probability.
- Atmospheric CO_2 concentrations of 380 ppm (in 2100)
- Global CO_2 emissions peak no later than 2020.
- Annual gross emissions are estimated to be reduced from around 52 $GtCO_2e$ in 2020, to around 38 $GtCO_2e$ (2030), to around 28 $GtCO_2e$ (2040), and around 19 $GtCO_2e$ (2050).
- Energy sector will be free of coal use in 2030–2035 and diesel use in 2040–2045. Natural gas use is offset by CCS technologies and nuclear use is incremental.
- Negative emissions technologies such as BECCS are used, in addition to afforestation, starting from 2030.

We derived a scenario to meet the 1.5 °C target discussed in this paper. This scenario includes the use of CO_2 removal technologies, particularly BECCS and direct air CCS from the year 2030, while noting their technological and political uncertainties. This 1.5 °C with Human Carbon Sink (1.5S) Scenario consists of a pathway to meet both the 2 °C target (with 75% probability) and the 1.5 °C target (with 50% probability), considering the use of all carbon sinks. This scenario is expressed in $GtCO_2e$ with detailed information on amounts of each GHG.

2) Mitigation pathway towards 2 °C in 2100 using CCS: Rogelj et al. 2011

Rogelj et al. (2011) used the MESSAGE model to reanalyse 12 scenarios with the use of CCS to meet the the 2 °C target with more than 66% probability. The main characteristics of this pathway are:

- The global average temperature increase is limited to the 2 °C target with above 66% probability
- Cumulative GHG emissions of 2,500 $GtCO_2e$ (over the 21st century)
- Atmospheric CO_2 concentrations of 425 ppm (in 2100)
- Global CO_2 emissions peak between 2010 and 2020
- Annual gross emissions are estimated from the paper at

around 45 $GtCO_2$ in 2015, to around 44 $GtCO_2$ (2020), to around 20 $GtCO_2$ (2050)
- Negative emissions technologies such as fossil CCS and BECCS are used, in addition to afforestation, starting from 2030.

Compared to Rockström et al. (2017), this scenario allows a wider time window and a less strict emissions budget, leading to a lower probability of meeting the target.

However, while the paper states "more than 70% of the 'likely' scenarios assume global net negative CO_2 emissions from industry and energy sectors using BECCS to achieve CO_2 concentrations peaking before 2020", it provides no proof of such technology. Regardless, based on this paper, we derived the 2 °C with Human Carbon Sink (2S) Scenario. A follow-up study on this paper found that it will not be feasible to achieve the 2 °C target if CCS is not available and the full potential of land-based mitigation measures is not realised, unless demand is low (Rogelj et al. 2013).

3) Mitigation pathway towards 1.5 °C in 2100 without using CCS: Ranger et al. 2012

This paper did not meet a number of our criteria, especially because (i) it did not assume a global agreement to reduce emissions and (ii) it had limitations in regard to emissions coverage – but it did include the only resource found (as of early 2018) on pathways towards meeting the 1.5 °C target without using CCS technologies. Ranger et al. reported the results of three experiments to assess feasibility of available emissions pathways towards the 1.5 °C target using a 'probabilistic simple climate model'. The three experiments were conducted using different assumptions on post-2012 emissions due to changes in fossil fuel consumption. The MAGICC model was then used to estimate the impact of those different emissions pathways on the global climate. The key objective to conducting these experiments was to identify requirements of emissions pathways in order to meet the 1.5 °C target. Of the three experiments, we adopted the most plausible one.

The first experiment considered emission pathways in which global emissions peak in 2015, fall to zero in 2021, and remain zero thereafter. Although theoretical, these experimental scenarios are helpful in conducting sensitivity test of 1.5 °C goal achievement. These zero-emissions scenarios are not considered realistic, but are a useful sensitivity test of the feasibility of reaching a 1.5 °C goal (Ranger et al. 2012). The second experiment highlighted pathways that assume early reductions (starting in 2012) to meet the 1.5 °C target and avoid overshooting this goal with at least a 50% chance of succeeding. The paper concludes that emissions need to be reduced at a rate of 4.5–6% annually, and that this should have started in 2012. It is unlikely that this rate will be achieved considering the lack of political will and the trend in global emissions at the time of writing. The third experiment was deemed "plausible": emissions reductions begin in 2015 and reductions are faster from 2020, allowing warming to exceed 1.5 °C globally temporarily.

From the experiments, Ranger at al. concluded that a pathway to meet the 1.5 °C target with at least 50% probability needs to meet three criteria: *early action*, including reaching a peak in annual global emissions in 2015 and reduce to a maximum of 44 $GtCO_2e$ by 2020, *rapid reductions* at 5% annual reduction from 2020, and *annual emissions to reach close to zero* (less than 2 $GtCO_2e$) or below by 2100 and continue to fall in the next century (Ranger et al. 2012). Such a pathway may have the following characteristics:

- The global average temperature increase is limited to 1.5 °C with more than 50% probability
- Cumulative GHG emissions of around 1,800 $GtCO_2e$ (over the 21st century)
- Atmospheric CO_2 concentrations below 450 ppm (in 2100)
- Amount of annual global emissions peaked in 2015
- Annual gross GHG emissions estimated at around 49 $GtCO_2e$ in year 2015, to around 40 $GtCO_2e$ (2020), to around 12 $GtCO_2e$ (2050). Global emissions have to be reduced by 5% every year (rapid annual reductions).
- Annual emissions have to reach close to zero (at least less than 2 $GtCO_2e$) or below zero by 2100 and continue to fall in the next century (zero or negative emissions).
- Warming will exceed 1.5 °C ('overshoot') temporarily. "Strong and early action" may limit the overshoot duration to a few decades, but there is a lack of information on what this action entails.

Ranger et al. did not estimate any net negative total GHG emissions in its original pathways, but it acknowledges the need to elaborate potentials of carbon sink technologies. The report stated that widespread use of negative emissions technologies may be necessary to compensate for reduction of emissions from sectors that are challenging to mitigate, such as agriculture, and to increase probability of meeting the targets. Therefore, research on those technologies needs to be improved. Based on this paper, we derived a 1.5 °C scenario based on Demand-side Measure (1.5D(a)) Scenario.

4) Mitigation pathway towards 1.5 °C in 2100 without using CCS: Van Vuuren et al. 2018

This paper used the IMAGE IAM to identify a number of pathways to reduce emissions to achieve a radiative forcing level of 1.9 W/m^2 in year 2100, a level that corresponds to keeping warming below 1.5 °C. Van Vuuren et al. (2018) applied the Shared Socioeconomic Pathway 2 (SSP2), a global and publicly accessible scenario that used 'middle-of-the road assumptions' on future demography (global population growth to approximately 9 billion people in the year 2050, followed by a stable growth), economic growth, technological innovations, and lifestyles as basic assumptions. The basic scenario was then developed into alternative pathways by changing the assumptions, most of which relate to the 2020–2050 period (Van Vuuren et al. 2018).

The paper provided six alternative pathways: "Efficiency", "Renewable electricity", "Agricultural intensification", "Low non-CO_2", "Lifestyle change", "Low population", and an "All" pathway. The level of human carbon sink utilisation differs among alternative pathways; the "Low non-CO_2" and "All" pathways assume the lowest reliance on human carbon sinks. Based on these two pathways, we derived 1.5C scenario with Demand-side Measure (1.5D(b)(c)) Scenarios.

The main characteristics of the "Low non-CO_2" pathway are:

- Assumes increased abatement of non-CO_2 gases, increasing towards a maximum in 2050, when it stabilises

until 2100. Half of the maximum abatement is estimated to be achieved in 2030.
- Maximum reductions of methane from gas/oil production, coal production, enteric fermentation in ruminants, sewage, landfills, and animal waste/manure.
- Maximum reductions of nitrous oxide from fertiliser use, animal waste/manure, transportation/adipic and nitric acid production/plant residues, and fluorinated-gases.
- Cultivated meat grown from mostly corn and small amounts of soy replace meat-like products (including eggs).

The "All" pathway combines all of the alternative pathways.

- Radiative forcing in 2100 at around 1.9 W/m^2
- Global GHG emissions peak around 2020
- Negative emissions technologies such as BECCS are used to a limited extent.

A.3. Assumptions of negative emission technologies

Our literature review found that the pathways to meet the 2 °C and 1.5 °C targets are highly sensitive to the use of negative emission technologies. For the 2 °C target, there is a divergence in the views and projections involving the necessity of using CCS as a carbon sink for industrial GHG emissions. For this target, one of the benefits of CCS technologies is it increases cost-effectiveness of global mitigation (Blanford et al. 2014; Fuss et al. 2014; Magné, Kypreos, and Turton 2010).

Research suggested that without utilisation of CCS, very early action is needed in addition to higher energy efficiency, more utilisation of renewable energy, and less promotion of "clean fossil" (Magné, Kypreos, and Turton 2010), such as building new fossil-power plants with integrated gasification combined cycle technology. Ranger et al. (2012), who provided the pathway selected for this study, excluded negative emissions technologies in their scenario, but identified its importance for improving the probability of limiting warming to 1.5 °C with a warning that emissions still need to significantly decrease from 2015 and using those technologies may allow for a temporary overshoot of the target.

Other research argued that CCS technology utilisation will be the chosen mitigation action in several economies if a carbon price is introduced and reaches 30 USD/tCO_2 in around 2020, but it will be phased out from 2050 and replaced by clean energies including nuclear (Mi et al. 2012). A small proportion of CCS technologies may also be utilised to mitigate GHG emissions from natural gas power plants (Rockström et al. 2017). Discussions on CCS have covered not only CCS technologies to mitigate emissions from fossil fuel power generators ("fossil CCS"), but also CCS technologies paired with bioenergy production (BECCS) as well as direct air CCS. These CCS technologies have already been deployed at various scales despite the ongoing debates on their technological, environmental, safety, and political impacts.

A popular concept of fossil CCS proposed by Global CCS Institute (n.d.) is to use it in combination with enhanced oil recovery, which includes piping CO_2 captured at a CCS plant to a nearby oil field to increase oil production, therefore increasing cost recovery.

The concept of BECCS is based on the combination of a net-zero emissions bioenergy production (in which, the amount of CO_2 emissions from combustion of biomass for energy generation is absorbed, at the same exact amount, by new growth of biomass) and use of land or ocean carbon sinks for capture and storage of carbon emissions. This combination theoretically results in net-zero emission power generation. BECCS is the type of "negative emissions technology" most widely selected in assessment models made to meet the requirements of the global average temperature limits of 2 °C and below, although many challenges need to be addressed including the issue of land use relative to other needs such as food security and biodiversity conservation (Fuss et al. 2014).

Direct air CCS, on the other hand, does not pose land use issues. One of the technologies for CO_2 removal is 'air capture' which separates the gas from the ambient air, then utilises industrial processes to convert it to pure CO_2 that can be reused or disposed (Keith 2009). Some prototype facilities are already running and have been capturing CO_2 on a small scale, building the capacity to operate a commercial-scale plant that can generate synthetic fuel (Semeniuk 2017; Wilkinson 2018).

For the 1.5 °C target, most of the scenarios that we found include utilisation of CCS technologies until 2050. Some researchers argued that the use of CCS technology to achieve a quarter of the required total emissions reduction could be replaced by nuclear and/or solar or wind power generation, as long as energy demand is reduced by 20% by 2100 (Van Vuuren et al. 2007). This can be done by increasing energy efficiency. On the other hand, other research estimated that the use of BECCS can only be reduced or abandoned if it is substituted with early and deep emission reductions during 2020–2030 while increasing energy efficiency and the use of direct air CCS (Rockström et al. 2017).

While economic and social debates continue on whether or not large-scale negative emission technologies including BECCS are necessary in the future, mainstream literature agrees that a drastic reduction of energy demands as soon as possible is necessary to achieve both the 2 °C and 1.5 °C targets (Edenhofer et al. 2010; Rogelj 2013; Rogelj et al. 2015; Rockström et al. 2017). We need to take advantage of developments in science and technologies to help bring about a drastic reduction in emissions to achieve the Paris Agreement goal, but we cannot solely rely on these technologies.

Annex B. Methodology of Current Lifestyle Footprint Estimation

B.1. Methodology of current footprint estimation

In this study, the lifestyle carbon footprints are calculated by multiplying the physical or monetary amount of the consumption of products or services per capita, per year (e.g., kg-food/capita/year, passenger km/capita/year, euro/capita/year) and the carbon intensity of the relevant products or services (e.g., $kgCO_2e$/kg-food, $kgCO_2e$/euro), as shown in the formula below:

The annual lifestyle carbon footprint of a specific item ($kgCO_2e$/capita/year)
= the amount of consumption of item (units)
x the carbon intensity of the item ($kgCO_2e$/unit).

This calculation is carried out at the most detailed level of items (see Table B.1) available from the data sources. For the nutrition domain, examples of items include rice, wheat, potatoes, oranges, beef, chicken, milk, and cheese. The number of items slightly differs among countries due to the availability of data and classification of items.

Then, the estimated carbon footprints of each item are aggregated to give the footprint at the component level, using a weighted average. For nutrition, the components are such foods as cereals, vegetables, fruits, meat, and dairy products. See Chapter 3 and Annex C for the results. The number of components is unified across countries wherever possible, but housing has slightly different components due to differently classified energy sources. Consumer goods, leisure and services also vary in components due to differences in how the data is divided up over the sectors.

The carbon footprints of the six domains are likewise estimated by totalling the components, which are in turn totalled to obtain the total annual lifestyle carbon footprint, as shown in the following:

Total annual lifestyle carbon footprint of all items ($kgCO_2e$/capita/year)
= Σ_i (the amount of consumption of item i [unit]
x the carbon intensity of item i [$kgCO_2e$/unit]).

B.2. Finland

1) Specific methodology and data sources

To estimate the lifestyle carbon footprint per capita in Finland, a combination of bottom-up and top-down approaches was used. For the three domains (i.e., nutrition, housing and mobility), country-specific bottom-up LCI databases were used whenever available to estimate footprints, otherwise global LCI databases such as Ecoinvent (Wernet et al. 2016) or product specific LCA studies were used to supplement intensity data. The annual consumption amount per capita was collected from the national statistics (e.g., Official Statistics of Finland 2017a) and surveys (Finnish Transport Agency 2012).

For the other domains (i.e., consumer goods, leisure and others), a top-down approach using calculations of GHG emissions caused from the Finnish economy in 2002 and 2005 (Seppälä et al. 2009) was used. In this methodology, monetary and physical input-output tables obtained from Statistics Finland and mixed lifecycle impact data were used to assess the climate impact in CO_2 equivalents for different product groups. Apart from this, CO_2 emissions from tobacco consumption were estimated using a bottom-up approach based on consumption data from Official Statistics of Finland and a Japanese estimate for intensity.

The specific data sources for consumption amount and carbon intensities for average Finns are summarised in Tables B.2 and B.3

Table B.1. Number of items and components under different domains

Domains	Number of components (number of items)				
	Finland	Japan	Brazil	China	India
Nutrition	10 (63)	10 (55)	10 (32)	10 (51)	10 (47)
Housing	4 (18)	4 (20)	4 (14)	4 (15)	4 (11)
Mobility	7 (11)	8 (16)	7 (7)	8 (8)	7 (7)
Consumer goods	6 (7)*	10 (112)	1 **	1 **	1 **
Leisure	3 (3)*	6 (10)	1 **	1 **	1 **
Services	5 (5)*	13 (58)	1 **	1 **	1 **
Total	35 (107)	51 (271)	24 (53)	25 (74)	24 (65)

*Note: *Items are aggregated according to the product groups of the study by Seppälä et al. (2009). **Items are aggregated as components according to the study by Hertwich and Peters (2009).*

Table B.2. Data sources of consumption amounts (Finland)

Domain	Components	Source	Remarks
Nutrition	Coffee	Coffee and Roasting Federation Finland (n.d.) Coffee measures: Paulig Ltd. (2016)	Consumption of roasted coffee/capita/year. 2016 data. Converted to ready-made coffee (liquid) based on dosing recommendations by Finnish coffee company.
Nutrition	All other	Natural Resource Institute Finland (2017)	Consumption of food commodities/capita by commodity and year. 2016 data not available for all food products therefore data from 2006–2015 used for peas, juices, milk powder, fish products, fresh fruits, berries, game meat, oil products and canned and frozen vegetables. Food loss at household and distribution side included in total consumption amounts in statistics.
Housing	Living space	Official Statistics of Finland (2018b)	Average floor space per household divided by average no. of household members
Housing	Electricity, mix: hydro, biomass, wind, natural gas, oil deriv., waste, peat, coal and deriv.	Total electricity consumption: Official Statistics of Finland (2017a) The share of different energy sources: Finnish Energy (2016) Transmission loss: Honkapuro et al. (2015)	Total electricity consumption of Finnish households divided by population. Electricity consumption of heating free-time residential buildings excluded. Share of different electricity sources based on information published by Finnish Energy. Transmission loss in Finland is only 1%. Losses from production and transmission of electricity are included in electricity consumed.
Housing	District heat	Official Statistics of Finland (2017a)	Total district heat consumption of Finnish households divided by population. District heat consumption of heating of free-time residential buildings excluded.
Housing	Other energy: wood, peat, coal, heating oil, natural gas	Official Statistics of Finland (2017a)	Total district heat consumption of Finnish households divided by population. Consumption of other energy forms for heating of free-time residential buildings excluded.
Housing	Water	Motiva Ltd. n.d.	Annual total water consumption/capita. Including household consumption
Mobility	Air travel	Finnish Transport Agency (2018) Finnish Transport Agency (2012)	Operated annual distance of domestic flights 2016 & international flights 2004–2005. Only annual distances of international flights available in 2004 survey. Relative increase (in %) of domestic flights from 2004 to 2011 used to extrapolate total annual distance of domestic and international flights in 2011. Survey method changed in 2016, therefore, data 2011-2016 not comparable.
Mobility	Bicycle	Finnish Transport Agency (2018)	Daily total cycling distance/capita multiplied by number of days in a year. Including electric bicycles. Business travel-related km excluded.
Mobility	Passenger car (taxi)	Finnish Transport Agency (2018)	Daily total driving distance/capita multiplied by number of days in a year Business travel-related km excluded.
Mobility	Ferry	Official Statistics of Finland (2017b)	Annual total no. of operated ferry trips divided by population 2016. Business travel-related km excluded.
Mobility	Other forms of private transportation	Finnish Transport Agency (2018)	Daily total driving distance/capita multiplied by number of days in a year. Includes km travelled by scooter, moped, motorcycle, snowmobile, golf-car, quad bike, microcar, rowing boat, etc. Business travel-related km excluded.
Mobility	Train	Finnish Transport Agency (2018)	Daily total operating distance multiplied by number of days in a year Business travel-related km excluded.
Mobility	Tram/metro	Finnish Transport Agency (2018)	Daily total operating distance/capita multiplied by number of days in a year. Business travel-related km excluded.
Mobility	Walking	Finnish Transport Agency (2018); Finnish Transport Agency (2012)	Daily total walking distance/capita multiplied by number of days in a year. Walking, running, kicksledge, wheelchair, rollator included in total distance travelled. Business travel-related km excluded.
Goods	Tobacco	National Institute for Health and Welfare and Official Statistics of Finland (2017)	Annual total cigarettes consumed by people over 15 years old, allocated to whole population.
Goods	All other	Seppälä et al. (2009)	Annual total personal GHG emissions 2005 divided by Finnish population 2005. Products categorised based on Classification of Individual Consumption by Purpose ("COICOP" hereafter). Inc furnishing & housekeeping (C05), clothes & shoes (C03), outdoor equip. (C092/91), audio-visual equip. (C091), books, paper & magazines (C095), mixed goods & services (C127, C121/122). Brackets indicate COICOP classification. This classification system means Finn consumer goods are not comparable with other case countries. Some categories might include products classified differently in our study, e.g.,home appliances in C05.
Leisure	All	Seppälä et al. (2009)	Annual total personal GHG emissions 2005 divided by the Finnish population 2005. Based on COICOP. Including recreational & cultural services (C094), travel expenditures abroad (P312Y), hotels (C11). Brackets indicate COICOP classification. Share of eating out excluded, as already included in food domain. Weighted ave % of eating out share of total nutrition calculated from freq. of dining in restaurants or other places outside home in EU.
Services	All	Seppälä et al. (2009)	Annual total personal GHG emissions 2005 divided by Finnish population 2005. Based on COICOP. Including services related to telecommunication (C08), insurance & finance (C125, C126), healthcare services (C06), education (C10), social services (C124). Brackets indicate COICOP classification.

Table B.3. Data sources of carbon intensity (Finland)

Domain	Components	Source	Remarks
Nutrition	Low-fat milk, skimmed milk, cheese, game meat & edible offals, chicken, eggs, margarine, butter-vegetable mixtures, potato flour	Kaskinen et al. (2011)	Domestic values used if available. Most coefficients based on EU studies and case countries with similar conditions.
Nutrition	Beer, wine, coffee	Berners-Lee (2011)	Average values used for beer & wine. For coffee, value for cup of black coffee used.
Nutrition	All other	Wernet et al. (2016)	Domestic values used if available. Mainly EU values used, or global averages.
Housing	Living space	Wernet et al. (2016); Ministry of the Environment, Finland (2017)	Multi-storey building; includes building materials, energy for construction, and disposal of building. Also included is electricity for construction, maintenance & demolition. Excludes operation. Lifecycle of building 80 yrs. EU value. Ecoinvent value given in m^3, therefore is multiplied by average/min. height of Finnish rooms (legislated).
Housing	Electricity: community waste	Official Statistics of Finland (n.d.)	Calorific values & emission coefficients of fuels converted into CO_2 emissions/kWh. Only direct emissions included.
Housing	Electricity: other (hydro, biomass, wind, natural gas, oil deriv., peat)	Wernet et al. (2016)	Finnish values. Electricity production. Finnish values high voltage. Weighted averages calculated for each sub-domain based on Ecoinvent V3.3. electricity mix breakdown.
Housing	District heat	Salo et al. (2017)	Domestic value for district heat. Based on calculation of GHG emissions from Finnish district heating 2009-2013; Includes emissions from entire fuel consumption chain.
Housing	Wood for heating	Salo et al. (2017)	Value for wood & pellets used for heating: estimated emissions from harvesting.
Housing	Heating (peat, coal, heavy heating oil, light heating oil, natural gas)	Official Statistics of Finland (n.d.); Hieta (2010)	Calorific values & emission coefficients of fuels converted into CO_2 emissions per kWh. Includes share of prod & distribution: calculations based on share of production & distribution during whole lifecycle of district heating.
Housing	Water	Wernet et al. (2016)	Tapwater, EU value.
Consumer goods	All	Seppälä et al. (2009)	Annual total personal GHG emissions 2005 divided by Finn population 2005.
Mobility	Airplane	Wernet et al. (2016)	Intracontinental flights: EU average; including aircraft manufacturing & use of airport; maintenance not taken into account in the coefficient.
Mobility	Bicycle	Wernet et al. (2016)	City bicycles, global average. Operation, maintenance & use of road infrastructure included.
Mobility	Car	Salo et al. (2017); VTT Technical Research Centre of Finland Ltd (2017)	Average transport unit emissions for car transport, including emissions from fuel consumption & production, and car manufacturing; Maintenance not taken into account in the coefficient. Estimate of average fuel consumption based on shares of petrol & diesel of different car types (LIPASTO database).
Mobility	Ferry	VTT Technical Research Centre of Finland Ltd (2017); Kotakorpi, Lähteneoja, and Lettenmeier (2008)	Transport unit emissions for ferries. Average value for cruise ships. Separate coefficients for cruises to Estonia & Sweden. Infrastructure, production & maintenance-related emissions added based on FinMIPS.
Mobility	Motorcycle (and other forms of private transportation)	VTT Technical Research Centre of Finland Ltd (2017)	Average transport unit emissions for motorcycle transport; includes operation, production & maintenance of scooters and use of road infrastructure.
Mobility	Train	VTT Technical Research Centre of Finland Ltd (2017); VR Group Ltd (2017); Salo et al. (2017)	Unit emissions for rail transport. Coefficient based on electricity consumption of railway transportation. Share of renewable electricity 90%. Emissions from production & infrastructure included; maintenance not taken into account in the coefficient.
Mobility	Tram/metro	VTT Technical Research Centre of Finland Ltd (2017); Salo et al. (2017)	Unit emissions for rail transport. Renewable electricity used. Emissions from production & infrastructure included.
Mobility	Bus	VTT Technical Research Centre of Finland Ltd (2017); Salo et al. (2017)	Unit emissions for bus transport. Average value for coach buses 41g/person*km; for city buses 53g/person*km. Coefficient balanced on basis of mileage share between coaches (38%) and city buses (62%). Emissions from production & infrastructure included.
Mobility	Walking		No emissions calculated for walking.
Goods	Tobacco	Nansai et al. (2012)	Intensity per cigarette calculated from Japanese monetary based intensity & average cost of different Japanese tobacco brands.
Goods	All other	Seppälä et al. (2009)	Annual total personal GHG emissions 2005 divided by Finn population 2005.
Leisure	All	Seppälä et al. (2009) Eating out rate: Statista Ltd (2015)	Annual total personal GHG emissions 2005 divided by Finn population 2005.
Services	All	Seppälä et al. (2009)	Annual total personal GHG emissions 2005 divided by Finn population 2005.

2) Validation of estimations

To validate the estimated carbon footprint in Finland, three alternative data sources were used and compared using three types of data and methodologies, as summarised in Table B.4.

The first alternative data source, Alternative 1, is a calculation of GHG emissions caused from the Finnish economy in 2002 and 2005 on the basis of input-output tables (Seppälä et al. 2009). In this methodology, monetary and physical input-output tables for 150 industries and 918 products obtained from Statistics Finland and mixed lifecycle impact data were used to assess the climate impact in CO_2 equivalent. For the comparison, public consumption and investments were separated from household consumption (on the basis of the Classification of Individual Consumption by Purpose, COICOP) and therefore actual individual GHG emissions for main final use product groups (housing, food and transportation) were obtained. This data source is used as part of this study's estimation of household goods and others (leisure and non-leisure) because sufficient consumption and/or carbon intensity data for household goods, leisure and non-leisure related products and services was not available. The strength of this I/O-based data is its coverage and detailed classification of products and services but data availability is limited, thus values used in this study are based on calculations made for readily classified product groups (Seppälä et al. 2009, Appendix 5, figure b). Detailed data on the sub-categories under each product group was not available and therefore monetary based carbon intensities ($kgCO_2e$/Euro) obtained from the study of Seppälä et al. (2009) were used to derive average values for each product group. Also, data on consumed amounts of different products and services was not available.

The comparison with Alternative 1 indicates relatively small differences in nutrition and housing, relatively large differences in mobility and the overall difference in the three domains' subtotal is 10%. The small difference in nutrition and housing could be related to differences in the coefficients used in Alternative 1, because the data used in Alternative 1 and this study are both based on national statistics. The notably lower value for mobility in Alternative 1 is probably the result of lower carbon intensities. For example, carbon intensities used in Alternative 1 only take into account emissions from direct fuel consumption and vehicle purchases, and emissions related to infrastructure are excluded.

The second alternative data, Alternative 2, is based on the GHG emissions of the average Finn in 2010 (Salo and Nissinen 2017), and is a development of the ENVIMAT model used in Alternative 1 but with fixed capital, such as buildings included. In this methodology, 66 product categories based on monetary input-output tables were multiplied with the intensity factors previously defined in the ENVIMAT model. These 66 product categories were aggregated into four consumption domains: nutrition, housing, mobility, and other goods and services. The strength of this I/O-based study is its coverage, as in the study of Seppälä et al. (2009). Nevertheless, the data availability of sub-categories under each domain is even more limited compared to the study of Seppälä et al. (2009).

The overall difference in the three domains is relatively high (21%), due to the large difference in the housing sector (80%). The study of Salo et al. (2017) takes into account land use, land use change, and forestry (LULUCF), which has been excluded in our study. In addition, the notable difference in the housing sector might be explained by how products and services related to housing were categorised, and also the coefficients used. In the study of Salo and Nissinen (2017), the housing sector includes emissions related to direct energy use in housing, the emissions related to residential buildings, services used for technical maintenance, but also furniture and other items, which are classified under consumer goods in our study. Heating energy, electricity and maintenance services account for 72% (3.2 tonnes/

Table B.4. Comparison of lifestyle carbon footprints for Finland

Consumption domain	Estimates of this study	Alternative 1: Finnish I/O based estimation		Alternative 2: Finnish I/O based estimation		Alternative 3: International I/O based estimation	
	CF (kg)	CF (kg)	Difference	CF (kg)	Difference	CF (kg)	Difference
Nutrition	1,750	1,580	–9.7%	1,800	+2.9%	1,550	–11%
Housing	2,500	2,790	+11%	4,500	+80%	4,150	+66%
Mobility	2,790	1,990	–29%	2,200	-21%	2,330	+13%
Subtotal (3 domains)	**6,910**	**6,350**	**–9.8%**	**8,500**	**+21%**	**8,040**	**+17%**
Consumer goods	1,330	1,330	0.0%			1,940	+47%
Subtotal (4 domains)	**8,240**	**7,680**	**–7%**			**9,980**	**+19%**
Leisure & services	2,060	2,060	0.0%	3,000*	-11%	3,240	+58%
Total (all domains)	**10,430**	**9,740**	**-6.6%**	**11,500**	**+10%**	**13,220**	**+27%**

Note: Estimation of household goods and others in this study uses Alternative 1 Finnish I/O estimation.
** Includes consumer goods, leisure & services. 'Difference' expresses the difference in summed values of consumer goods, leisure & services given in each Alternative compared with our study.*

cap/yr) of the total per capita GHG emissions in the housing sector, which might be related to differences in the coefficients used in Alternative 2, because the data used in Alternative 2 and this study are both based on national statistics. The reason for the lower value for mobility might be the similar to in Alternative 1, i.e., that carbon intensities exclude emissions related to infrastructure.

The third alternative data, Alternative 3, is based on the regional input-output (MRIO) analysis of Hertwich and Peters (2009). The overall difference in the three domains is relatively high (17%), although the comparison indicates relatively small differences in the nutrition and mobility sectors and relatively large differences in housing. Nutrition and mobility have smaller values in Alternative 2, and housing is approximately 66% higher compared to the estimation in this study. The sources and sinks of land use, land use change and forestry (LULUCF) are not included in Alternative 2 either and therefore exclusion of LULUCF in this study does not explain the relatively large difference in housing, but it might be due the aggregation system used in the study of Hertwich and Peters (2009), which could lead to different estimates, as was the case for Japan. The MRIO-based analysis by Hertwich & Peters covers only 57 sectors whereas 151 sectors are covered in the study of Seppälä et al (2009). The difference in the household goods domain is also large and in the domain "Others" (leisure and non-leisure products and services) even larger. The methodology and data used in Alternative 1 is based on more detailed input-output data for Finland, which provides more detailed classifications and groupings of commodities compared to MRIO-based analysis.

B.3. Japan

1) Specific methodology and data sources

For estimation of lifestyles carbon footprint per capita in Japan, country-specific intensity data was used whenever available. Some of the items for which country-specific data was not available were supplemented by the global LCI databases, such as the Ecoinvent database (Wernet et al. 2016) or other sources used in the estimation of carbon footprint in other case countries in this study. The LCI database used in other case countries (e.g., Ecoinvent) typically contains intensity data for European or North American countries and RoW, which is expected to differ from that of Japan.

The lifestyle carbon footprints in Japan were estimated through a combination of bottom-up and top-down approaches. For the three main domains (i.e., nutrition, housing, and mobility), bottom-up LCI databases such as Ministry of the Environment of Japan (2016) and Japan Environmental Management Association For Industry (2012) and published LCA case studies for individual products were used to enable discussion based on the physical consumption units. Direct GHG emissions of households such as combustion of fuels are also estimated from emission intensity and amount of fuel consumption per capita. Some of the direct emissions of non-CO_2 at households, such as HFCs from fridges and air conditioners in the housing and mobility domains are estimated from the table of GHG emissions based on the national inventory included in the *Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables* (3EID) database (Nansai 2013). The annual amount of consumption (e.g., kg of food, passenger km of mobility, and GJ energy consumption) per capita were estimated from nation-wide total consumption amounts, from official statistics, divided by the population.

For the other domains (i.e., consumer goods, leisure, and others) and some indirect emissions in the main three domains, the intensity databases based on the top-down approach using input-output analysis were utilised to increase the coverage of the estimation. The amounts of consumption per capita were estimated as monetary values from the final demand of the household sector in purchaser's price from the national input-output table of 2005 (Ministry of Internal Affairs and Communications, Japan 2009). The carbon intensities per expenditure were estimated from the Global Link Input-Output (GLIO) databases (Nansai et al. 2012), which is compatible with the 2005 input-output table. In addition, some of the footprints from production, construction, and maintenance of owned products in housing and mobility domains (e.g., owned vehicles, construction and maintenance of houses) are also estimated from the I/O table and the GLIO database, and added to the footprint estimated from the bottom-up approach.

As a limitation of the data sources, it should be noted that the intensity data from Japan Environmental Management Association For Industry (2012) was calculated before the Great East Japan Earthquake in 2011. Since then, the composition of grid electricity has significantly changed, and now less nuclear power and more thermal power is used. Therefore, the study might underestimate the indirect emissions from the consumption of food products, which this database is mostly used for. In addition, the intensity data from the GLIO model (Nansai et al. 2012) is based on the I/O table in 2005. The I/O table is generally updated every five years, but the update of the intensity database is usually delayed by several years. As for the calculations of this study, the latest available GLIO database was produced in 2005. The updated 3EID database is currently available for 2011, which provides the intensity data, however, the intensity data from 3EID is based on the domestic technology assumption and does not consider the difference in efficiency of imported products, which the GLIO model can consider. Also, Japan's economy was not operating normally in 2011 due to the Great East Japan Earthquake. Considering these reasons, the study uses intensity from the 2005 GLIO database for the consumption goods, leisure, and services domains.

The specific data sources for consumption amount and carbon intensity for average Japanese are summarised in Tables B.5 and B.6.

Table B.5. Data sources of consumption amount (Japan)

Domain	Components	Source	Remarks
Nutrition	All components (food intake)	Food intake: Ministry of Health, Labour and Welfare, Japan (2016)	Amount of food intake for each item converted into amount of food supply to households considering the share of food loss and non-edible part.
Nutrition	All components (food loss)	Food loss: Ministry of Agriculture, Forestry and Fisheries, Japan (2014a)	Food loss at households assumed as average for all items (3.7%)
Nutrition	Vegetables, fruits, eggs, fishes (share of edible part)	Edible part share: Ministry of Agriculture, Forestry and Fisheries, Japan (2016)	Edible part share calculated as proportion of net supply to gross supply. Non-edible share of fish assumed as half of calculated amount. Other items not specified in the food balance sheet assumed free of non-edible parts.
Nutrition	Vegetables (share of greenhouse farming)	Greenhouse vegetables: Ministry of Agriculture, Forestry and Fisheries, Japan (2012b) Total vegetables: Ministry of Agriculture, Forestry and Fisheries, Japan (2012a)	Greenhouse farmed vegetables divided by total vegetables produced.
Housing	Living space (size)	Ministry of Internal Affairs and Communications, Japan (2013)	Total no. of dwellings x average floor space, divided by total no. of household members.
Housing	Living space (construction)	Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017e)	Total area of constructed houses/year divided by population, distinguishing wood and others.
Housing	Living space (repair and maintenance)	Ministry of Internal Affairs and Communications, Japan (2016)	Household repairs & maintenance expenditure divided by average household size.
Housing	Electricity, urban gas, kerosene, LPG, renewable energy, steam and heat	Agency for Natural Resources and Energy, Japan (2018b)	GJ converted to kWh for electricity (1GJ = 277.8 kWh)
Housing	Water	Ministry of Land, Infrastructure, Transport and Tourism, Japan (2016c)	Waste water assumed as same amount as water supply.
Mobility	Car (gasoline, hybrid, light gas oil)	Driving distance: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017b) Occupancy ratio: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017c)	Annual total driving distance x occupancy ratio, divided by population.
Mobility	Car (electric)	No. of cars: Automobile Inspection and Registration Information Association (2017) Average distance: Next Generation Vehicle Promotion Center (2012) Occupancy ratio: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017c)	No. of owned electric passenger vehicles x average operating distance x average occupancy ratio, divided by population.
Mobility	Motorbike	No. of cars: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017d) Average distance: Japan Automobile Manufacturers Association (2016)	No. of owned motorbikes x average operating distance, divided by population.

Mobility	Bus, car (taxi)	Ministry of Land, Infrastructure, Transport and Tourism, Japan(2016a) Occupancy rate for taxi: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017c) Customer ride rate for taxi: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2005)	Total passenger distance divided by population. Bus has capacity of 11 or more. Taxi includes hires and has capacity up to 10.
Mobility	Train	Ministry of Land, Infrastructure, Transport and Tourism, Japan (2016b)	Total passenger distance divided by population.
Mobility	Airplane (domestic)	Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017a)	Total passenger distance divided by population.
Mobility	Airplane (interna-tional)	Average Flight Distance: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017a) Frequency of international air trips: Ministry of Justice, Japan (2017)	No. of Japanese departures from airports x average round trip distance of international flights operated by Japanese airlines, divided by population.
Mobility	Ferry (domestic)	Ministry of Land, Infrastructure, Transport and Tourism, Japan (2015b)	Total passenger distance divided by population.
Mobility	Ferry (international)	Frequency of international sea trips: Ministry of Justice, Japan (2017)	No. of Japanese departures from ports x round trip of Fukuoka-Busan distance, divided by population.
Mobility	Bicycle	Owaki (2010)	Daily average cycling distance/capita x no. of days.
Mobility	Walking	Frequency of trips and Average time for walking trips: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2015a) Average speed of walking: Yoshida and Fujioka (n.d.)	Inner city walking trips & walking related to trips using train & bus (weighted ave. of holidays and weekdays). Distance from walking trips estimated from frequency of trips x ave. time/trip and ave. walking speed (ave. of men and women, 1 & 2 persons). Walking distance related to bus and train estimated from frequency of bus and train trips x assumed distance from sations. Distance from station calculated as area weighted ave. of utility area (300m diameter for bus, 750m for train).
Mobility	Car, motorcycle, bicycle (products and maintenance)	Ministry of Internal Affairs and Communications, Japan (2009)	Including car, motorcycle, bicycle, tyres & tubes, automobile engines & parts, automobile repairs (purchaser price). Amount distributed to relevant transportation mode based on passenger distance share.
Mobility	Car, motorcycle, bus, train (normal), bicycle, foot (share of business purpose)	Ministry of Land, Infrastructure, Transport and Tourism, Japan (2012)	Proportion of business purpose trips of all purpose trips excluded from mobility demand in this study (commuting was included). Weighted average of weekdays & weekends. All surveyed cities in Japan.
Mobility	Train (bullet), flight (domestic), ferry (share of business purpose)	Japan Travel Bureau Foundation (2014)	Proportion of business and business-related domestic trips of all-purpose international trips excluded from mobility demand in this study.
Mobility	Flight (international) (share of business purpose)	JTB Tourism Research and Consulting Co. (2016)	Proportion of business domestic trips of all-purpose international trips was excluded from mobility demand in this study. Average of overnight & day trips.
Goods	All items	Ministry of Internal Affairs and Communications, Japan (2009)	Purchaser price. Products & materials not covered in other domains including appliances, ICV/AC equipment, furniture, clothes, sanitary goods, jewelry, sports/entertainment equipment, & tobacco.
Leisure	All items	Ministry of Internal Affairs and Communications, Japan (2009)	Purchaser price. Leisure activities outside of home, including amusement, sports, theatre, restaurant, & hotel (footprint from food intake included in nutrition domain are excluded from leisure domain).
Services	All items	Ministry of Internal Affairs and Communications, Japan (2009)	Purchaser price. Service consumption including finance & insurance, communication & information, broadcasting, ceremony, barber, beauty & cleaning, public bath; public service paid by households including education, medical, social welfare & nursing; and transport services paid by households.

Table B.6. Data sources of carbon intensity (Japan)

Domain	Components	Source	Remarks
Food	All other items	Japan Environmental Management Association For Industry (2012)	For items with no intensity data for exactly same category, data for similar product was assumed. Intensity for offals & other meats calculated as weighted ave. of beef, pork, & chicken.
Food	Beverages (non-alcoholic)	Intensity: Kajikawa (n.d.) Bottled share: Itoen Co. (2014)	Tea: Weighted ave. of bottled tea and home brewed tea. 30% bottled share. Coffee: Weighted ave. of canned coffee & home brewed coffee. 35% bottled share. Other: Average of tea & coffee. Excludes emissions from vending machines, distribution, & direct emissions from home brewing.
Food	Beverages (alcoholic)	Berners-Lee (2011)	Rice wine & Western alcoholic beverages assumed as same intensity for wine
Food	Meat (chicken)	Wernet et al. (2016)	
Food	All food items (food delivery and retail, wholesale to consumer)	Nemoto (2009)	Intensity for tomatoes & pork assumed for refrigerated & non-refrigerated food. Average of home delivery & supermarket.
Food	All food items (food loss, before consumer)	Ministry of the Environment, Japan (2017)	Share of food loss (edible part) from supply chain (nonstandard, returned, unsold, & left-over) of gross food supply (4.1%)
Housing	Living space (construction, repair and maintenance)	Ministry of the Environment, Japan (2016)	Construction: intensity/unit price divided by unit price/sq. metre. Repair & maintenance: construction repair intensity/unit price.
Housing	Grid electricity (oil, LNG, coal, hydro, renewable, nuclear)	Intensity except for biomass: Central Research Institute of Electric Power Industry (2010) Intensity for biomass: Biomass Power Association (2016) Share of combined cycle and normal LNG: Agency for Natural Resources and Energy, Japan (2015) Transmission loss: Agency for Natural Resources and Energy, Japan (2018a)	Transmission loss estimated from difference of electricity supply & demand in April, 2017. Intensity for LNG power assumed as weighted average of normal & combined cycle LNG power based on power plant capacity.
Housing	Renewable energy (off-grid)	Kawamoto (2011)	Assumed as average of solar power generation system for households.
Housing	LPG, urban gas	Japan LP Gas Association (2009)	Including production & transport.
Housing	Kerosene	Japan Environmental Management Association For Industry (2012)	Burning kerosene in boiler including production
Housing	Steam and heat	Kayo et al. (2016)	Wood-based biomass district heating system.
Housing	Water (waste supply)	Ministry of the Environment, Japan (2015)	Average of water supply companies.
Housing	Water (wastewater)	Sano et al. (2012)	Average of water treatment schemes.
Mobility	Car (combustion, car (taxi), bus, train, ferry, flight	Ministry of the Environment, Japan (2016)	Emission intensity/passenger distance.
Mobility	Car (hybrid, electric)	Improved intensity for hybrid and electric car: Japan Automobile Research Institute (2011) Intensity of normal car: Ministry of the Environment, Japan (2016)	Intensity for hybrid car and electric car assumed as proportion of gasoline-fuelled HEV and Japanese electricity mix based BEV of gasoline-fuelled ICEV, respectively (64%, 37%; standard case, JC08 mode).
Mobility	Motorcycle	Wernet et al. (2016)	
Mobility	Car, motorcycle, bicycle (products and maintenance)	Nansai et al. (2012)	GHG emission intensity/purchaser price based on global link input-output (GLIO) model using 2005 input-output table. Proportion of indirect emissions to direct emissions for taxis assumed as same as combustion engine owned cars.
Mobility	Flight, train (indirect emissions)	Shibahara et al. (2009)	Indirect emissions estimated from proportion of production-phase emissions to use-phase emissions (Tokyo-Osaka flight & bullet train, excluding infrastructure).
Mobility	Bus (indirect emissions)	Shibahara et al. (2009)	Indirect emissions estimated from proportion of production-phase emission to use-phase emissions (ordinary bus).
Mobility	Ferry (indirect emissions)	Ministry of the Environment, Japan (2009)	Indirect emissions estimated from proportion of production-phase emissions to use-phase emissions (tanker).

Goods, leisure, service	All items	Nansai et al. (2012)	GHG emission intensity per purchaser price based on global link input-output (GLIO) model using 2005 input-output table.
Mobility and goods	Cars (HFCs), home appliances (HFCs)	Nansai (2013)	Direct emissions of HFCs from fridges & ACs estimated from tables included in 2005 3EID database.
Leisure	Restaurants, cafes (eat-out share)	Eat-out rate: Ministry of Health, Labour and Welfare, Japan (2016)	Eat out share estimated from data of frequency of eat outs (average of men & women, average of max. & min.). Footprint from food intake deducted from leisure domain but included in nutrition domain.

2) Validation of estimations

To validate the estimated carbon footprint in Japan, three alternative data sources were used, and the estimated lifestyles carbon footprints were compared using three types of data and methodologies, as summarised in Table B.7.

Table B.7. Comparison of lifestyles carbon footprint in Japan

Consumption domain	Estimates of this Study	Alternative 1: Japanese I/O based estimation		Alternative 2: International LCA based estimation		Alternative 3: International I/O based estimation	
	CF (kg)	CF (kg)	Difference	CF (kg)	Difference	CF (kg)	Difference
Nutrition	1,400	1,280	−9%	1,200	−14%	1,050	−25%
Housing	2,430	2,110	−13%	2,080	−14%	2,480	+2%
Mobility	1,550	1,820	+17%	2,200	+42%	2,100	+36%
Subtotal (3 domains)	**5,370**	**5,210**	**−3.1%**	**5,480**	**+2.0%**	**5,640**	**+4.9%**
Consumer goods	1,030	1,030	0.0%	-	-	1,820	+76%
Subtotal (4 domains)	**6,410**	**6,240**	**−2.6%**	-	-	**7,450**	**+16%**
Others	1,230	1,300	+5.1%	-	-	2,480	+101%
Total (all domains)	**7,640**	**7,540**	**−1.4%**	-	-	**9,940**	**+30%**

Note: Data from authors based on Ministry of Internal Affairs and Communications, Japan (2009), Nansai et al. (2012), Hertwich and Peters (2009), and other data sources specified in this section. Estimation of household goods and others in this study uses the Japanese I/O estimation. In the leisure domain (part of others), footprint induced from the food ingredients from restaurants is deducted because it is included in the nutrition domain. For Alternative 3, construction, clothes, and trade domains were included in housing, consumer goods, and others domains, respectively.

The first alternative data source, Alternative 1, is an input-output table based estimation using the 2005 input-output table (Ministry of Internal Affairs and Communications, Japan 2009) and global link input-output (GLIO) database (Nansai et al. 2012). In this methodology, GHG emission coefficients based on purchaser price for over 400 commodities were obtained from the GLIO database. These coefficients were multiplied by the expenditures of final demand from households and divided by the total number of population to estimate the per capita annual carbon footprint for each category. The categories were then combined into the relevant consumption domains in this study. Although more recent input-output tables are available in Japan, the 2011 table was not used due to the impacts of the large earthquake that year; and there is no GHG emission coefficients data currently available for the 2016 table. In this study, this data source was used as part of the estimation of consumer goods, leisure, and services, and part of mobility (production and maintenance of owned vehicle). The strength of this top-down data is its coverage, but the data is only available in monetary value and cannot be directly used to analyse based on the level of service provision such as kg of food, km of mobility demand, and square metres of housing space.

In comparison with Alternative 1, the overall difference in the three domains is 3.1%. The estimation of this study for these three domains is based on the combination of bottom-up LCA data and I/O analysis-based data. The estimation of housing in this study tends to overestimate by 13% compared to the estimation from the first alternative method. This is partly due to the difference in the energy mix estimation between this study (assumed as 2015) and the first alternative estimation (2005), where the latter has a higher share of nuclear power in the grid electricity. Conversely, the mobility domain in this study tends to underestimate by 17% compared to the estimation from Alternative 1. This could be partly due to the slightly decreasing trend of the ownership of cars in recent years and underestimation of the indirect emissions from public transport in this study because of the non-exhaustive nature of the methodology. The nutrition domain in this study also overestimated by 9%. This is partly because our estimation includes all the footprints from nutritional intake gained from eating out at restaurants, while the Alternative 1 method assigned this to another domain. Another reason may be the westernisation of eating habits, which is also high-carbon, such as the growing trend in meat consumption. Other domains in this study use the same data source as the Alternative 1 estimation. The difference of 5.1% in other domains is due to the deduction of footprint induced from the food ingredients from restaurants in the leisure domain, which is included in the nutrition domain in the main estimation of the study.

The second alternative data, Alternative 2, is the carbon intensity data used in the estimation of other case countries (e.g., Finland, India, Brazil, and China), of Ecoinvent (Wernet et al. 2016). Although this carbon intensity data is not specific to Japan, the data from Europe or other Asian countries can provide a rough estimate of the carbon intensity of the consumption in Japan. The data used here includes global averages, values from other developed countries, or values of the Rest of the World (RoW) depending on data availability. Comparison with the Alternative 2 method indicates that the estimation with country-specific intensity data in the mobility domain tends to be smaller than the one using international data. This could partly be because Japan's transportation sector is relatively efficient due to its high utilisation of public transport in urban areas, higher occupancy rate of flights, and higher replacement with newer, more efficient vehicles, all of which may contribute to lower emission intensity in this sector in Japan. Conversely, the estimates of nutrition and housing from domestic LCA data tend to be slightly larger than international LCA data by 14%, which could be due to the lower efficiency of the food and building sector in Japan due to small scale farming in limited land area and large share of wooden constructed, detached houses.

The third alternative data, Alternative 3, is based on the estimated footprint categorised into consumption domains based on multiple regional input-output (MRIO) analysis (Hertwich and Peters 2009). In this estimation for comparison, the household share is assumed as 72% because country-specific values of footprint from household demand are not available to the public. The strengths of this data are its coverage of countries and sectors. However, the sectoral disaggregation is only 57, which is rough due to the input-output data used in this methodology (GTAP), so aggregated sectors may cause large errors in the estimates. The estimation made by the Alternative 3 method tends to be larger than the main estimates in this study. There are relatively small differences in the three domains of nutrition, housing, and mobility, which is the primary focus of this study. The errors in other domains are much larger, which could be partly due to the assumption of household footprint share or differences in categorisation of items between domains. Yet, the methodology and data used in this study for these domains are based on the Japanese input-output table based data, which has more detailed disaggregation of commodities. The top-down I/O based estimation is subject to errors due to sectoral aggregations. In particular, the roughly aggregated categories of GTAP sectors may not provide as accurate estimations as the Japanese I/O based estimation (the Alternative 1 method), which confirms the estimations in this study do not greatly differ from the top-down estimates.

B.4. Brazil, China, and India

Table B.8. Data sources of consumption domains (China, Brazil, and India)

Domain	Components	Source	Remarks
Nutrition	All	Food and Agriculture Organisation (2017)	Food supply quantity, kg/capita/year. Data from 2013.
Housing	Energy (Brazil)	EPE – Empresa de Pesquisa Energética (2017)	Annual energy consumption of residential sector (Table 3.4.a) 2016 divided by Brazil 2016 population to achieve annual energy consumption/capita.
Housing	All other (Electricity, energy and domestic water consumption)	WBCSD (2015a) WBCSD (2016) WBCSD (2015b)	Data for footprint calculation from material footprint calculation for previous D-mat project with CSCP & WBCSD.
Mobility	Walking (India)	NationMaster (n.d.)	Total daily time for walking x 4 km/h.
Mobility	All other	WBCSD (2015a) WBCSD (2016) WBCSD (2015b)	Data for footprint calculation from material footprint calculation for previous D-mat project with CSCP & WBCSD.
Goods, Leisure, Services	All	Hertwich and Peters (2009)	Regional input-output (MRIO) analysis.

Table B.9. Data sources of carbon intensity (China, Brazil, and India)

Domain	Components	Source	Remarks
Nutrition	Oilseed, oil & fat, rape & mustard seed, sesame	Kaskinen et al. (2011)	Country-specific values used if available. Most coefficients used based on European studies & case countries with similar conditions.
Nutrition	Beer, wine, coffee, tea	Berners-Lee (2011)	Average values used.
Nutrition	All other	Wernet et al. (2016)	Country-specific values used if available.
Housing	Living space	Wernet et al. (2016)	Multi-storey building; includes building materials, energy for construction, and disposal of building. Lifecycle of bldg: 80 yrs. EU value.
Housing	Electricity	Wernet et al. (2016)	Country-specific values used for different types of production. Average values for each type calculated based on shares given in Ecoinvent country-specific electricity production mix data sheet. Transmission & transformation loss taken into account.
Housing	Energy (All other)	Wernet et al. (2016)	Country-specific values used if available. Global values for kerosene, LPG, firewood & charcoal.
Housing	Water	Wernet et al. (2016)	Tap water, global value.
Mobility	Car (Brazil)	Dardiotis et al. (2015)	Average CO_2 emissions from comparison of two FFVs (flexible fuel vehicles; 85% ethanol, 15% gasoline).
Mobility	All other	Wernet et al. (2016)	Country-specific values used if available.
Goods, Leisure, Services	All	Hertwich and Peters (2009)	Regional input-output (MRIO) analysis.

Annex C. Supplementary Table of Results

The detailed estimation results of lifestyle carbon footprints in the case countries are given in Table C.1 (comparison among countries) and Table C.2-6 (country-specific results).

Table C.1. Current annual lifestyle carbon footprint per capita in case countries

Domains	Finland		Japan		China		Brazil		India	
	CF (kg)	%	CF (kg)	%	CF (kg)	%	CF (kg)	%	CF (kg)	%
Nutrition	1,750	17	1,400	18	1,050	25	1,040	37	510	26
Housing	2,500	24	2,430	32	1,350	33	470	17	400	21
Mobility	2,790	27	1,550	20	1,090	26	480	17	700	36
Total (3 domains)	**7,050**	**68**	**5,380**	**70**	**3,490**	**84**	**1,980**	**70**	**1,600**	**83**
Consumer goods	1,330*	13	1,030	13	290**	7	270**	9.6	160**	8
Total (4 domains)	**8,370**	**80**	**6,410**	**83**	**3,780**	**91**	**2,250**	**80**	**1,760**	**91**
Others (leisure & services)	2060*	20	1,240	17	380**	9	560**	20	170**	9
Total (all domains)	**10,430**	**100**	**7,650**	**100**	**4,160**	**100**	**2,810**	**100**	**1,930**	**100**

*Note: *Values from Seppälä et al. 2009. **Values from Hertwich and Peters (2009).*

Table C.2. Current annual lifestyle carbon footprint per capita in Finland

Domains and components	CF ($kgCO_2e$)	CF (%)	Amount (total)	Amount (%)
Nutrition	**1750**	**17%**	**940 kg**	-
Cereals	70	4.2%	80 kg	8.5%
Vegetables (incl. potatoes)	60	3.2%	130 kg	14%
Beans/nuts	4	0.2%	3 kg	0.3%
Dairy	630	36%	200 kg	21%
Eggs	30	1.8%	10 kg	1.3%
Fish	60	3.2%	20 kg	1.7%
Meat	650	37%	80 kg	8.6%
Fruits	50	2.6%	80 kg	8.7%
Beverages	160	8.8%	290 kg	31%
Others	50	2.9%	50 kg	4.8%

Housing	**2,500**	**24%**	**40.3 m²**	-
Construction and maintenance	400	16%	40.3 m²	-
Electricity	860	34%	3,940 kWh	36%
Hydro grid electricity	40	1.4%	930 kWh	8.6%
Biomass grid electricity	40	1.5%	640 kWh	5.9%
Wind grid electricity	4	0.2%	180 kWh	1.7%
Natural gas electricity	130	5.0%	210 kWh	1.9%
Waste/ oil derivates, grid electricity	20	0.7%	70 kWh	0.6%
Nuclear grid electricity	20	0.6%	1,330 kWh	12%
Coal and derivates, grid electricity	440	18%	410 kWh	3.8%
Peat grid electricity	180	7.3%	170 kWh	1.6%
Other energy supply	1,230	49%	6,850 kWh	64%
District heating	950	38%	3,570 kWh	33%
Light heating oil	220	8.7%	680 kWh	6.3%
Wood	40	1.4%	2,510 kWh	23%
Natural gas	20	0.6%	70 kWh	0.7%
Other heating sources	10	0.3%	20 kWh	0.2%
Water consumption	10	0.6%	51 m³	-
Mobility	**2,790**	**27%**	**16,470 km**	-
Airplane	370	13%	2,180 km	13%
Car	2,240	80%	11,200 km	68%
Other private transportation	120	4.2%	810 km	4.9%
Train	0.1	0.03%	750 km	4.5%
Bus	52	1.9%	890 km	5.3%
Ferry	8	0.3%	40 km	0.2%
Bicycle	4	0.1%	260 km	1.6%
Walking	0	0.0%	350 km	2.1%
Consumer goods	**1,330**	**13%**	**€ 3,020**	-
ICT/AV equipment	110	8.0%	€ 270	8.6%
Furniture	360	27%	€ 800	26%
Clothes	260	19%	€ 640	21%
Sports/entertainment	240	18%	€ 350	11%
Paper/stationery	90	6.8%	€ 220	7.3%
Other	270	21%	€ 740	26%
Sub-total (4 domains)	**8,400**	**80%**		
Leisure	**570**	**5.5%**	**€ 1,620**	-
Services	**1,480**	**14%**	**€ 5,740**	-
Grand Total (6 domains)	**10,430**	**100%**	-	-

Table C.3. Current annual lifestyle carbon footprint per capita in Japan

Domains and components	CF ($kgCO_2e$)	CF (%)	Amount	Amount (%)
Nutrition	**1,400**	**18%**	**800 kg**	-
Cereals	270	19%	160 kg	20%
Vegetables	140	9.8%	150 kg	19%
Beans/nuts	30	1.9%	20 kg	2.5%
Dairy	180	13%	50 kg	6.3%
Eggs	30	2.0%	20 kg	2.0%
Fish	100	7.4%	30 kg	3.7%
Meat	330	23%	40 kg	4.6%
Fruits	60	4.2%	50 kg	6.2%
Beverage	140	10%	230 kg	29%
Others	130	9.2%	50 kg	6.5%
Housing *1	**2,430**	**32%**	**39.4 m^2**	-
Construction/maintenance *2	480	20%	39.4 m^2	-
Electricity	1,330	55%	2120 kWh	51%
Renewable/hydro grid electricity	8	0.3%	310 kWh	7.4%
Oil grid electricity	150	6.3%	200 kWh	4.7%
LNG grid electricity	490	20%	890 kWh	21%
Coal grid electricity	680	28%	680 kWh	16%
Nuclear grid electricity	1	0.03%	40 kWh	0.9%
Other Energy	530	22%	2070 kWh	49%
Kerosene	190	7.7%	730 kWh	17%
LPG	110	4.5%	430 kWh	10%
Urban gas	230	9.5%	890 kWh	21%
Renewable off-grid/steam and heat	2	0.1%	20 kWh	0.5%
Water/wastewater	90	3.7%	110 m^3	-
Mobility	**1,550**	**20%**	**10,970 km**	-
Airplane	160	10%	1,660 km	15%
Car	1,250	80%	5,000 km	46%
Motorcycle	10	0.8%	90 km	0.8%
Train	80	5.0%	3,120 km	28%
Bus	40	2.8%	490 km	4.5%
Ferry	10	0.9%	20 km	0.2%
Bicycle	6	0.4%	270 km	2.4%
Walking	0	0.0%	310 km	2.9%

Consumer goods	**1,030**	**13%**	**358,600 JPY**	-
Home appliances	120	12%	38,200 JPY	11%
ICT/AV equipment	200	20%	73,400 JPY	20%
Furniture/wood products	40	4.0%	14,100 JPY	3.9%
Clothes	220	21%	73,300 JPY	20%
Sports/entertainment	80	8.1%	32,100 JPY	9.0%
Paper/stationery	20	1.6%	3,800 JPY	1.1%
Sanitation	120	12%	39,600 JPY	11%
Jewellyries	30	2.7%	9,700 JPY	2.7%
Tobacco	40	3.5%	31,700 JPY	8.8%
Others	160	15.5%	42,600 JPY	12%
Leisure	**580**	**8%**	**220,000 JPY**	-
Services	**650**	**9%**	**444,300 JPY**	-
Grand total	**7,650**	**100%**	-	-

*Note: *1 Sum of per capita footprint from construction and maintenance, electricity, other energy, and water divided by average size of house per capita.*
**2 Area of living space per capita.*

Table C.4. Current annual lifestyle carbon footprint per capita in China

Domains and components	CF ($kgCO_2e$)	CF (%)	Amount	Amount (%)
Nutrition	**1,050**	**25%**	**900 kg**	-
Cereals	100	9.1%	150 kg	17%
Vegetables (incl. potatoes)	110	11%	420 kg	46%
Beans/nuts	10	0.9%	10 kg	1.3%
Dairy	60	6.0%	30 kg	3.7%
Eggs	80	7.1%	20 kg	2.1%
Fish	120	12%	40 kg	38%
Meat	460	44%	60 kg	6.8%
Fruits	20	2.0%	100 kg	10%
Beverages	50	4.6%	50 kg	5.3%
Others	50	4.6%	40 kg	4.1%
Housing	**1,350**	**32%**	**35 m^2**	-
Construction and maintenance	360	27%	35 m^2	-
Electricity	470	35%	460 kWh	30%
Other energy supply	500	37%	1,050 kWh	70%
Water	20	1.3%	49 m^3	-
Mobility	**1,090**	**26%**	**8,130 km**	-
Airplane	50	4.2%	420 km	5.1%
Car	600	54%	1,770 km	22%
Motorcycle	240	22%	1,740 km	22%
Public transportation	200	19%	2,550 km	31%
Ferry	1	0.1%	5 km	0.1%
Bicycle	20	1.4%	1,150 km	14%
Walking	0	0.0%	500 km	6.2%
Consumer goods	**290**	**7.0%**	-	-
Clothes	70	23%	-	-
Manufactures products	220	77%	-	-
Sub-total (4 domains)	**3,780**	**91%**	-	-
Leisure & Services	**380**	**9.1%**	-	-
Grand Total (6 domains)	**4,160**	**100%**	-	-

Table C.5. Current annual lifestyle carbon footprint per capita in Brazil

Domains and components	CF ($kgCO_2e$)	CF (%)	Amount	Amount (%)
Nutrition	**1,040**	**37%**	**590 kg**	-
Cereals	210	20%	120 kg	21%
Vegetables (incl. potatoes)	6	0.6%	20 kg	4.1%
Beans/nuts	40	3.8%	70 kg	12%
Dairy	110	11%	40 kg	5.9%
Eggs	20	1.7%	4 kg	0.7%
Fish	40	3.4%	10 kg	1.7%
Meat	450	43%	50 kg	7.9%
Fruits	6	0.6%	30 kg	5.4%
Beverages	90	8.4%	200 kg	34%
Others	80	7.9%	40 kg	7.2%
Housing	**470**	**17%**	**21 m^2**	-
Construction and maintenance	220	46%	21 m^2	-
Electricity	120	25%	640 kWh	46%
Other energy supply	110	22%	750 kWh	54%
Water	30	6.6%	85 m^3	-
Mobility	**480**	**17%**	**4,250 km**	-
Airplane	70	14%	610 km	14%
Car	190	39%	1,130 km	27%
Motorcycle	20	4.3%	150 km	3.6%
Public transportation	200	42%	2,080 km	49%
Ferry	-	-	-	-
Bicycle	1	0.2%	80 km	2.0%
Walking	0	0.0%	190 km	4.6%
Consumer goods	**270**	**9.6%**	-	-
Clothes	60	22%	-	-
Manufactures products	210	78%	-	-
Sub-total (4 domains)	**2,300**	**80%**	-	-
Leisure & Services	**560**	**20%**	-	-
Grand Total (6 domains)	**2,810**	**100%**	-	-

Table C.6. Current annual lifestyle carbon footprint per capita in India

Domains and components	CF ($kgCO_2e$)	CF (%)	Amount	Amount (%)
Nutrition	**510**	**26%**	**490 kg**	-
Cereals	150	30%	150 kg	30%
Vegetables (incl. potatoes)	70	13%	120 kg	24%
Beans/nuts	15	2.9%	20 kg	5.0%
Dairy	150	30%	90 kg	17%
Eggs	10	2.0%	3 kg	0.5%
Fish	20	3.5%	5 kg	1.0%
Meat	20	4.8%	4 kg	0.8%
Fruits	10	2.6%	60 kg	12%
Beverages	1	0.1%	3 kg	0.6%
Others	60	11%	50 kg	9.4%
Housing	**400**	**21%**	**19 m^2**	-
Construction and maintenance	200	48%	19 m^2	-
Electricity	150	42%	140 kWh	18%
Other energy supply	30	6.4%	640 kWh	82%
Water	20	3.8%	44 m^3	-
Mobility	**700**	**36%**	**5,500 km**	-
Airplane	20	2.1%	130 km	2.4%
Car	320	46%	830 km	15%
Motorcycle	170	24%	1,250 km	23%
Public transportation	190	27%	2,130 km	39%
Waterways		0.0%	-	-
Bicycle	10	1.0%	480 km	8.8%
Walking	0	0.0%	670 km	12%
Consumer goods	**160**	**8.1%**	-	-
Clothes	40	25%	-	-
Manufactures products	120	75%	-	-
Sub-total (4 domains)	**1,860**	**91%**	-	-
Leisure & Services	**170**	**8.8%**	-	-
Grand Total (6 domains)	**1,930**	**100%**	-	-

Annex D. Estimation of the domain share of lifestyle carbon footprint targets

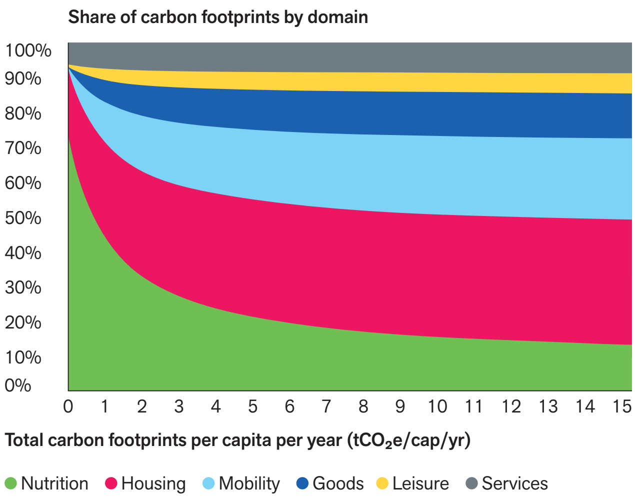
In Chapter 3, the estimated lifestyle carbon footprints for each domain are compared with the long-term targets of carbon footprints by 2030 and 2050. The targets proposed in Chapter 2 are for the total lifestyle carbon footprints across domains. To indicate the gaps between current footprints and targets for a specific domain, the targets should be allocated to each domain. When considering reductions in lifestyle carbon footprints, different rates of reduction may apply to different domains. Some domains, such as nutrition, are considered as essentials, thus making reductions more difficult, other than less-essential consumptions such as parts of leisure and mobility. The shares of lifestyle carbon footprint across domains are expected to vary as total lifestyle carbon footprints decrease.

To consider this difference, the shares of lifestyle carbon footprint for domains (nutrition, housing, mobility, consumer goods, leisure, and services) were estimated from the prediction model using the microdata of the 2004 National Survey of Family Income and Expenditure (NSFIE) of Japan (Ministry of Internal Affairs and Communications, Japan 2004). The analysis was conducted as part of this study using anonymised microdata provided by the National Statistics Center, Japan. First, the item-level carbon footprints of over 47,000 sample households were calculated by multiplying annual expenditure on items from the NSFIE data and greenhouse gas intensity data from the GLIO database (Nansai et al. 2012). However, as item categorisation differed between the NSFIE, which is consumption based, and GLIO, which is production based, a concordance between these two categories was established, then the annual household carbon footprints at the item level were aggregated to domain levels. To predict carbon footprint allocation to domains, bivariate regression models using weighted least square regression were constructed to predict footprints in each domain by total per-capita lifestyle carbon footprint. Intercepts are conditioned as positive to avoid a negative share of any domains being predicted for smaller total footprints. The regression formula is as follows:

$$\textit{Footprint of domain } d = \alpha_d + \beta_d \times \textit{ total footprint per capita}$$

Based on the regression models, the shares of lifestyle carbon footprint by domain were predicted as shown in Figure D.1 and Table D. 1. The size of target footprint squares indicated in the skyline charts (Figures 3.4, 3.6, 3.8) were estimated using the predicted share for 2.5 tCO_2e/capita/year (1.5 degree targets by 2030) and 0.7 tCO_2e/capita/year (1.5 degree targets by 2050). The current footprint squares are based on the mean intensity and total amount of physical consumption in the domain. The shape of the target footprint squares (horizontal to vertical ratio) results from the assumption that the average intensity and total amount of physical consumptions are proportionally reduced in each domain. For the nutrition domain, the decrease in amount was reduced to be one-third and compensated by faster reduction of intensity.

Figure D.1 Predicted lifestyle carbon footprint share of consumption domains



Note: Estimated by authors based on anonymised microdata of 2004 National Survey of Family Income and Expenditure (Ministry of Internal Affairs and Communications, Japan 2004) provided by the National Statistics Center, Japan and GLIO database (Nansai et al. 2012).

Table D.1 Predicted Lifestyle Carbon Footprint Share of Consumption Domains (Total footprints equivalent to the 1.5 degree targets by 2030, 2040, and 2050)

Total lifestyle carbon footprints per-capita (tCO_2e/capita/year)	Predicted lifestyle carbon footprint share of domains (%)					
	Nutrition	Housing	Mobility	Goods	Leisure	Services
0.7	50%	26%	9%	5%	3%	7%
1.4	38%	29%	14%	8%	4%	8%
2.5	29%	31%	17%	10%	4%	8%

Note: Estimated by authors based on anonymised microdata of 2004 National Survey of Family Income and Expenditure (Ministry of Internal Affairs and Communications, Japan 2004) provided by the National Statistics Center, Japan and GLIO database (Nansai et al. 2012).

Annex E. Review of Low-carbon Lifestyle Options

To identify promising options to reduce lifestyle carbon footprints, we reviewed the literature currently available, including scientific articles and technical reports that indicate lifestyle and behaviour-related carbon reduction options with quantified potential impacts. While we were interested in the global perspective, most came from Europe or North America. The sources used for most of the examples were Hawken (2017), Hersey et al. (2009), Tynkkynen (2016, 2015), Salo and Nissinen (2017) and Finnish Innovation Fund Sitra (2017) and their background materials.

Tables E.1 to E.4 present examples of promising solutions in the domains of nutrition, housing, mobility, and consumer goods. They represent both production- and consumption-oriented measures, with similar types of options grouped onto the same line, as well as information on the approaches used (Absolute reduction, Modal shift, and Efficiency improvement).

Table E.1. Low-carbon lifestyle options identified for nutrition

Options	Approaches			
	Reduction	Modal shift	Efficiency	References
Plant-rich food (incl. vegetarian, vegan)		V		Hawken (2017); Salo and Nissinen (2017); Henkel AG & Co. KGaA, Wuppertal Institute for Climate, Environment and Energy (2018); Shrink That Footprint (n.d.); Finnish Innovation Fund Sitra (2017)
Low-carbon protein instead of red meat (inc. poultry, fish)		V		Shrink That Footprint (n.d.); Finnish Innovation Fund Sitra (2017)
Reduction of food loss and waste	V		V	Hawken (2017); Salo and Nissinen (2017); Tynkkynen (2015)
Supply chain improvement after farms			V	Hersey et al. (2009)
Production improvement at farms			V	Hersey et al. (2009); Hawken (2017); Tynkkynen (2015)
Reduction of excess nutrition	V			Finnish Innovation Fund Sitra (2017)
Renewable electricity in food supply chain			V	Hersey et al. (2009)
Alternative dairy products (plant-based)		V		Finnish Innovation Fund Sitra (2017)
Reduction of sweets and alcohol	V	V		Hersey et al. (2009)
Manure management and composting			V	Tynkkynen (2015)

Table E.2. Low-carbon lifestyle options identified for housing

Options	Approaches			
	Reduction	Modal shift	Efficiency	References
Renewable energy (geothermal, solar, wind)		V		Yue, You, and Darling (2014); Salo and Nissinen (2017); Hawken (2017); Rohn, Pastewski, and Lettenmeier (2013); Finnish Innovation Fund Sitra (2017)
Smaller living space	V			Yue, You, and Darling (2014); Hawken (2017); Rohn, Pastewski, and Lettenmeier (2013); Finnish Innovation Fund Sitra (2017)
Improved efficiency of construction			V	Salo and Nissinen (2017); Hersey et al. (2009)
Heat pump for temperature control		V	V	Hawken (2017); Salo and Nissinen (2017); Salo et al. (2017); Official Statistics of Finland (2017a); Finnish Innovation Fund Sitra (2017)
Sharing of housing space	V	V		Finnish Innovation Fund Sitra (2017)
Reduction of air conditioning needs (optimised room temperature)	V			Finnish Innovation Fund Sitra (2017)
Reduction of new housing infrastructure	V			Hersey et al. (2009)

Energy efficient home appliances		V	V	Tynkkynen (2015); Finnish Innovation Fund Sitra (2017); Salo and Nissinen (2017)
Improved insulation (inc. window sealing, curtains)	V		V	Hawken (2017); Finnish Innovation Fund Sitra (2017)
Saving of hot water	V			Salo and Nissinen (2017); Finnish Innovation Fund Sitra (2017)
District heating		V		Hawken (2017)
Reduction of home electricity use (monitoring, peak management)	V			Finnish Innovation Fund Sitra (2017)
Recycled and low-impact building materials			V	Hersey et al. (2009)
LED lighting		V	V	Salo and Nissinen (2017); Finnish Innovation Fund Sitra (2017)
Bioenergy for heating		V		Tynkkynen (2015)

Table E.3. Identified low-carbon lifestyles options (mobility)

Options	Approaches			References
	Reduction	Modal shift	Efficiency	
Travelling less often/closer destination	V			Salo and Nissinen (2017); Finnish Innovation Fund Sitra (2017)
Reduction of flights	V	V		Hersey et al. (2009); Finnish Innovation Fund Sitra (2017)
Reduction of car use (inc. public transport, Mobility as a Service i.e. MaaS, bicycle)	V	V		Salo and Nissinen (2017); Finnish Innovation Fund Sitra (2017)
Electric vehicles		V	V	Hawken (2017); Tynkkynen (2015); Finnish Innovation Fund Sitra (2017)
Moving closer to work and services	V			Hersey et al. (2009)
Car-sharing		V	V	Hersey et al. (2009); Salo and Nissinen (2017); Finnish Innovation Fund Sitra (2017)
Vehicle fuel efficiency			V	Hersey et al. (2009); Tynkkynen (2015)
Efficient airplanes			V	Hersey et al. (2009); Hawken (2017)
Hybrid cars		V	V	Hawken (2017)
Telework/telepresence	V			Hawken (2017); Hersey et al. (2009); Finnish Innovation Fund Sitra (2017)
Improved public transport			V	Hersey et al. (2009); Hawken (2017)
Closer weekend leisure/hobbies	V			Finnish Innovation Fund Sitra (2017)
Biogas-fueled vehicles		V	V	Tynkkynen (2015); Salo and Nissinen (2017); Finnish Innovation Fund Sitra (2017)
Ridesharing		V	V	Hawken (2017); Finnish Innovation Fund Sitra (2017)

Table E.4. Identified low-carbon lifestyles options (for consumer goods)

Options	Approaches			References
	Reduction	Modal shift	Efficiency	
Renewable electricity in manufactured goods supply chain			V	Hersey et al. (2009)
Improved manufacturing efficiency			V	Salo and Nissinen (2017); Hersey et al. (2009)
Remanufacturing	V	V	V	Parker et al. (2015)
Reuse, repair, and refurbish	V	V		Parker et al. (2015); Willis (2010)
Waste prevention	V			Hersey et al. (2009)
Reduction in clothes consumption	V			Hersey et al. (2009)
Reduction in electronics consumption	V			Hersey et al. (2009)
Reduction in smoking	V			Hersey et al. (2009)
Reduction in floor coverings	V			Hersey et al. (2009)
Reduction in chemical product consumption	V			Finnish Innovation Fund Sitra (2017)
Reduction in jewellery consumption	V			Hersey et al. (2009)
Bioplastic		V	V	Hawken (2017)
Sharing of manufactured goods	V			Finnish Innovation Fund Sitra (2017)
Household waste recycling (plastic, metal, glass, rubber, textile)		V	V	Hawken (2017)
Paper recycling		V	V	Hawken (2017); Hersey et al. (2009)

Annex F. Assumptions of Low-carbon Options

In this study, country-specific footprint reduction impacts of selected low-carbon lifestyle options were estimated for Finland and Japan. The options were selected from a global list based on the literature review in Annex E considering their local applicability and availability of data. The assumptions used for defining full implementation (maximum level of reductions) and data sources are listed in Table F.1 and F.2. The estimated impacts for full- and partial-implementation summarised in Chapter 4 are based on these assumptions.

Table F.1. Assumption of full implementation of low-carbon lifestyles options (Finland)

Domain	Option	Assumption	Data source (if any)
Nutrition	Low-carbon protein instead of red meat	Half of red meat (beef and other) will be substituted by chicken, half by fish.	
	Vegetarian diet (lacto-ovo)	Keeping the total amount of food purchase and beverage purchase the same, the share of intake of different food items will follow the share of US Vegetarian Data. The amount of consumed alcohol is not affected due to absence of data on alcohol consumption of vegetarians.	Orlich et al. (2014)
	Alternative dairy products (plant-based)	Carbon intensity of dairy (milk) is substituted by oatmilk intensity and dairy (others) is substituted by intensity of soya yoghurt.	
	Vegan diet	Keeping the total amount of food purchase and beverage purchase the same, the share of intake of different food items will follow the share of Finnish Vegan Data. The amount of consumed alcohol is not affected due to absence of data on alcohol consumption of vegans.	Elorinne et al. (2016)
	Reduction of sweets and alcohol	Consumption of sweets/snacks and alcohol will be eliminated.	
	Food loss reduction (household side)	Food loss at household level will be eliminated (reflected in purchased food amount).	Katajajuuri et al. (2014)
	Food loss reduction (supply side)	Food loss in production & distribution phases will be eliminated (reflected in carbon intensity).	Katajajuuri et al. (2014)
	Food production efficiency improvement	All food industries will achieve intensity-based CO_2/energy reduction target (9.5%) by 2030 based on National Climate and Energy Politics (Ministry of Agriculture and Forestry) (allocated to remaining years: −7.3% intensity-based reduction/year)	Ministry of Agriculture and Forestry, Finland (2014)
	Smaller intake of food per day	Daily total intake of food products is 10% less, which is reduced evenly over all food products.	
Housing	Renewable wind-based electricity	100% substitution of fossil fuel grid electricity by wind grid electricity.	
	Renewable based heating	100% shift of non-electricity fossil fuel to off-grid renewable energy.	
	Lowering temperature at home	Lowering the temperature at home by 2 degrees is equivalent to 10% saving in heating costs.	Motiva (2018a); Official Statistics of Finland (2017a) Share of energy and electricity used for heating: Official Statistics of Finland (2017a)
	Smaller living space	Size of living space will be12% (approx 5m^2) smaller assuming that energy & electricity used for heating is proportionally reduced due to reduced size of housing. Reduction in housing size is based on Inno-scenario for Low Carbon Finland 2050.	VTT, Technical Research Centre of Finland Ltd (2012) Share of energy and electricity used for heating: Official Statistics of Finland (2017a)
	Heat pump for room heating	All heating by natural gas, heating oil & district heating will be substituted by air heat pump.	Motiva (2018b); Official Statistics of Finland (2017a) Share of energy used for heating: Official Statistics of Finland (2017a)
	Saving hot water	Hot water and water use will be reduced by 33% (same rate as water saving shower), which will reduce related energy consumption.	Motiva Ltd. (2018c); Official Statistics of Finland (2017a) Share of energy and electricity used for water heating: Official Statistics of Finland (2017a)
	Efficiency improvement of buildings	Improvement of buildings decreases heating demand by 43% (kWh/m^2), which is the average of three alternative scenarios for Low Carbon Finland 2050.	Official Statistics of Finland (2017a); VTT, Technical Research Centre of Finland Ltd (2012) Share of energy and electricity used for heating: Official Statistics of Finland (2017a)

Domain	Option	Assumption	Data source (if any)
	Rent a guest room to a tourist	Renting 23 m^2 space for 27 weeks. Assuming that the one will save space, electricity used for heating and lightning, and energy used for heating used for the rented space during that week. Size of rented space is equal to average room size in Finland. Occupancy rate based on occupancy rate of Finnish hotels, etc. accommodations.	Official Statistics of Finland (2017b); Official Statistics of Finland (2018a, b) Share of energy used for heating & electricity used for heating & lightning: Official Statistics of Finland (2017a)
	Efficiency improvement (home appliances)	Efficiency of home appliances using electricity will be improved by 19% (same annual rate as most ambitious target of household goods manufacturer).	Official Statistics of Finland (2017a); Panasonic (n.d.) Share of electricity used for home appliances: Official Statistics of Finland (2017a)
Mobility	Reduction of flights	All domestic flights will be substituted by train. All international flights will be substituted by domestic trip by train of only one-tenth distance.	
	Car-free private travelling	All private car trips for non-commuting will be substituted by train & bus (50%, 50%).	Finnish Transport Agency (2018)
	Car-free commuting with public transpor-tation	All private car trips for commuting to workplace and schools will be substituted by public transportation (33% bus, 33% train, 33% tram/metro).	Finnish Transport Agency (2018)
	Car-free commuting with electric bicycle	All private car trips for commuting to workplace and schools will be substituted by electric bicycle.	Finnish Transport Agency (2018); VTT Technical Research Centre of Finland Ltd (2017)
	Hybrid car	All combustion engine cars will be substituted by hybrid cars.	
	Live closer to workplace	All private car, bus, train and tram/metro trips for commuting to workplace and school distance will be one-fifth and be substituted by 50% bicycle and 50% walking.	Finnish Transport Agency (2018)
	Vehicle fuel efficiency improvement	Efficiency of all types of cars, motorcycle, and bus will improve by 29%, assuming same annual rate between 2017 and 2030 as in the commitment by car manufacturers by 2050.	Toyota Motor Corporation (2016)
	Electric car	All combustion engine cars will be substituted by electric cars.	
	Telework (white collar workers)	All private car, bus, train and metro/tram trips for commuting to workplace are eliminated among white collar workers.	Finnish Transport Agency (2018); Official Statistics of Finland (2018c)
	Ride sharing	All private and taxi cars occupancy rates will become 2 persons per car.	VTT Technical Research Centre of Finland Ltd (2017)
Goods	Reduction from goods	Uniform reduction of footprints across goods domain.	
Leisure	Reduction from leisure	Uniform reduction of footprints across leisure domain.	
Services	Reduction from services	Uniform reduction of footprints across services domain.	

Table F.2. Assumption of full implementation of low-carbon lifestyles options (Japan)

Domain	Option	Assumption	Data source (if any)
Nutrition	Low-carbon protein instead of red meat	Half of red meat (beef and other) will be substituted by chicken, half by fish.	
	Vegetarian diet (lacto-ovo)	Keeping the total amount of food purchase and beverage purchase the same, the share of non-beverage food item purchases will follow the share suggested by the Japanese Vegetarian Food Guide (no fish or meat).	Nakamoto et al. (2009)
	Alternative dairy products (plant-based)	Carbon intensity of dairy (milk) and dairy (others) will become same as beans/nuts.	
	Reduction of sweets & alcohol	Consumption of sweets/snacks and alcohol will be eliminated.	
	Food loss reduction (household side)	Food loss at household level will be eliminated (reflected in pur-chased food amount).	Ministry of Agriculture, Forestry and Fisheries, Japan (2014a)
	Food loss reduction (supply side)	Food loss in production and distribution phases will be eliminated (reflected in carbon intensity).	Ministry of the Environment, Japan (2017)
	Food production effi-ciency improvement	Efficiency of all types of food supply will improve by 13%, assuming same annual rate between 2017–2030 as in top 30% ambitious intensity-based CO_2 or energy 2030 reduction voluntary targets among food industries.	Ministry of Agriculture, Forestry and Fisheries, Japan (2014b)
Housing	Electricity mix shift (national plan 2030)	Grid electricity mix will shift to that proposed in government energy mix plan 2030 (LNG 27%, Oil 3%, Coal 26%, Nuclear 22–20%, Renewable 22–24%).	Ministry of Economy, Trade and Industry, Japan (2015)

	Renewable grid electricity	100% substitution of fossil fuel grid electricity by renewable grid electricity	
	On-site renewable energy	100% shift of non-electricity fossil fuel (kerosene, LPG, urban gas) to off-grid renewable energy	
	Smaller living space (average size of apartment)	Size of house will reduce to average size of apartment (26.2 m^2/capita) assuming energy for air conditioning and lighting (27% of total energy for housing) will be proportionally reduced due to reduced size of housing.	Size of apartment: Ministry of Internal Affairs and Communications, Japan (2013) Share of air conditioning & lighting: Agency for Natural Resources and Energy, Japan (n.d.)
	Heat pump for room heating	All heating by kerosene & gas will be substituted by air conditioner assuming that energy requirement of heating will be reduced by improvement of energy conversion efficiency (COP 0.85 to 4).	Share of heating energy: Agency for Natural Resources and Energy, Japan (2016a) Improvement of energy conversion efficiency: Mitsubishi Electric (n.d.)
	Insulation of housing	All house insulation will meet national standard 1999, which has estimated weighted average improvement of 45.7% in heating & cooling energy (25.7% of housing energy).	Agency for Natural Resources and Energy, Japan (2016b)
	Saving of hot water	Hot water & water use will be reduced by 35% (same rate as for water saving shower), which will reduce related energy consumption.	Share of hot water in total housing energy: Agency for Natural Resources and Energy, Japan (2016a) Share of fuels in water heating: Energy Information Center (2017) Reduced waste use by water saving shower: TOTO Ltd. (n.d.)
	Efficiency improvement (electricity generation)	Electricity generation efficiency for fossil fuels will be improved by 20 to 30% assuming the level of Integrated coal Gasification Fuel Cells combined cycle (IGFC) and Gas Turbine Fuel Cells combined cycle (GTFC)	Ministry of Economy, Trade and Industry, Japan (2015)
	Efficiency improvement (home appliance)	Efficiency of home appliances using electricity and fuel will be improved by 22.9% & 14.0%, respectively, assuming same annual improvement rate between 2017–2030 as the most ambitious 2030 target by household goods manufacturer.	Electricity appliances: Panasonic Corporation n.d. Gas equipment: Rinnai (2018)
Mobility	Reduction of flights (domestic)	All domestic flights will be substituted by bullet train.	
	Reduction of flights (international)	All international flights for leisure will be substituted by domestic trips by bullet train with only 10% distances.	Share of leisure purpose overseas trip: JTB Tourism Research and Consulting (2016)
	Car-free private travel (public transport)	All private car trips for non-commuting will be substituted by 50% train, 50% bus.	Share of non-commuting car trips: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2012)
	Car-free commuting (public transport)	All private car trips for commuting to workplace & schools will be substituted by 50% train, 50% bus.	Share of commuting car trips: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2012)
	Hybrid car	All combustion engine cars will be substituted by hybrid cars.	
	Live closer to workplace (20% distance)	All private car, bus, and normal train trips for commuting to workplace and school will be 20% of original distance and substituted by 50% bicycle & 50% walking.	
	Closer weekend leisure (20% distance)	All private car, bus, and normal train trips for commuting to workplace and school will be 20% of original distance and substituted by 50% bicycle & 50% walking.	
	Vehicle fuel efficiency improvement	Efficiency of all types of cars, motorcycles & buses will improve by 29%, assuming same annual rate between 2017–2030 as in commitment by car manufacturers by 2050.	Toyota Motor Corporation (2016)
	Electric car	All combustion engine cars will be substituted by electric cars.	
	Telework (white collar workers)	All private car, bus & normal train trips for commuting to workplace are eliminated among white collar workers.	Share of commuting trips: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2012) Share of white collar workers: Ministry of Internal Affairs and Communications, Japan (2018)
	Ride sharing (2 persons in a car)	All private & taxi car occupancy rates will become 2 persons/car.	Current average occupancy rate: Ministry of Land, Infrastructure, Transport and Tourism, Japan (2017c)
Goods	Reduction from goods	Uniform reduction of footprints across goods domain.	
Leisure	Reduction from leisure	Uniform reduction of footprints across leisure domain.	
Services	Reduction from services	Uniform reduction of footprints across services domain.	

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This report fills a gap in the existing research by establishing global targets for lifestyle carbon footprints. It proposes globally unified per capita targets for the carbon footprint from household consumption in the years 2030, 2040 and 2050. Current average carbon footprints of Finland, Japan, Brazil, India and China are estimated and compared to the targets. The report identifies options for reducing lifestyle carbon footprints and assesses the impact of such options in the context of Finland and Japan. It concludes with suggestions and implications in terms of how to proceed towards lifestyles compatible with 1.5 °C target.

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