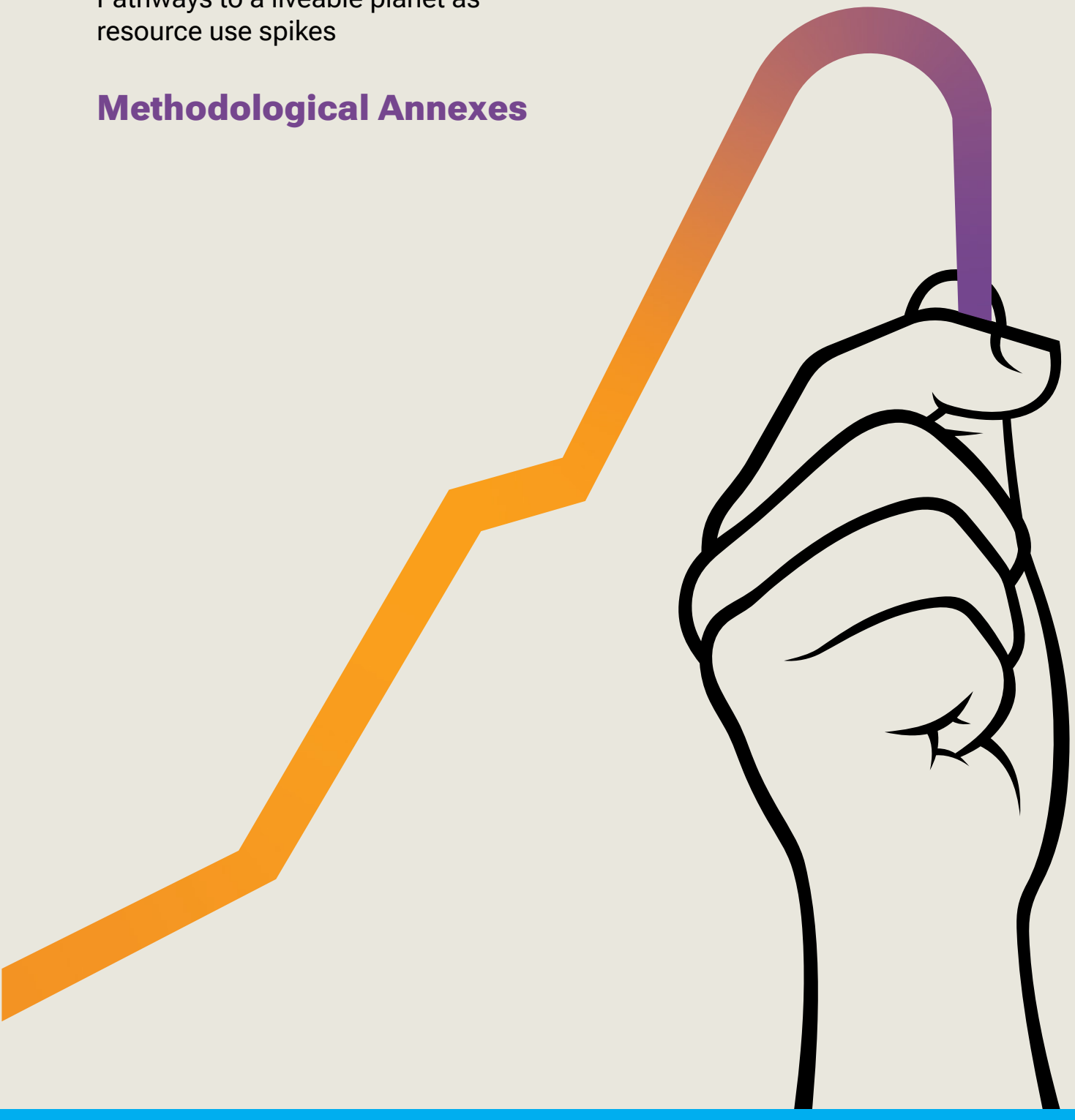
UN environment programme

Bend the trend

Pathways to a liveable planet as resource use spikes

Methodological Annexes



International Resource Panel

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Annex 1: Regional and income grouping

As the 2019 edition, GRO quantitative results are provided for seven world regions and four income groups. The following details apply to regions and income groups used in chapters 2 and 3. For chapter 4, the regional and income grouping rely on the country and regional groups of the underpinning models (see section 8.4 below).

- World regions (Table A1.1) are: Africa, Asia and the Pacific, Europe, Latin America and the Caribbean, North America, West Asia (Middle East), and Eastern Europe, Caucasus and Central Asia (EECCA). This classification is adapted from UNEP regional classification, differing in two main aspects: i) GRO classification includes the region "Eastern Europe, Caucasus and Central Asia" (EECCA), which aggregates new countries after the fall of the Soviet Union; and ii) GRO regional classification for dependent territories have been allocated to a region based on their geographical location and not based on the location of the country to which they belong.
- Income groups (Table A1.1) consider: low income, lower-middle income, upper-middle income and high income. Countries are classified according to the following ranges of Gross National Income (GNI) using the World Bank Atlas method[1], for 2020: low income, $1,045 or less; lower middle-income, between $1,046 and $4,095; upper middle-income, between $4,096 and $12,695; high-income, $12,696 or more.

Table A1.1: Country allocation to regions and income groups.

Country	ISO-alpha3 Code	Region name	Income group
Afghanistan	AFG	Asia + Pacific	Low income
Albania	ALB	Europe	Upper middle income
Algeria	DZA	Africa	Lower middle income
Andorra	AND	Europe	High income
Angola	AGO	Africa	Lower middle income
Antigua	ATG	Latin America + Caribbean	High income
Argentina	ARG	Latin America + Caribbean	Upper middle income
Armenia	ARM	EECCA	Upper middle income
Aruba	ABW	Latin America + Caribbean	High income
Australia	AUS	Asia + Pacific	High income
Austria	AUT	Europe	High income
Azerbaijan	AZE	EECCA	Upper middle income
Bahamas	BHS	Latin America + Caribbean	High income
Bahrain	BHR	West Asia	High income
Bangladesh	BGD	Asia + Pacific	Lower middle income
Barbados	BRB	Latin America + Caribbean	High income
Belarus	BLR	EECCA	Upper middle income
Belgium	BEL	Europe	High income
Belize	BLZ	Latin America + Caribbean	Lower middle income
Benin	BEN	Africa	Lower middle income
Bermuda	BMU	Latin America + Caribbean	High income
Bhutan	BTN	Asia + Pacific	Lower middle income
Bolivia	BOL	Latin America + Caribbean	Lower middle income
Bosnia and Herzegovina	BIH	Europe	Upper middle income
Botswana	BWA	Africa	Upper middle income
Brazil	BRA	Latin America + Caribbean	Upper middle income
British Virgin Islands	VGB	Latin America + Caribbean	High income
Brunei Darussalam	BRN	Asia + Pacific	High income
Bulgaria	BGR	Europe	Upper middle income
Burkina Faso	BFA	Africa	Low income
Burundi	BDI	Africa	Low income
Cambodia	KHM	Asia + Pacific	Lower middle income
Cameroon	CMR	Africa	Lower middle income
Canada	CAN	North America	High income
Cape Verde	CPV	Africa	Lower middle income
Cayman Islands	CYM	Latin America + Caribbean	High income
Central African Republic	CAF	Africa	Low income
Chad	TCD	Africa	Low income
Chile	CHL	Latin America + Caribbean	High income
China	CHN	Asia + Pacific	Upper middle income
Colombia	COL	Latin America + Caribbean	Upper middle income
Congo	COG	Africa	Lower middle income
Costa Rica	CRI	Latin America + Caribbean	Upper middle income
Côte d'Ivoire	CIV	Africa	Lower middle income
Croatia	HRV	Europe	High income
Cuba	CUB	Latin America + Caribbean	Upper middle income

1 Data: World Bank, GNI per capita, Atlas method (current US$), World Bank national accounts data, and OECD National Accounts data files, https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups. Atlas methodology details: https://datahelpdesk.worldbank.org/knowledgebase/articles/378832-what-is-the-world-bank-atlas-method

Cyprus	CYP	Europe	High income
Czechia	CZE	Europe	High income
Democratic People's Republic of Korea	PRK	Asia + Pacific	Low income
Democratic Republic of the Congo	COD	Africa	Low income
Denmark	DNK	Europe	High income
Djibouti	DJI	Africa	Lower middle income
Dominican Republic	DOM	Latin America + Caribbean	Upper middle income
Ecuador	ECU	Latin America + Caribbean	Upper middle income
Egypt	EGY	Africa	Lower middle income
El Salvador	SLV	Latin America + Caribbean	Lower middle income
Eritrea	ERI	Africa	Low income
Estonia	EST	Europe	High income
Eswatini	SWZ	Africa	Lower middle income
Ethiopia	ETH	Africa	Low income
Fiji	FJI	Asia + Pacific	Upper middle income
Finland	FIN	Europe	High income
France	FRA	Europe	High income
French Polynesia	PYF	Asia + Pacific	High income
Gabon	GAB	Africa	Upper middle income
Gambia	GMB	Africa	Low income
Gaza	PSE	West Asia	Lower middle income
Georgia	GEO	EECCA	Upper middle income
Germany	DEU	Europe	High income
Ghana	GHA	Africa	Lower middle income
Greece	GRC	Europe	High income
Greenland	GRL	Europe	High income
Guatemala	GTM	Latin America + Caribbean	Upper middle income
Guinea	GIN	Africa	Low income
Guyana	GUY	Latin America + Caribbean	Upper middle income
Haiti	HTI	Latin America + Caribbean	Lower middle income
Honduras	HND	Latin America + Caribbean	Lower middle income
Hong Kong	HKG	Asia + Pacific	High income
Hungary	HUN	Europe	High income
Iceland	ISL	Europe	High income
India	IND	Asia + Pacific	Lower middle income
Indonesia	IDN	Asia + Pacific	Lower middle income
Iran	IRN	Asia + Pacific	Lower middle income
Iraq	IRQ	West Asia	Upper middle income
Ireland	IRL	Europe	High income
Israel	ISR	West Asia	High income
Italy	ITA	Europe	High income
Jamaica	JAM	Latin America + Caribbean	Upper middle income
Japan	JPN	Asia + Pacific	High income
Jordan	JOR	West Asia	Upper middle income
Kazakhstan	KAZ	EECCA	Upper middle income
Kenya	KEN	Africa	Lower middle income
Kuwait	KWT	West Asia	High income
Kyrgyzstan	KGZ	EECCA	Lower middle income
Lao People's Democratic Republic	LAO	Asia + Pacific	Lower middle income
Latvia	LVA	Europe	High income
Lebanon	LBN	West Asia	Upper middle income
Lesotho	LSO	Africa	Lower middle income
Liberia	LBR	Africa	Low income
Libya	LBY	Africa	Upper middle income
Liechtenstein	LIE	Europe	High income
Lithuania	LTU	Europe	High income
Luxembourg	LUX	Europe	High income
Macao	MAC	Asia + Pacific	High income
Madagascar	MDG	Africa	Low income
Malawi	MWI	Africa	Low income
Malaysia	MYS	Asia + Pacific	Upper middle income

Maldives	MDV	Asia + Pacific	Upper middle income
Mali	MLI	Africa	Low income
Malta	MLT	Europe	High income
Mauritania	MRT	Africa	Lower middle income
Mauritius	MUS	Africa	Upper middle income
Mexico	MEX	Latin America + Caribbean	Upper middle income
Moldova	MDA	EECCA	Upper middle income
Monaco	MCO	Europe	High income
Mongolia	MNG	Asia + Pacific	Lower middle income
Montenegro	MNE	Europe	Upper middle income
Morocco	MAR	Africa	Lower middle income
Mozambique	MOZ	Africa	Low income
Myanmar	MMR	Asia + Pacific	Lower middle income
Namibia	NAM	Africa	Upper middle income
Nepal	NPL	Asia + Pacific	Lower middle income
Netherlands	NLD	Europe	High income
Netherlands Antilles	NA	Latin America + Caribbean	
New Caledonia	NCL	Asia + Pacific	High income
New Zealand	NZL	Asia + Pacific	High income
Nicaragua	NIC	Latin America + Caribbean	Lower middle income
Niger	NER	Africa	Low income
Nigeria	NGA	Africa	Lower middle income
North Macedonia	MKD	Europe	Upper middle income
Norway	NOR	Europe	High income
Oman	OMN	West Asia	High income
Pakistan	PAK	Asia + Pacific	Lower middle income
Panama	PAN	Latin America + Caribbean	Upper middle income
Papua New Guinea	PNG	Asia + Pacific	Lower middle income
Paraguay	PRY	Latin America + Caribbean	Upper middle income
Peru	PER	Latin America + Caribbean	Upper middle income
Philippines	PHL	Asia + Pacific	Lower middle income

Poland	POL	Europe	High income
Portugal	PRT	Europe	High income
Qatar	QAT	West Asia	High income
Republic of Korea	KOR	Asia + Pacific	High income
Romania	ROU	Europe	Upper middle income
Russian Federation	RUS	EECCA	Upper middle income
Rwanda	RWA	Africa	Low income
Samoa	WSM	Asia + Pacific	Lower middle income
San Marino	SMR	Europe	High income
Sao Tome and Principe	STP	Africa	Lower middle income
Saudi Arabia	SAU	West Asia	High income
Senegal	SEN	Africa	Lower middle income
Serbia	SRB	Europe	Upper middle income
Seychelles	SYC	Africa	High income
Sierra Leone	SLE	Africa	Low income
Singapore	SGP	Asia + Pacific	High income
Slovakia	SVK	Europe	High income
Slovenia	SVN	Europe	High income
Somalia	SOM	Africa	Low income
South Africa	ZAF	Africa	Upper middle income
South Sudan	SSD	Africa	Low income
Spain	ESP	Europe	High income
Sri Lanka	LKA	Asia + Pacific	Lower middle income
Sudan	SDN	Africa	Low income
Suriname	SUR	Latin America + Caribbean	Upper middle income
Sweden	SWE	Europe	High income
Switzerland	CHE	Europe	High income
Syrian Arab Republic	SYR	West Asia	Low income
Taiwan	TWN	Asia + Pacific	
Tajikistan	TJK	EECCA	Lower middle income
Thailand	THA	Asia + Pacific	Upper middle income

Togo	TGO	Africa	Low income
Trinidad and Tobago	TTO	Latin America + Caribbean	High income
Tunisia	TUN	Africa	Lower middle income
Türkiye	TUR	Europe	Upper middle income
Turkmenistan	TKM	EECCA	Upper middle income
Uganda	UGA	Africa	Low income
Ukraine	UKR	EECCA	Lower middle income
United Arab Emirates	ARE	West Asia	High income
United Kingdom of Great Britain & Northern Ireland	GBR	Europe	High income
United Republic of Tanzania	TZA	Africa	Lower middle income
United States of America	USA	North America	High income
Uruguay	URY	Latin America + Caribbean	High income
Uzbekistan	UZB	EECCA	Lower middle income
Vanuatu	VUT	Asia + Pacific	Lower middle income
Venezuela	VEN	Latin America + Caribbean	High income
Viet Nam	VNM	Asia + Pacific	Lower middle income
Yemen	YEM	West Asia	Low income
Zambia	ZMB	Africa	Lower middle income
Zimbabwe	ZWE	Africa	Lower middle income

Annex 2: From sectors to provisioning systems

Table A2.1: Sector classification in GRO 2024.

Note: Compared to the GRO 2019, beverages, textiles, wearing apparel, leather, wood, and paper are classified as biomass products; nitrogen fertilizer and plastics manufacturing are classified as fossil resource products; and transport via pipelines is classified under remaining economy. The provisioning system "energy", mark with an asterisk in the table, includes impacts related to the production of fuels and wood, and the supply of electricity and hot water used by households. The impacts related to the energy production and consumption for other end-uses is allocated to the respective provisioning systems,(e.g., energy consumption of the built environment is allocated to the built environment).

Sector in EXIOBASE3 (Stadler *et al.*, 2018)	**Sector grouping (resource type and remaining economy) GRO 2019**	**Sector grouping (resource type and remaining economy) GRO 2024**	**Provisioning system (only refers to end sectors; intermediate sectors are assigned to end sectors)**
Cultivation of paddy rice	biomass	biomass	Food
Cultivation of wheat	biomass	biomass	Food
Cultivation of cereal grains nec	biomass	biomass	Food
Cultivation of vegetables, fruit, nuts	biomass	biomass	Food
Cultivation of oil seeds	biomass	biomass	Food
Cultivation of sugar cane, sugar beet	biomass	biomass	Food
Cultivation of plant-based fibers	biomass	biomass	Clothing
Cultivation of crops nec	biomass	biomass	Food
Cattle farming	biomass	biomass	Food
Pigs farming	biomass	biomass	Food
Poultry farming	biomass	biomass	Food
Meat animals nec	biomass	biomass	Food
Animal products nec	biomass	biomass	Food
Raw milk	biomass	biomass	Food
Wool, silk-worm cocoons	biomass	biomass	Clothing
Manure treatment (conventional), storage and land application	biomass	biomass	Food
Manure treatment (biogas), storage and land application	biomass	biomass	Food
Forestry, logging and related service activities (02)	biomass	biomass	Energy*

Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	biomass	biomass	Food
Mining of coal and lignite; extraction of peat (10)	fossil resources	fossil resources	Energy*
Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	fossil resources	fossil resources	Energy*
Extraction of natural gas and services related to natural gas extraction, excluding surveying	fossil resources	fossil resources	Energy*
Extraction, liquefaction, and regasification of other petroleum and gaseous materials	fossil resources	fossil resources	Energy*
Mining of uranium and thorium ores	metals	metals	Energy*
Mining of iron ores	metals	metals	Other
Mining of copper ores and concentrates	metals	metals	Other
Mining of nickel ores and concentrates	metals	metals	Other
Mining of aluminium ores and concentrates	metals	metals	Other
Mining of precious metal ores and concentrates	metals	metals	Other
Mining of lead, zinc and tin ores and concentrates	metals	metals	Other
Mining of other non-ferrous metal ores and concentrates	metals	metals	Other
Quarrying of stone	non-metallic minerals	non-metallic minerals	Other
Quarrying of sand and clay	non-metallic minerals	non-metallic minerals	Other
Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.	non-metallic minerals	non-metallic minerals	Food
Processing of meat cattle	biomass	biomass	Food
Processing of meat pigs	biomass	biomass	Food
Processing of meat poultry	biomass	biomass	Food
Production of meat products nec	biomass	biomass	Food
Processing vegetable oils and fats	biomass	biomass	Food
Processing of dairy products	biomass	biomass	Food
Processed rice	biomass	biomass	Food
Sugar refining	biomass	biomass	Food
Processing of Food products nec	biomass	biomass	Food

Manufacture of beverages	remaining economy	biomass	Food
Manufacture of fish products	remaining economy	biomass	Food
Manufacture of textiles	remaining economy	biomass	Clothing
Manufacture of wearing apparel; dressing and dyeing of fur	remaining economy	biomass	Clothing
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	remaining economy	biomass	Clothing
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	remaining economy	biomass	Built environment
Re-processing of secondary wood material into new wood material	biomass	biomass	Built environment
Pulp	biomass	biomass	Other
Re-processing of secondary paper into new pulp	biomass	biomass	Other
Paper	remaining economy	biomass	Other
Manufacture of coke oven products	fossil resources	fossil resources	Energy*
Petroleum Refinery	fossil resources	fossil resources	Energy*
Plastics, basic	fossil resources	fossil resources	Other
Re-processing of secondary plastic into new plastic	fossil resources	fossil resources	Other
N-fertiliser	non-metallic minerals	fossil resources	Food
P- and other fertiliser	non-metallic minerals	non-metallic minerals	Food
Chemicals nec	fossil resources	fossil resources	Other
Manufacture of rubber and plastic products	remaining economy	fossil resources	Other
Manufacture of glass and glass products	non-metallic minerals	non-metallic minerals	Built environment
Re-processing of secondary glass into new glass	non-metallic minerals	non-metallic minerals	Other
Manufacture of ceramic goods	non-metallic minerals	non-metallic minerals	Built environment
Manufacture of bricks, tiles and construction products, in baked clay	non-metallic minerals	non-metallic minerals	Built environment
Manufacture of cement, lime and plaster	non-metallic minerals	non-metallic minerals	Built environment
Re-processing of ash into clinker	non-metallic minerals	non-metallic minerals	Built environment
Manufacture of other non-metallic mineral products n.e.c.	non-metallic minerals	non-metallic minerals	Built environment

Processing of nuclear fuel	metals	metals	Energy*
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	metals	metals	Built environment
Re-processing of secondary steel into new steel	metals	metals	Built environment
Precious metals production	metals	metals	Other
Re-processing of secondary preciuos metals into new preciuos metals	metals	metals	Other
Aluminium production	metals	metals	Other
Re-processing of secondary aluminium into new aluminium	metals	metals	Other
Lead, zinc and tin production	metals	metals	Other
Re-processing of secondary lead into new lead, zinc and tin	metals	metals	Other
Copper production	metals	metals	Other
Re-processing of secondary copper into new copper	metals	metals	Other
Other non-ferrous metal production	metals	metals	Other
Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	metals	metals	Other
Casting of metals	metals	metals	Other
Manufacture of machinery and equipment n.e.c.	remaining economy	remaining economy	Other
Manufacture of office machinery and computers	remaining economy	remaining economy	Other
Manufacture of electrical machinery and apparatus n.e.c.	remaining economy	remaining economy	Other
Manufacture of radio, television and communication equipment and apparatus	remaining economy	remaining economy	Other
Manufacture of medical, precision and optical instruments, watches and clocks	remaining economy	remaining economy	Other
Manufacture of motor vehicles, trailers and semi-trailers	remaining economy	remaining economy	Mobility
Manufacture of other transport equipment	remaining economy	remaining economy	Mobility
Manufacture of tobacco products	remaining economy	remaining economy	Other
Manufacture of fabricated metal products, except machinery and equipment	remaining economy	remaining economy	Other
Manufacture of furniture; manufacturing n.e.c.	remaining economy	remaining economy	Other
Recycling of waste and scrap	remaining economy	remaining economy	Other
Recycling of bottles by direct reuse	remaining economy	remaining economy	Other
Production of electricity by coal	remaining economy	remaining economy	Energy*
Production of electricity by gas	remaining economy	remaining economy	Energy*
Production of electricity by nuclear	remaining economy	remaining economy	Energy*
Production of electricity by hydro	remaining economy	remaining economy	Energy*
Production of electricity by wind	remaining economy	remaining economy	Energy*
Production of electricity by petroleum and other oil derivatives	remaining economy	remaining economy	Energy*
Production of electricity by biomass and waste	remaining economy	remaining economy	Energy*
Production of electricity by solar photovoltaic	remaining economy	remaining economy	Energy*
Production of electricity by solar thermal	remaining economy	remaining economy	Energy*
Production of electricity by tide, wave, ocean	remaining economy	remaining economy	Energy*
Production of electricity by Geothermal	remaining economy	remaining economy	Energy*
Production of electricity nec	remaining economy	remaining economy	Energy*
Transmission of electricity	remaining economy	remaining economy	Energy*
Distribution and trade of electricity	remaining economy	remaining economy	Energy*
Manufacture of gas; distribution of gaseous fuels through mains	remaining economy	remaining economy	Energy*
Steam and hot water supply	remaining economy	remaining economy	Energy*
Collection, purification and distribution of water	remaining economy	remaining economy	Water, sewage, health
Construction	remaining economy	remaining economy	Built environment
Re-processing of secondary construction material into aggregates	remaining economy	remaining economy	Built environment
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	remaining economy	remaining economy	Mobility

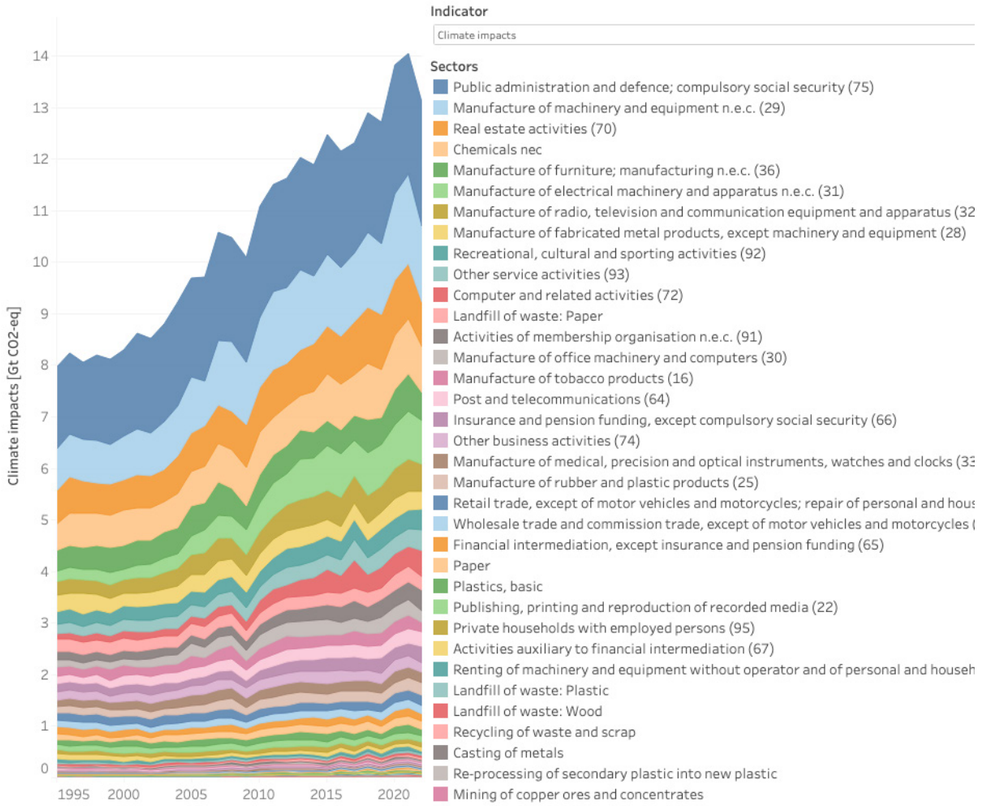
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods	remaining economy	remaining economy	Other
Wholesale trade and commission trade, except of motor vehicles and motorcycles	remaining economy	remaining economy	Other
Retail sale of automotive fuel	remaining economy	remaining economy	Mobility
Hotels and restaurants	remaining economy	remaining economy	Food
Transport via railways	remaining economy	remaining economy	Mobility
Other land transport	remaining economy	remaining economy	Mobility
Transport via pipelines	fossil resources	remaining economy	Mobility
Sea and coastal water transport	remaining economy	remaining economy	Mobility
Inland water transport	remaining economy	remaining economy	Mobility
Air transport	remaining economy	remaining economy	Mobility
Supporting and auxiliary transport activities; activities of travel agencies	remaining economy	remaining economy	Mobility
Post and telecommunications	remaining economy	remaining economy	Other
Financial intermediation, except insurance and pension funding	remaining economy	remaining economy	Other
Insurance and pension funding, except compulsory social security	remaining economy	remaining economy	Other
Activities auxiliary to financial intermediation	remaining economy	remaining economy	Other
Real estate activities	remaining economy	remaining economy	Other
Renting of machinery and equipment without operator and of personal and household goods	remaining economy	remaining economy	Other
Other business activities	remaining economy	remaining economy	Other
Public administration and defence; compulsory social security	remaining economy	remaining economy	Other
Publishing, printing and reproduction of recorded media	remaining economy	remaining economy	Other
Computer and related activities	remaining economy	remaining economy	Other
Research and development	remaining economy	remaining economy	Education
Education	remaining economy	remaining economy	Education
Health and social work	remaining economy	remaining economy	Water, sewage, health
Activities of membership organisation n.e.c.	remaining economy	remaining economy	Other
Recreational, cultural and sporting activities	remaining economy	remaining economy	Other
Other service activities	remaining economy	remaining economy	Other
Extra-territorial organizations and bodies	remaining economy	remaining economy	Other
Private households with employed persons	remaining economy	remaining economy	Other
Incineration of waste: Food	remaining economy	remaining economy	Food
Incineration of waste: Paper	remaining economy	remaining economy	Other
Incineration of waste: Plastic	remaining economy	remaining economy	Other
Incineration of waste: Metals and Inert materials	remaining economy	remaining economy	Other
Incineration of waste: Textiles	remaining economy	remaining economy	Clothing
Incineration of waste: Wood	remaining economy	remaining economy	Other
Incineration of waste: Oil/Hazardous waste	remaining economy	remaining economy	Other
Biogasification of food waste, incl. land application	remaining economy	remaining economy	Food
Biogasification of paper, incl. land application	remaining economy	remaining economy	Energy*
Biogasification of sewage slugde, incl. land application	remaining economy	remaining economy	Energy*
Composting of food waste, incl. land application	remaining economy	remaining economy	Food
Composting of paper and wood, incl. land application	remaining economy	remaining economy	Other
Waste water treatment, food	remaining economy	remaining economy	Water, sewage, health
Waste water treatment, other	remaining economy	remaining economy	Water, sewage, health
Landfill of waste: Food	remaining economy	remaining economy	Food
Landfill of waste: Paper	remaining economy	remaining economy	Other
Landfill of waste: Plastic	remaining economy	remaining economy	Other
Landfill of waste: Inert/metal/hazardous	remaining economy	remaining economy	Other
Landfill of waste: Textiles	remaining economy	remaining economy	Clothing
Landfill of waste: Wood	remaining economy	remaining economy	Other
Households	households	households	Households (private mobility & heating for climate impacts)

Annex 3: Targets for biodiversity loss

For land-use related biodiversity loss, Nathani *et al*. (2019) suggest a threshold for the global species extinction risk method recommended by UNEP for assessing land use impacts (Frischknecht and Jolliet 2017) that is aligned with the planetary boundary proposed by Steffen *et al*. (2015). This metric reflects potential extinction of species within a specific time associated with resource uses or emissions and is similar to the species Range-Size Rarity indicator provided by IUCN (2019). The suggested threshold (Nathani *et al.* 2019) is based on the global species extinction of 0.001%/year (10 per million per year from Steffen *et al.* (2015)) and considers a timeframe of the recent "Anthropocene" (at the start of the Middle Ages, when global human population was more natural with ~200 million people (Klein Goldewijk *et al.* 2010): Over the last 1500 years), mankind would be "allowed" to cause loss of 1.5% of species, in order to have an acceptable impact. In principle, the species loss is triggered by land use change and could also be derived on the impacts per year resulting from land use change (see below). However, land use is preventing re-growth of natural ecosystems and thus the impact can be allocated to current land use too (and potentially reversed by conservation efforts).

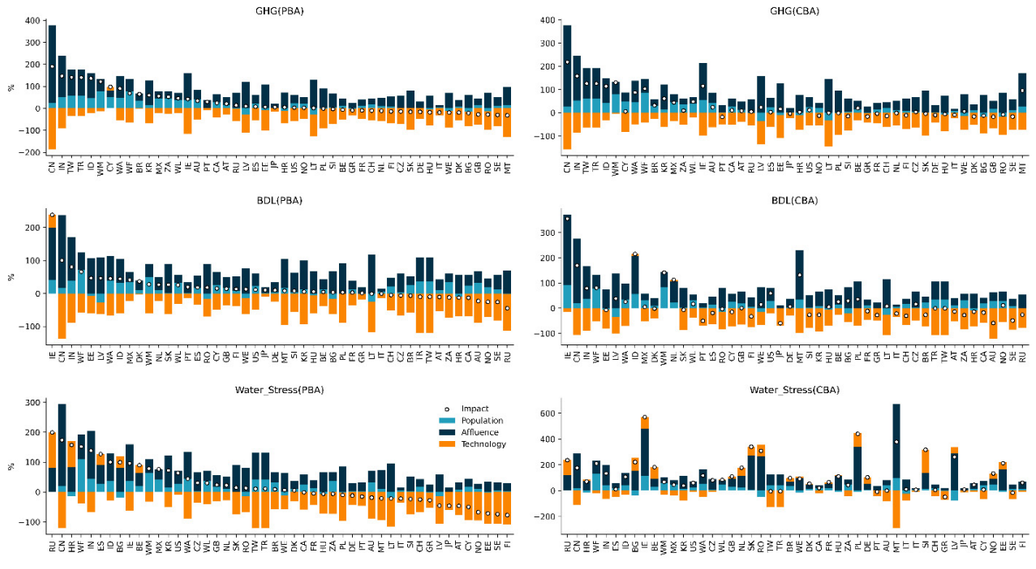
Annex 4: Temporal development of climate impacts related to "other" provisioning systems

Figure A4.1: Temporal development of climate impacts related to "other" provisioning systems (other than the ones indicated in Figures 3.6, 3.7, 3.10, 3.11).



Annex 5: Drivers of environmental impacts (IPAT)

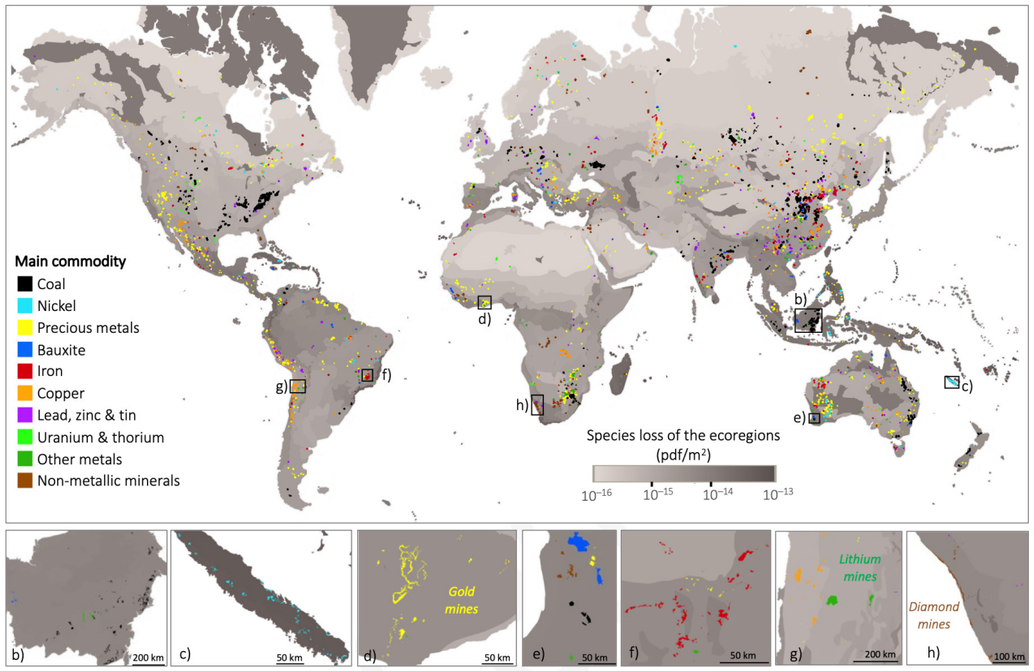
Figure A5.1: Driver by country. Production perspective (left) and consumption perspective (right) for climate change (above), land-related biodiversity loss (middle) and water stress (below).



Annex 6: Biodiversity impacts from mining

Figure A6.1. Mining area data set from Cabernard and Pfister (2021) (Cabernard and Pfister 2022; Maus et al. 2020; UNEP SETAC 2016; Cabernard and Pfister 2022; Maus et al. 2020) (total 57,277 km2 (S&P Global Market Intelligence 2020)) colored by main commodity based on the active mines of the SNL Metals & Mining Database and their location in ecoregions.

Note: The ecoregions are colored by the global species loss in potentially disappeared fraction (pdf) per square meter based on UNEP-SETAC (2016). b–h) Hotspots of mining-related biodiversity loss are shown for those countries and commodities where most of the related impacts are caused. Source: Cabernard and Pfister (2021).



Annex 7: Overview of the multi-model framework and scenario implementation

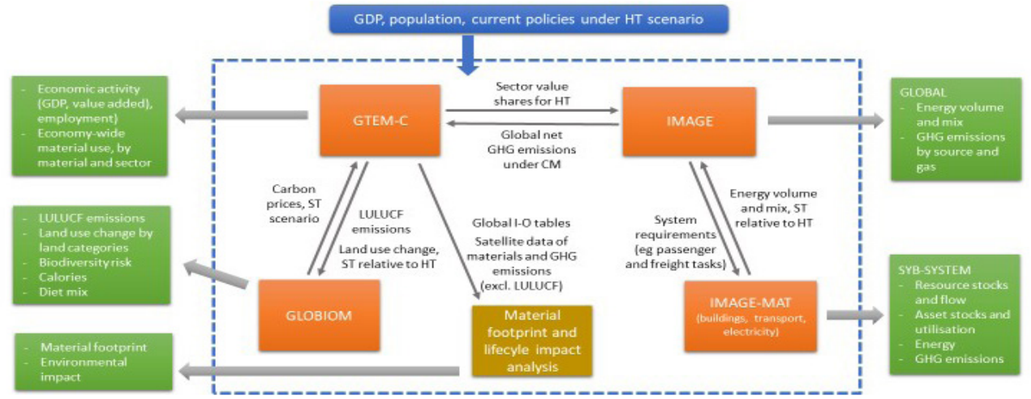
7.1. Modelling framework

The scenario links the global economic model (GTEM) and land use model (GLOBIOM) used in GRO19 with a global systems model used for integrated assessment (IMAGE), which includes a new materials stock and flow module (IMAGE-MAT). This stregthens the modelling framework and provides new insights into how different pathways for key stocks (such as of buildings and vehicles) shape future resource and energy requirements, and associated impacts.

- GTEM-C (Global Trade and Environmental Model-Core) is a global recursive dynamic Computable General Equilibrium (CGE) economic model. It estimates economic outcomes on macroeconomic (e.g. GDP, national income) and sectoral level (e.g. sector output, inter-sector input-output flows) variables. GTEM-C can estimate shifts in industrial GHG emissions from policy and technological change scenarios. GTEM-C can also provide economy-wide, multi-sector and multi-region material use projections for 61 material categories consistent with the IRP's material flow database.
- IMAGE is an Integrated Model to Assess the Global Environment. It is systems dynamics model that simulates environmental consequences of human activities by integrating across sub-models for land, energy, climate, and policy responses. This allows IMAGE to undertake integrated assessment, exploring the long-term dynamics and impacts of global changes that result from interacting socio-economic and environmental factors, and simulating the environmental consequences of human activities worldwide. The model can be used to explore the long-term pathways for future environmental and sustainable development problems as well as possible response strategies, and their implications for climate change, biodiversity and human well-being. The IMAGE modelling framework has been developed by the IMAGE team under the authority of PBL Netherlands Environmental Assessment Agency.
- IMAGE-MAT (Integrated Model to Assess the Global Environment-Materials) is a comprehensive integrated modelling framework of interacting human and natural systems. The model framework is suited to large scale (mostly global) and long-term (up to the year 2100) assessments of interactions between human development and the natural environment and integrates a range of sectors, ecosystems and indicators. The impacts of human activities on the natural systems and natural resources are assessed and how such impacts hamper the provision of ecosystem services to sustain human development. The model identifies socio-economic pathways and projects the implications for energy, land, water and other natural resources, subject to resource availability and quality. Unintended side effects, such as emissions to air, water and soil, climatic change, and depletion and degradation of remaining stocks (fossil fuels, forests), are calculated and taken into account in future projections.
- GLOBIOM (Global Biosphere Management Model) is a recursively dynamic, partial equilibrium model of land use-based activities, including agriculture, forestry and bioenergy sectors (Havlik et al. 2014). The model is used for analysing policy impacts in the medium-term as well as long-term outlook exercises (up to 2100). It models 18 globally important crops, a range of livestock production activities, forestry commodities, and first- and second-generation bioenergy. Production is spatially explicit and considers land management, resource/water availability, and physiographic characteristics influencing the productive capability of the land system. The model features detailed GHG emissions (spatially and by AFOLU sources), including land use change emissions. Bilateral trade flows are represented in quantity terms, with a spatial equilibrium approach (Takayama and Judge 1964), which allow a high level of precision in the modelling of trade policies.

These four models have different approaches to represent interactions between human and environmental systems and their focus is complementary. The modelling for GRO24 implements a series of 'soft links' through data exchanges and shared scenario assumptions, as shown in Figure A7.1 below. This allows the models to run individually under homogeneous assumptions to provide coherent integrated results. Key results from individual model runs were reviewed and model implementation was iterated where required to ensure consistency in modelled trends. The following flow chart illustrates the framework and data flows.

Figure A7.1: Key data linkages and outputs in the IRP modelling framework used for GRO24[1]



7.2. Model scope and primary sources for reported results

Each model provides results for a wide range of variables, many of which overlap across the models and are used to ensure consistency across key results.

Reporting of scenario results in Chapter 4 is aligned to the relative strengths of each model in the multi-model framework.

- GTEM is used for results for economic activity and total resource use by category
- GLOBIOM is used for results for land and food outcomes
- IMAGE is used for results for energy and greenhouse gas emissions
- IMAGE-MAT is used for results for materials use, energy and emissions from buildings and transport

7.3. Scenario assumptions and implementation

In the Historical Trend scenario, GDP and population projections are common inputs for all the models. We use historical GDP data up until 2020 and incorporate the International Monetary Fund's GDP projection until 2027 to account for the impact of COVID on the economy. From 2028 onwards, we use SSP2 real GDP projections from OECD (Dellink *et al*. 2017) as the long-term GDP trend as most SSPs studies have done (Riahi *et al.* 2017). Population projections follow a similar approach, utilizing historical data up to 2020 and SSP2 population projection from IIASA from 2021 onward (KC and Lutz 2017). In the Historical Trend scenario, GTEM-C, IMAGE-MAT, and GLOBIOM models account for current policies influencing resource use and environmental impacts based on SSP2 (Fricko *et al.* 2017). IMAGE adopts the sector value shares from GTEM-C to ensure greater consistency in this scenario. Additionally, GTEM-C relies on GLOBIOM results to constrain the growth rates of major crops and timber and account for land use change emissions.

In the Climate Mitigation scenario, the GHG emissions pathway from IMAGE-MAT is employed as a target in GTEM-C. This facilitates the derivation of a carbon price pathway and GDP implications that align with a 2-degree world scenario. Although IMAGE-MAT and GTEM-C may differ in terms of their endogenously estimated carbon prices due to differences in model scope and structure, they maintain consistency regarding the desired climate outcome and emission pathways. In the Sustainability Transition scenario, coupled with a resource efficiency policy package, the estimated GHG emissions align with a 1.5-degree scenario. GLOBIOM results are in line with a 1.5-degree climate outcome in the Sustainability Transition scenario (Frank *et al.* 2021).

We complement or ensure consistency between IMAGE-MAT estimates of material demand for construction and

1 Notes: The figure focuses on the most important linkages to ensure coherence and does not show linkages used for calibration and consistency. Source: GRO24 scenario modelling team.

transportation with GTEM projections for the 61 material classes reported in the IRP's material flow database.

GTEM-C is responsible for reporting economy-wide material use. However, we draw on the results from IMAGE-MAT and GLOBIOM for details of material use in buildings, transport, and electricity generation (IMAGE-MAT), and in agriculture and forestry (GLOBIOM). To facilitate the material footprint analysis and environmental impact analysis, we utilize GTEM-C's projections of economic flows to construct a global Input-Output table. This enables a comprehensive assessment of the material footprint and environmental impact at a global level.

The table below maps the measures that make up the *Sustainability Transition* scenario presented in Chapter 4 to the policy principles and guidelines in Chapter 5.

Table A7.1: Mapping of Chapter 5 recommendation to the Sustainability transition policy packages and societal shifts in Chapter 4.

Critical aspects for the transitions	Recommendation	GTEM	IMAGE	GLOBIOM	How it is modelled
Institutionalization of natural resource use governance	1. Global and national institutionalization of natural resource use within global sustainability agendas and environmental agreements				Not explicitly represented
	2. Definition of global and national resource use paths				Not explicitly represented
	3. Internalizing the environmental and social costs of resource extraction	YES	YES (climate)	YES (land use)	Carbon levy, resource extraction tax Enforce protected area for land use
Directing finance towards sustainable resource use	4. Redirecting, repurposing and reforming public subsidies for sustainable resource use	PARTLY			Fossil fuel subsidies and crop-based biofuels are phased out
	5. Channelling private finance towards sustainable resource use				Not explicitly, but the scenario explores great increase in innovation to enable the scale up of resource efficiency
	6. Incorporating resource-related risk into Public and Central Bank mandates				No
Making trade an engine of sustainable resource use	7. Trade governance for fairness and sustainable resource use				Not explicitly, but the scenario explores the implementation of a resource tax with provisions to avoid increased inequality consequences
	8. Enabling local resource value retention in producer countries	PARTLY			The scenarios models a return of carbon revenues as part of global dividend
Mainstreaming sustainable consumption options	9. Developing action plans to improve access to sustainable goods and services	INDIRECTLY	INDIRECTLY	YES	Shifts in demand and changes in relative prices favor less damaging alternative. Diet shift away from red meat, to other protein
	10. Regulating marketing practices leading to overconsumption, and raising awareness	INDIRECTLY	INDIRECTLY	YES	Shifts in demand and changes in relative prices favor less damaging alternative Diet shift away from red meat, to other protein
Creating circular, resource-efficient and low-impact solutions and business models	11. Setting up monitoring systems to identify priorities and develop ambitious circular economy action plans	YES	YES	YES	Strong resource efficiency policies. Circular policies not explicitly represented
	12. Developing and reinforcing regulation to boost circular economy business models				Yes: the resource efficiency policies are based, among other, on a resource levy, whose revenue is assumed to be used to support resource efficiency innovation
	13. Building circular economy capacity and coalitions				Not explicitly, yet assumptions of the scenario require joint and decisive global collaboration
Food	Reducing the demand of the most impactful food commodities	PARTLY		PARTLY	Diet shift away from red meat, to other protein
	Reducing food loss and food waste	YES		YES	Fast reduction of loss & waste: 50% reduction of food waste from 2020 levels by 2050
	Protecting and restoring productive land while meeting demand for nutrition			YES	Land use protections on biodiverse areas fully enforced by 2030 High investment in R&D resulting in high yield growth Improved water application efficiency Improve agricultural productivity

Built environment	Assure sustainability of the new building stock	YES	YES		Building materials include recycled content and timber Lightweighting/ lean design for new buildings Lifetime extension for new buildings
	Retrofitting the existing building stock		PARTLY		Improved energy efficiency of existing buildings
	More intensive use of buildings	YES	YES		Lower floor space per capita Higher household occupancy
	Decarbonizing material production	YES	PARTLY		Detailed representation
Mobility	Cities moving towards active mobility and public transportation	PARTLY	YES		Modal shift towards active and public transport
	Reducing carbon-intensive frequent traveling modalities	PARTLY	YES		Reduced overall demand for travel (through increased teleworking and service accessibility)
	Decreasing emissions intensity of transport modalities	YES	YES		More intensive use of vehicles Vehicle lifespan extension Vehicle lightweighting
Energy	Decarbonizing electricity supply through the scaling up of low-resource renewable energies and increased energy	YES	YES	YES	Accelerated uptake of renewable electricity Doubling of the rate of energy efficiency by 2030
	Decarbonizing fuels	YES	YES		Detailed representation

7.3.1. Scenario implementation and cross-model coordination use GTEM

The modelling uses GTEM to integrate and coordinate across models, to ensures consistent and coherent results across the suite of issues and models.

This draws on the economy-wide coverage of the multi-se multi-region GTEM model. The version of GTEM used here has 34 countries and regions and more than 30 industry sectors, including agriculture, mining, energy (including petroleum products, gas, and electricity), heavy industry, manufacturing, construction, transport, utilities, and services). Consistent with this, GTEM provides projections of multiple dimensions of economic activity, including sector output, production inputs (labour and capital), trade, resource extraction, trade, and use (by resource categories); energy supply and demand; and greenhouse emissions.

The *Sustainability Transition* scenario is modelled in GTEM as a series of steps (or departures) from the underlying *Historical Trends* scenario.

1. Resource Efficiency (RE) shift is modelled as a stand-alone package, using the method developed for previous IRP analysis set out in Global Resource Outlook of the International Resource Panel (2019), as described in chapter.
2. Climate and Energy (CE) shift is modelled as a stand-alone package. This first calibrates total primary energy to align with the IEA Net Zero Emissions scenario (IEA 2023), which projects somewhat higher energy use than IMAGE. The global emissions budget is then imposed from IMAGE and met through a combination of gradual deployment of technology-based CDR (to avoid a high overshoot path) and additional abatement driven by an exogenous global carbon levy, as required to achieve the global emissions trajectory.
3. Step 3 combines the RE and CE treatments and calibrates productivity and shifts in output for each agricultural sector to be consistent with GLOBIOM projections for the Food and Land (FL) shift, including diet shift as described in the chapter. This results in projected aggregate resource use and greenhouse emissions that are lower than Step 1 and Step 2 as stand-alone packages.
4. Produce the *Sustainability Transition* scenario, based on step 3, by applying the global resource dividend as a redistribution of national income (not GDP) across countries, redistributing the value of the carbon levy on an equal per capita basis. The final emission outcome is consistent with a 1.5°C global emissions trajectory (IPCC 2021).

7.3.2. Scenario implementation in GLOBIOM

The following table summarises key technical assumptions in the GLOBIOM modelling.

Table A7.2: Key technical assumptions in the GLOBIOM modelling.

	Baseline scenario	**Sustainability transition scenario**
Crop productivity and management	Business as usual investment in R&D resulting in medium yield growth 0.46 % p.a in Global North 0.6% p.a in Global South (based on SSP2 growth rates) Moderate improvement in water application efficiency 1.5% per decade based on Hanasaki *et al.* (2013)	High investment in R&D resulting in high yield growth 0.51% p.a. in Global North and 0.66% p.a in Global South (based on SSP1 growth rates) Improved water application efficiency 3% per decade based on Hanasaki *et al.* (2013)
Livestock feed conversion efficiency	Moderate efficiency growth Annual feed conversion efficiency change from 0.10% in the Global North to 0.24% in the Global South (based on SSP2 growth rates from Herrero *et al.* 2014)	Enhanced efficiency growth Annual feed conversion efficiency change from 0.10% in the North to 0.26% in the South (based on SSP1 growth rates Herrero *et al.* 2014).
Diets	The BAU diets follows the projections from the FAO at the horizon 2050 (Alexandratos and Bruinsma 2012). These diets are classified as moderate consumption growth and increasing share of livestock products in the diet.	Future diets become more sustainable with less per capita meat consumption than under the baseline despite higher income per capita growth. In developed regions overconsumption is reduced and in developing countries food consumption increases but through vegetal calories.
Food security measures	No targeted measures to reduce undernourishment.	Halting undernourishment by 2030 (limiting undernourishment <2.5% of total population) through increased calorie intake levels in regions with undernourishment

Agricultural waste	Medium reduction of losses & wastes Losses and wastes in the processing chains reduced from 12% to 7.5% in the Oilseed and Pulses sector and from 7% to 3% in the dairy sector over 2000 and 2050 (based on SSP2 assumptions)	Fast reduction of losses & wastes 50% reduction of food waste from 2020 levels by 2050
Climate Mitigation	No climate mitigation efforts for the agriculture sector.	Climate mitigation efforts by the agriculture sector are strong and the sector faces taxes on GHG emissions attributed to agricultural production and land use change of 275 USD 2000/tCOeq in 2050. The aim is to limit temperature increases to 1.5 C by 2100.
Biodiversity protections	No land use protections on biodiverse areas.	Land use protections cover at least 17% all biodiverse areas (UNEP- WCMC 2008), and are fully enforced and effective by 2030
Protections for water resources	No environmental flow protections	Environmental flow protections are fully enforced by 2030 and reduce the water available for use by irrigation (Pastor *et al.* 2019)

7.3.3. Scenario implementation in IMAGE and IMAGE-MAT

In the analysis, we used the IMAGE and IMAGE-MAT models for the following scenarios:

- The Historical Trends (HT) scenario, based on current policies and default projections
- Resource efficiency (RE) scenario, including options to reduce material use (see below)
- Sustainability scenario (ST), combining the RE scenario with climate mitigation to stay well below 2 degrees C.

The assumptions of the RE scenario are listed in the table below, focusing on the built environment, transportation (vehicles), and electricity generation.

Sectors	IMAGE	IMAGE-MAT	End-of-Life
Buildings	Lower per capita residential floorspace (m^2/cap) Higher household occupancy	Lower commercial floorspace (m^2/cap) Housing type shift (%) Lightweight & substitution (kg/m^2) Lifetime extension for new buildings	For all materials: • EoL Reuse (sectoral) • Material specific EoL recycling rates (%)
Transport	Modal shift lower overall demand for transport (pkm/tkm)	Higher annual vehicle mileage (km/yr) Vehicle lightweighting (kg/vehicle) Vehicle lifetime extension	
Electricity	Higher electrification (sector specific assumptions) Higher demand & generation	Lightweight renewable generation (kg/MW) Lightweight grid auxiliaries Longer lifetimes (renewables & grid-lines)	

Assumptions are further specified in quantitative terms, throughout this appendix.

IMAGE resource efficiency measures for the built environment

Assumptions of per capita floorspace (Edelenbosch *et al.* 2022)

Relevant for building stock, flows calculated from demolition + stock growth

Residential Floorspace (m^2/cap)	2020	Baseline 2060	RE 2060
North America	54.3	56.6	30.4
Latin America + Caribbean	19.1	28.8	27.6
Europe	41.3	49.3	30.7
EECCA	20.3	27.7	24.8
Africa	10.3	16.2	16.2
West Asia	21.2	26.8	26.8
Asia + Pacific	16.9	25.1	24.7
World	**20.0**	**26.6**	**23.7**

Assumptions on Commercial floorspace (own assumptions based on Deetman *et al.* 2020)

Relevant for building stock, flows calculated from demolition + stock growth

Commercial Floorspace (m^2/cap)	2020	Baseline 2060	RE 2060
North America	21.7	24.3	17.1
Latin America + Caribbean	4.4	11.5	8.1
Europe	14.4	21.8	15.3
EECCA	4.5	12.5	8.8
Africa	1.7	5.8	4.2
West Asia	3.7	9.0	6.5
Asia + Pacific	3.6	11.4	8.3
World	**5.0**	**11.1**	**8.1**

Assumptions on residential building types (based on Fishman *et al.* 2021)

Relevant for new buildings

Factors are: urbanization and shift from detached to high-rise housing, and within the multi-family homes a shift from row houses to apartments.

Assumptions on building life spans (based on Zhong *et al.* 2021)

Relevant for new buildings
- 30% mean lifetime increase on houses with long lifetimes
- 60% mean lifetime increase on houses with medium lifetimes
- 90% mean lifetime increase on houses with short lifetimes
- 90% mean lifetime increase on commercial buildings

Material intensity of buildings (based on: Marinova *et al.* 2019; IRP 2020; Zhong *et al.* 2021)

Relevant for new buildings (see details in the dedicated tables below):
- Lightweighting of new housing: region specific penetration rate (by 2050) ranging from 35%-93%
  - 17% less steel
  - 15% less concrete
  - 19% less aluminium
- Material substitution in all new housing (wood-construction): 20% penetration (assumed, based on 2 ResEff sources)
  - Remaining steel use: 7%
  - Remaining concrete use: 40%
  - Resulting wood use: 360%
- Service/Commercial buildings:
  - 40% penetration of lightweighting (rest same as residential)
  - 20% penetration rate of substitution (wood-construction)
  - Remaining steel use: 31%, 41% for concrete

Resulting global average material intensities per m2 UFA:

Residential Material Intensity (kg/m^2)	**2020**	**RE 2060**
Steel	70	53
Concrete	1009	828
Wood	48	72
Copper	0.5	0.5
Aluminium	2.0	1.8
Glass	3.7	3.7

Commercial Material Intensity (kg/m^2)	**2020**	**RE 2060**
Steel	86	69
Concrete	820	681
Wood	17	33
Copper	3.3	3.3
Aluminium	4.4	4.0
Glass	5.7	5.7

Resource efficiency measures for Transportation

In the IMAGE model, the following developments in the construction and use of vehicles are implemented for the Resource Efficiency scenario (Edelenbosch *et al.* 2022):
- Partial transition from short-distance aviation to rail.
- Reduce overall transport demand in person kilometers in line with increased teleworking and alternative tourism (25% reduction in activity)
- Relax link between economic growth and demand for travel and freight

So far, no specific assumptions have been made for freight transport. Long distance freight transport is expected to be reduced under 2D assumptions, as a result of a reduction in fossil fuel use. This is not yet implemented in IMAGE.

Additional transport-related assumptions in IMAGE-MAT are the following:
Intensity of use (based on Morfeldt and Johansson 2022)
Relevant for vehicle stocks, with consequences for flows
Passenger cars:
- 20% increase in annual milage (= intensity of use / more efficient use), from about 14.500 km/yr (average) to ca. 16.900 km/yr, with a regional maximum average milage of 21.000 km/yr

Bicycles:
- 30% increase in annual milage – from 2400 km/yr to 3120 km/yr

Other vehicles:
- 10% increase in annual milage, applied to:
  - Busses
  - Rail (freight/passenger)
  - Small/medium/inland ships, no change for (very) large international ships
  - Light/Medium trucks, no change for heavy trucks

Vehicle life spans (based on Norris 2013; IRP 2020; Rodrigue 2020; Deetman 2021)

Relevant for new vehicles

Mean lifetimes (yr) **Vehicle**	**2020**	**RE 2060**	**Change %**
Airplane	20.5	22.5	10%
Rail	34	47	Ca. 40%
Ships	29	38	33%
Trucks	10	12	10%
Bus	13	15.6	20%
Bicycle	10	12	20%
Car	15	18	22.5%

Vehicle lightweighting (based on IRP 2020 and Deetman 2021)

Relevant for new vehicles

- Overall weight reduction of about 18% applied to 47% (penetration rate) of new motorized road-vehicles (net. -8.4% wt.)
- Potential reduction for other vehicles is half that (assumed, ca. 4.2% weight reduction), ocean ships not affected
- Note that this goes against current trends of increasingly heavy vehicles, not accounted for in the baseline.

Vehicle weight (kg) **Vehicle**	2020	RE 2060	Change %
Airplane	78200	74900	4.2%
Rail	813500	779400	4.2%
Ships (inl.)	322000	308500	4.2%
Trucks	8630	7990	8.2%
Bus	11090	10260	8.2%
Bicycle	17.2	16.5	4.2%
Car	1500	1380	8.2%

Resource efficiency options for the electricity system

Demand for electricity as well as the technologies for electricity generation are key variables in IMAGE. In the Current Policies as well as the 2 degrees scenario, both demand and technologies undergo considerable modifications.

Specifically for the Resource Efficiency some additional modifications are made in IMAGE:
Some electricity demand reduction
- Lower appliance ownership
- Further electrification of transport

Some electrification measures (increased electricity, later in the scenario):
- Electrification of space heating (resistance heaters and heatpumps)
- Electrification in Industry (a.o. electric crackers)

Higher electrification rates are mostly an effect of higher carbon prices under the 2-Degree climate policy scenario.

Additionally, the following assumptions have been made in IMAGE-MAT:

Lightweighthing (own assumptions in reference to Deetman *et al.* 2020)

Relevant for new equipment
- Weight reduction of grid auxiliary equipment (transformers & substations) of 10% (assumed) by 2050
- No change to material intensities for fossil generation technologies or distribution/transmission cables
- Specific weight reduction of renewable generation technologies (applied to all materials):

Weight reduction (%) **Technology**	**2050**
Solar PV	20%
Solar PV residential	10%
CSP	30%
Wind onshore	20%
Wind offshore	10%
Wave energy	30%
Auxiliary grid-equipment	10%

Life span increase of electricity generation technologies (based on Van Vuuren 2007 and others)
Relevant for new equipment

Technology mean lifetime (yr) **Vehicle**	2020	RE 2060	Change %
Solar PV	25	33	32%
Solar PV residential	25	33	32%
CSP	25	28	10%
Wind onshore	25	30	20%
Wind offshore	25	30	20%
Wave energy	25	25	0%
Grid-lines	40	48	20%

Note that higher lifetimes are reportedly possible, but replacement is often more economically feasible. Moreover, innovation is still going rapidly in this sector, so old equipment will be outdated quite soon.

Re-use and recycling

Re-use refers to components or parts of appliances, which can be used again within the same sector. This can lead to a reduced demand from these sectors. Recycling refers to waste materials that can, once processed and brought back in good condition, be used again economy-wide, and thereby have the potential to replace virgin materials.

In IMAGE, production and use of two specific materials is modelled already: steel and cement. These are highly relevant for CO2-emissions. The re-use and recycling modules from IMAGE-MAT enable a better representation of the fraction of secondary materials in the total supply, reducing the need for primary materials. This connection however is not yet realized. IMAGE still works with a fixed primary-secondary material rate throughout the modelling period, which leads to results that do not show the benefits of re-use and recycling.

Assumptions on re-use (based on IRP 2020 and other sources: Solar PV + Solar PV residential: ETIP Photovoltaics 2017; Virtuani *et al.* 2019; Heath *et al.* 2020; Annigoni *et al.* 2021; Duran *et al.* 2021; Wind Onshore + Wind Offshore: Ziegler *et al.* 2018; Ford 2019; Wiser and Bolinger 2019; Siemens (no date); Menberg *et al.* 2021; Dorias and Chivers 2022; CSP: Chu and Meisen 2011; Grid-Lines: Zhang *et al.* 2007)

2020	**Steel**	**Concrete**	**Wood**	**Copper**	**Aluminium**	**Glass**
Electricity	5.3%	0%	10%	11%	10.8%	6%
Buildings	3.6%	0%	10%	11%	10.8%	6%
Vehicles	6.9%	0%	10%	11%	10.8%	6%

2050 (RE)	Steel	Concrete	Wood	Copper	Aluminium	Glass
Electricity	23.8%	21%	45.5%	33%	34.5%	68%
Buildings	17.9%	21%	36.6%	33%	34.5%	68%
Vehicles	20.4%	21%	45.5%	27.5%	28.6%	68%

Re-use rates differ a lot between sectors. On average, re-use rate is assumed to increase by ca. 30%-pt.

Recycling (based on IRP 2020 and multiple other sources: Buildings: Tam and Tam 2006; Höglmeier *et al.* 2013; Ciacci *et al.* 2017; Hopkinson *et al.* 2019; Zhong *et al.* 2021; van Oorschot *et al.* 2023; Vehicles: Directive 2012/19/EU 2012; Rahman *et al.* 2016; Ciacci *et al.* 2017; Electricity: Ardente *et al*. 2019; Dworak *et al*. 2021; General: Hatayama *et al*. 2009; Ciacci *et al.* 2017; Harder 2018; Passarini *et al.* 2018; Myers *et al*. 2019; American Iron and Steel Institute 2021; USGS 2021)

Relevant for outflow from both old and new stock

Recycling rates as provided refer to end-of-life recycling rates. These are presently already quite high, except for concrete which presently is used mainly as a road filler. To some extent, downcycling is included in these EoL RR as well – quality loss of materials often occurs, making secondary materials less versatile than primary materials. Note that due to long life spans of the applications and a growing demand, EoL RR are much higher than the Recycled Content (RC) of total material supply. When stocks saturate, EoL RR may approach RC values. This is not expected to occur within the modelled time period.

2020	Steel	Concrete	Wood	Copper	Aluminium	Glass
Electricity	77%	0%	25%	74%	80%	46%
Buildings	83%	0%	25%	69%	85%	38%
Vehicles	79%	0%	25%	70%	84%	46%

2050 (RE)	Steel	Concrete	Wood	Copper	Aluminium	Glass
Electricity	93%	37%	30%	91%	95%	95%
Buildings	92%	37%	30%	92%	95%	95%
Vehicles	94%	37%	30%	86%	95%	95%

7.4. Regions and countries in the scenario modelling

The table below indicates the GTEM countries and regions. This regional aggregation includes 34 regions, including 28 countries and six combined regions within specific geographies. This grouping does not imply any opinion on the legal status of any country, territory or area. Each country and region is allocated to an income group, as shown in Table A7.3. This allocation is based on current income, fitting to the thresholds specified in Annex 1, and results in around one sixth of global population being classified as low income, one third each classified as lower-middle and upper-middle income, and one sixth high income. This allocation does not change in response to projected changes in income over time.

Table A7.3: GTEM countries and regions used in the GRO24 modelling.

Geography	GTEM regions	Income status	Underlying GTAP countries and regions
Asia-Pacific	Australia	High income	Australia
	Bangladesh	Lower middle income	Bangladesh
	China	Upper middle income	China
	India	Lower middle income	India
	Indonesia	Lower middle income	Indonesia
	Iran	Lower middle income	Iran
	Japan	High income	Japan
	Pakistan	Lower middle income	Pakistan
	Philippines	Lower middle income	Philippines
	Rest of Asia + Pacific	Upper middle income	New Zealand, Hongkong, Mongolia, Taiwan, Brunei Darussalam, Cambodia, Lao People's Democratic Republic, Malaysia, Singapore, Nepal, Sri Lanka, Rest of East Asia, Rest of Oceania, Rest of southeast Asia, Rest of South Asia
	South Korea	High income	South Korea
	Thailand	Upper middle income	Thailand
	Viet Nam	Lower middle income	Viet Nam
North America	Canada	High income	Canada
	United States of America	High income	United States of America
Latin America + Caribbean	Argentina	Upper middle income	Argentina
	Brazil	Upper middle income	Brazil
	Mexico	Upper middle income	Mexico
	Rest of Latin America + Caribbean	Upper middle income	Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Dominican Republic, Jamaica, Puerto Rico, Trinidad and Tobago, Caribbean, Rest of South America, Rest of Central America
Europe	France	High income	France
	Germany	High income	Germany
	Italy	High income	Italy
	Rest of Europe	High income	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Norway, Albania, Rest of EFTA, Rest of Europe
	Turkey	Upper middle income	Turkey
	United Kingdom	High income	United Kingdom
EECCA	Rest of EECCA	Lower middle income	Belarus, Ukraine, Kazakhstan, Kyrgyzstan, Armenia, Azerbaijan, Georgia, Rest of Eastern Europe, Rest of Form Soviet Union
	Russian Federation	Upper middle income	Russian Federation

West Asia	Rest of West Asia	Upper middle income	Israel, Bahrain, Jordan, Kuwait, Oman, Qatar, United Arab Emirates, Rest of Western Asia
	Saudi Arabia	High income	Saudi Arabia
Africa	Egypt	Lower middle income	Egypt
	Ethiopia	Low income	Ethiopia
	Nigeria	Lower middle income	Nigeria
	Rest of Africa	Low income	Morocco, Tunisia, Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Senegal, Togo, Central Africa, South Central Africa, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe, Botswana, Namibia, Rest of North Africa, Rest of Western Africa, Rest of Eastern Africa, Rest of South African Customs Union, Rest of the World
	South Africa	Upper middle income	South Africa

7.5. Projected national income and economic activity by income group

The table below reports model results for average per capita national income (GNI) and economic activity (GDP) for each income group as a whole for 2020, 2040 and 2060. The results for 2020 are model results following calibration from GTAP base year data to replicate observed emissions, energy use and GDP growth by region, used for both scenarios. The results for 2040 and 2060 are model projections for the *Sustainability Transition* scenario.

Variations in income level within aggregated sub-regions flow through to the average GNI and GDP of the whole income groups. In practice, the aggregation raises the average income for the low-income and lower-middle income groups somewhat. This is the result of the African low-income combined region including a number of lower-middle income countries and the EECCA lower-middle income combined region including a number of upper-middle income countries.

	Income Group				World
	Low	Lower-middle	Upper- middle	High	
Average national income (GNI) per capita* (USD real 2020)					
2020	1,510	2,700	11,080	46,120	12,210
2040	2,670	5,680	20,880	61,620	18,220
2060	5,650	10,500	29,420	77,440	24,630
Average economic activity (GDP) per capita* (USD real 2020)					
2020	1,580	2,800	10,800	46,650	12,240
2040	2,940	6,190	19,730	64,520	18,480
2060	6,430	11,790	28,650	81,410	25,570
Annual growth in GNI and GDP per capita, 2020 to 2060					
GNI 2020-2060	3.4%	3.5%	2.5%	1.3%	1.8%
GDP 2020-2060	3.6%	3.7%	2.5%	1.4%	1.9%
Share of global economic activity (Gross World Product, equivalent to world GDP)					
2020	1.6%	8.2%	32.3%	57.9%	100.0%
2040	2.4%	12.4%	35.8%	49.3%	100.0%
2060	4.4%	17.6%	34.2%	43.8%	100.0%
Share of global population					
2020	12.5%	35.8%	36.6%	15.2%	100.0%
2040	15.2%	37.1%	33.5%	14.1%	100.0%
2060	17.6%	38.2%	30.5%	13.8%	100.0%

Table A7.4: Average national income, economic activity, and population by income group, 2020-2060.1

1 Notes: *rounded to nearest US$10

Annex 8: References

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