The Working Group III report

MITIGATION OF CLIMATE CHANGE – ECONOMIC SECTORS AND TECHNOLOGIES

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DEMAND-SIDE ASPECTS OF MITIGATION AND MITIGATION POTENTIAL

Demand-side mitigation and new ways of providing services can help **Avoid** and **Shift** final service demands and **Improve** service delivery. Rapid and deep changes in demand make it easier for every sector to reduce GHG emissions in the near and mid-term.

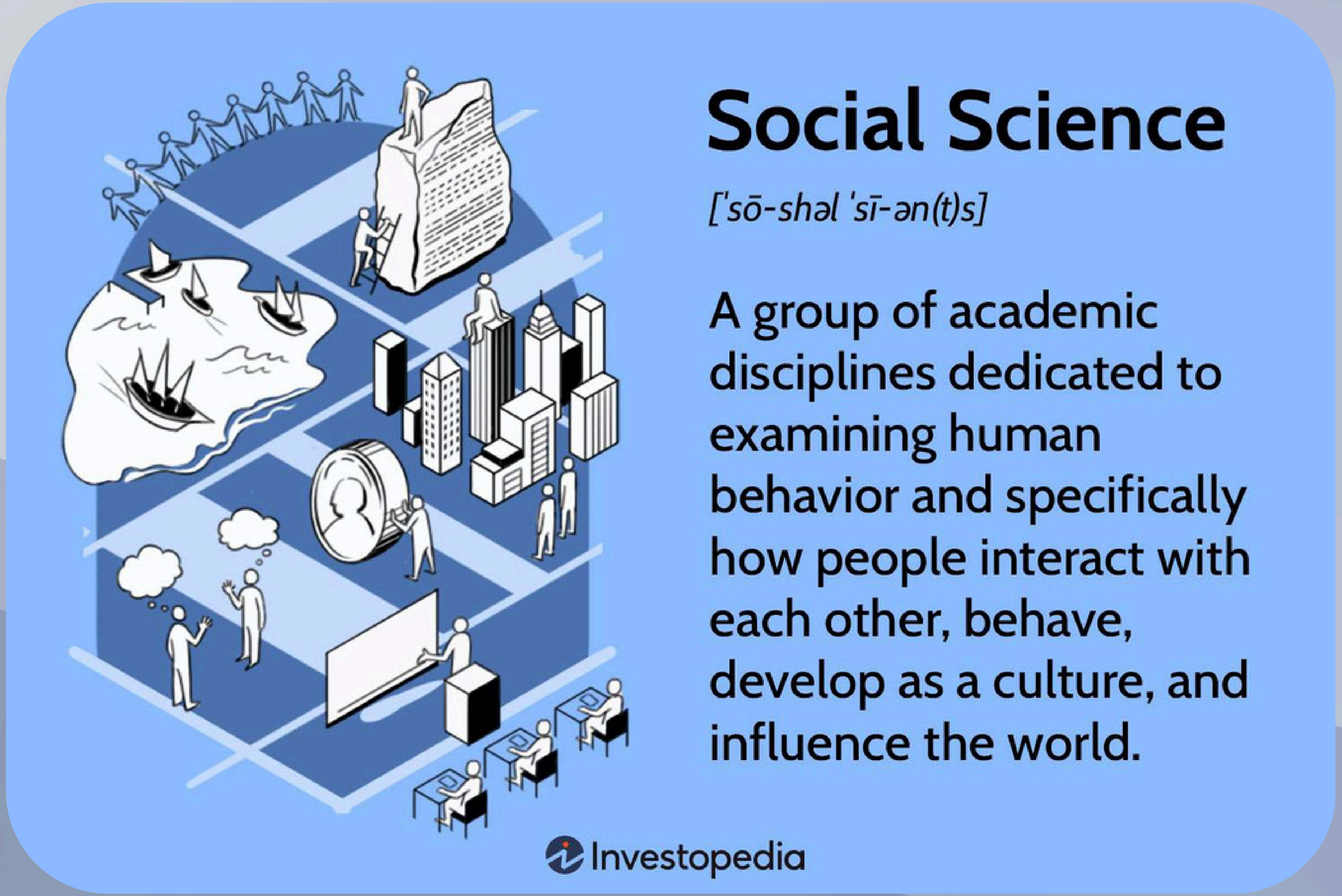
SUSTAINABLE DEVELPOMENT AND DEMAND

- A core operational principle for sustainable development is <u>equitable access to services to provide well-being for all</u>
- Sustainable development is not possible without changes in consumption patterns
- Improved well-being and higher social equity offer opportunities for delinking demand for services from emissions

Lamb, William F., and Julia K. Steinberger. "Human well-being and climate change mitigation." Wiley Interdisciplinary Reviews: Climate Change 8.6 (2017): e485;
Lin, David, et al. "Ecological footprint accounting for countries: updates and results of the National Footprint Accounts, 2012–2018." Resources 7.3 (2018): 58.

THE MODELS OF STAKEHOLDERS' DECISIONS ASSESSED BY IPCC

- From **AR1 to AR4**, rational choice was the implicit assumption.
- The **AR5** introduced a broader range of goals and decision processes
- The **AR6** - social science perspective introduced in:
  - New perspectives
  - New actors



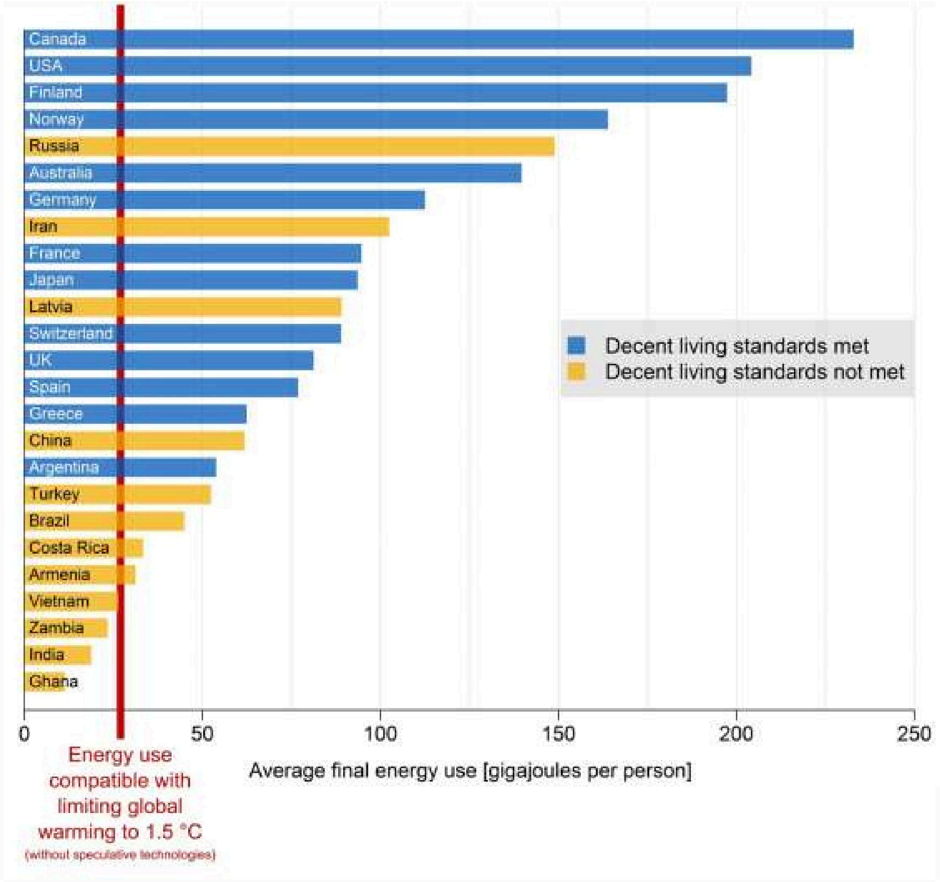
THE ACTORS

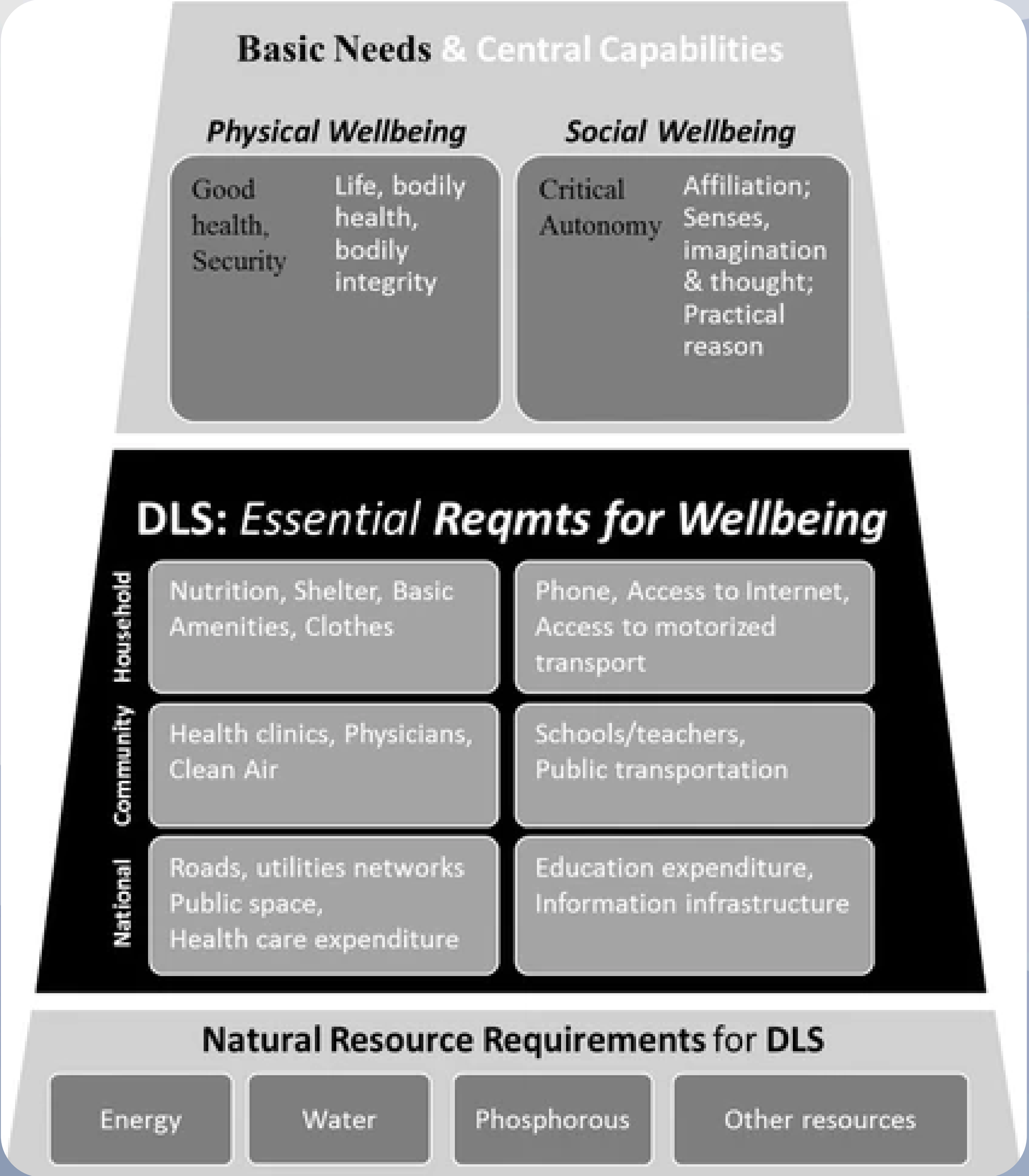
1. individuals
2. groups and collectives
3. corporate actors
4. institutions
5. infrastructure actors

DECENT LIVING STANDARDS

Current measures of human development, such the Human Development Index (income, life expectancy, literacy), or the Multidimensional Poverty Index (MPI) inadequately measure the extent of human deprivation, particularly with regard to the means that enable basic human well-being. **These requirements need to available and affordable to all.**

We propose a Decent Living Standard, which entails material requirements at the household, community and national scale.

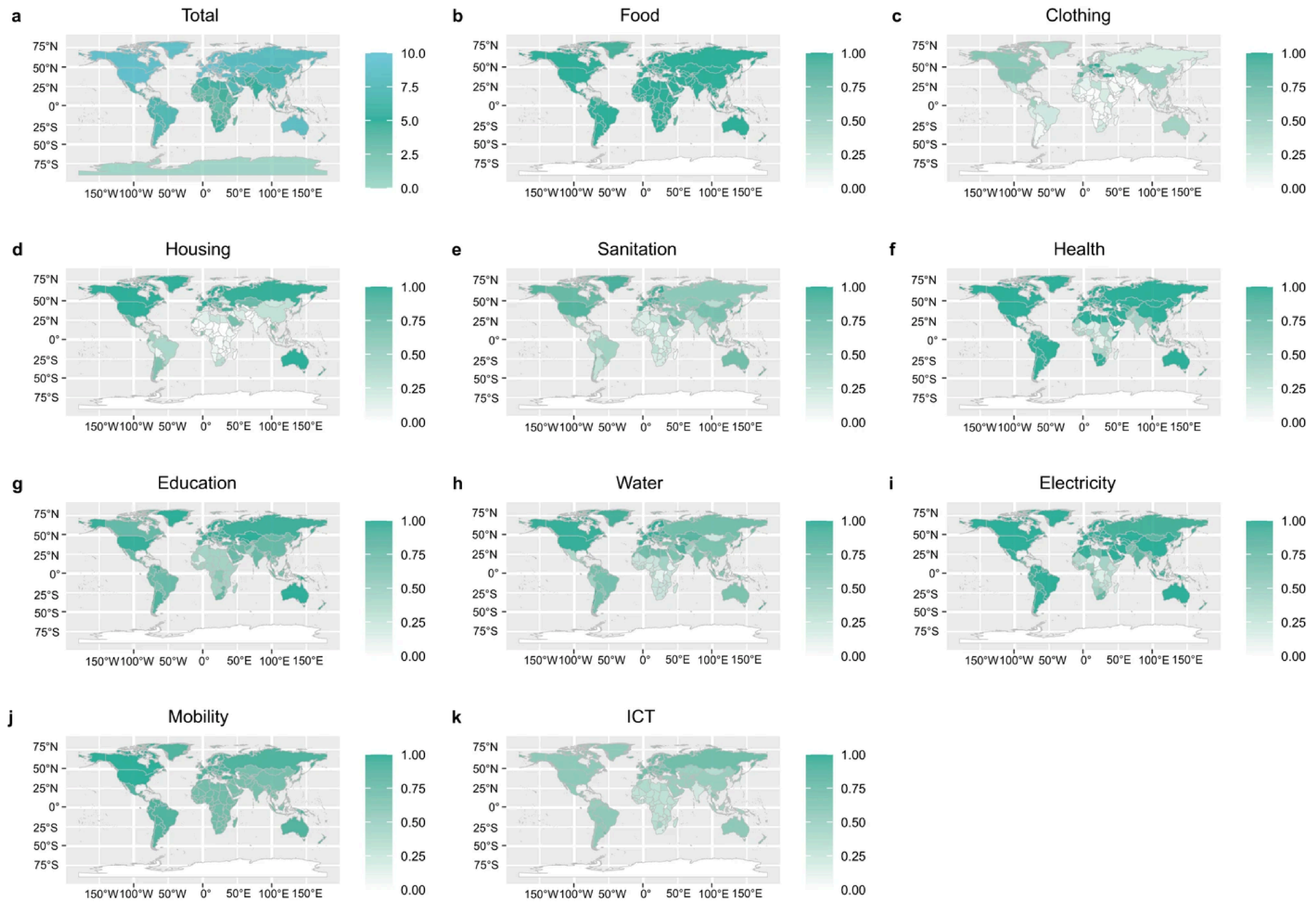




https://www.decentlivingenergy.org/dls.html;

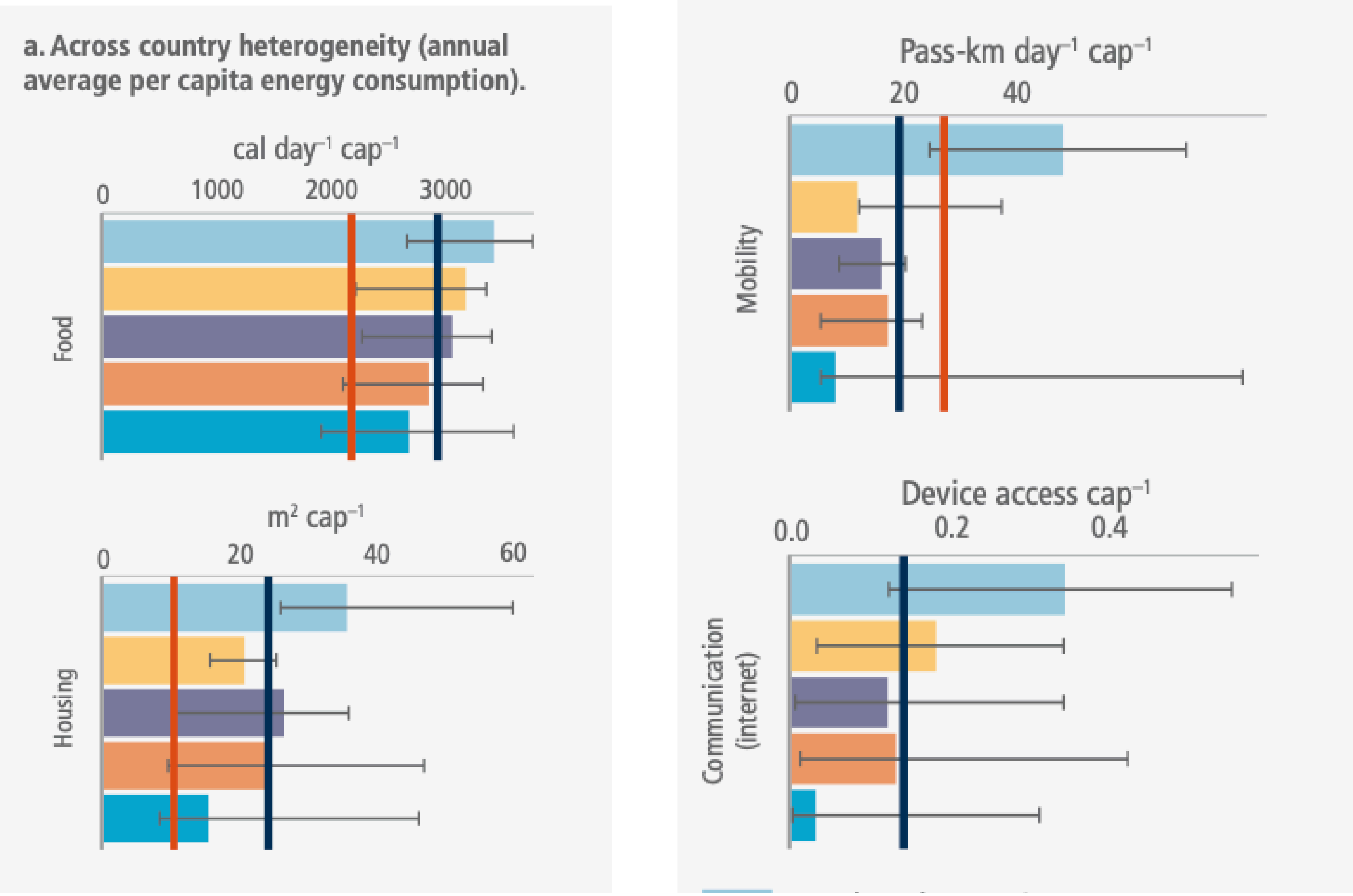
Rao, N.D., Min, J. Decent Living Standards: Material Prerequisites for Human Wellbeing.Soc Indic Res 138, 225–244 (2018). https://doi.org/10.1007/s11205-017-1650-0;

DECENT LIVING STANDARDS

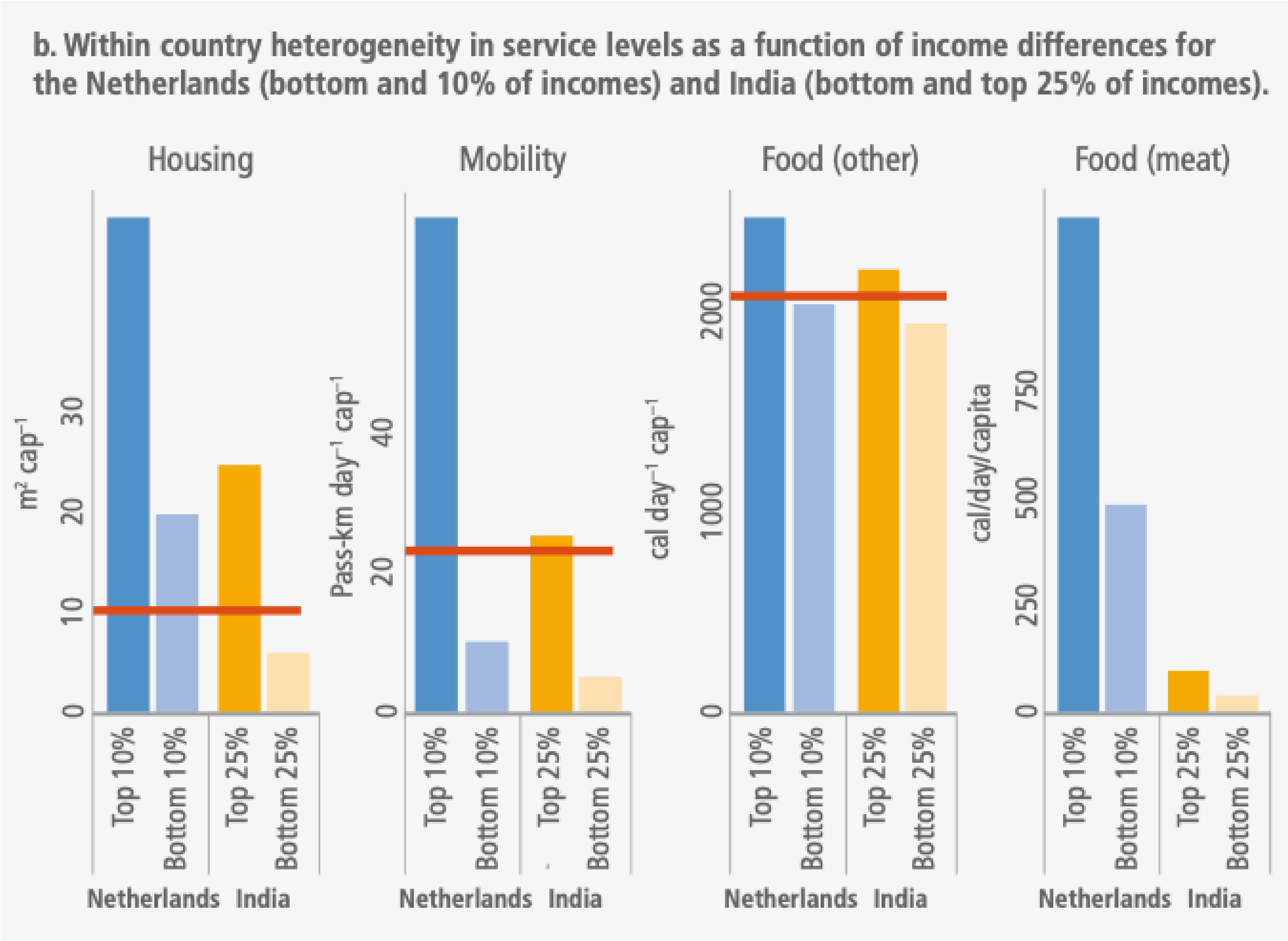


Huo, J., Meng, J., Zheng, H. et al. Achieving decent living standards in emerging economies challenges national mitigation goals for CO2 emissions. Nat Commun 14, 6342 (2023). https://doi.org/10.1038/s41467-023-42079-8

DECENT LIVING STANDARDS

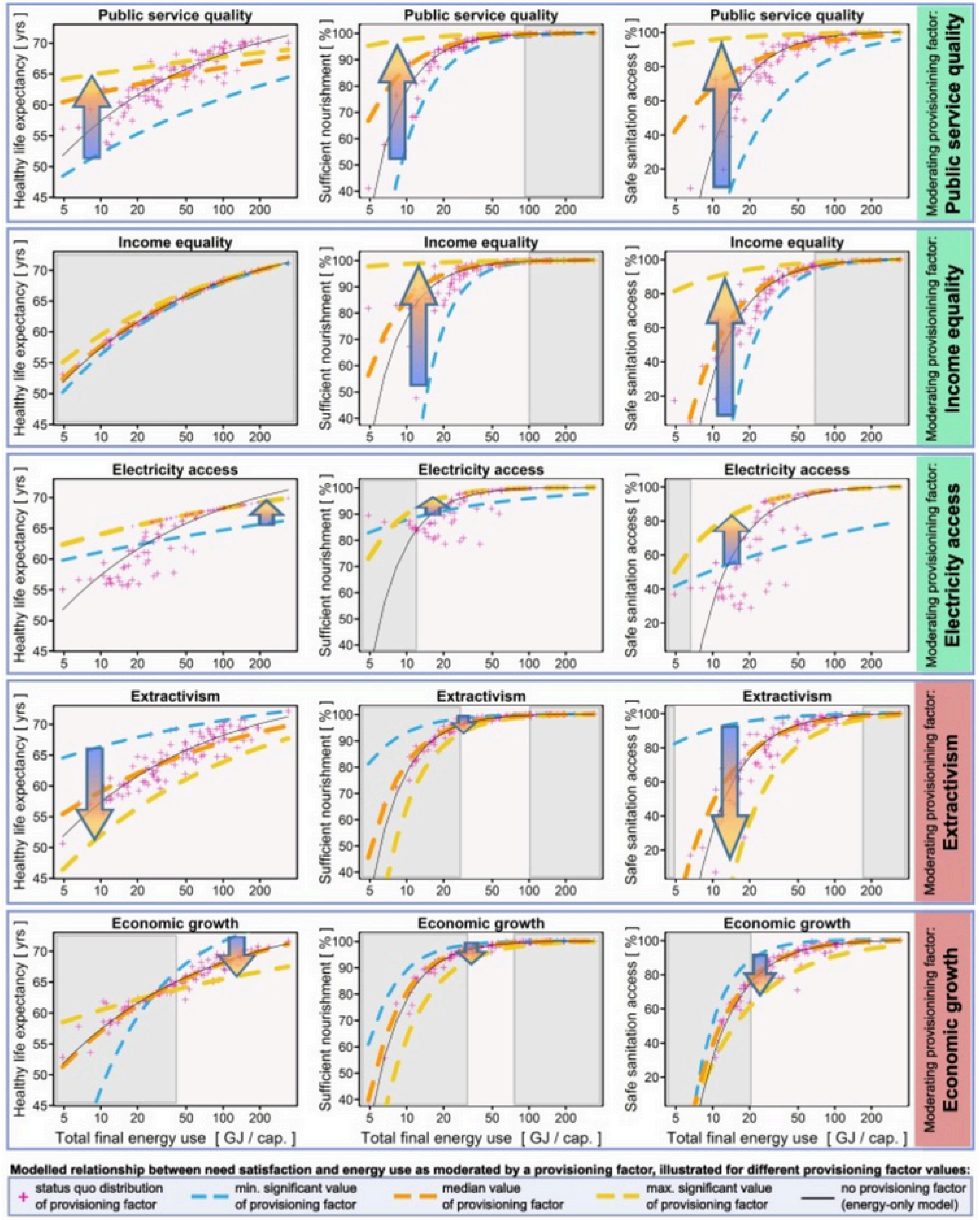


DECENT LIVING STANDARDS



- Inequitable societies use energy and resources less efficiently.
- Consumption reductions, both voluntary and policy-induced, can have positive and **double-dividend** effects on efficiency as well as reductions in energy and materials use

DECENT LIVING STANDARDS



- income equality, public service access, electricity access

- extraactivism, economic growth

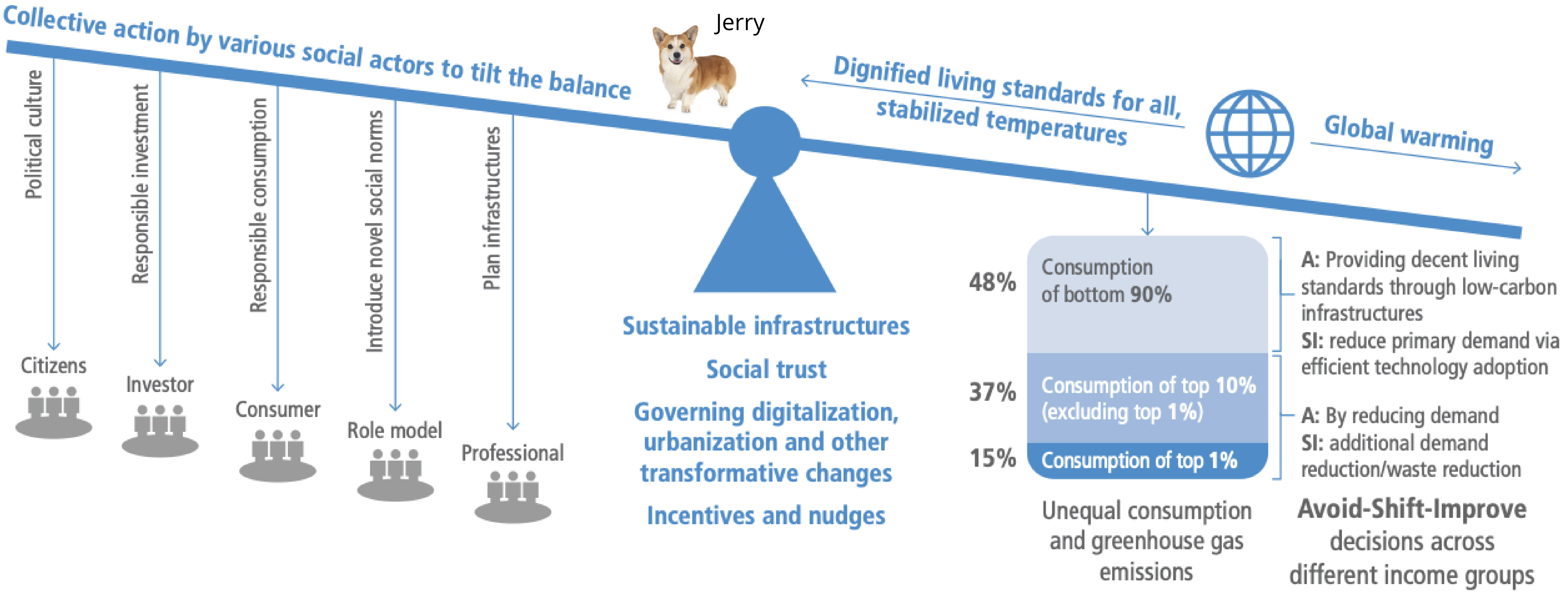
DECENT LIVING STANDARDS

Ambitious *low-emissions demand-side scenarios suggest that well-being could be* <u>*maintained or improved*</u> *while reducing global final energy demand, and some current literature estimates that it is possible to meet decent living standards for all within the 2°C warming window.*

DEMAND-SIDE SOLUTIONS

Demand side mitigation is about more than behavioural change. Reconfiguring the way services are provided while simultaneously changing social norms and preferences will help reduce emissions and access. Transformation happens through societal, technological and institutional changes.

(a) Tilting the balance towards less resource intensive service provisioning



DEMAND-SIDE SOLUTIONS

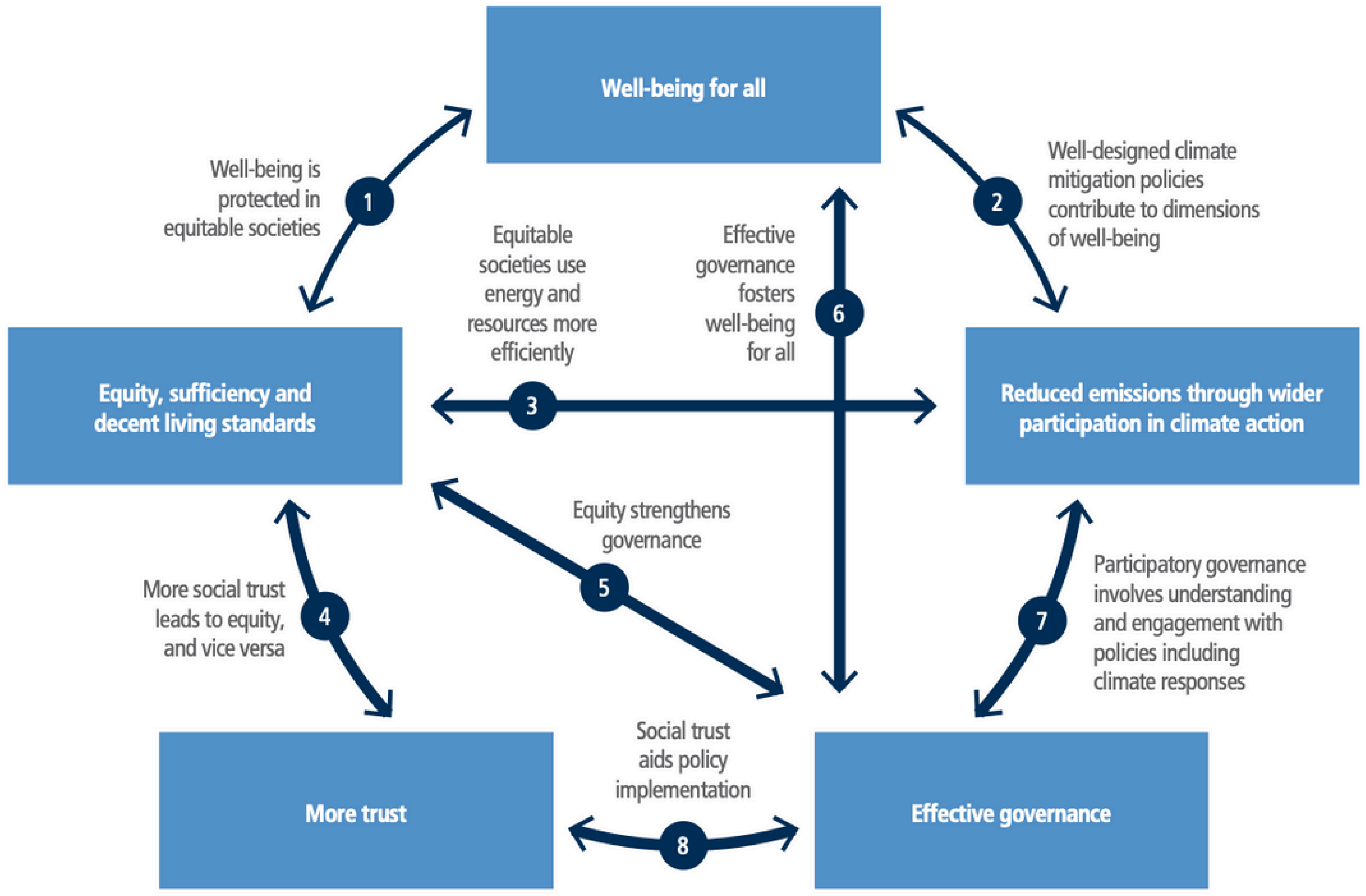


Figure 5.5 | Well-being, equity, trust, governance and climate mitigation: positive feedbacks. Well-being for all, increasingly seen as the main goal of sustainable economies, reinforces emissions reductions through a network of positive feedbacks linking effective governance, social trust, equity, participation and sufficiency. This diagram depicts relationships noted in this chapter text and explained further in the Social Science Primer (Chapter 5 Supplementary Material I). The width of the arrows corresponds to the level of confidence and degree of evidence from recent social sciences literature.

ENABLING MITIGATION

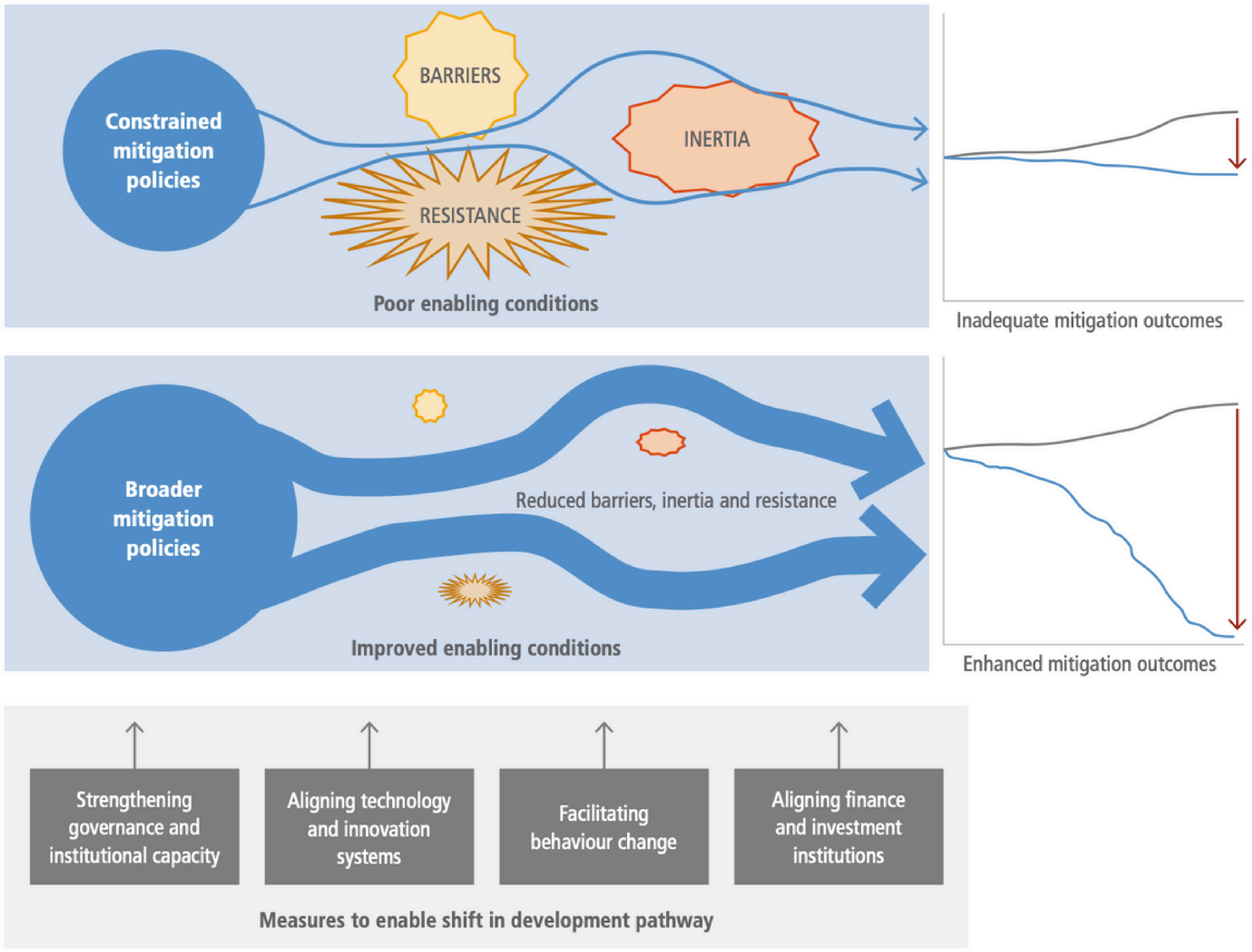


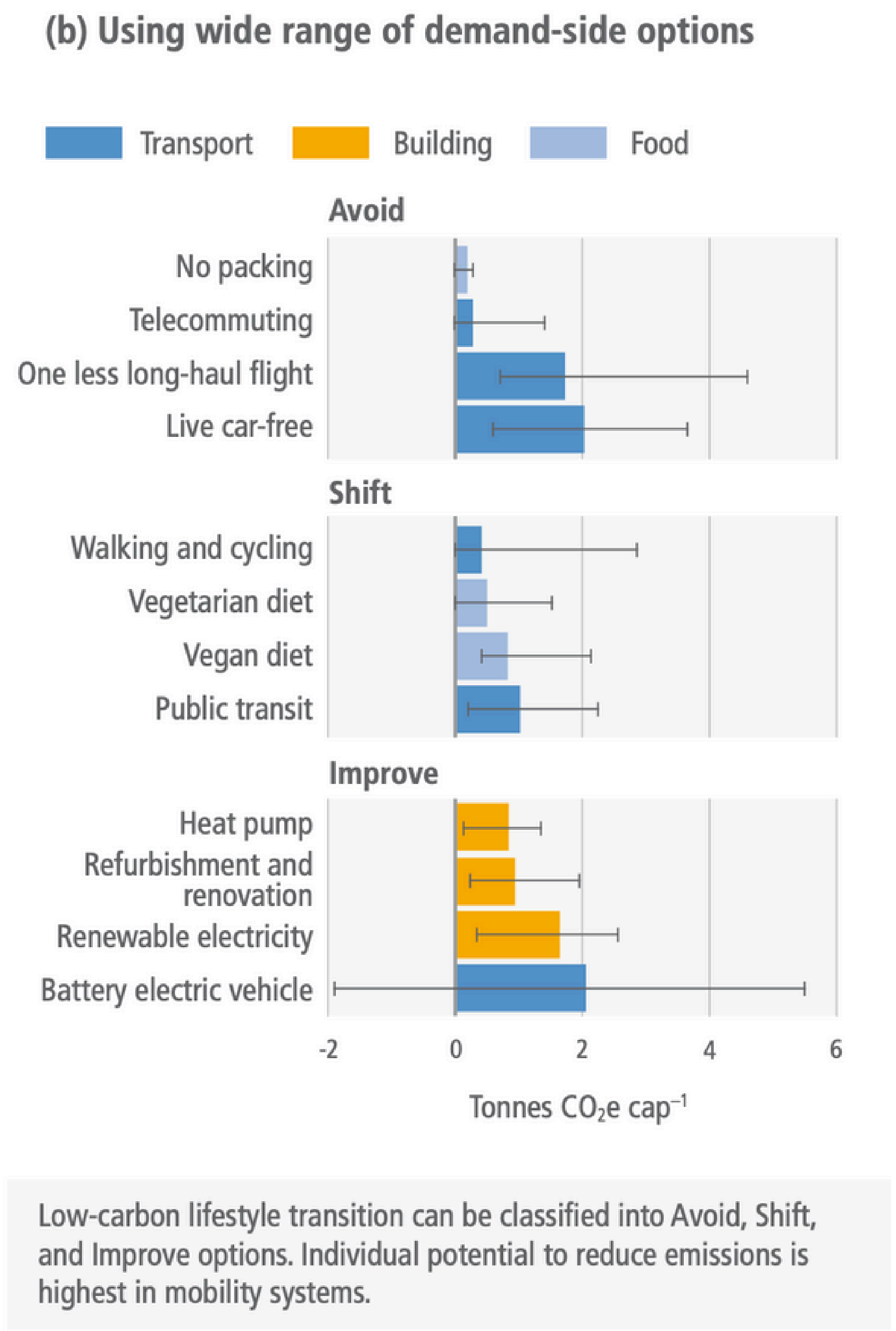
Figure 4.6 | Obstacles to mitigation (top panel) and measures to remove these obstacles and enable shift in development pathways (lower panel).

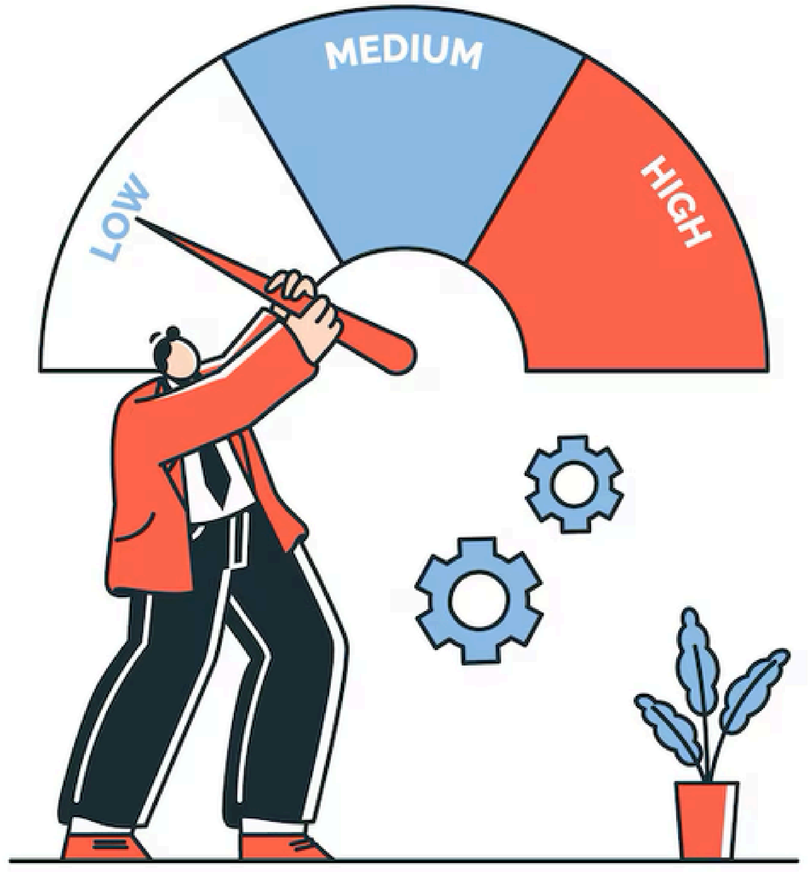
AVOID-SHIFT-IMPROVE APPROACH

Avoid the unnecessary wasteful and resource demanding options

Shift to more sustainable options

Improve the efficiency and effectiveness

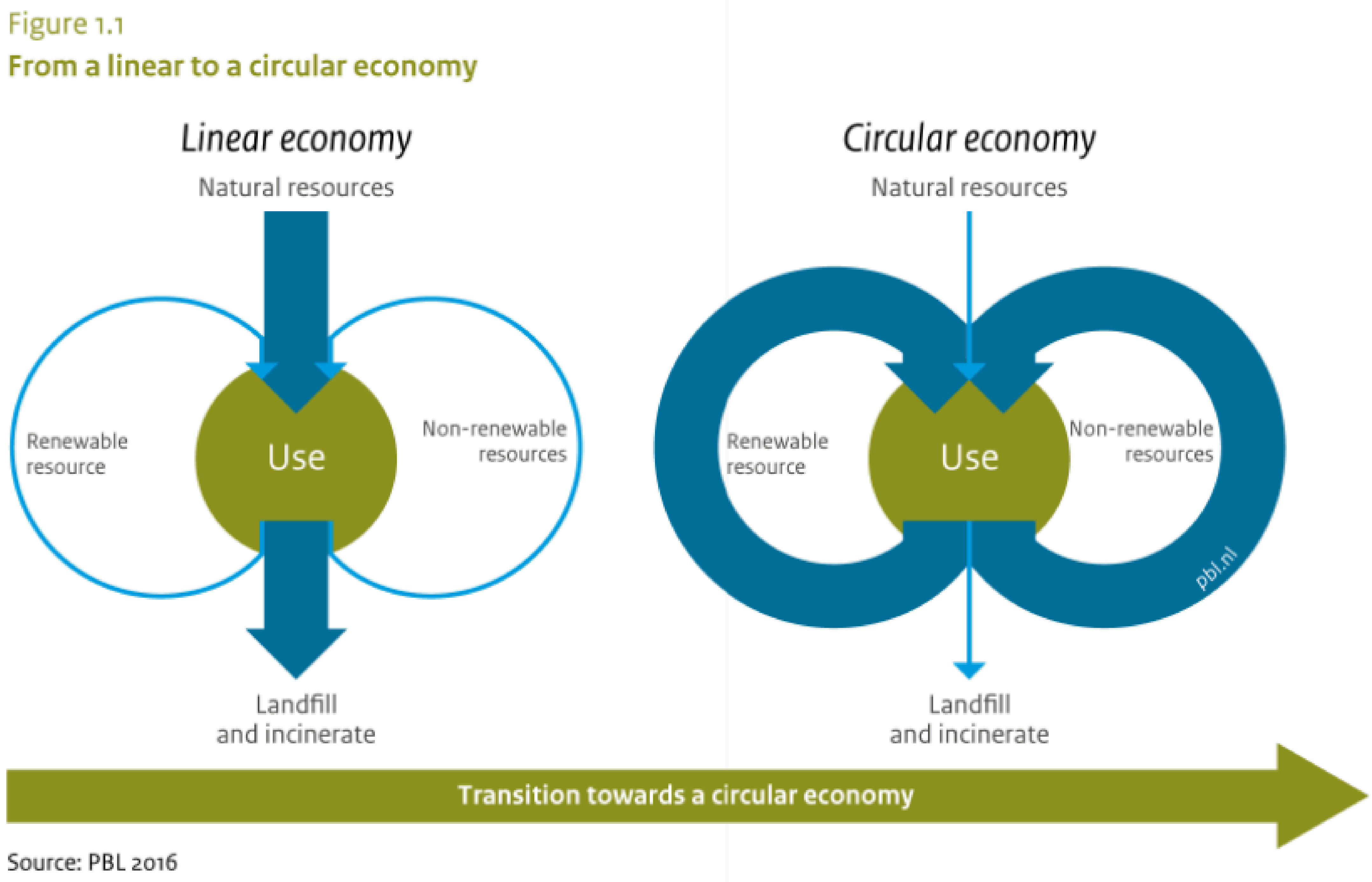




LIFESTYLE CHANGES

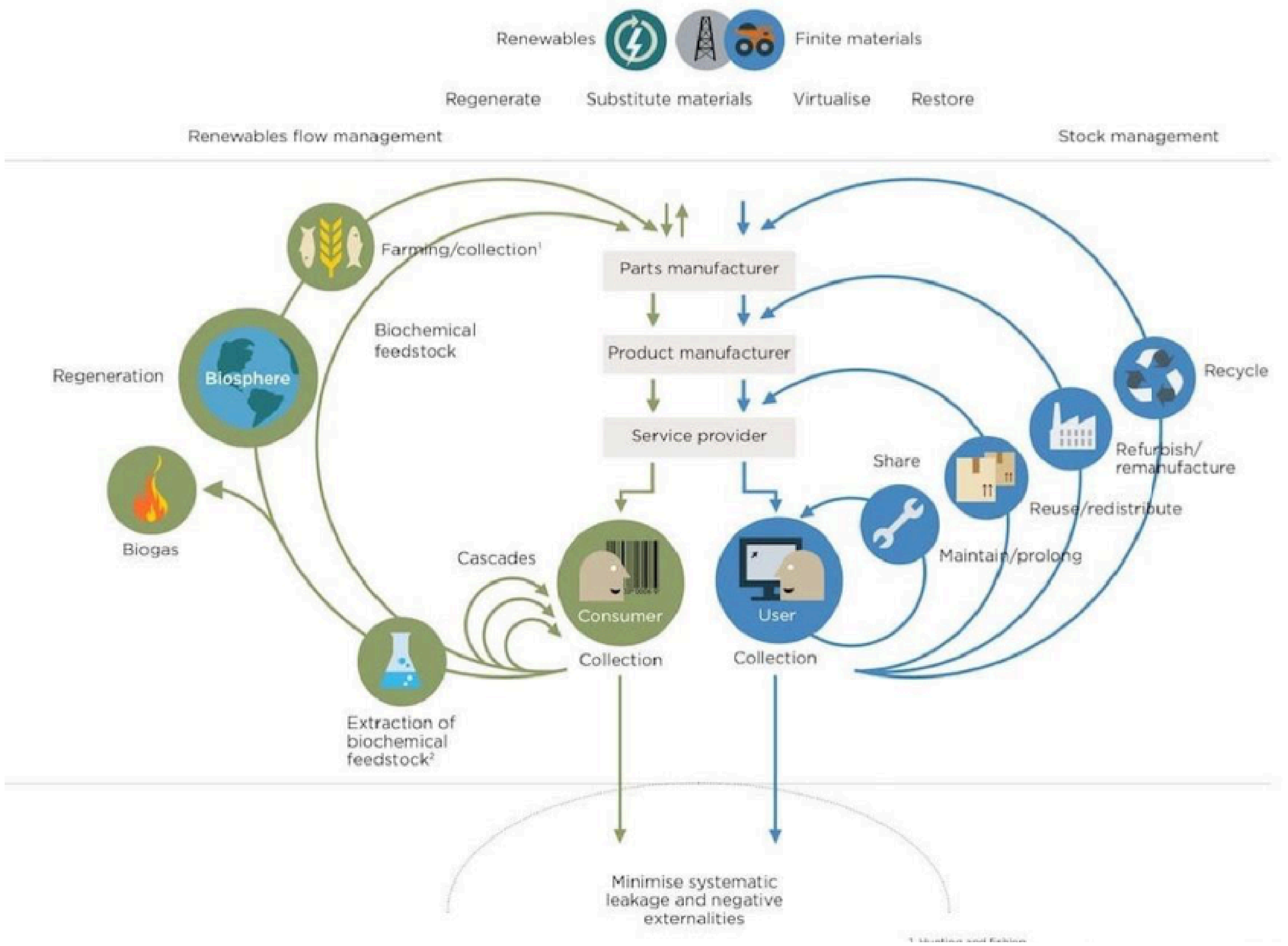
TECHNOLOGY ENABLED TRANSFORMATIONS

CIRCULAR ECONOMY



Potting, José, et al. "Circular economy: measuring innovation in the product chain." Planbureau voor de Leefomgeving 2544 (2017).

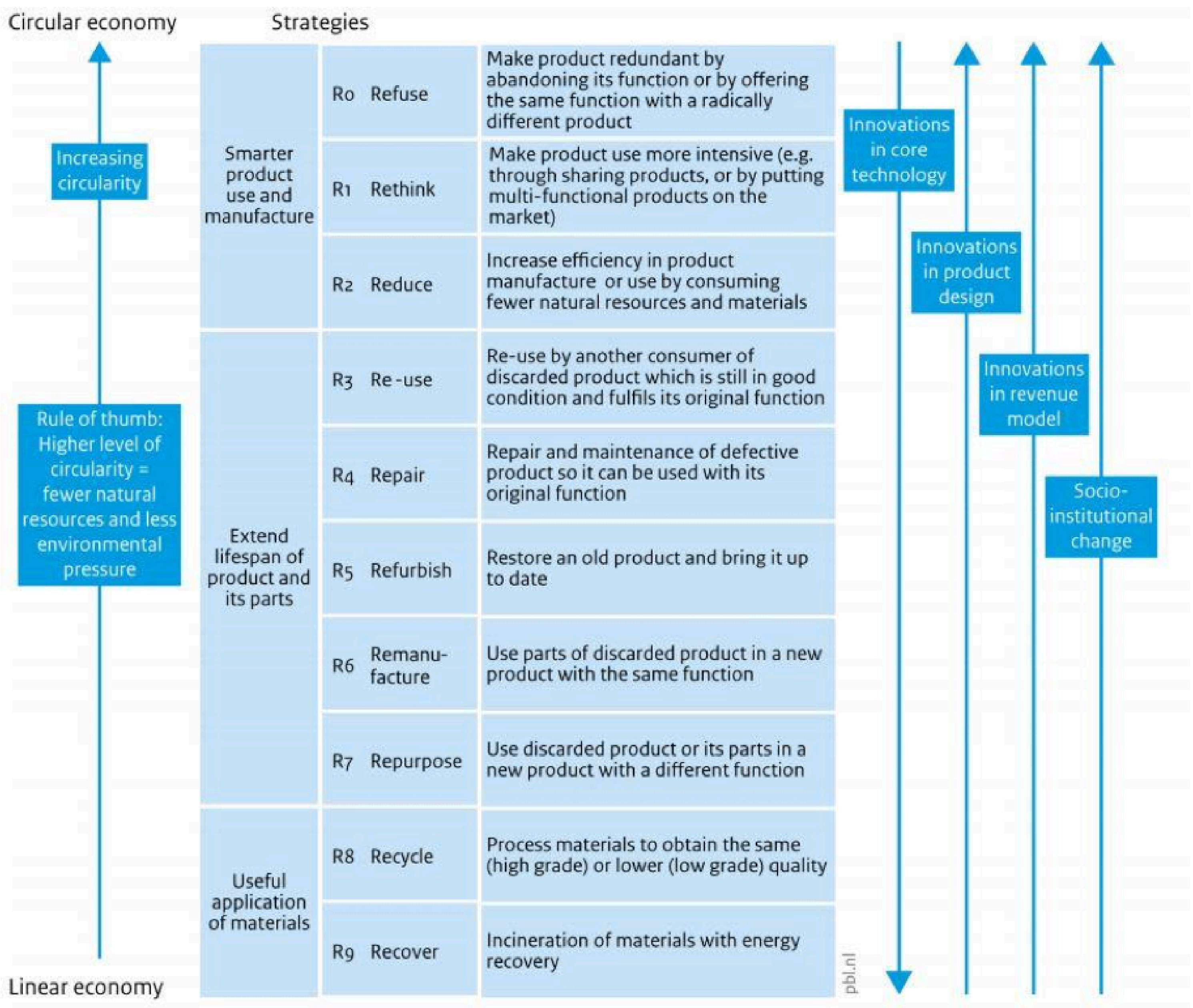
CIRCULAR ECONOMY - THE BUTTERFLY DIAGRAM



Ekins, Paul, et al. "The circular economy: What, why, how and where." (2020).

CIRCULAR ECONOMY

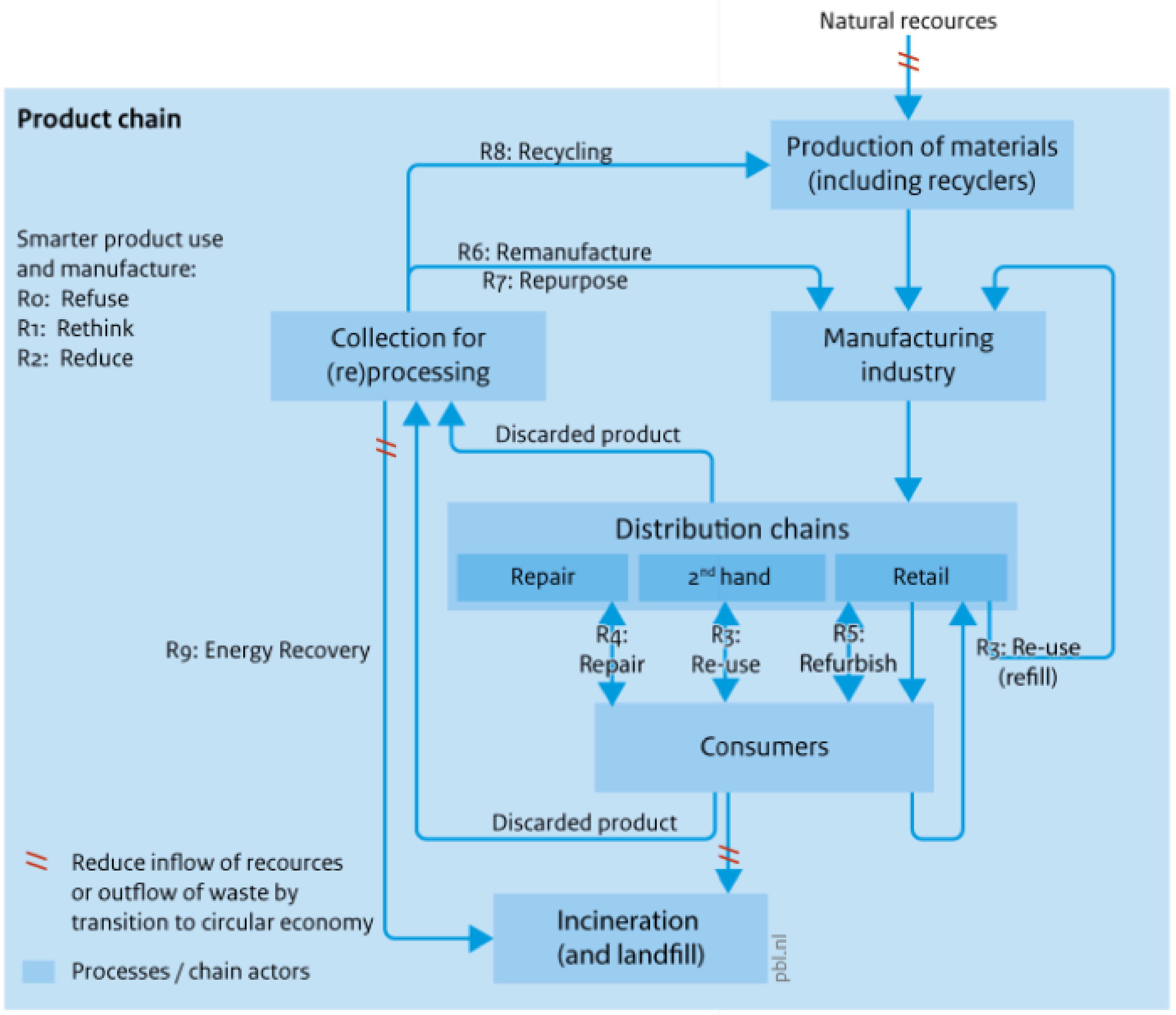
Figure 2.1. Circularity strategies within the production chain, in order of priority



Source: Potting et al. (2017), Figure 1 : 5

Figure 2.2

Circularity strategies and the role of actors within the production chain



Source: PBL

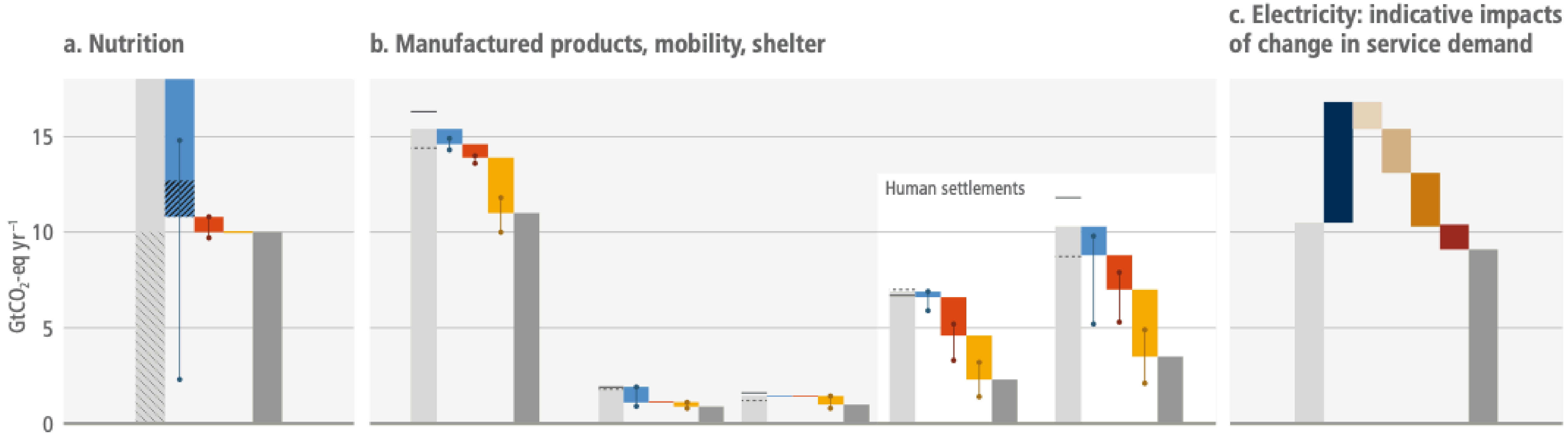
Potting, José, et al. "Circular economy: measuring innovation in the product chain." Planbureau voor de Leefomgeving 2544 (2017).

Figure 5.6 | Two-way link between demand-side climate mitigation strategies and multiple dimensions of human well-being and SDGs. All demand-side mitigation strategies improve well-being in sum, though not necessarily in each individual dimension. Incumbent business (in contrast to overall economic performance) may be challenged. Source: Creutzig et al. (2021b).

SDGs	2	6	7,11	3	6	7	11	11	4		1,2,8,10	5,10,16	5,16	10,16	11,16	8	9,12
Mitigation strategies/ Well-being dimensions	Food	Water	Air	Health	Sanitation	Energy	Shelter	Mobility	Education	Communication	Social protection	Participation	Personal Security	Social cohesion	Political stability	Economic stability	Material provision
Sufficiency (adequate floor space, etc.)	[+1] •••	[+2] ••••	[+2] •••••	[+3] •••••	[+1] •	[+3] ••••	[+1] •	[+1] ••	[+1] ••	[+2] •••	[+1] ••	[+1] ••		[+2] •••••		[+2] ••••	[+2] ••••
Efficiency	[+2] •	[+2] ••••	[+3/–1] ••••	[+3/–1] •••••	[+1] •	[+3] ••••	[+2] ••••		[+1] •••	[+1] •••		[+1] ••••	[+1] •••	[+2/–1] ••••		[+2] •••••	[+2/–1] ••••
Lower carbon and renewable energy	[+2/–1] •••	[+2/–1] ••••	[+3] •••••	[+3] •••••		[+3] ••••	[+1] •••	[+1] •••	[+1] •••	[+2] •••		[+1] •••	[+1] •••	[+2/–1] ••••		[+2/–1] •••••	[+2] ••••
Food waste	[+1] •••	[+2] ••••	[+2] ••••	[+2] •••	[+1] ••	[+1] ••••				[+1] ••	[–1/+1] •••	[+1] •••			[+1] •	[+1] ••	
Over-consumption	[+1] •	[+1/–1] •	[+1/–1] •	[+3] ••••		[+1/–1] •						[+2] ••••			[+1] •		
Plant based diets	[+2] •••	[+2] ••••	[+3] •••••	[+3] •••						[–1] •••	[+3] •••••	[+1] ••••		[–1] •	[+2] •		
Teleworking and online education system	[+1] ••		[+3] ••••	[+2] ••••		[+2] ••••	[+1] ••	[+2] ••••	[–1] •••	[+2] ••••	[+1] ••••	[+2] ••••	[+1/–1] ••••	[+2] ••••	[+2] •••	[+2] •••	
Non-motorised transport	[+2] ••	[+1] ••	[+1] •••••	[+3] •••••		[+2] ••••		[+3] •••••	[+1] ••••	[+3] •••	[+1] •••	[+1] ••	[+2] ••••	[+2] •••	[+2] ••	[+2] •••	
Shared mobility	[+1] ••		[+3] •••	[+2] ••••		[+1] •••		[+2] ••••		[+1] •••	[+2] •••	[+1] •••	[+1/–1] •••	[+1/–1] ••••	[–1] ••••	[+2] ••••	[+2] ••••
Electric vehicles (EVs)	[+1] •••		[+2] ••••	[+1] ••••	[+1] ••••	[+3] ••••		[+2] ••••			[+3] •••••	[+2] •••				[+2] ••••	[–1] ••
Compact city	[+2/–1] •••	[+1] ••	[+2/–1] •••	[+3/–1] ••••	[+1] ••	[+3/–1] •••••	[–1] •••••	[+3] •••••	[+1] •••••	[+1/–1] •••	[+2] ••	[+1] ••	[+1] ••••	[+1/–1] •••••		[+1] ••••	[+1] ••
Circular and shared economy	[+2] ••••	[+1] •••	[+2] •••	[+2] •••		[+3] •••	[+2/–1] •••	[+3] •••••	[+1] ••••	[+1] ••••	[+1] •••	[+1] •••	[+2] ••••	[+1] ••	[+1] ••	[+2] ••	[+3] •••
Systems approach in urban policy and practice	[+1] •••	[+2] •••	[+2] •••	[+3] •••	[+1] •••	[+3] •••	[+2] •••	[+3] •••		[+1] ••	[–1] ••	[+1] •••	[+2] •	[+1] ••		[+1] ••	[+3] •••••
Nature-Based Solutions	[+2] •••	[+1/–1] •••••	[+3/–1] ••••	[+3] •••••	[+1] •••	[+3] •••	[+1/–1] •••	[+1] •••	[+2] ••••		[+2] ••	[+3] ••	[+1] •••	[+2/–2] •••		[+3] ••••	[+1] ••
Using less material by design	[+2] ••	[+2] •••	[+3] •••	[+2] ••	[+2] •••	[+3] ••••	[+2] ••••	[+2] ••••	[+1] ••	[+2] •••	[+1] ••	[+1] •••	[+1] ••	[+1] ••	[+1] ••	[+2] •••	[+3] ••
Product life extension	[+2] ••	[+2] •••	[+3] •••	[+2] ••	[+2] •••	[+3] ••••	[+2] ••••	[+2] ••••	[+1] ••	[+2] •••	[+1] ••	[–1] ••••	[+1] ••	[+1] ••	[+1] ••	[+2] •••	[+3] ••
Energy efficiency	[+2] ••	[+2] •••	[+3] •••	[+1] ••	[+2] •••	[+3] ••••	[+2] ••••	[+2] ••••	[+1] ••	[+2] •••	[+2] ••••	[+2] •••	[+1] ••		[+1] ••	[+2] •••	[+2] ••
Circular economy	[+2] •••	[+2] •••	[+3] •••	[+1] ••	[+2] •••	[+3] ••••	[+2] ••••	[+2] ••••	[+1] ••	[+2] •••	[+1] ••	[+1] •••	[+2] ••	[+1] ••		[+2] •••	[+3] ••

High positive impact [+3]
Medium positive impact [+2]
Low positive impact [+1]
Overall neutral
No impact
Low negative impact [–1]
Medium negative impact [–2]
• Confidence level

Demand-side mitigation can be achieved through changes in socio-cultural factors, infrastructure design and use, and end-use technology adoption by 2050.



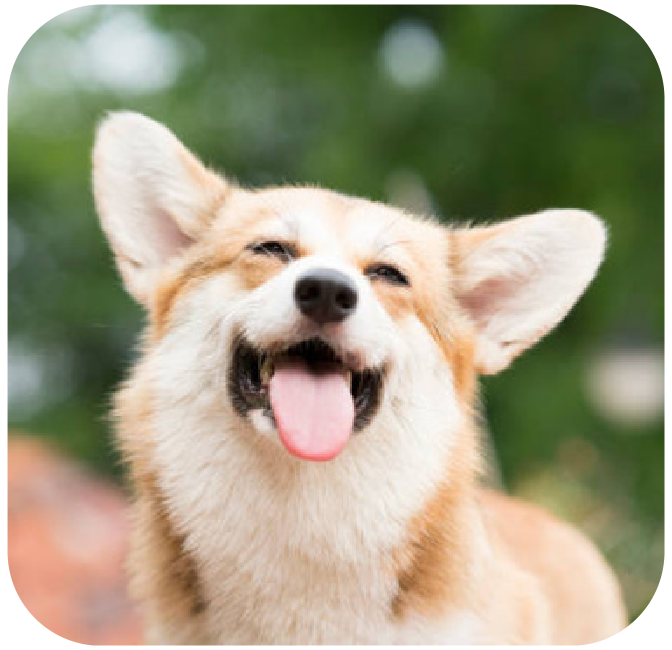
End-use sectors	Food	Industry	Aviation	Shipping	Land transport	Buildings	Electricity
Services for well-being	Nutrition	Manufactured products	Mobility			Shelter	
	Socio-cultural factors	Socio-cultural factors					Additional electrification (+60%)
	Dietary shift (shifting to balanced, sustainable healthy diets), avoidance of food waste and over-consumption	Shift in demand towards sustainable consumption, such as intensive use of longer-lived repairable products	Avoid long-haul flights; shift to trains wherever possible	Currently not applicable	Teleworking or telecommuting; active mobility through walking and cycling	Social practices resulting in energy saving; lifestyle and behavioural changes	Additional emissions from increased electricity generation to enable the end-use sectors' substitution of electricity for fossil fuels, e.g. via heat pumps and electric cars {Table SM5.3; 6.6}
	Infrastructure use	Infrastructure use					Industry; Land transport; Buildings; Load management[2] — Demand-side measures −73%
	Choice architecture[1] and information to guide dietary choices; financial incentives; waste management; recycling infrastructure	Networks established for recycling, repurposing, remanufacturing and reuse of metals, plastics and glass; labelling low-emissions materials and products	Currently not applicable	Currently not applicable	Public transport; shared mobility; compact cities; spatial planning	Compact cities; rationalisation of living floor space; architectural design; urban planning (e.g., green roof, cool roof, urban green spaces etc.)	Reduced emissions through demand-side mitigation options (in end-use sectors: buildings, industry and land transport) which has potential to reduce electricity demand[3]
	End-use technology adoption	End-use technology adoption					
	Currently estimates are not available (for lab-based meat and similar options – no quantitative literature available, overall potential considered in socio-cultural factors)	Green procurement to access material-efficient products and services; access to energy-efficient and CO_2 neutral materials	Adoption of energy-efficient technologies; technologies with improved aerodynamics	Adoption of energy-efficient technology/ systems	Electric vehicles; shift to more efficient vehicles	Energy-efficient building envelopes and appliances; shift to renewables	

Total emissions 2050: Mean ---- IEA-STEPS — IP_ModAct

AFOLU
Direct reduction of food related emissions, excluding reforestation of freed up land
Emissions that cannot be avoided or reduced through demand-side options are assumed to be addressed by supply-side options

Total emissions 2050
Socio-cultural factors
Infrastructure use
End-use technology adoption

Add. electrification
Industry
Land transport
Buildings
Load management



SOCIAL SCIENCE OF DEMAND AND SOCIAL ASPECT OF MITIGATION - KEY TAKEAWAYS

- The assessment of the social science literature and regional case studies reveals how **social norms, culture, and individual choices** interact with **infrastructure and other structural changes** over time.

- **Demand side mitigation is about more than behavioral change.** Reconfiguring the way services are provided while simultaneously changing social norms and preferences will help reduce emissions and improve access.

- Transformation happens through **societal, technological and institutional changes**.

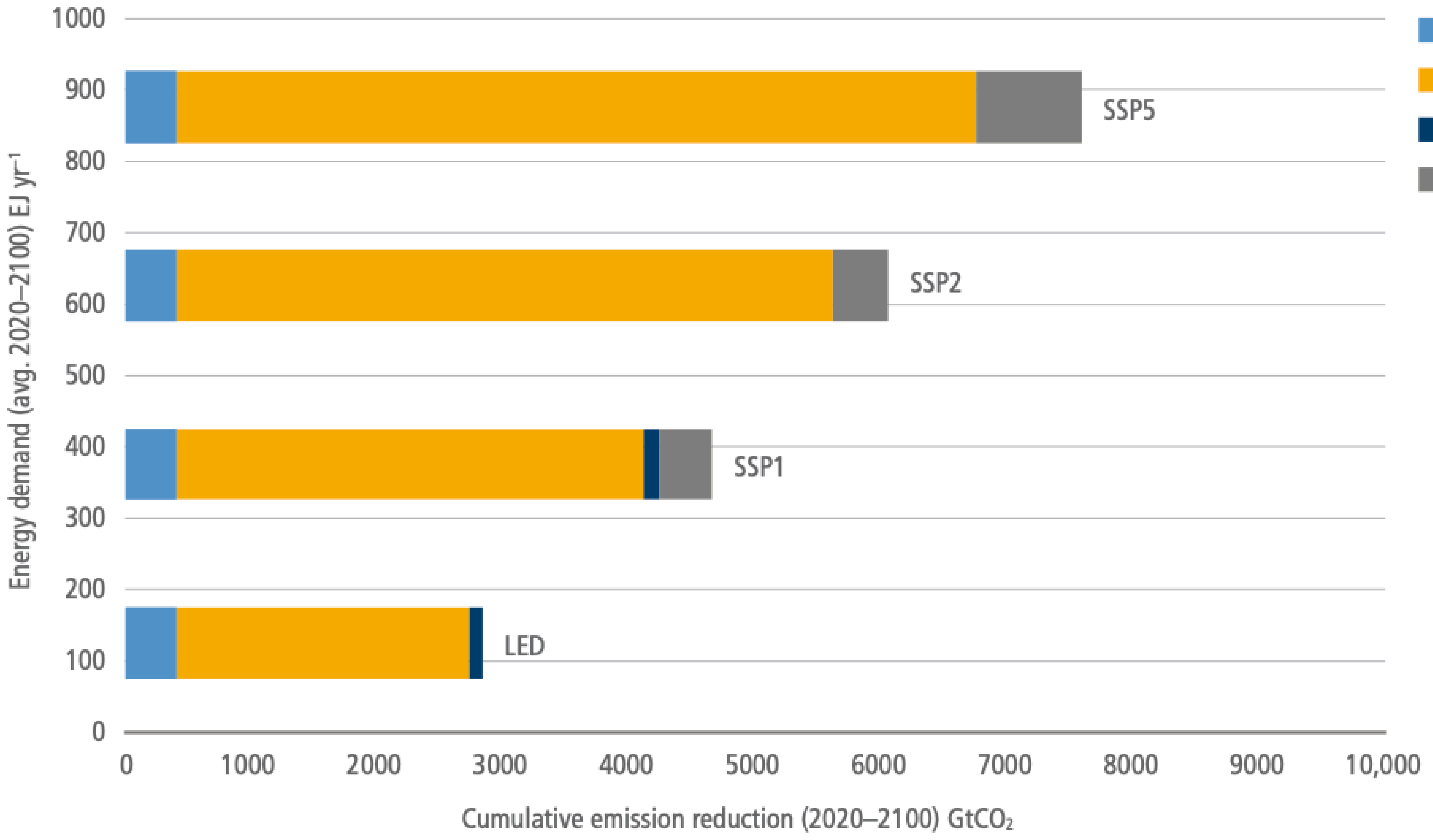
- **People's well-being comes from services** and not primary energy and physical resources. Focusing on demand for services and the different social and political roles people play broadens the understanding of actors in climate action.

ENERGY

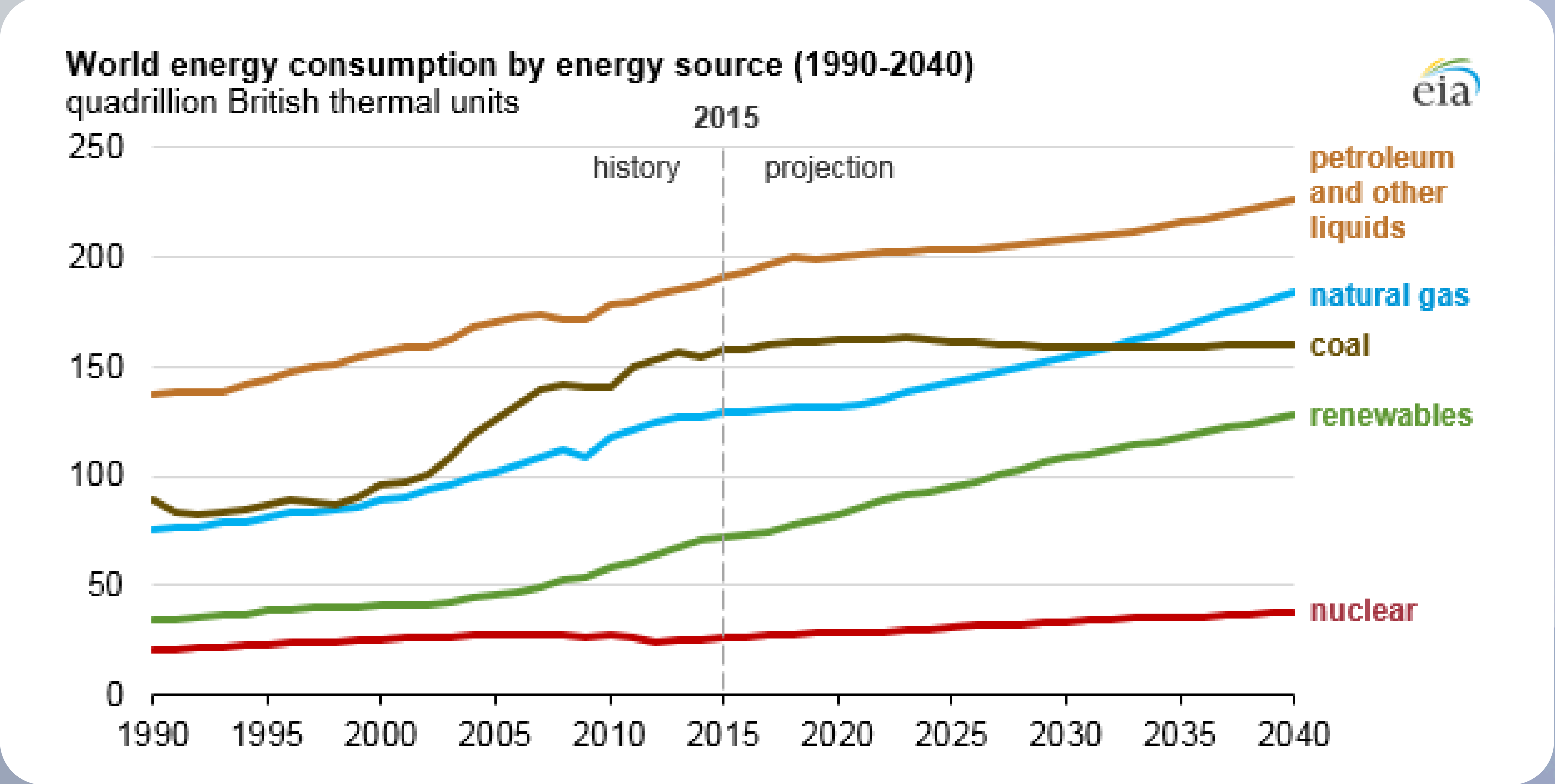
Energy sector is probably the most crucial in transitioning to a low-demand economy, as it indirectly influences other sectors as well.

ENERGY DEMAND

Energy demand scenarios projections

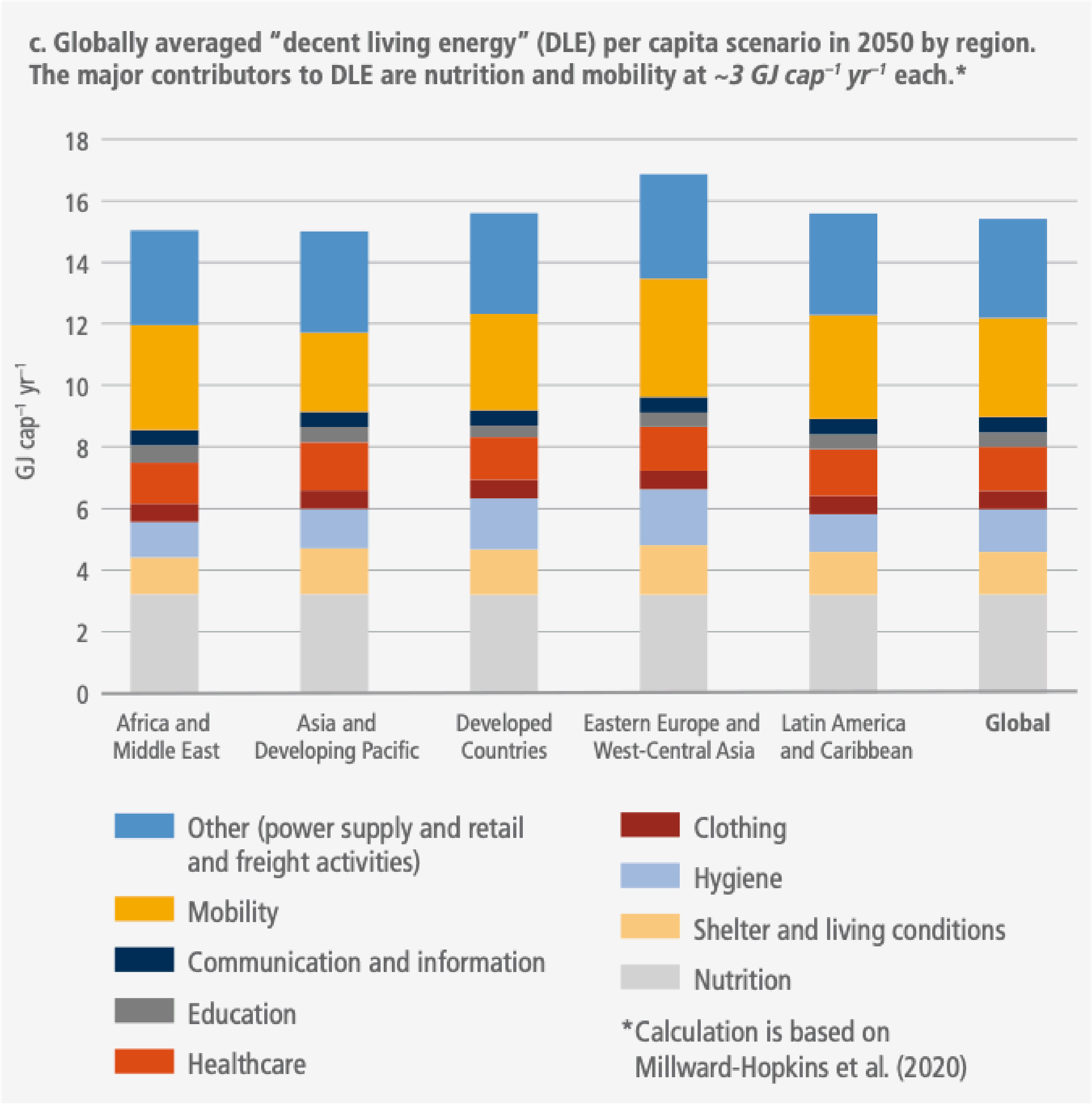


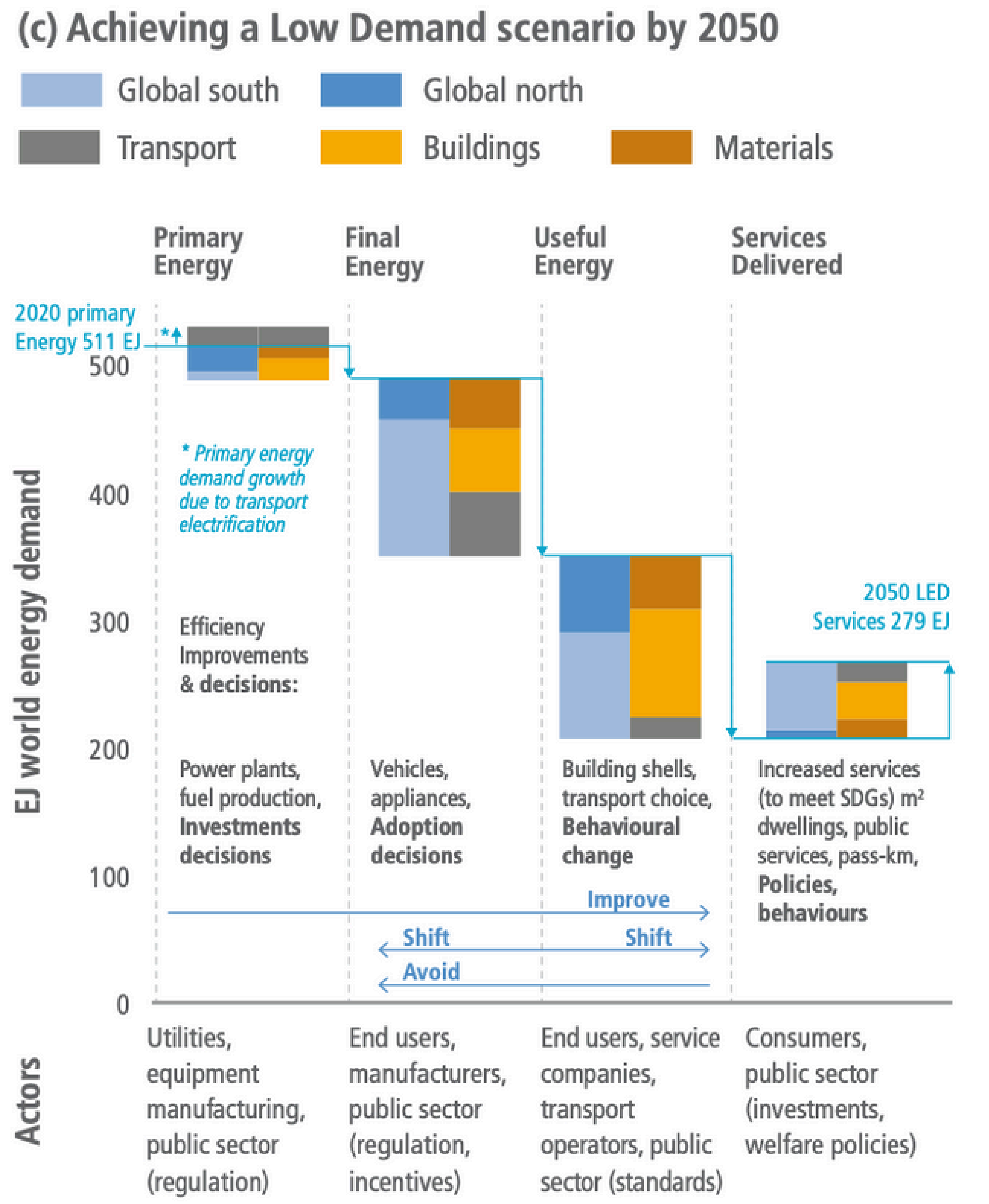
ENERGY DEMAND



https://www.eia.gov/todayinenergy/detail.php?id=32912

ENERGY DEMAND FOR DECENT LIVING





Improved service provisioning systems enable increases in service levels and at the same time a reduction in upstream energy demand by 45%.

MITIGATION ACCELERATION

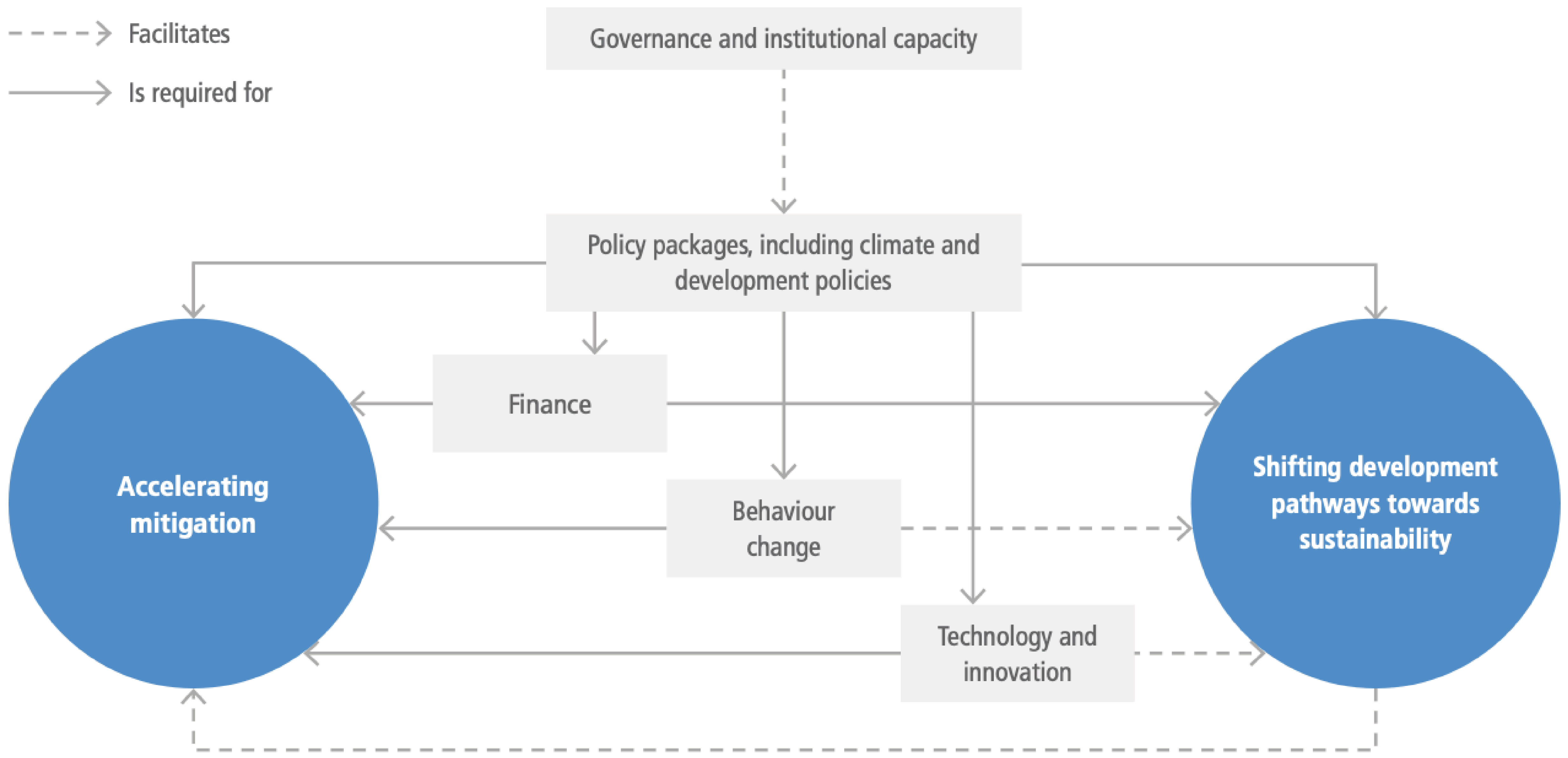


Figure 4.8 | Enabling conditions for accelerating mitigation and shifting development pathways towards sustainability.

MITIGATION - ENERGY

- Cooperation and integration
- Reduced fossil fuels usage
- More energy from electricity
- Energy sources that capture CO2
- Hydrogen, ammonia and bio-energy
- DACCS (direct air) i BECCS (bioenergy with carbon capture and storage) methods

https://naukaoklimacie.pl/aktualnosci/trzy-pytania-o-beccs

MITIGATION - ENERGY - CURRENT ENERGY USE (2019)

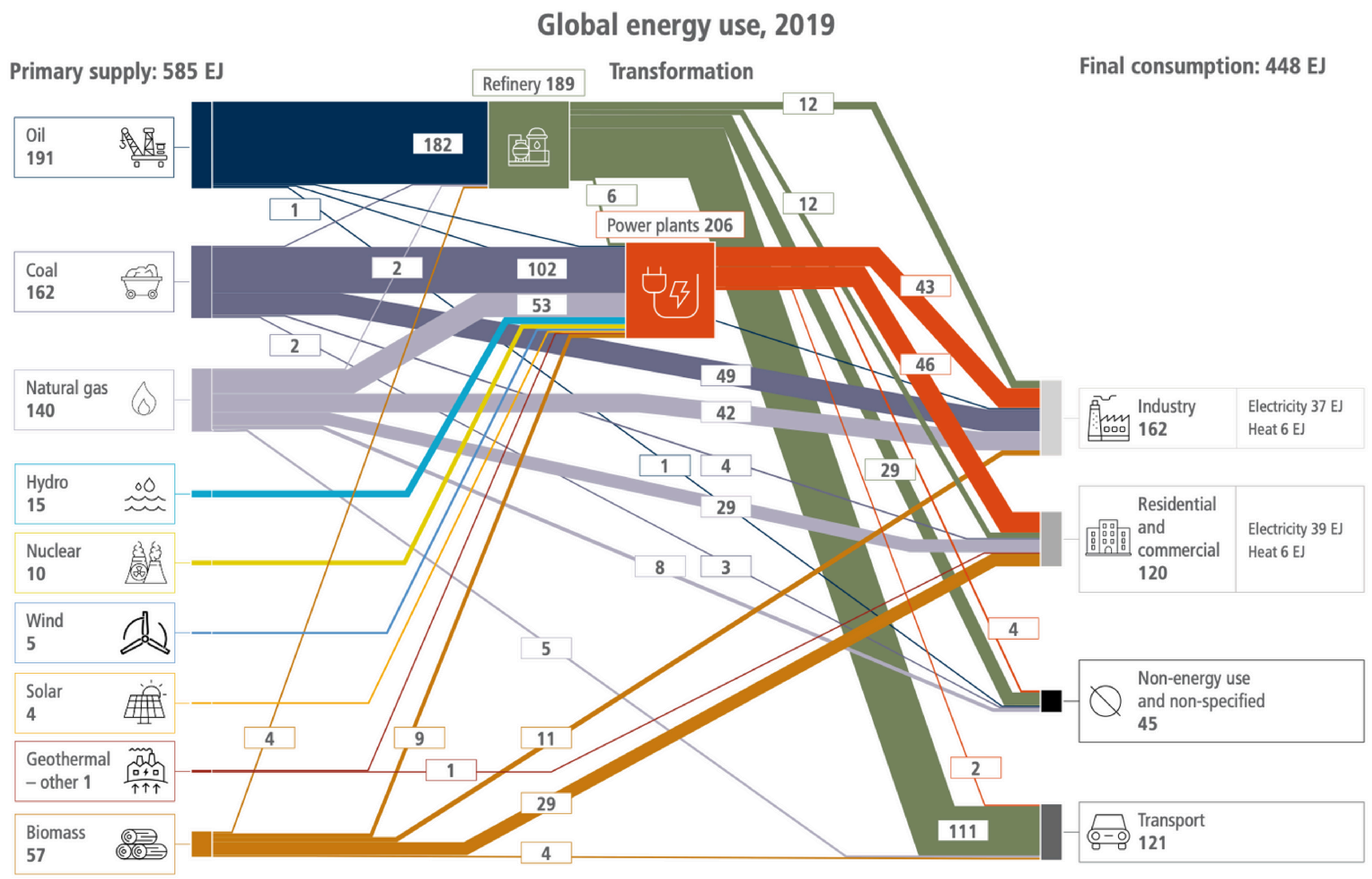
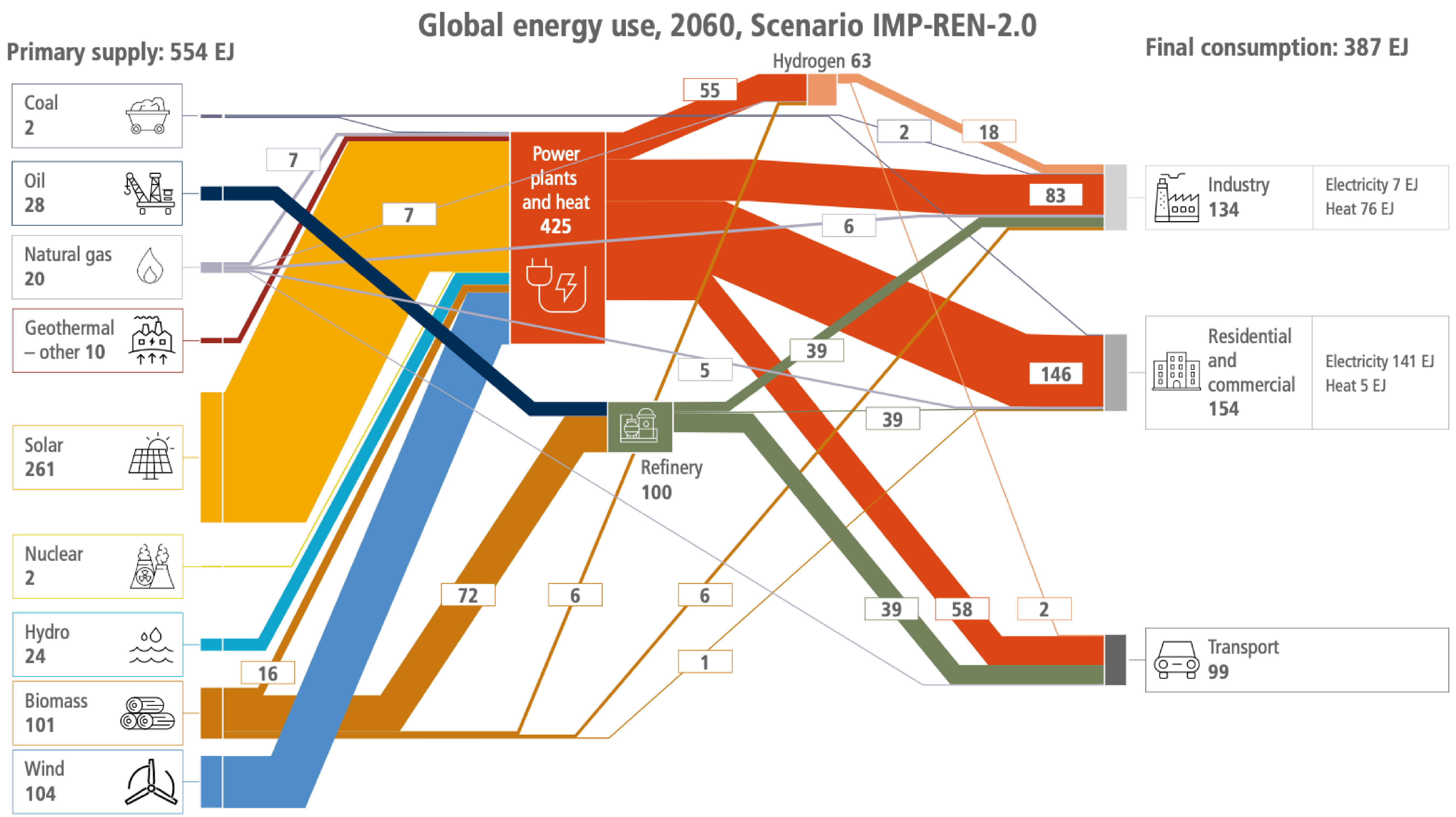


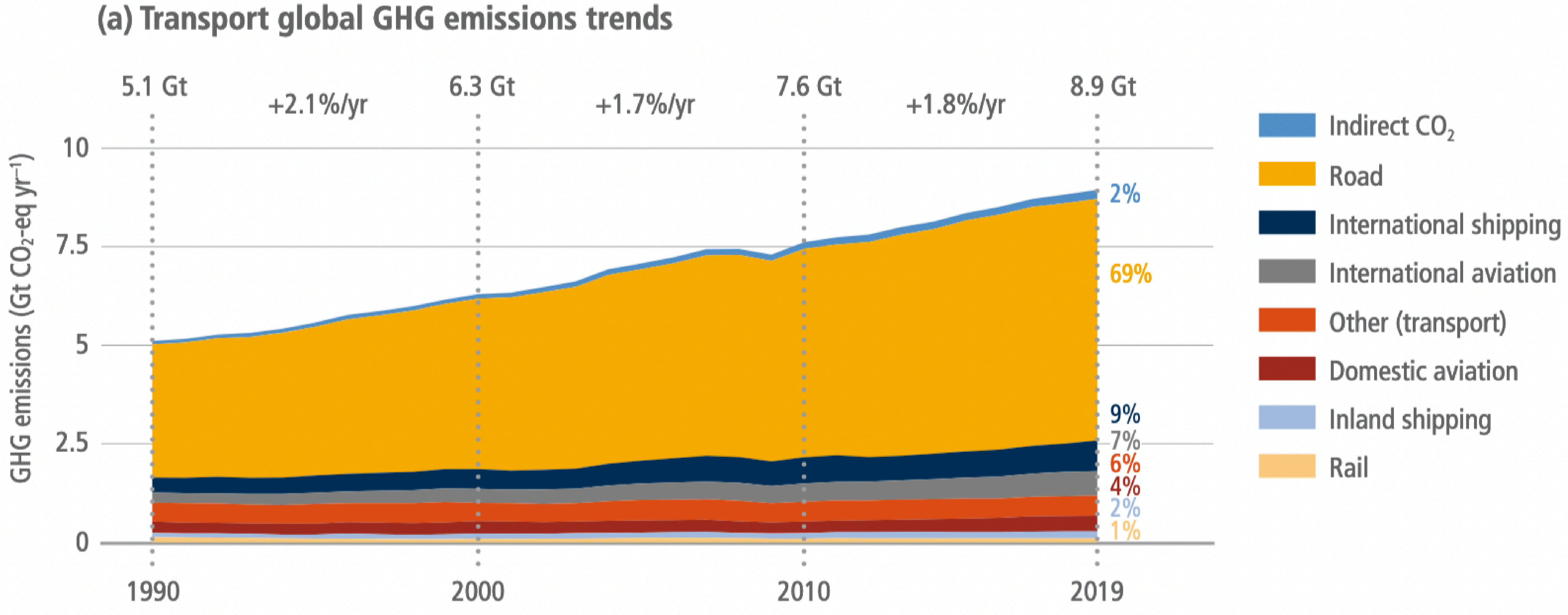
Figure TS.11 | Global energy flows within the 2019 global energy system (top panel) and within two illustrative future, net-zero CO_2 emissions global energy system (bottom panels).

MITIGATION - ENERGY - PROGNOSIS (2060)



TRASPORTATION

In 2019, direct GHG emissions from the transport sector accounted for 23% of global energy-related CO2 emissions. Emissions from shipping and aviation continue to grow rapidly. Transport-related emissions in developing regions of the world have increased more rapidly than in Europe or North America. CO2 emissions from transport could grow in the range of 16% and 50% by 2050. **There is a growing need for systemic infrastructure changes** that enable behavioural modifications and reductions in demand for transport services that can in turn reduce energy demand.



CHANGE OF TRANSPORT INFRASTRUCTURE AND TECHNOLOGY

- Digitalisation of public transport services
- Compact land use
- Less car-depended transport
- Protected pedestrian and bike pathways
- Battery Electric Vehicles
- Micro-mobility
- Availability of lithium-ion batteries
- Charging infrastructure

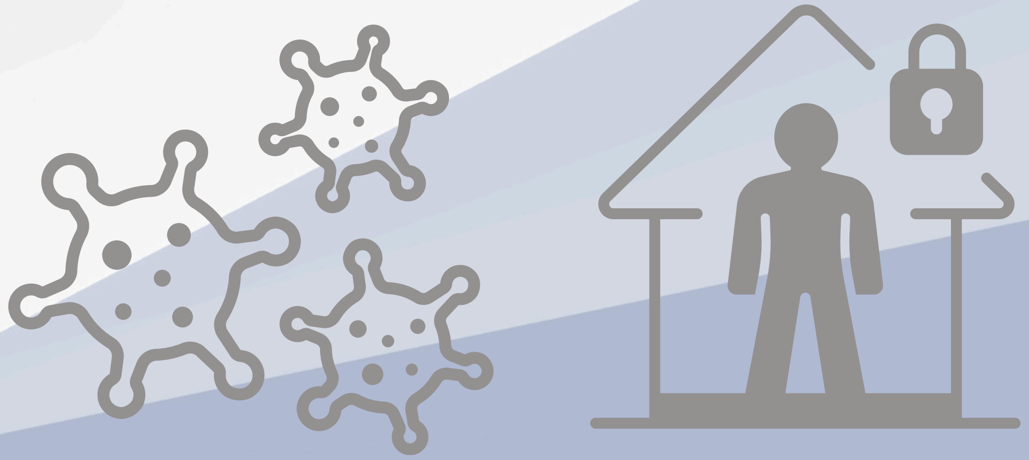
CHANGE OF TRANSPORT INFRASTRUCTURE AND TECHNOLOGY

- Battery-electric long-range trucks
- Hydrogen-based fuel
- Bio fuel
- Low-carbon fuels have not yet reached commercial scale
- Lack of R&D
- Electrification plays the key role in land-based transport

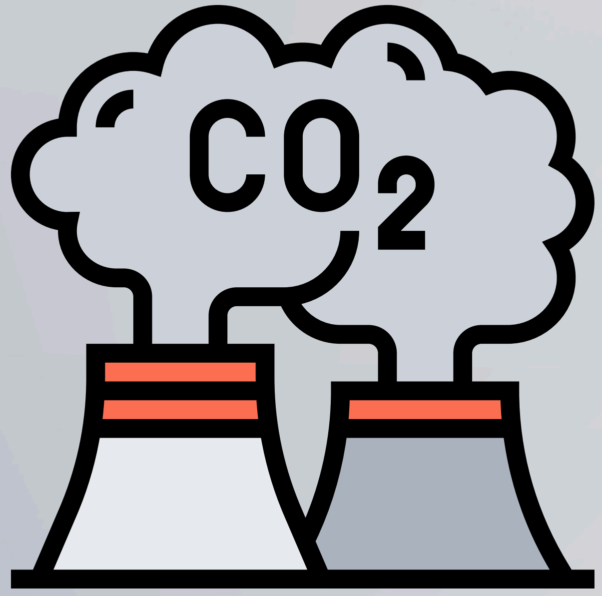
NATIONAL AND INTERNATIONAL GOVERNANCE

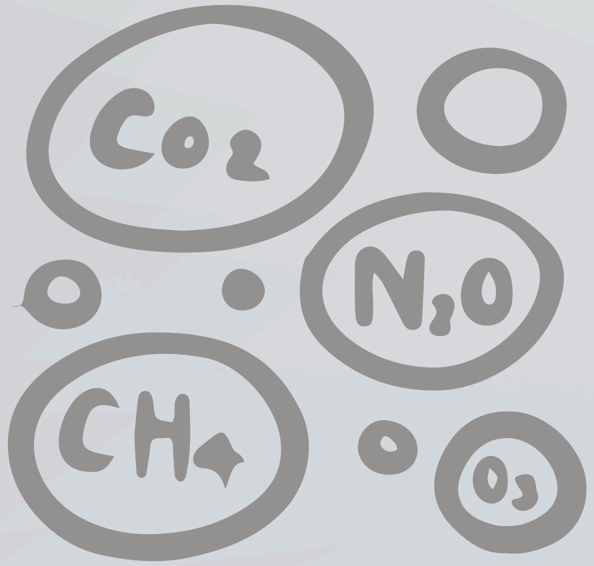
- The deployment of low-carbon aviation and shipping fuels require changes to national and international governance structures
- International Civil Aviation Organization and International Maritime Organization established emissions reductions targets with **minimal commitment to new technologies**.
- Legislated climate strategies are emerging at all levels of government

THE EFFECT OF COVID-19 ON TRANSPORTATION DEMAND



- Behavioural interventions can reduce GHG emissions related to transport
- Home office during lock-down reduced numbers of work and personal journeys as well as promoting local active transport.
- Less routes taken by plane (Polzin & Choi, 2021)





GHG REMOVAL 2020-2100

- Counterbalancing residual emissions
- Essential element in limiting global warming
- Anthropogenic activities removing CO2
- Methods carbon dioxide removal CDR deployment vary depending on costs, availability and constraints

GHG REMOVAL METHODS

CDR methods vary in terms of:

- maturity (from lower maturity e.g. ocean alkalinisation to higher maturity e.g., reforestation)
- removal process
- time scale of carbon storage
- storage medium
- cost and governance requirements
- mitigation potential (from lower e.g. blue carbon management to higher e.g. agroforestry

THE IMPACTS, RISKS AND CO-BENEFITS OF CDR

Benefits:

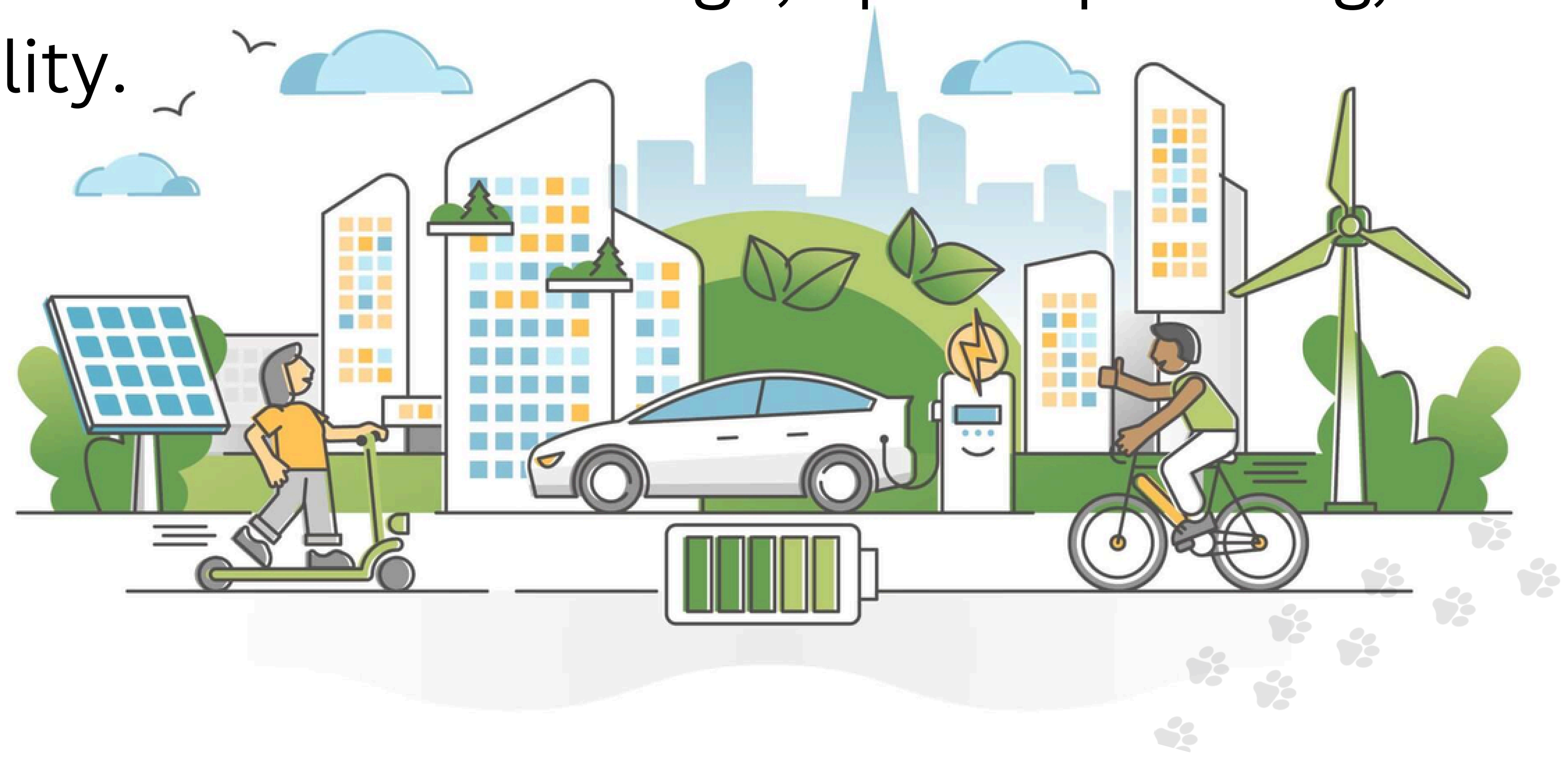
- reforestation and improved forest management
- soil carbon sequestration
- peatland restoration

Risks:

Afforestation or production of biomass for BECCS can have harmful socio-economic and enviromental impacts. B Biodiversity, local livelihoods, food and water security could be compromised

URBAN SYSTEMS

Urban mitigation strategies fall into two main categories: **sector-specific approaches**, such as clean energy, sustainable transport, and construction, often supported by electrification; and **systemic approaches** focused on urban design, spatial planning, and integrating urban forms to achieve carbon neutrality.



EMBEDDING CLIMATE CHANGE IN URBAN PLANNING AND DESIGN

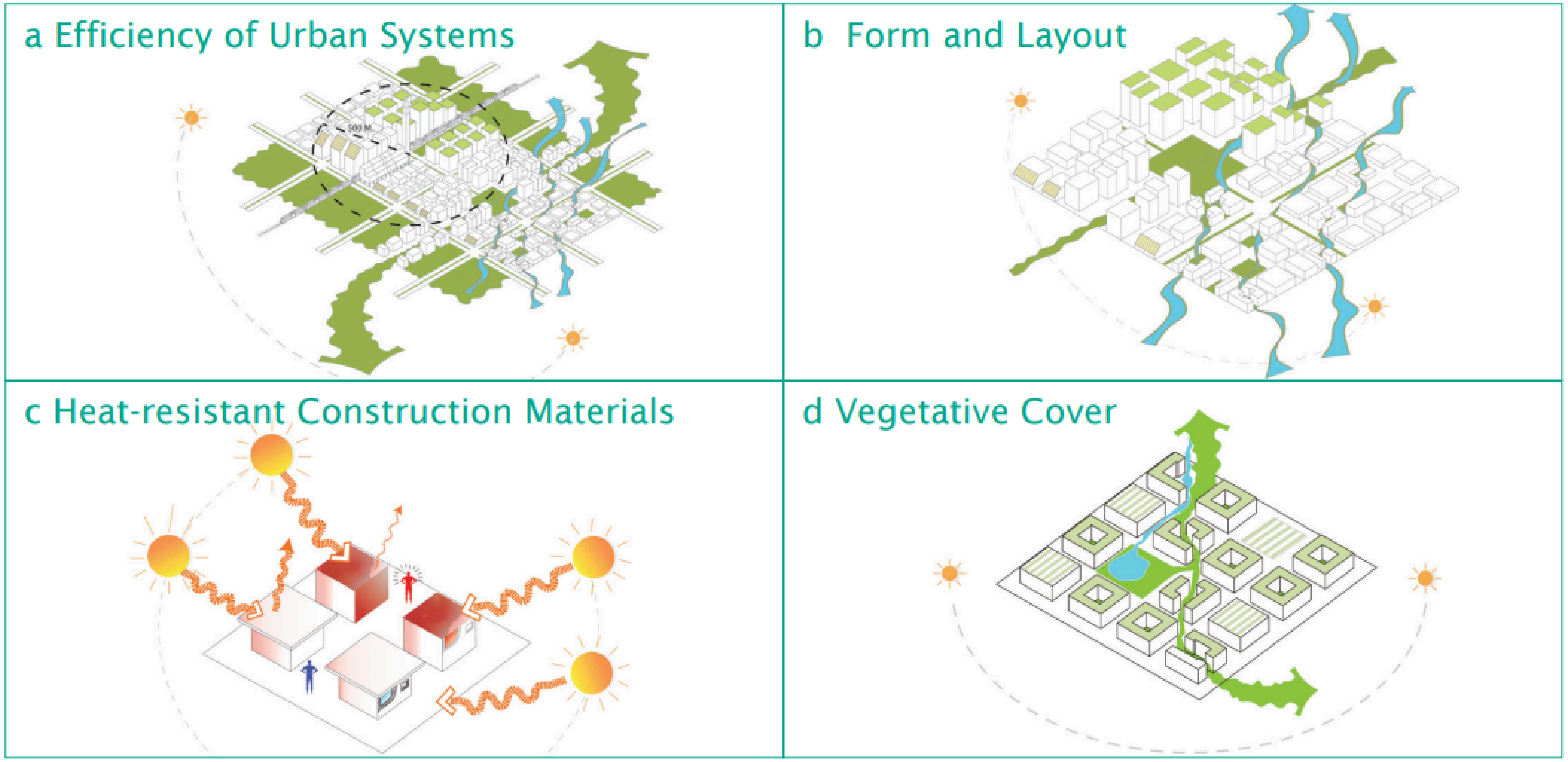


Figure 5: *Main strategies used by urban planners and designers to facilitate integrated mitigation and adaptation in cities: (a) reducing waste heat and greenhouse gas emissions through energy efficiency, transit access, and walkability; (b) modifying form and layout of buildings and urban districts; (c) use of heat-resistant construction materials and reflective surface coatings; and (d) increasing vegetative cover. Source: Urban Climate Lab, Graduate Program in Urban & Regional Design, New York Institute of Technology, 2015.*

TECHNOLOGICAL AND ECONOMIC ASPECTS OF CARBON MITIGATION IN ESTABLISHED CITIES

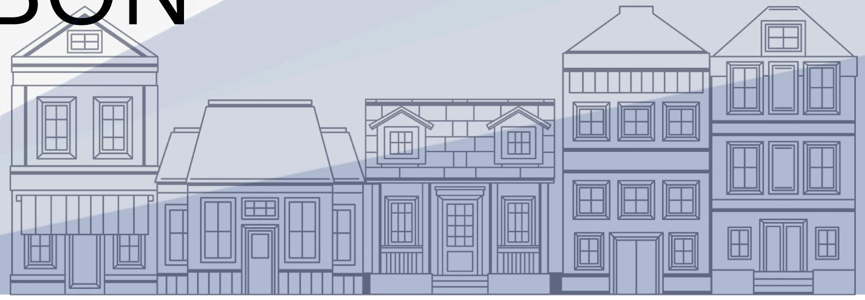
Technological Aspects:

- Building Retrofitting: Upgrading existing infrastructure for energy efficiency (e.g., improved insulation, efficient HVAC systems).
- Electrification: Transitioning urban energy systems to renewable energy sources, such as solar or wind, for heating, cooling, and transportation.
- Urban Green Infrastructure: Enhancing urban forests, green roofs, and permeable surfaces to sequester carbon and reduce energy use.
- Transport Modal Shift: Electrifying public transport and promoting cycling and walking to reduce emissions.

Economic Aspects:

- Cost of Retrofitting: Deep retrofits can be expensive, but they reduce energy costs over time.
- Infrastructure Financing: High initial investment is required, with potential long-term savings.
- Funding Challenges: Established cities often rely on public-private partnerships and policy incentives to finance large-scale retrofits.
- Job Creation: Retrofitting and green infrastructure projects generate local employment.

TECHNOLOGICAL AND ECONOMIC ASPECTS OF CARBON MITIGATION IN RAPIDLY GROWING CITIES



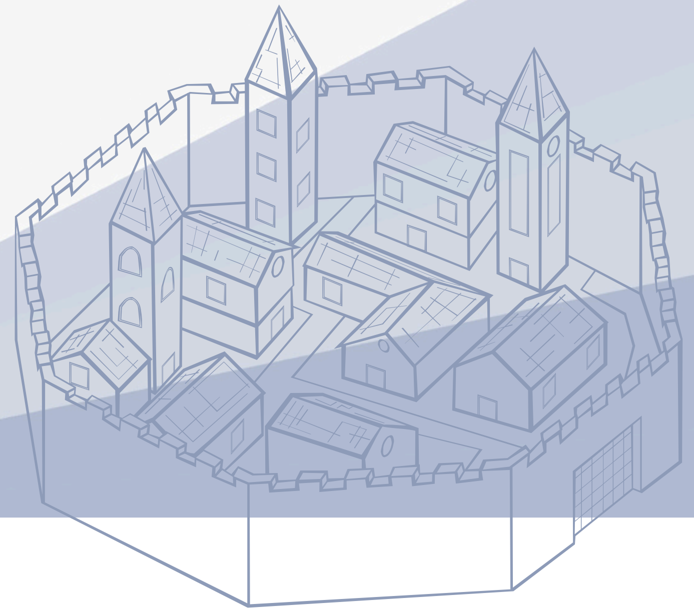
Technological Aspects:

- Compact Urban Design: Integrated planning to co-locate housing and jobs, reducing reliance on private vehicles.
- Leapfrogging Technologies: Adopting low-carbon solutions, such as advanced building materials and efficient energy systems, bypassing carbon-intensive practices.
- Urban Planning for Resilience: Incorporating bioclimatic designs and blue-green infrastructure to manage energy needs and climate adaptation.
- Efficient Transport Networks: Building transit-oriented developments with efficient public transport systems.

Economic Aspects:

- Lower Lock-In Costs: Strategic urban planning avoids future costs of retrofitting inefficient systems.
- International Support: Access to climate funds and international investments can support technology adoption.
- Cost-Effective Innovation: Growing cities often benefit from economies of scale in implementing low-carbon solutions.

TECHNOLOGICAL AND ECONOMIC ASPECTS OF CARBON MITIGATION IN NEW AND EMERGING CITIES



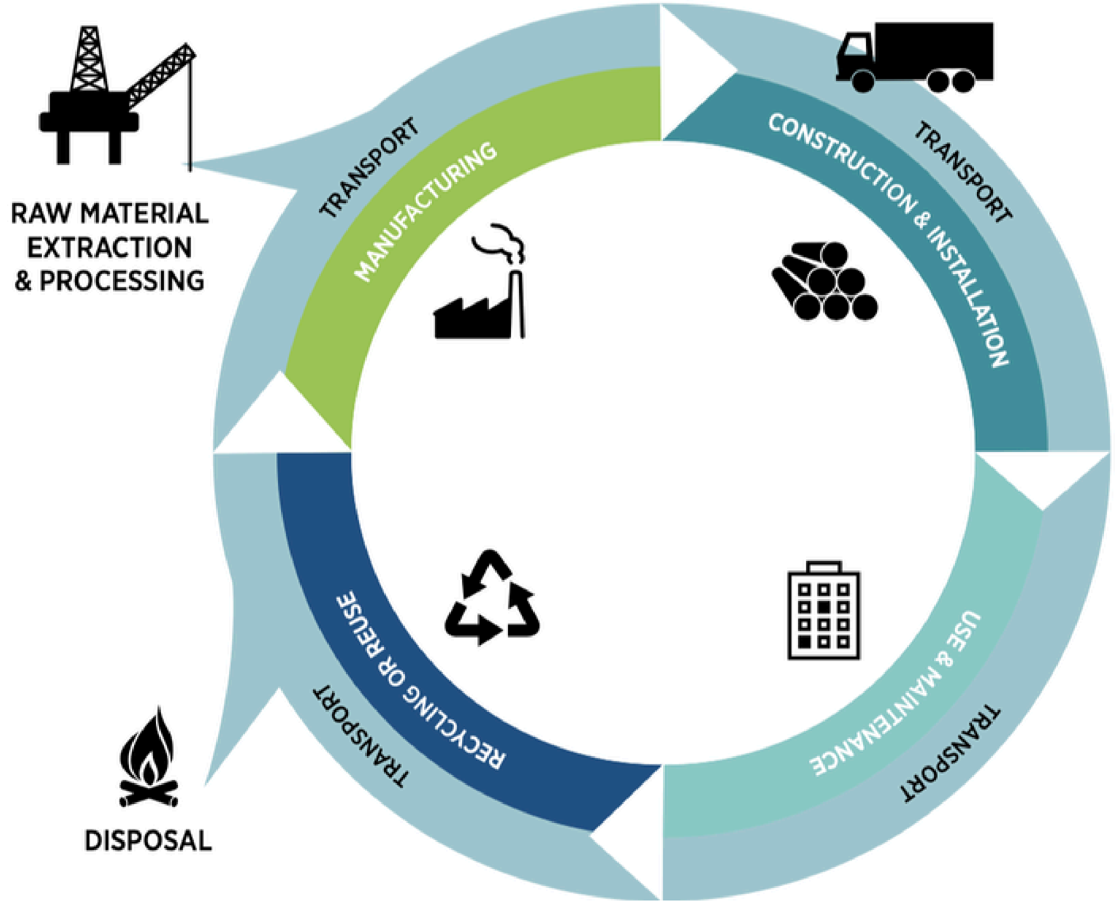
Technological Aspects:

- Net-Zero Building Design: Incorporating energy-efficient and net-zero principles from the start (e.g., passive solar heating, energy storage technologies).
- Integrated Energy Systems: Leveraging renewable energy grids and distributed energy resources to decarbonize at the outset.
- Mixed-Use Development: Designing walkable, mixed-use urban areas to minimize transport emissions.
- Digital Infrastructure: Using smart city technologies for energy optimization and urban planning.

Economic Aspects:

- Upfront Investment: High initial costs for advanced infrastructure, but with reduced long-term operational expenses.
- Economic Growth Potential: New cities can attract investments by showcasing sustainable and innovative urban development.
- Incentives for Private Sector: Partnerships with developers and businesses can offset public costs through incentives.
- Carbon Markets: Participation in carbon credit programs to finance mitigation efforts.

BUILDINGS



POTENTIAL EXPOSURE

Raw material extraction:
- Petroleum and byproducts

Construction and installation:
- Monomers (e.g., vinyl chloride and BPA)
- Additives (e.g., phthalates)
- Polymer dust

Use and maintenance:
- Leaching
- Additives (e.g., phthalates)
- Flame retardants
- UV stabilizers

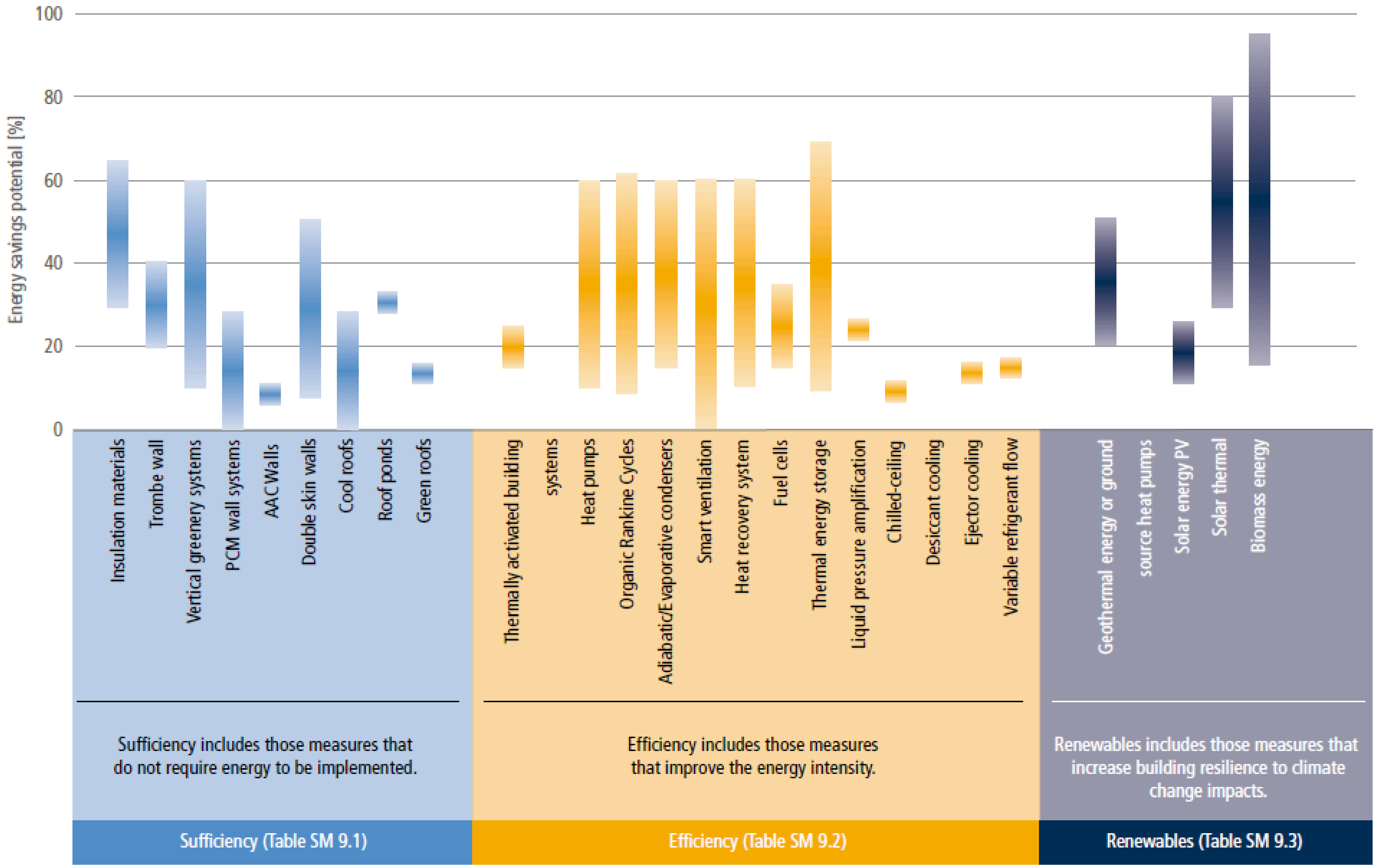
Recycling or reuse:
- Monomers (e.g., vinyl chloride and BPA)
- Additives (e.g., phthalates)

Disposal:
- Dioxins, furans, hydrochloric acid (by fire)
- Leaching
- Monomer after disposal

Total GHG emissions in the building sector reached 12 $GtCO_2$-eq in 2019, equivalent to 21% of global GHG emissions that year, of which 57% were indirect CO_2 emissions from offsite generation of electricity and heat, followed by 24% of direct CO_2 emissions produced on-site and 18% from the production of cement and steel used for construction and/or refurbishment of buildings. If only CO_2 emissions would be considered, the share of buildings CO_2 emissions increases to 31% out of global CO_2 emissions. Energy use in residential and non-residential buildings contributed 50% and 32% respectively, while embodied emissions contributed 18% to global building CO_2 emissions. Global final energy demand from buildings reached 128.8 EJ in 2019, equivalent to 31% of global final energy demand. Residential buildings consumed 70% out of global final energy demand from buildings. Electricity demand from buildings was slightly above 43 EJ in 2019, equivalent to more than 18% of global electricity demand. Over the period 1990–2019, global CO_2 emissions from buildings increased by 50%, global final energy demand grew by 38%, with 54% increase in non-residential buildings and 32% increase in residential ones. Among energy carriers, the growth in global final energy demand was strongest for electricity, which increased by 161%.

MITIGATION TECHNOLOGICAL OPTIONS AND STRATEGIES TOWARDS ZERO CARBON BUILDINGS

There are many technologies that can reduce energy use in buildings (Finnegan et al. 2018; Kockat et al. 2018 a), and those have been extensively investigated. Other technologies that can contribute to achieving carbon zero buildings are less present in the literature.



Energy savings potential of technology strategies for climate change mitigation in buildings.

CARBON-NEUTRAL BUILDINGS

HOTEL BAUHOFSTRASSE, GERMANY

SCGZERO+, CHINA

"THE MOST SUSTAINABLE BUILDING IS THE ONE THAT IS ALREADY BUILT."
- CARL ELEFANTE

KLEINE RITTERGASSE 11, GERMANY

7 Ways to Retrofit Buildings for Energy Efficiency

Retrofitting represents one of the best opportunities to improve the environment in our cities.

bloomberg.com

PROPOSED SOLUTIONS FOR MITIGATION

For Developed Countries:

1. Policy Reforms: Strengthen governance to address principal-agent problems and align incentives across stakeholders.
2. Financial Mechanisms: Increase funding for retrofits through public-private partnerships and subsidies.

For Developing Countries:

1. Capacity Building: Invest in institutional structures and training to enhance decarbonization efforts.
2. Supportive Finance Models: International funding and low-interest loans to reduce cost barriers for high-performance buildings.
3. Improved Standards: Mandate efficient building codes for new constructions to prevent inefficiencies.
4. Affordable Retrofitting: Promote shallow retrofits with low-cost technologies as an entry point, while gradually scaling up deeper measures.

Shared Global Solutions:

1. Sufficiency Measures: Limit growth in floor area per capita, encourage shared spaces, and optimize building designs for energy use.
2. Circular Economy in Construction: Promote recycling of materials and reuse strategies.
3. Decarbonized Energy Supply: Transition to renewable energy sources for heating and cooling systems.

ECONOMIC IMPLICATIONS OF MITIGATION ACTIONS

1. **Short-Term Impacts**:
 • Investments in energy efficiency boost output and jobs, though partially offset by declines in other sectors (Yushchenko and Patel 2016; Thema et al. 2017).
 • Benefits are greatest during recessions and depend on domestic production capacity (Mirasgedis et al. 2014; Thema et al. 2017).
2. **Developing Countries**:
 • Local implementation enhances jobs, economy, and social well-being (Mills 2016).
 • Solar-LED lighting for 112 million households could create 2 million direct jobs (Mills 2016).
3. **Employment Intensity**:
 • Building retrofits: 9–30 jobs per $1M; efficient appliances: 7–16 jobs; clean cooking: 16–75 jobs (IEA 2020a).
 • Public budgets benefit from higher tax revenues and lower unemployment costs (Thema et al. 2017).
4. **Long-Term Benefits**:
 • Energy savings increase disposable income, boosting demand for labour-intensive goods and services (~8 jobs per $1M in savings) (Anderson et al. 2014).
 • Lower energy consumption reduces prices, cuts production costs, and improves productivity and energy security (IEA 2014; Thema et al. 2017).

MITIGATION - URBAN AND BUILDINGS

- Urbanization is a chance for decarbonization if done right
- Decarbonization and low emissions transformation
- Electrification, low-emission infrastructure and energy
- Spatial planning
- Better buildings
- Green and blue infrastructure role
- Cross-actor commitment, cooperation, comprehensive approach
- Shared/circular economy, digitalization

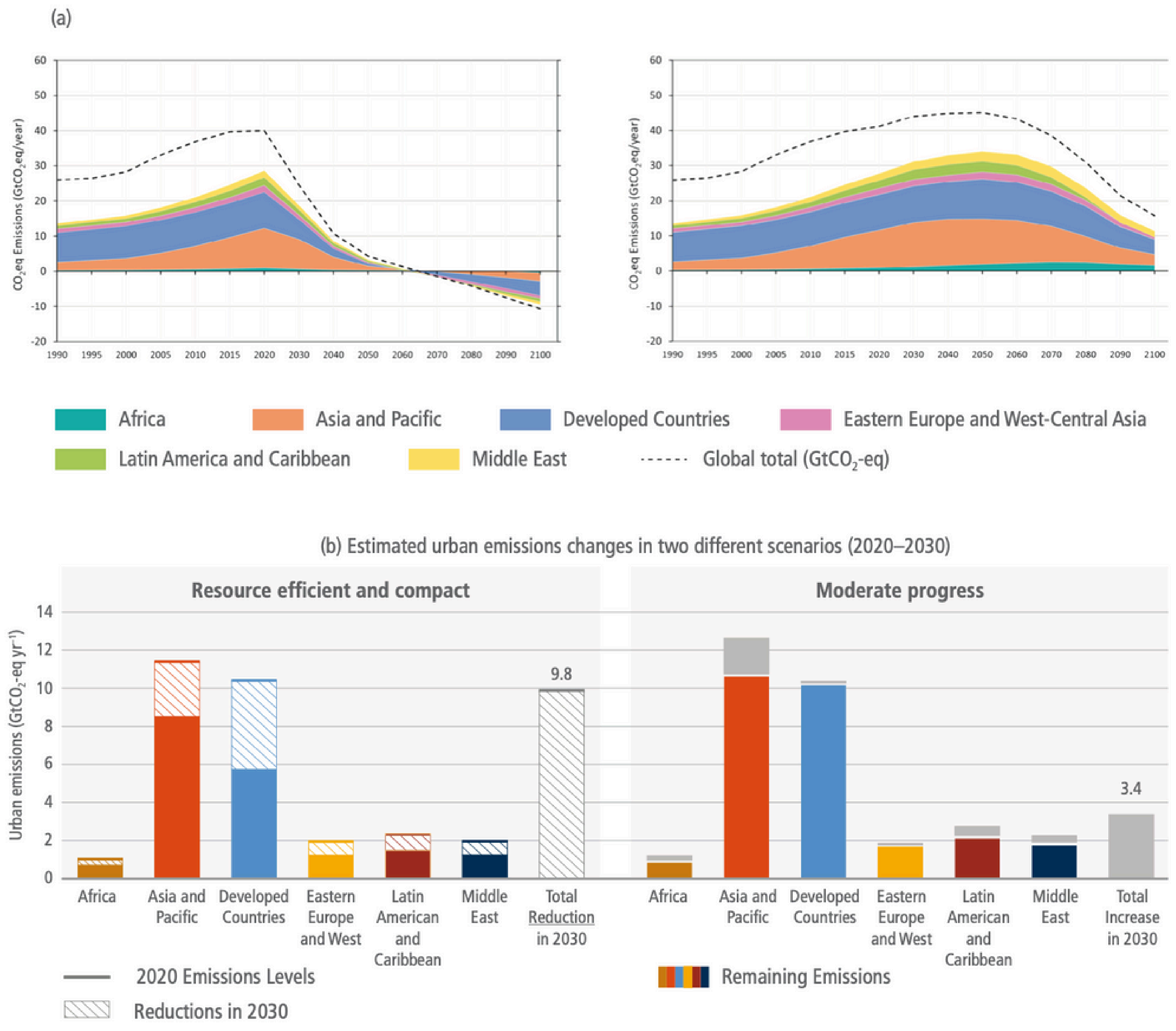
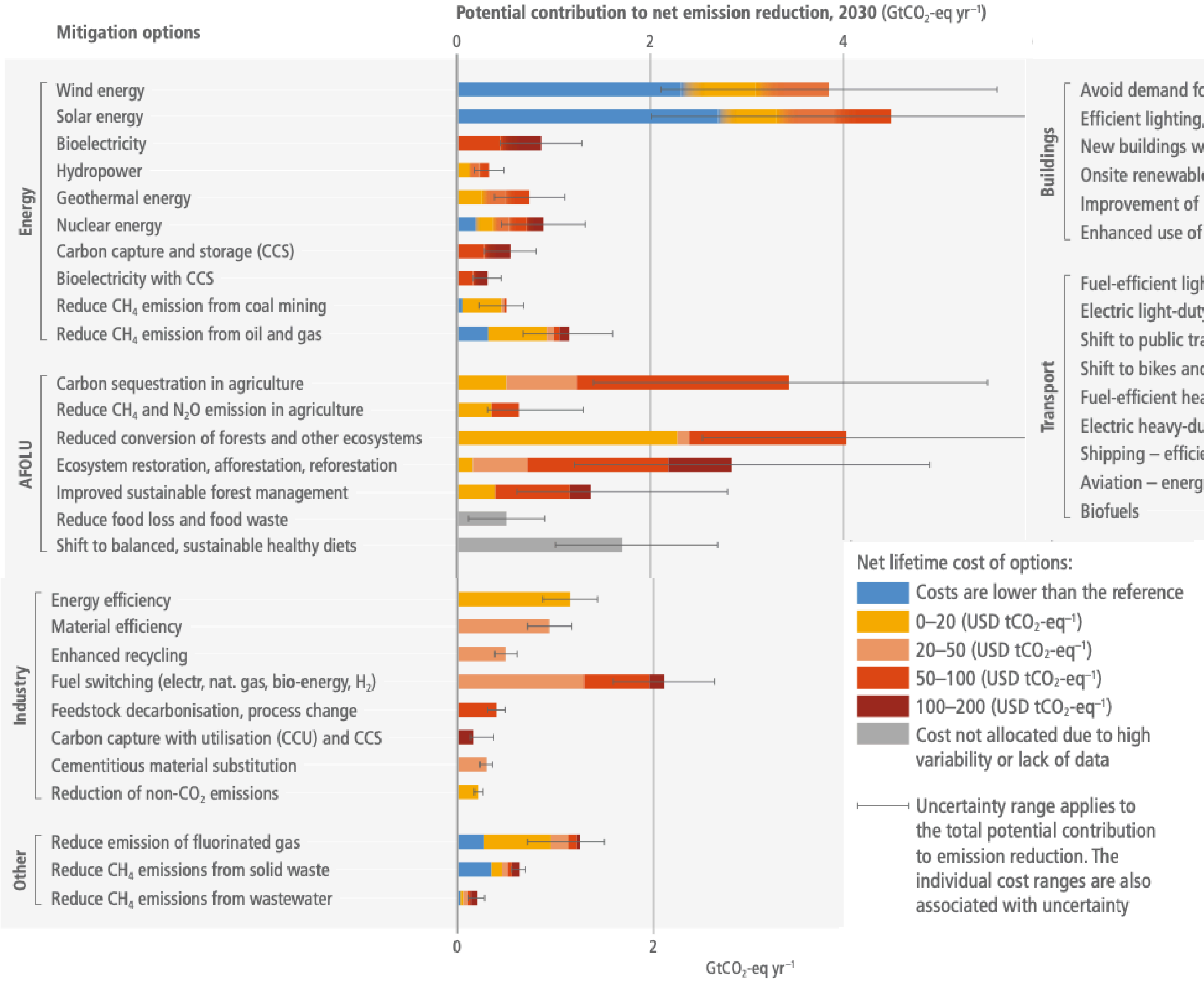


Figure TS.13 | Panel (a): carbon dioxide-equivalent emissions from global urban areas from 1990 to 2100. Urban areas are aggregated to six regional domains; Panel (b): comparison of urban emissions under different urbanisation scenarios ($GtCO_2$-eq yr^{-1}) for different regions.[21] {Figures 8.13 and 8.14}

COSTS OF IMPLEMENTING MITIGATIONS



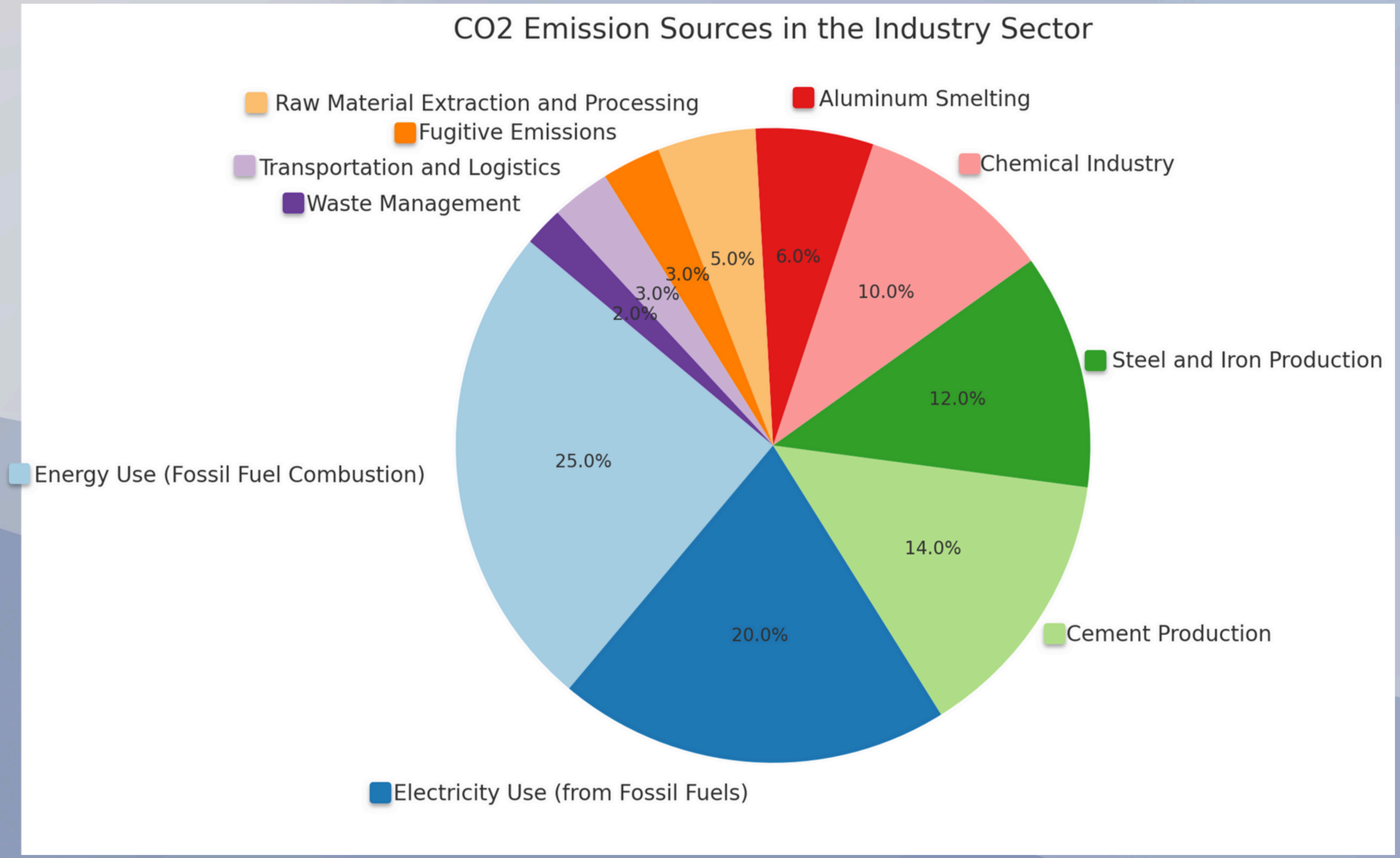
Introduction to the Industry Sector

Industrial sector: A major contributor to climate change.

2019 emissions data of industry sector:
- 24% of direct global GHG emissions (Scope 1).
- 34% including indirect emissions (Scope 2 & 3).

Drivers: Growing demand for materials, urbanization, and economic expansion.

Key challenges:
- Decarbonizing energy-intensive sectors.
- Scaling new technologies like hydrogen and CCUS.



Key focus

The largest incremental contributors to industrial emissions in 2010 –2019 were ***industrial processes at 40%,*** then indirect emissions (25%), and only then direct combustion (21%), followed by waste (14%).

Therefore, to stop emission growth and to switch to a zero-carbon pathway more mitigation efforts ***should be focused on industrial processes***, product use and waste decarbonisation, along with the transition to low-carbon electrification (Hertwich et al. 2020).

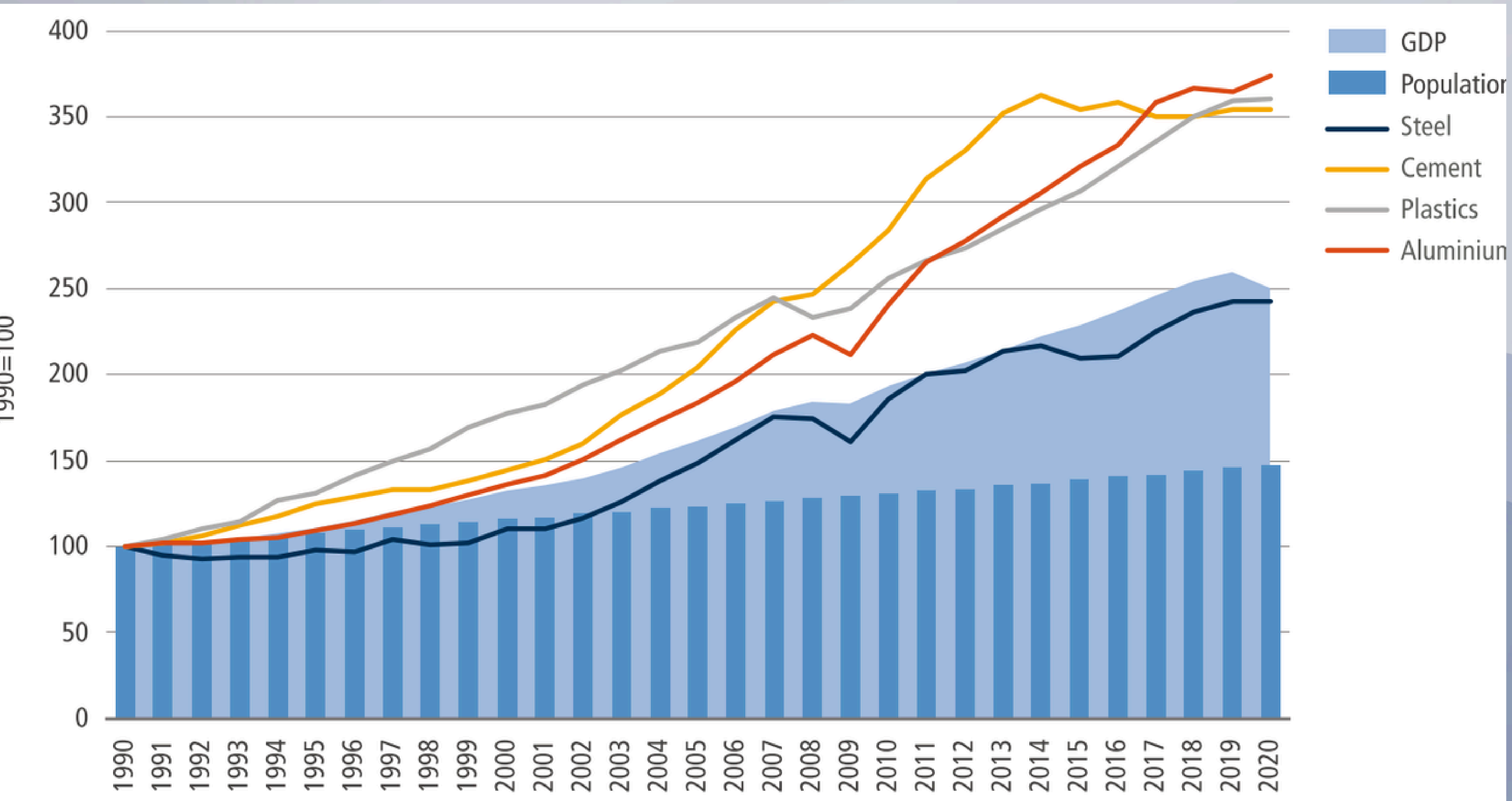
Strategic Mitigation Measures

Regarding industrial sector, ***six equally important strategies/mitigation measures*** are:

- (i) demand for materials;
- (ii) materials efficiency;
- (iii) circular economy and industrial waste;
- (iv) energy efficiency;
- (v) electrification and fuel switching; and
- (vi) CCUS, feedstock and biogenic carbon.

(1) Demand for Materials

Growth in global demand for selected key materials and global population, 1990–2019. Notes:



Principle: Reducing the demand for primary materials through optimization of design and consumption patterns.

Strategies:

- Reduce the accumulated material stock services
- Apply Lightweight materials for manufacturing.
- Enhance product durability.
- Adopt the shared economy practices (e.g., rental systems).

Benefits:

- Reduction in resource extraction.
- Lower environmental footprint.

(2) Materials Efficiency

Principle: **<u>Delivery of goods</u>** and services with **<u>less materials</u>** is the important strategy for reducing GHG emission in industry. Options to **<u>improve ME exist at every stage in the lifecycle</u>** of materials and products.

Strategies:

- Advanced manufacturing techniques (e.g., additive manufacturing).
- Process optimization through digital tools.
- Minimization of material offcuts and defects.

Benefits:

- Cost savings and improved product quality.
- Reduced material loss.

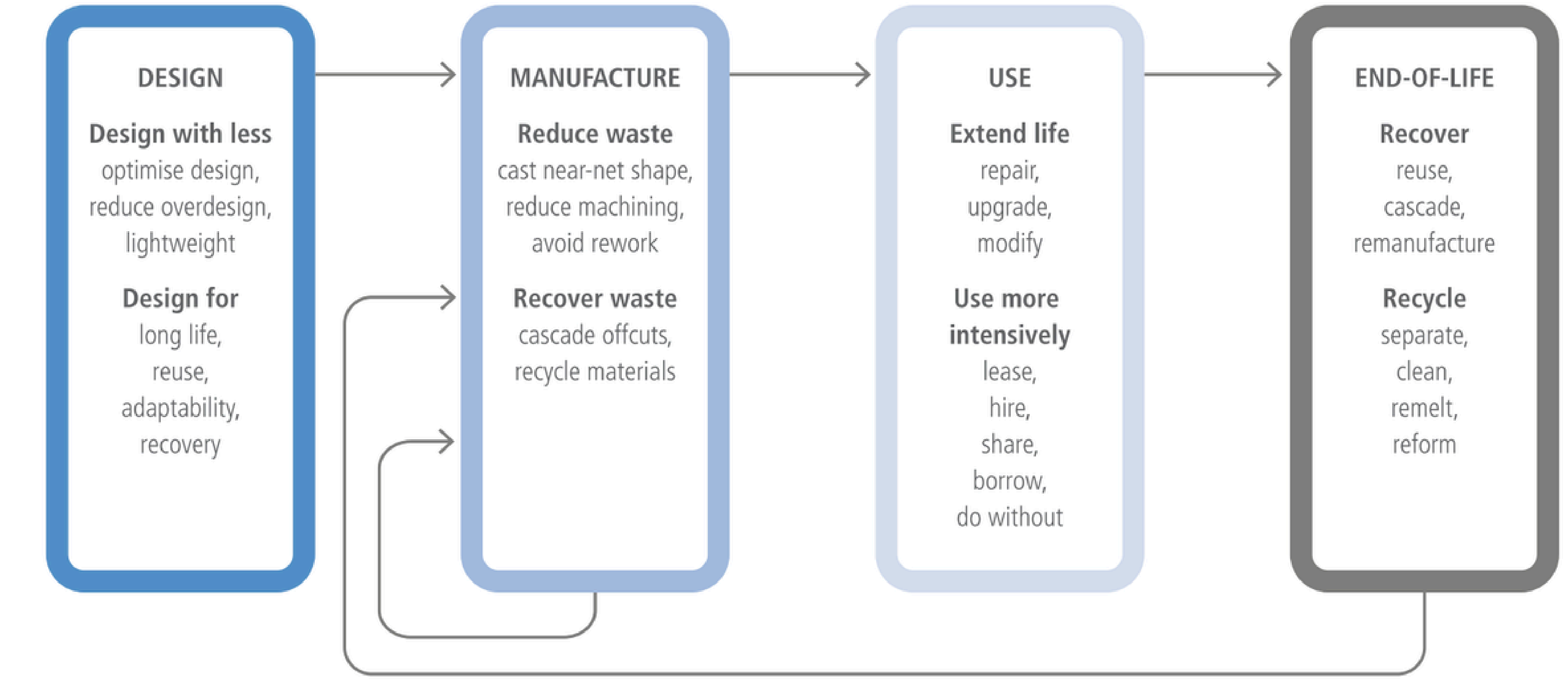


Figure 11.7 | Material efficiency (*ME*) strategies across the value chain. Source: derived from strategies in Allwood et al. (2012).

(3) Circular Economy and Industrial Waste

Principle: Closing the loop for materials and energy flows by incorporating policies and strategies for more efficient energy, materials and water consumption, while emitting minimal waste to the environment.

Strategies:

- Avoid linear production (usually "Extract – produce – use – discard")
- Design for recyclability (promote durable goods to be used, remanufactured and recycled)
- Systematic approach:
  - ***Micro level (within single company):*** Process integration and cleaner production (require eco-design regulations)
  - ***Meso level (between three or more companies):*** Industrial symbiosis: Using waste from one industry as input for another.
  - ***Macro level (cross-sectoral cooperation):*** Urban symbiosis or eco-industrial park
- Investment in advanced recycling technologies.

Benefits:

- Reduction in landfill waste.
- Enhanced resource recovery.

(4) Energy Efficiency

Principle: Reducing energy consumption per unit of output.

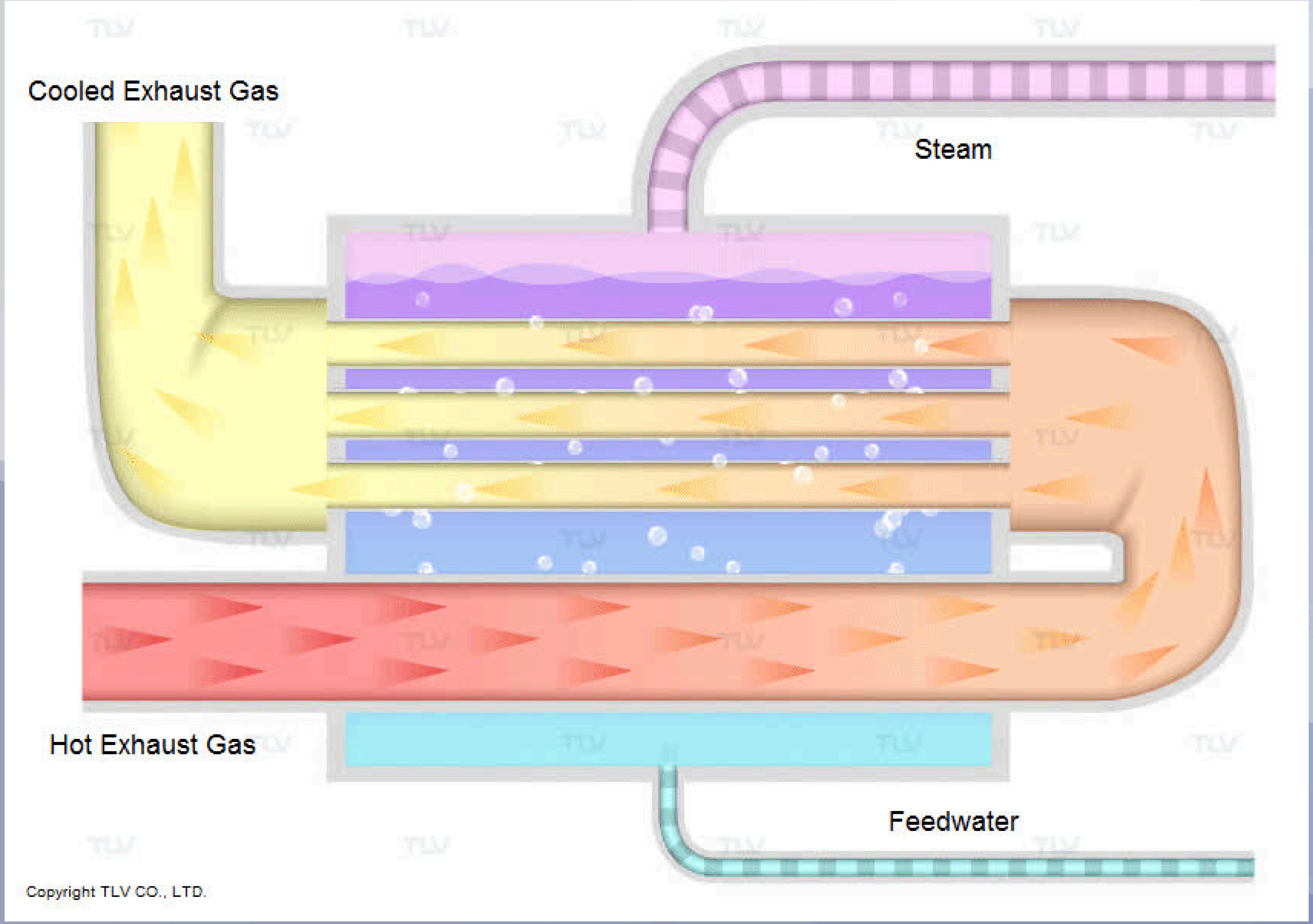
Strategies:

- **Heat-use Energy Efficiency Improvement: "Reduce, Reuse, and Recycle" concept for improved EF**
  - "Reduce": Reducing heat needs via improved thermal insulation
  - "Reuse": Waste Heat Recovery by applying EF equipment (Industrial high-temperature heat pumps to upgrade waste heat and facilitate electrification)
  - "Recycle": Waste heat to power (WHP) (40-57% of waste heat with high temperatures ~>150oC could be used for power generation.
- **Smart Energy Management**
  - ***Improve technology development:*** Digitalisation (Industry 4.0) to improve the process control by sensors, communications, analytics, digital twins, machine learning, virtual reality, simulating and computing techs.
  - ***Smart Energy Systems***: real-time monitoring to monitor energy supply and demand balance

Benefits:

- Significant energy cost savings.
- Lower GHG emission.

Example of Waste Heat to Power (WHP) system



Source: https://www.tlv.com/steam-info/steam-theory/energy-saving/waste-heat-recovery

(5) Electrification and Fuel Switching

Principle:

- A **transition** from high **GHG-fuels (coal, oil, natural gas)** to low-/**zero-GHG energy carriers**: biofuels, hydrogen, ammonia, direct solar heating, electricity, hydrogen ammonia, and synthetic fuels.
- GHG impact depends on production methods.

Strategies:

- ***Direct Electrification:*** Efficient for low-temp processes and lighter industries (e.g., textile. Food processing), reliant on clean energy
- ***Biofuels***: Renewable with potential for negative emissions (BECCS) (e.g., straw or food waste)
- ***Hydrogen:*** Clean hydrogen options (green, blue) for steelmaking, ammonia, and synthetic fuels, potential for export and grid balancing.

Benefits:

- Reduced dependency on fossil fuels.
- Decrease in carbon intensity.

(6) CCUS, Feedstock, and Biogenic Carbon

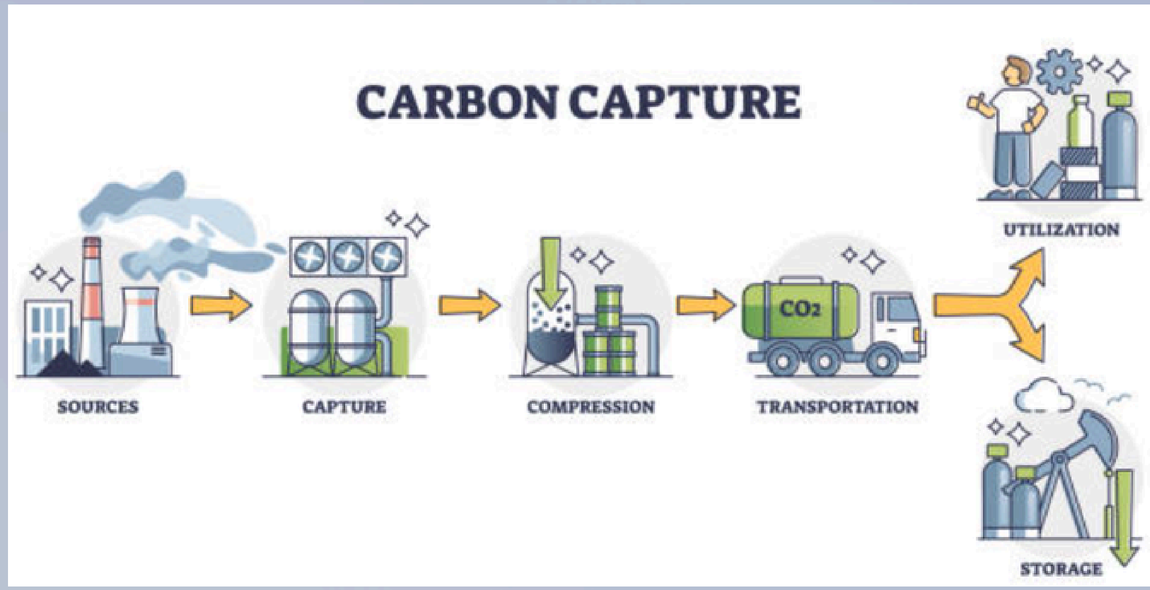
Principle: Carbon is foundational in fuels, chemicals, and materials. Carbon Capture Storage (CCS) and Carbon Capture Utilization (CCU) are strategies to manage CO2 emissions.

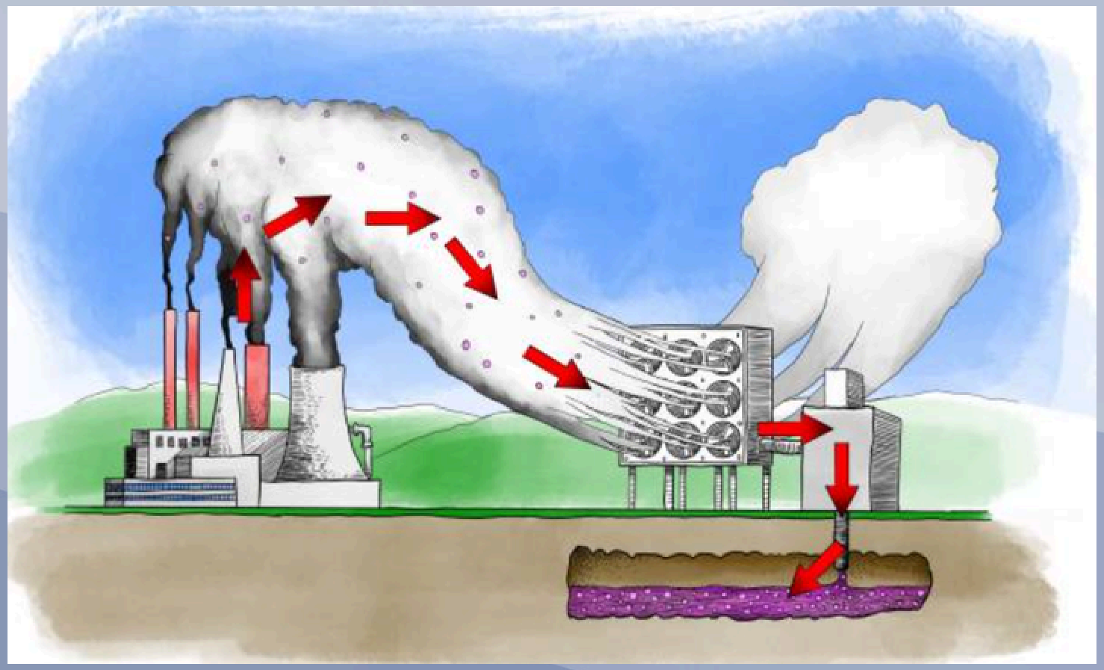
Strategies:

- **CCS (Carbon Capture and Storage):** Captures CO2 and stores it geologically for millennia. Key for reducing industrial emissions.
- **CCU (Carbon Capture and Utilization):** Reuses CO2 to create products like fuels and chemicals; impact on emissions depends on lifecycle analysis.
- Use of biogenic materials as raw materials (e.g., bio-based plastics).
- Development of carbon-neutral production pathways.

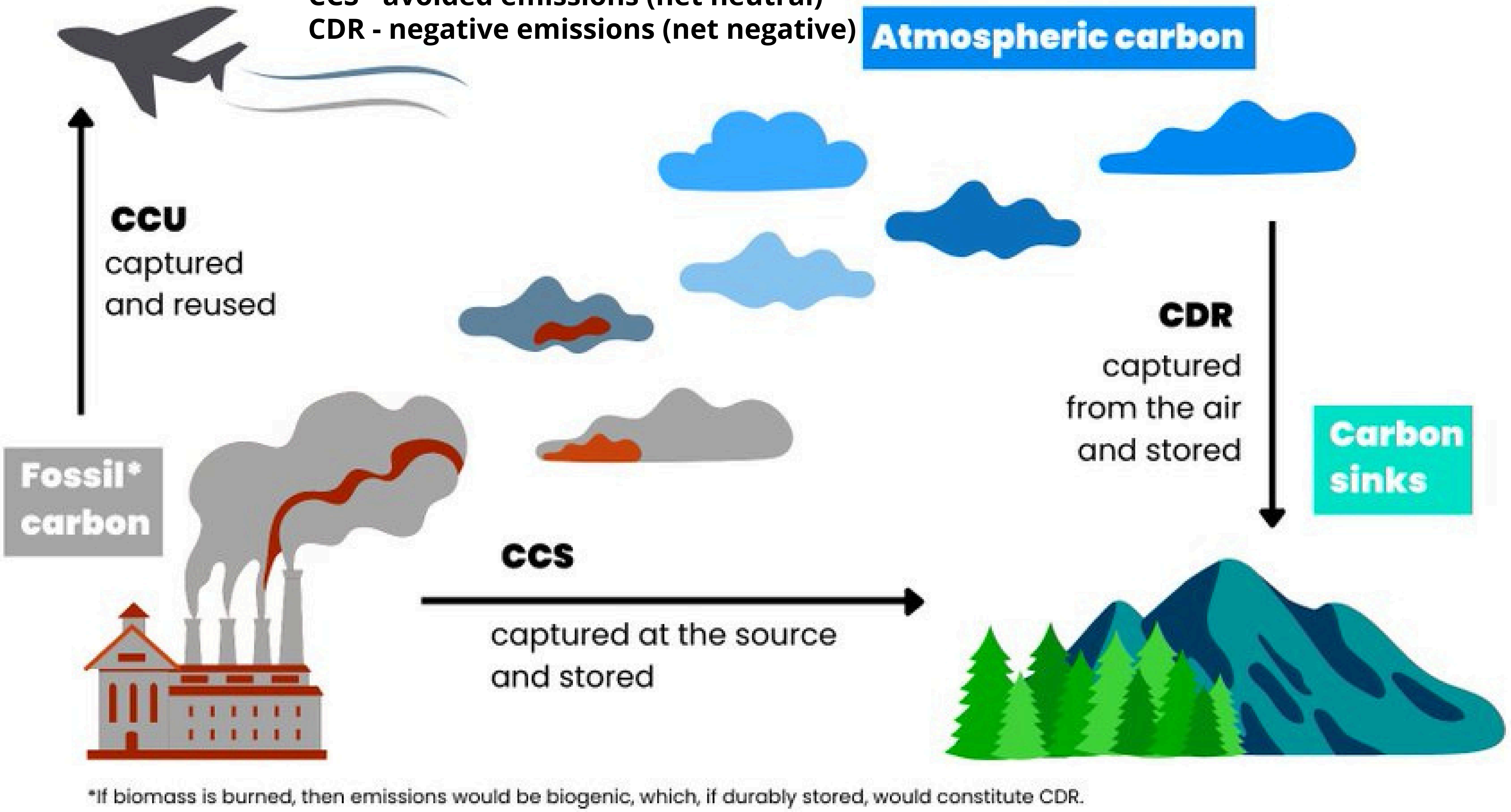
Benefits:

- Reduction in industrial emissions.
- Contribution to net-zero goals.





CCU - reduced emissions (net positive)
CCS - avoided emissions (net neutral)
CDR - negative emissions (net negative)



Recap of the six strategies

- Demand for Materials
- Materials Efficiency
- Circular Economy and Industrial Waste
- Energy Efficiency
- Electrification and Fuel Switching
- CCUS, Feedstock, and Biogenic Carbon

Challenges to Mitigation

Economic barriers:	○ High upfront costs for new technologies.
Technical obstacles:	○ Limited infrastructure for hydrogen and electrification.
Behavioral and organizational resistance:	○ Reluctance to change established processes.
Policy gaps:	○ Inconsistent regulations across regions.

Introduction to the AFOLU Sector

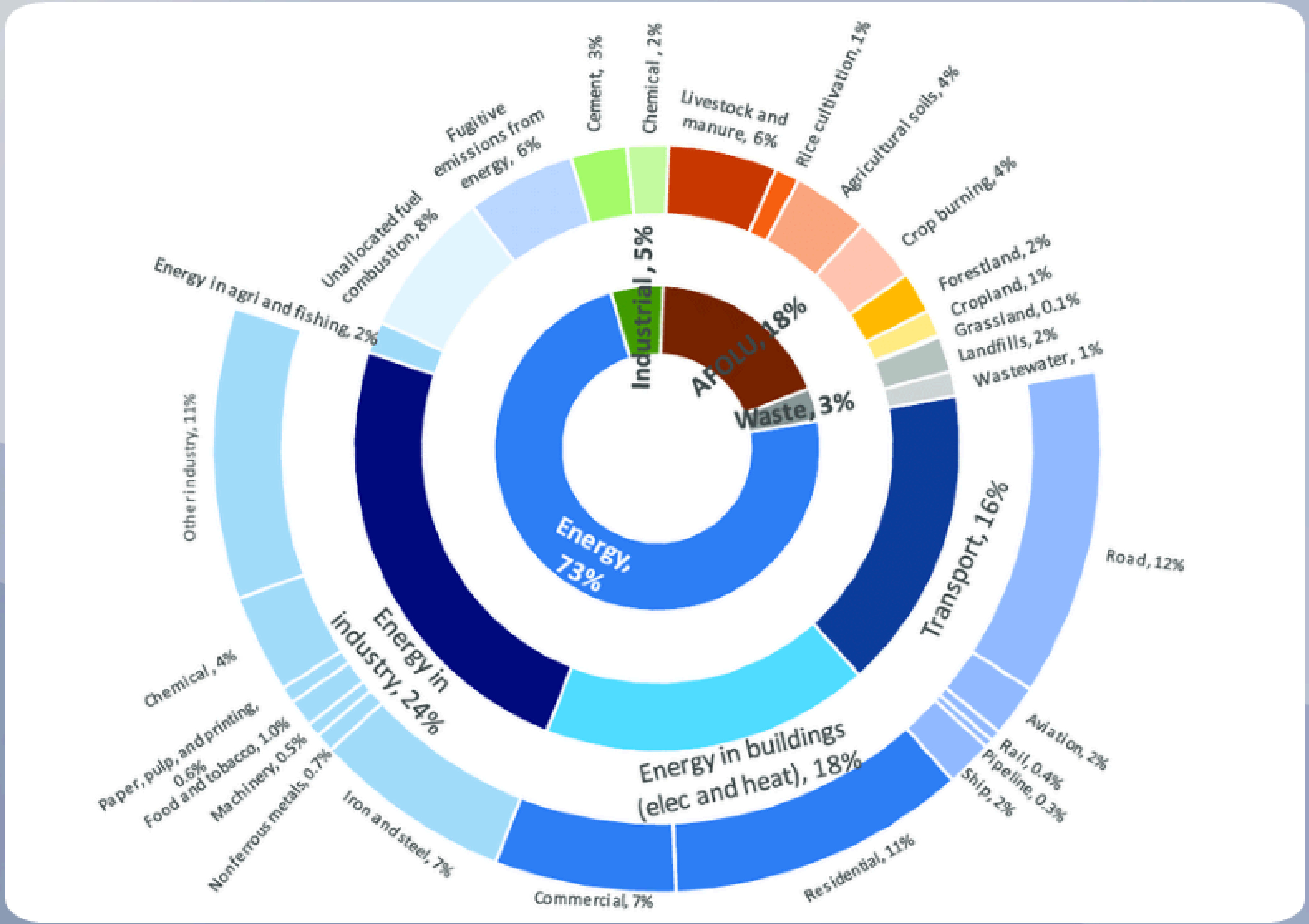
AFOLU accounts for upto 22% of global GHG emissions (2020 estimates).

Key sources:

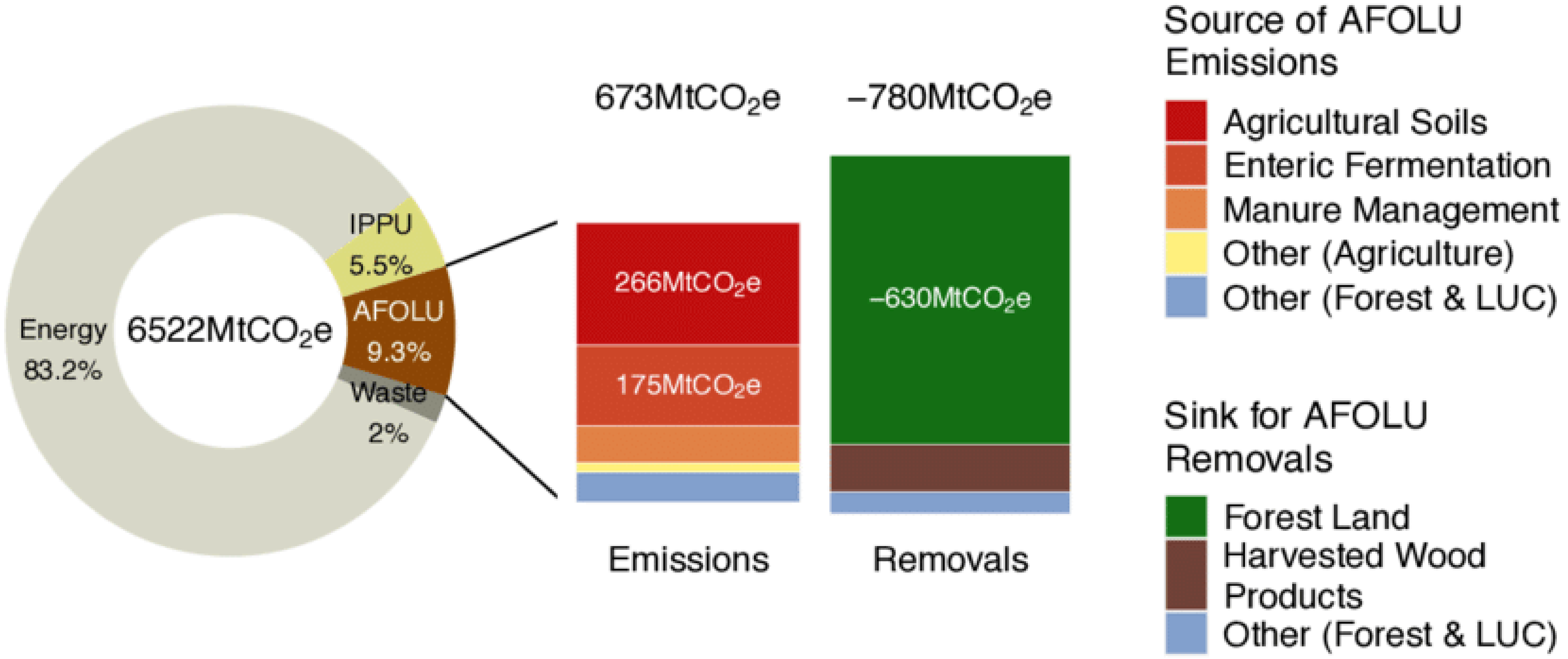
- Deforestation and land-use changes.
- Methane from livestock and rice paddies.
- Nitrous oxide from fertilizer use.

Role in mitigation:

- Provides significant carbon sequestration potential.
- Critical for achieving net-zero emissions.
- Supports biodiversity and ecosystem health



Emission Sources in AFOLU



Source: https://www.researchgate.net/profile/Grace-Wu-22/publication/347472020/figure/fig2/AS:970713284497409@1608447490677/Historical-share-of-GHG-emissions-from-Agriculture-Forestry-and-Other-Land-Use-AFOLU.png

Mitigation Measures

Measures are categorised as supply-side activities in:

- (i) forests and other ecosystems;
- (ii) agriculture;
- (iii) bioenergy and other land-based energy technologies; and
- (iv) demand-side activities.

(1) Forests and Other Ecosystems

Key Strategies:

- Reduce Deforestation and Degradation;
- Afforestation, Reforestation and Forest Ecosystem Restoration;
- Improved Forest Management;
- Fire management (forest and grassland / Savanna Fires);
- Reduce Degradation and Conversion of Gresslands, Savannas, Peatlands Activities.
- Peatland Restoration; and
- Reduce Conversion and implement restoration of Coastal Wetlands.

Mitigation Impact:

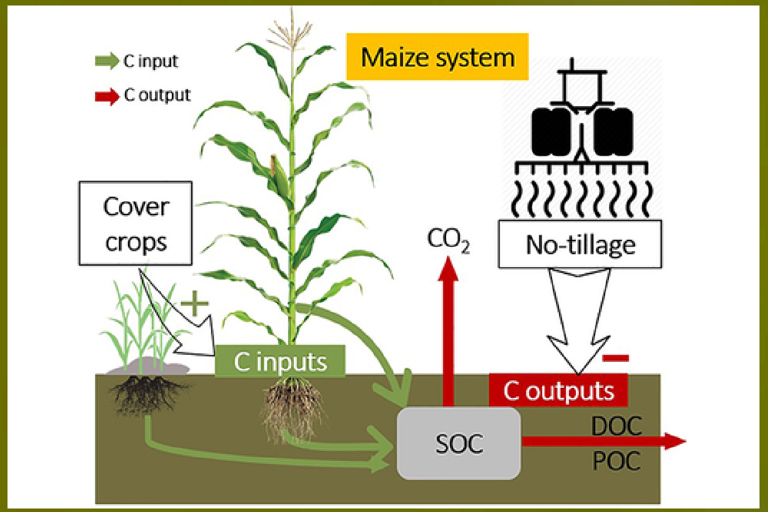
- 3.9–13.1 $GtCO_2$-eq/year potential by protecting, restoring, and managing natural ecosystems.

Co-Benefits:

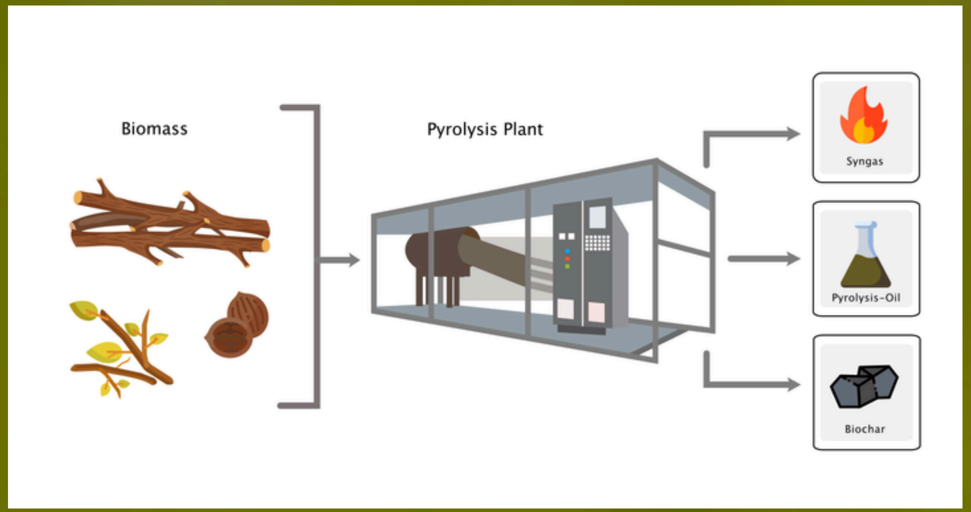
- Preserves biodiversity, enhances water regulation, and improves soil health.

(2) Agriculture

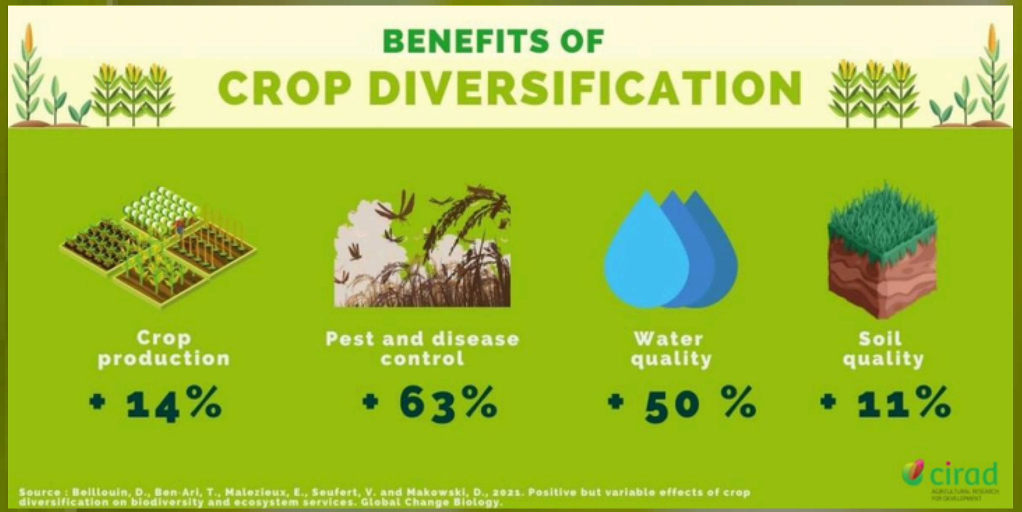
Key Strategies:



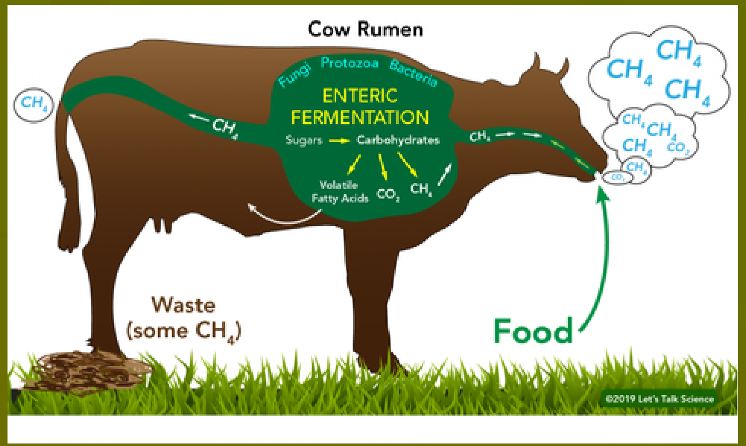
Conserve **tillage and covering crops** to improve and manage the soil carbon in Croplands and Grasslands



Biochar: remaining after the pyrolysis of biomass. Biochar sequesters carbon in soils, providing long-term carbon storage, enhancing soil health, and offsetting GHG.

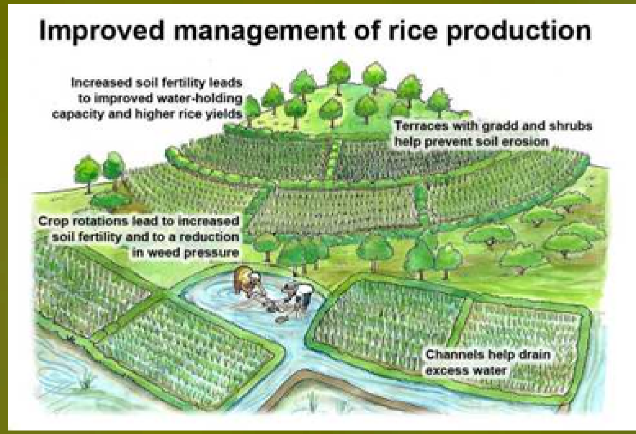


Agroforestry and crop diversification to boost resilience and carbon storage.

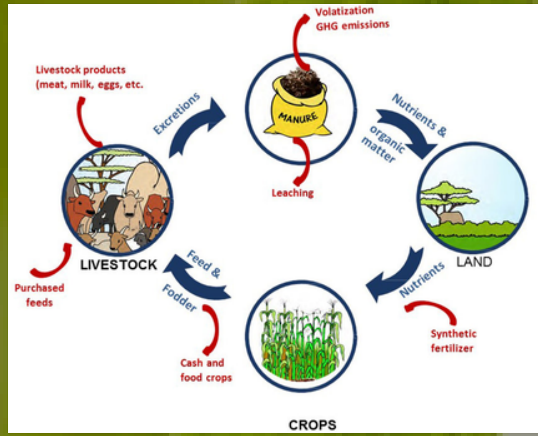


Enteric Fermentation:

- Feeding Practices: Improved feed quality and supply
- Supplements/Additives/Vaccines: Emerging technologies to redice emissions.
- Breeding & Husbandry: Apply advanced livestock management.



Improved Rice Management: Water and residue management, fertilizer application, and soil amendment.



Management of Crop Nutrient and Manure.

Mitigation Potential:
Estimated: 0.03–6.6 $GtCO_2$-eq/year by 2050 (IPCC SRCCL).

Benefits
Carbon capture and soil enhancement (medium agreement, robust evidence).
Climate resilience: Improves crop yield, water use efficiency, reduces emissions from compost/manure.

(3) Bioenergy and other land-based energy technologies (BECCS)

Key Strategies:

- Produces energy (heat, electricity, fuels) from biomass (e.g., organic waste, harvest residues, energy crops).
- Combined with BECCS or biochar, enables Carbon Dioxide Removal (CDR) via long-term carbon storage.
- Integrated with AFOLU practices like agroforestry, anaerobic digestion, and reforestation.

Mitigation Potential:

- 0.5–11.3 $GtCO_2$/year by 2050 (technical CDR potential).

Benefits:

- Displaces fossil fuels, reducing net GHG emissions.
- Enhances land carbon stocks and mitigates methane through biogas production.
- Supports renewable energy development and sustainable land use.

(4) Demand-side activities

Key Stategies:

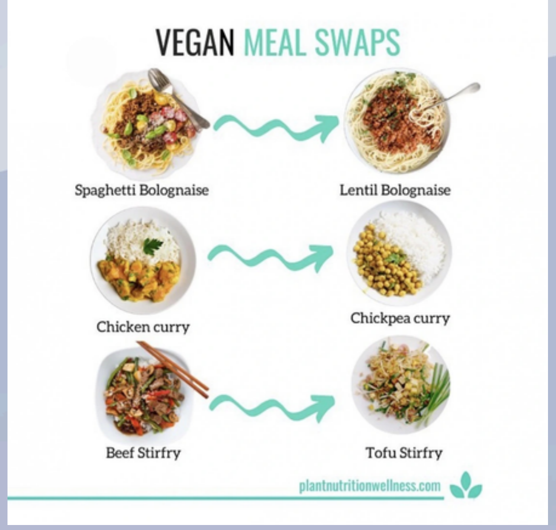
- **Sustainable Diets:** Shift to plant-based diets to
  - reduce emissions from livestock;
  - improve health and well-being;
  - minimize the environmental pressure and impact; and
  - Enhance economic stability of the agricultural sector.
- **Reduce food loss and waste (FLW):**
  - Investing in post-harvest technologies (in developing countries)
  - Promoting use of cosmetically imperfect products; and
  - Encouraging behavioral changes and consumption patterns.
- **Use of Bio-Based Materials:** Promote wood and bio-textiles in construction and manufacturing.

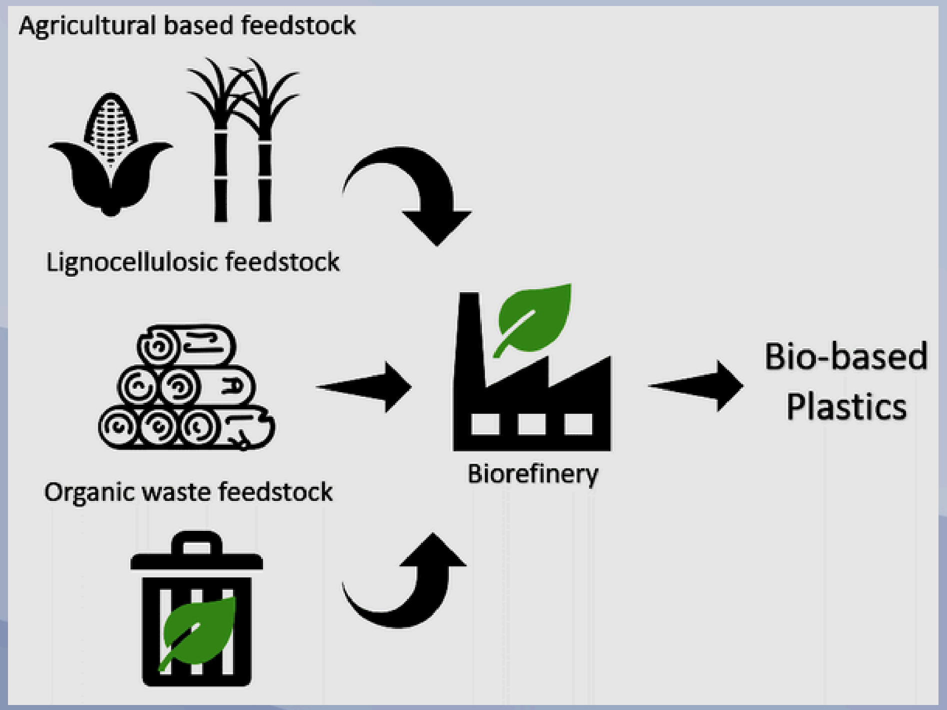
Mitigation Potential:

- Demand-side measures could achieve 1.1–3.6 $GtCO_2$-eq/year.

Co-benefits:

- GHG mitigation and reduced environmental stress
- Enhanced food security and poverty reduction; and
- Support SDG 12: Halve global FLW by 2030 and reduce food supply chain losses.





Challenges to Mitigation

Economic Barriers:	○ High costs of transitioning to sustainable systems. ○ Limited access to finance for small-scale farmers.
Social and Cultural Factors:	○ Resistance to changing traditional practices. ○ Conflicts over land use priorities.
Technical Hurdles:	○ Limited access to advanced technologies. ○ Lack of infrastructure for BECCS and other innovations.
Policy Gaps:	○ Insufficient integration of AFOLU into national climate plans. ○ Inconsistent enforcement of land-use regulations

Success Stories and Opportunities

Successes:

- Large-scale **reforestation projects in Brazil and China;**
- Adoption of methane-reducing feed supplements in livestock sectors; and
- Transition to sustainable **palm oil production in Southeast Asia.**

Conclusions:

- AFOLU is a key sector for achieving climate targets.
- Offers substantial mitigation potential through sequestration and emission reductions;
- Contributes to biodiversity, food security, and community resilience; and
- Requires a combination of sustainable practices, strong policies, and investments.

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