ENERGY TRANSITIONS COMMISSION

Economic growth in a low carbon world: How to reconcile growth and climate through energy productivity

An analysis of energy demand trends and drivers in low carbon scenarios prepared by Vivid Economics for the Energy Transitions Commission

January 2017

: vivideconomics

Disclaimer

This working paper has been produced by Vivid Economics in support of the work being undertaken by the Energy Transitions Commission (ETC).

The paper has contributed to the ETC's report Better Energy, Greater Prosperity available on the ETC website.

Vivid Economics have sole responsibility for the content and findings of this document, which should not be interpreted as recommendations made by the ETC.

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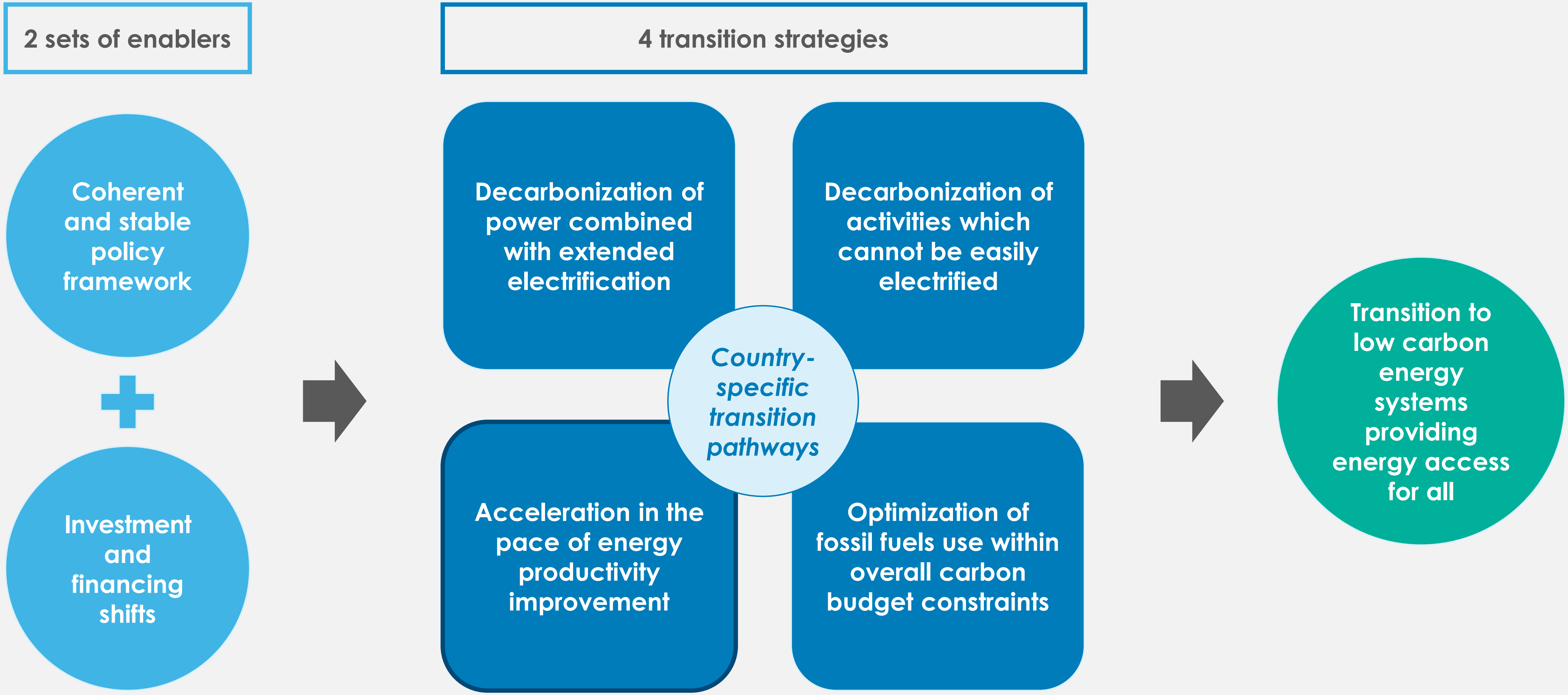
This research paper supports the work of the Energy Transitions Commission by analyzing energy demand trends and drivers in low carbon scenarios

The Energy Transitions Commission believes that accelerating energy transitions to low carbon energy systems providing energy access for all will require rapid but achievable progress along 4 dimensions. This research paper investigates the required acceleration in the pace of energy productivity improvement.



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Content

In the absence of a demand-side energy transition, global energy demand is likely to grow by 60% to 2050 and greater efforts will be required to decarbonise energy supply

We analysed 15 future energy demand scenarios to understand the extent and character of energy demand reductions that scenario teams believe are required to meet a 2˚C pathway versus “business-as-usual”.

Energy demand scenarios portray a future of continued economic growth.

Regardless of carbon emissions pathway, economic growth is assumed to continue, with average GDP per capita growth rates of 1.2% and 2.3% in OECD and non-OECD economies respectively to 2050. As a result, on average across scenarios:

- OECD economies increase GDP per capita from $38k in 2015 by 25% to 2030 and 60% to 2050;
- non-OECD economies increase GDP per capita from $10k in 2015 by 50% to 2030 and 150% by 2050; and
- China (~25% of the population of the non-OECD) increases GDP per capita from $13.5k by 100% to 2030 and by 270% to 2050.

Without a demand-side energy transition, continued economic growth will demand ever greater quantities of energy.

In the average of reference scenarios, unconstrained by climate mitigation action, energy per capita increases during 2010-2050 by:

- 13% in OECD economies, reaching 140 GJ/capita;
- 50% in non-OECD economies, reaching 55 GJ/capita; and
- 125% in China, reaching 107 GJ/capita.

In the absence of a demand-side transition, much greater decarbonisation efforts will be required to meet a 2˚C pathway.

With OECD and non-OECD populations reaching, on average, 1.3 and 8 billion respectively in 2050, these per capita increases in energy demand mean that, on average, 60% more exajoules of decarbonised energy supply will be required in 2050 in addition to the decarbonisation of present-day energy supply.

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A structural break in energy demand per capita is required to enable continued economic growth and provide energy services for all in a well below 2˚C pathway

Improving energy productivity[1] by 2.5% to 3% per year is essential to enable continued economic growth and provide energy services for all in a low carbon pathway.

- On average, low carbon scenarios exhibit energy productivity improvements of 2.5% per year.
- To achieve a well below 2˚C pathway, energy productivity improvements of at least 3% per year are required when combined with a 1% point per year increase in the share of zero-carbon energy.
- This is significantly higher than the historical average of 1.6% annual energy productivity improvements between 1990 and 2010.

A structural break in levels of energy demand per capita is needed to deliver high levels of energy productivity improvements.

In low carbon scenarios:

- Energy demand per capita halves in OECD economies, when historically it has been relatively constant.
- Non-OECD economies increase GDP per capita by a factor 3-4 with almost no growth in energy demand per capita.

Path dependency calls for immediate, rapid and accelerating improvements in energy productivity.

Only scenarios with early and accelerating reductions in demand growth lead to a 2˚C pathway. Even large demand reductions in later periods are not enough to get scenarios with limited early energy productivity improvements back on a 2˚C pathway.

Energy productivity improvements are as important as decarbonisation of energy supply for climate mitigation.

- These improvements account for 45% of gross carbon emissions reductions, on average, in low carbon scenarios.
- They can serve as insurance: faster energy productivity improvements now create space for higher economic growth and offer some protection against the uncertain delivery of advanced decarbonisation technologies.

1 GDP produced per unit of energy

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Radical improvements in energy productivity across the transport, industry and buildings sectors could reduce global energy demand by 60% compared to business as usual

If the most ambitious improvements across scenarios are combined into one 'stretch' scenario, global energy productivity could improve by more than 3% per year, leading to a 60% reduction in global energy demand compared to business as usual in 2050.

Energy productivity can be improved in two ways:

- **Energy efficiency of services:** technological improvements or shifts to more efficient practices provide a greater level of service (such as mobility in transport, comfort in buildings, tonnes of steel in industry) for a particular quantity of energy.
- **GDP productivity of services:** structural changes (such as denser urban forms) and behavioural changes (such as greater reuse of goods) enable more economic activity to be generated for a given level of energy services.

Radical energy efficiency improvements often drive reductions in energy demand across low carbon scenarios.

The energy efficiency improvements that deliver a 3% energy productivity improvement per year are a step change relative to historic levels, driven by strong assumptions on technological progress and on the building of an efficient capital stock:

- **in buildings:** stringent standards for new builds are implemented now and retrofit rates triple to 3% per year;
- **in transport:** most travel shifts to electric vehicles and shared modes; and
- **in industry:** countries that have yet to industrialise adopt emergent Best Available Techniques from day one.

Disruptive technologies and business models, rarely modelled in scenarios, could accelerate renewal of the capital stock.

For example, opportunities in digitisation and automation may bring sufficient ancillary benefits to justify rapid capital stock turnover; and new approaches for neighbourhood-scale retrofits could reduce their cost and increase their pace.

Structural and behavioural changes that improve GDP productivity of services constitute an additional reservoir of opportunities.

Relatively little emphasis is placed on radical improvements in the GDP productivity of services in low carbon scenarios. This is in contrast with recent trends that suggest structural changes, for example enabled through digital services, advanced materials, circular production, or compact urban forms could be a realistic route to improving energy productivity.

Read more

Transport energy demand could be reduced by nearly 70% relative to reference scenarios through a comprehensive combination of reduced travel needs, modal shifting and improved vehicle efficiency, alongside a large-scale fuel shift to electricity for passenger travel and alternative fuels for freight transport

In the average of reference scenarios, transport energy demand is set to increase by 75% relative to today, due almost entirely to a c.130% increase in non-OECD economies.

In the stretch scenario, OECD economies reduce their transport energy demand by 73%, and non-OECD economies by 66% versus reference scenarios. This is achieved through a comprehensive combination of reduced travel needs, modal shifting and improved vehicle efficiency, alongside a large-scale fuel shift to electricity for passenger travel and alternative fuels for freight transport:

- The largest contribution is from mechanical efficiency, especially efficiency gains from electrification.
- A reduction in the need to travel (thanks to smarter cities) and a modal shift (primarily to buses and rail) make a combined contribution of a scale similar to that of mechanical efficiency.

There is some divergence between scenarios that deeply electrify (moving to a 40-50% share of transport energy demand) versus those that combine electrification with biofuel use (reaching roughly 20% share of transport energy demand each). Countries will face an important decision about which pathway is best suited to their economic context.

New policy approaches are required to drive all levers at a greater scale and pace than seen to date through:

- Appropriate infrastructure choices (e.g. more compact cities, better rail systems, EV charging stations);
- Support to technological improvements (e.g. for batteries and perhaps advanced biofuels);
- Incentives driving behavioural change (e.g. toward shared transport).

In particular, emerging markets need to quickly adopt best practice urban system design and transport networks as they begin to rapidly develop these long-lived assets.

Read more

Industrial energy demand could be reduced by ~50% relative to reference scenarios, with a particular emphasis on avoiding 'leakage' by ensuring newly industrialising countries move quickly to emergent Best Available Technologies from the OECD in sectors such as iron and steel

In the average of reference scenarios, industrial energy demand is set to increase by 68% relative to today, due largely to a c.100% increase in non-OECD economies.

In the stretch scenario, both OECD and non-OECD economies reduce their industrial energy demand by about 50% versus reference scenarios. This is mostly achieved through a combination of greater process efficiency and fuel switching:

- The largest contribution is from process efficiency, especially from improved processes and the retirement of less efficient industrial capacity.
- The stretch scenario assumes a full substitution of hydrocarbons by electricity, hydrogen, biofuels and waste heat recovery.
- The potential of deeper structural changes such as the development of circular industrial systems and a shift away from energy intensive products appears to have been treated conservatively, with little radical change assumed in low carbon scenarios.

Emerging economies need to adopt Best Available Technologies in-step with more advanced countries – and this goes well beyond China, as newly industrialising countries account for an increasing share of industrial production growth.

Although some rapid improvements in production efficiency, recycling, and fuel switching (especially away from coal) can be achieved with current technologies, the technologies that will provide the deeper improvements necessary by 2050 remain uncertain.

New policy approaches combining targeted RD&D support as well as price and tax incentives for producers and consumers of industrial products are therefore required to:

- Drive faster rates of process efficiency improvement; and
- Explore and exploit the potential for new industrial technologies, more circular industrial systems, and larger scale shifts away from energy intensive industrial products.

Read more

Buildings energy demand could be reduced by two thirds relative to reference scenarios through increases in energy efficiency of buildings envelopes and equipment, alongside behavioural changes and switching from fossil fuels to electricity and district heating

In the average of reference scenarios, buildings energy demand is set to increase by 114% relative to today, due largely to a c.150% increase in non-OECD economies.

In the stretch scenario, OECD economies reduce their buildings energy demand by 72%, and non-OECD economies by 61%, versus reference scenarios. This is achieved through a combination of improvements to buildings envelopes, improved efficiency of equipment, and fuel switching to district heating and electricity.

- The largest contribution is from improved efficiency of equipment (e.g. air-conditioners), in part driven by increased electrification.
- The remainder mostly arises from improvements in buildings envelopes and the development of district heating.
- The potential for behavioural changes that reduce buildings energy demand (without impacting comfort levels) appears to have been treated conservatively.

Emerging markets and developed economies face different challenges and opportunities:

- Emerging markets need to move from almost no buildings with advanced, high-efficiency energy technologies to having 75-100% of their buildings using such technologies by introducing them quickly into their rapidly growing new buildings stock.
- Given their large base of existing buildings, developed countries need to both increase the penetration of more advanced technologies and induce existing building owners to undertake large scale retrofits.
- On the whole, emerging markets need leapfrog OECD economies, achieving energy use levels (per m2) that are 50% lower than those in developed countries by 2050, even as their GDP per capita continues to catch up.

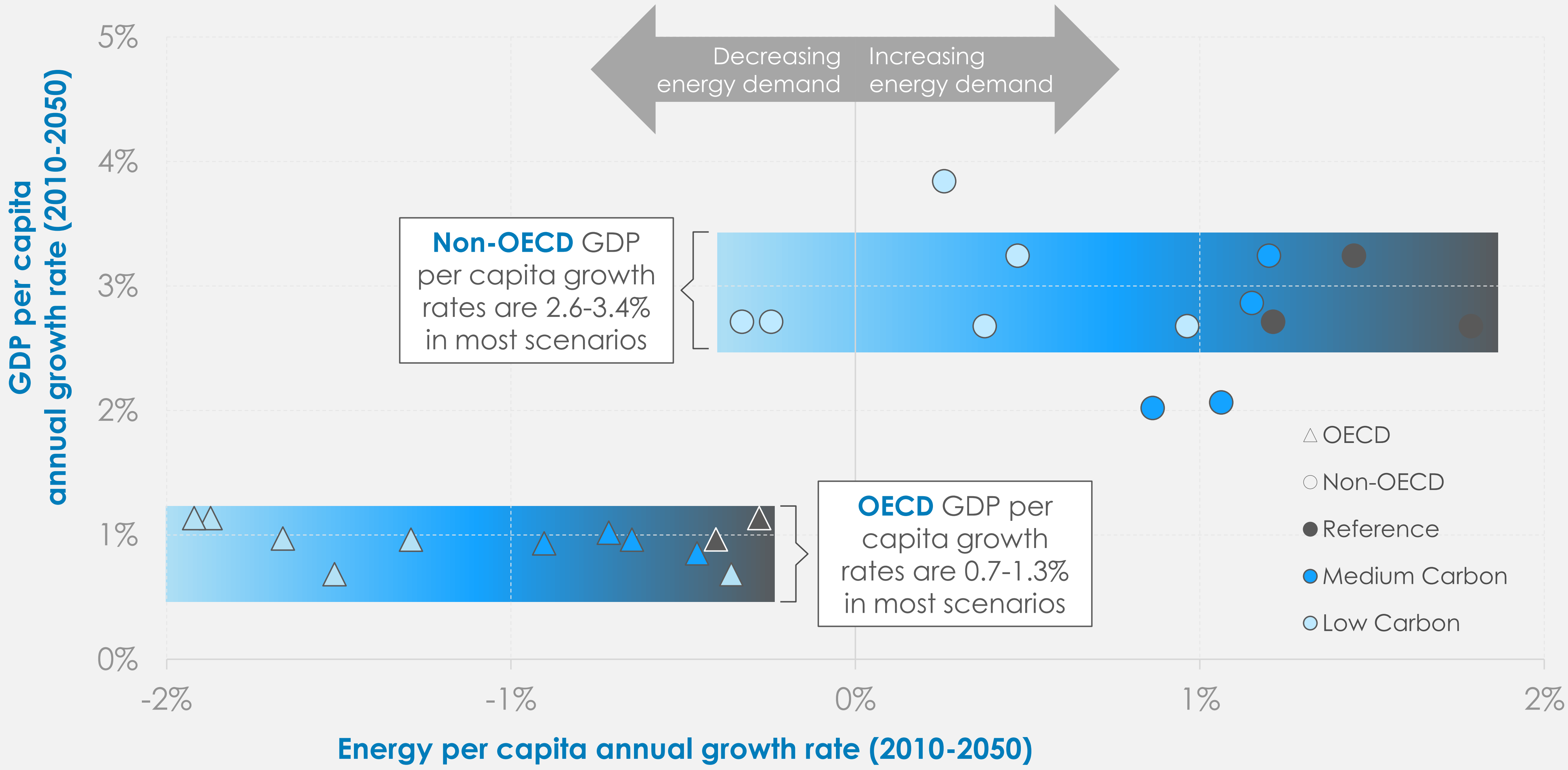
Although technology improvements (e.g. higher efficiency AC) have a role to play, new policy approaches combining the development and enforcement of standards with price incentives are critical to drive consumer choices toward energy reducing behaviours and investments at a pace far greater than historical experience.

Read more

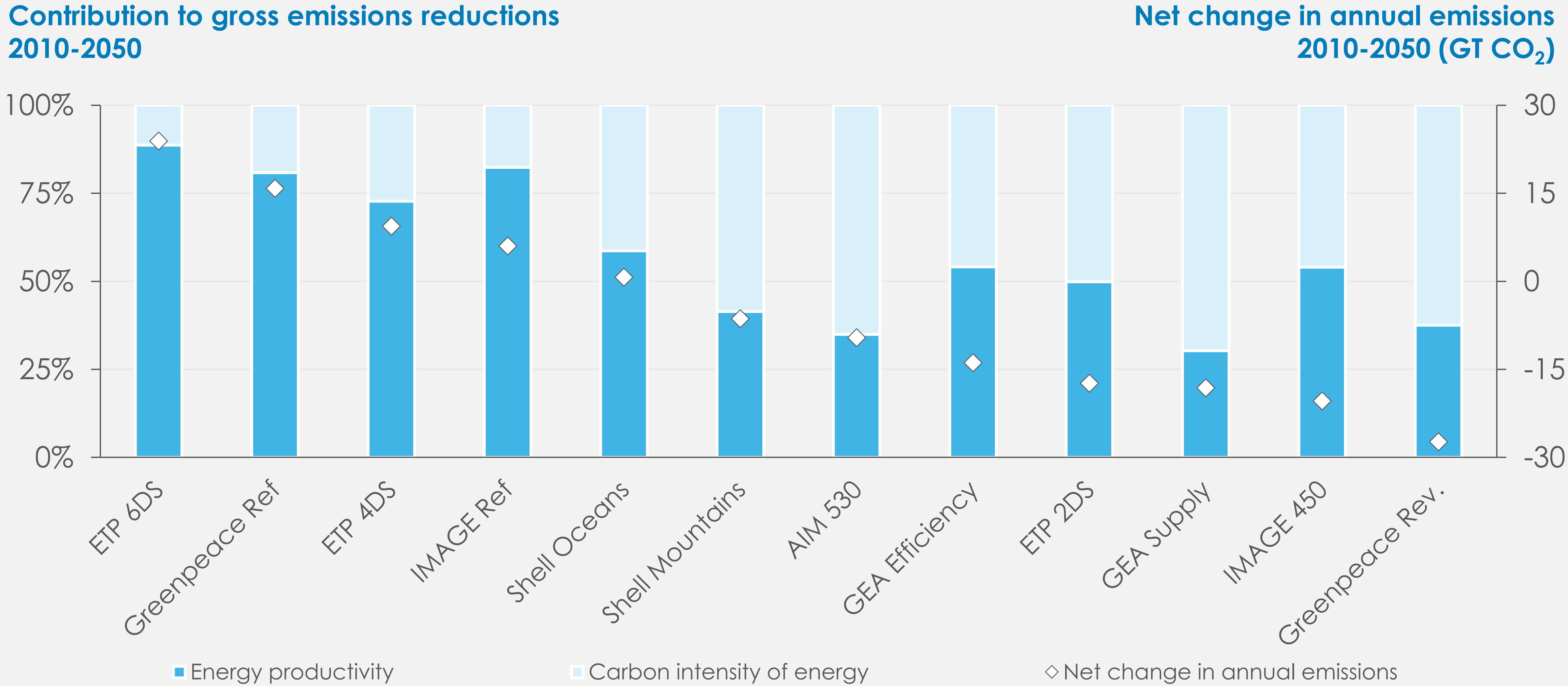
Macro findings

- Low carbon scenarios require a **structural break in energy demand**
- A well below 2˚C pathway requires **stretching energy productivity ambitions**

Reduced energy demand does not imply reduced economic growth: Low-carbon scenarios have the similar GDP growth as high-carbon scenarios, but radically lower energy demand



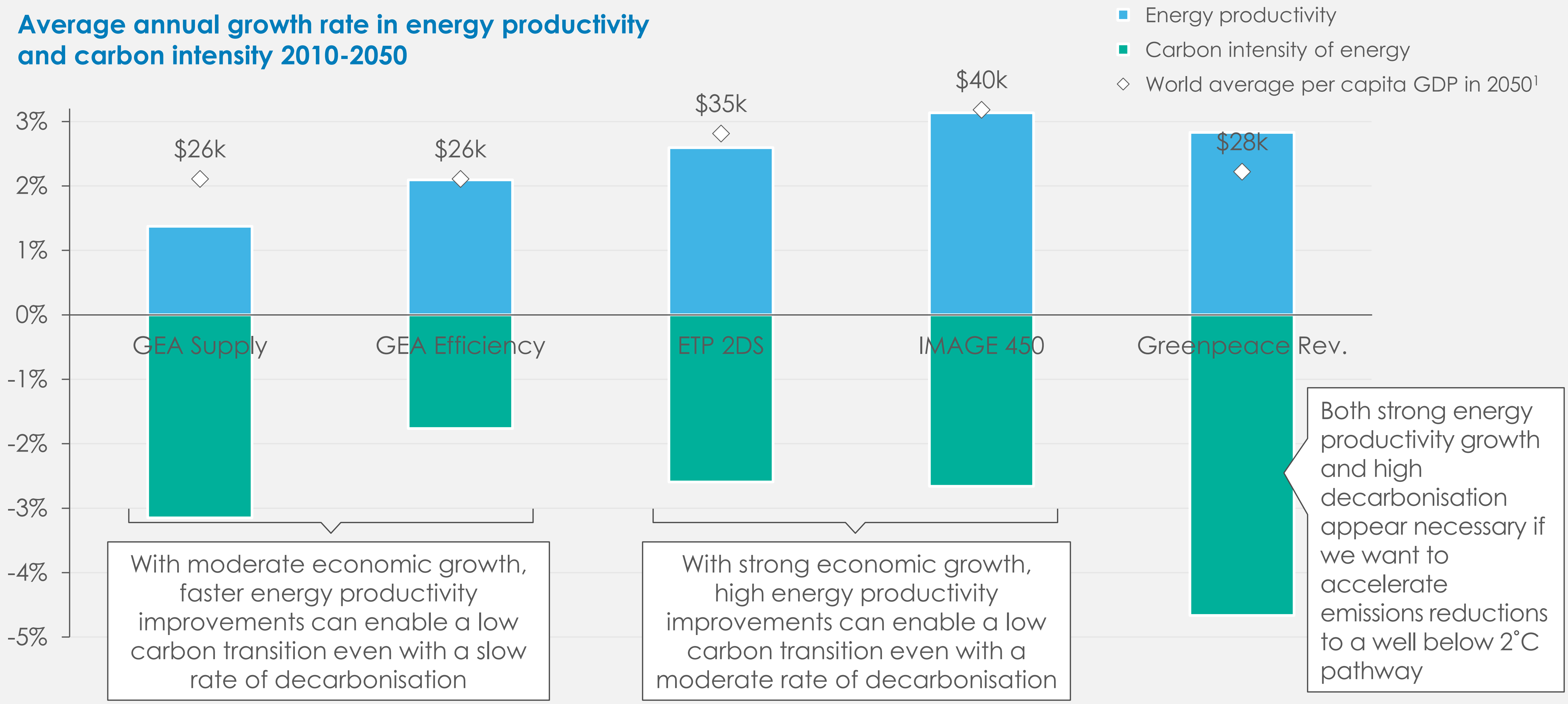
Improvements in energy productivity are as important as decarbonisation of energy supply: They account for 45% of gross carbon emissions reductions on average in low carbon scenarios



Note: GEA Supply is a high energy demand scenario that rests on an assumption of rapid deployment of advanced decarbonisation technologies. This includes abundant supply of intermittent renewables and carbon capture and storage (CCS)

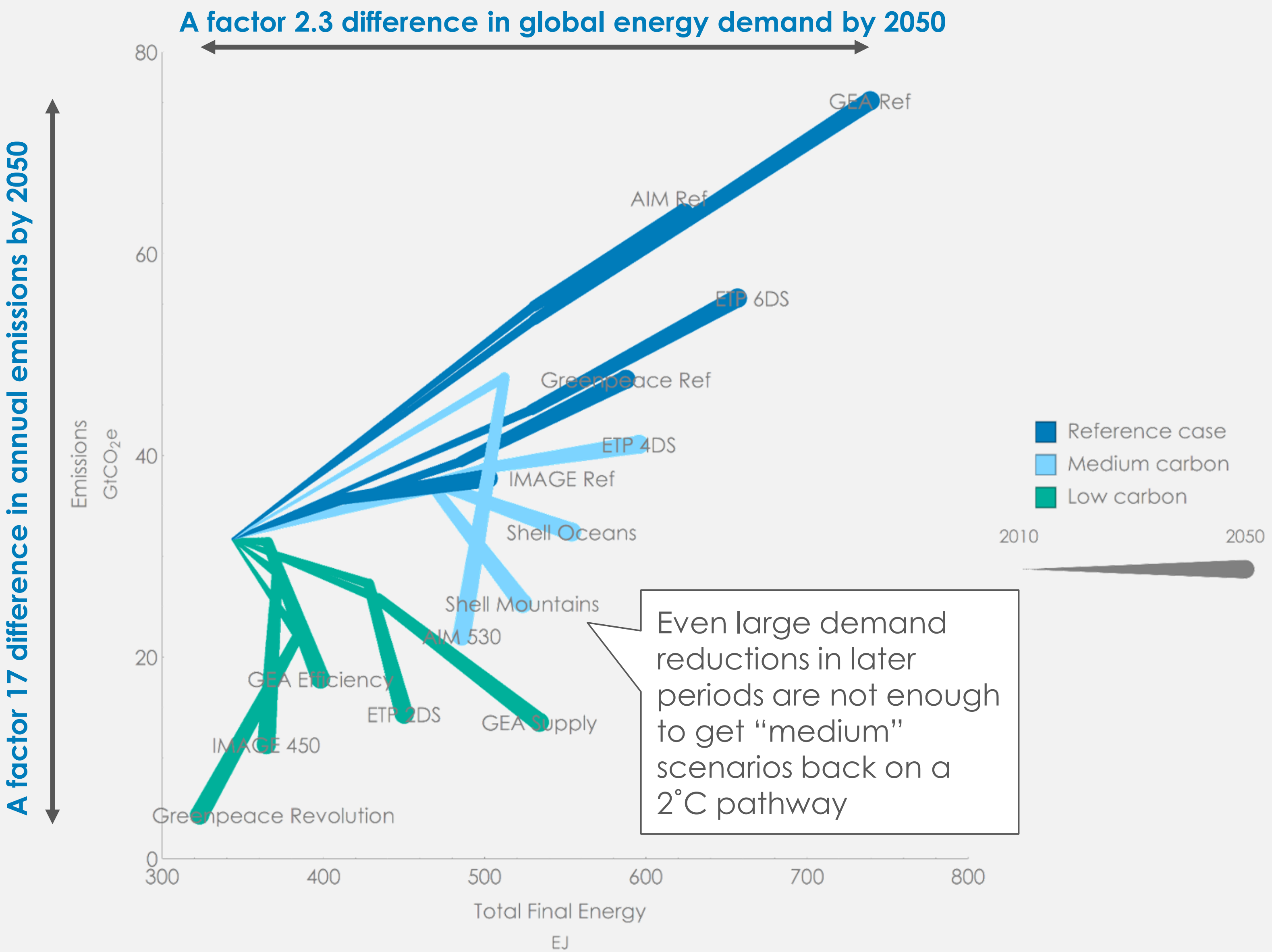
Energy productivity improvements serve as insurance: Faster energy productivity improvements enable the low carbon transition in case of higher growth and lower supply of decarbonisation

Average annual growth rate in energy productivity and carbon intensity 2010-2050



1 Denominated in 2011 USD (Purchasing Power Parity terms)

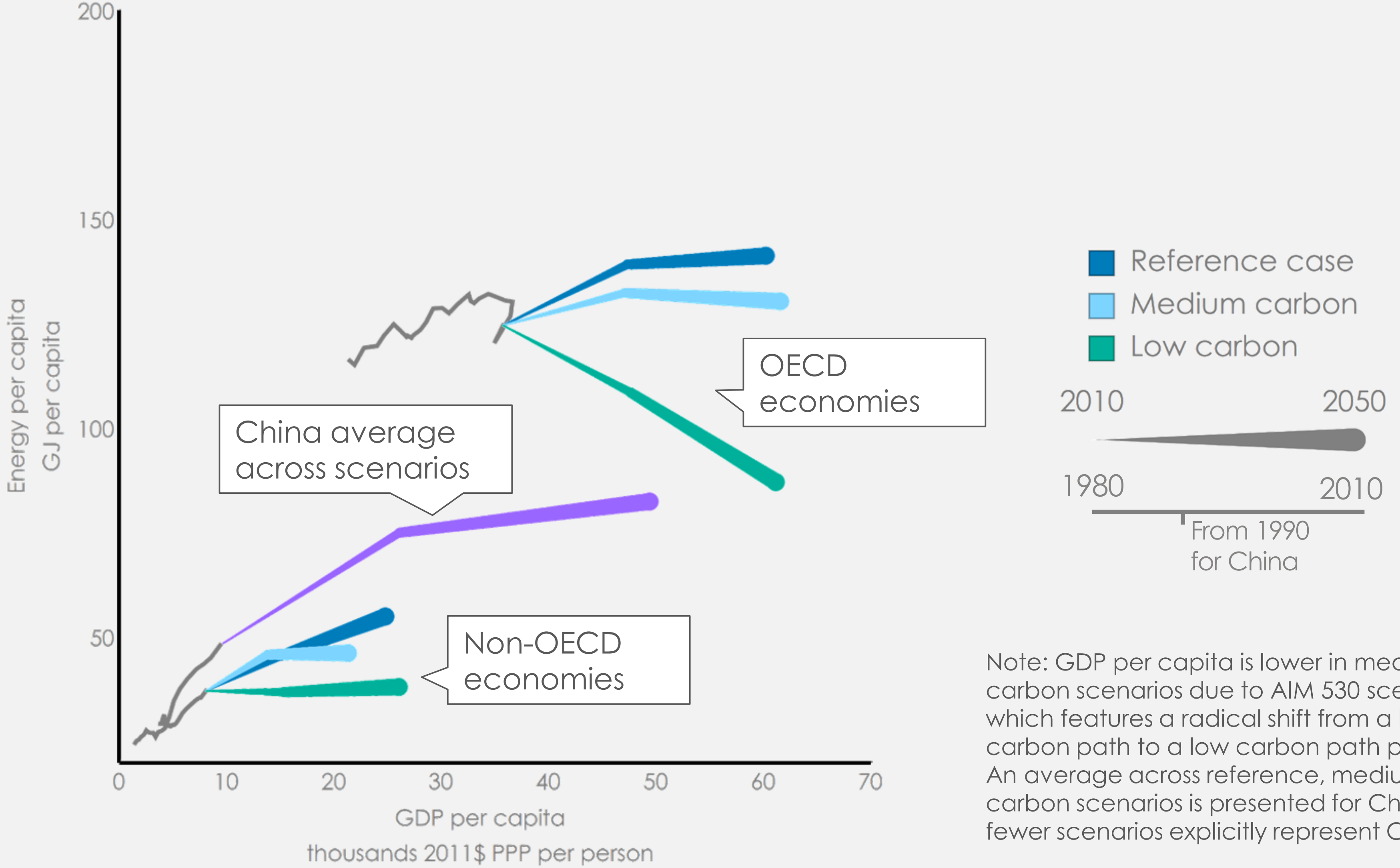
Path dependency calls for immediate and rapid reduction in energy demand growth: Only scenarios with early and accelerating reduction in demand growth lead to a 2˚C pathway



Even large demand reductions in later periods are not enough to get "medium" scenarios back on a 2˚C pathway

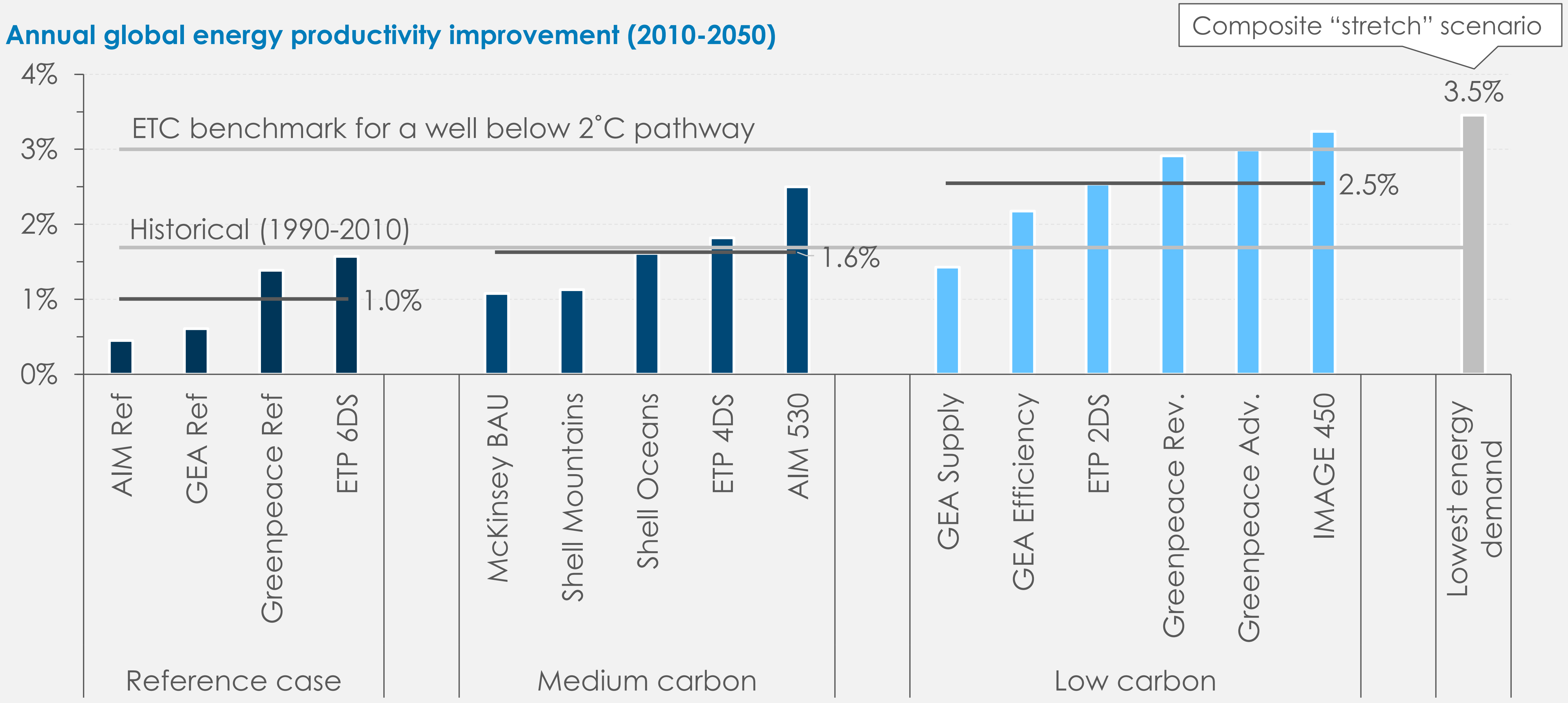
A structural break in the relationship between energy and GDP per capita is required:

Energy per capita halves in OECD economies and stabilises in non-OECD economies by 2050



Note: GDP per capita is lower in medium carbon scenarios due to AIM 530 scenario, which features a radical shift from a high carbon path to a low carbon path post-2030. An average across reference, medium and low carbon scenarios is presented for China as fewer scenarios explicitly represent China

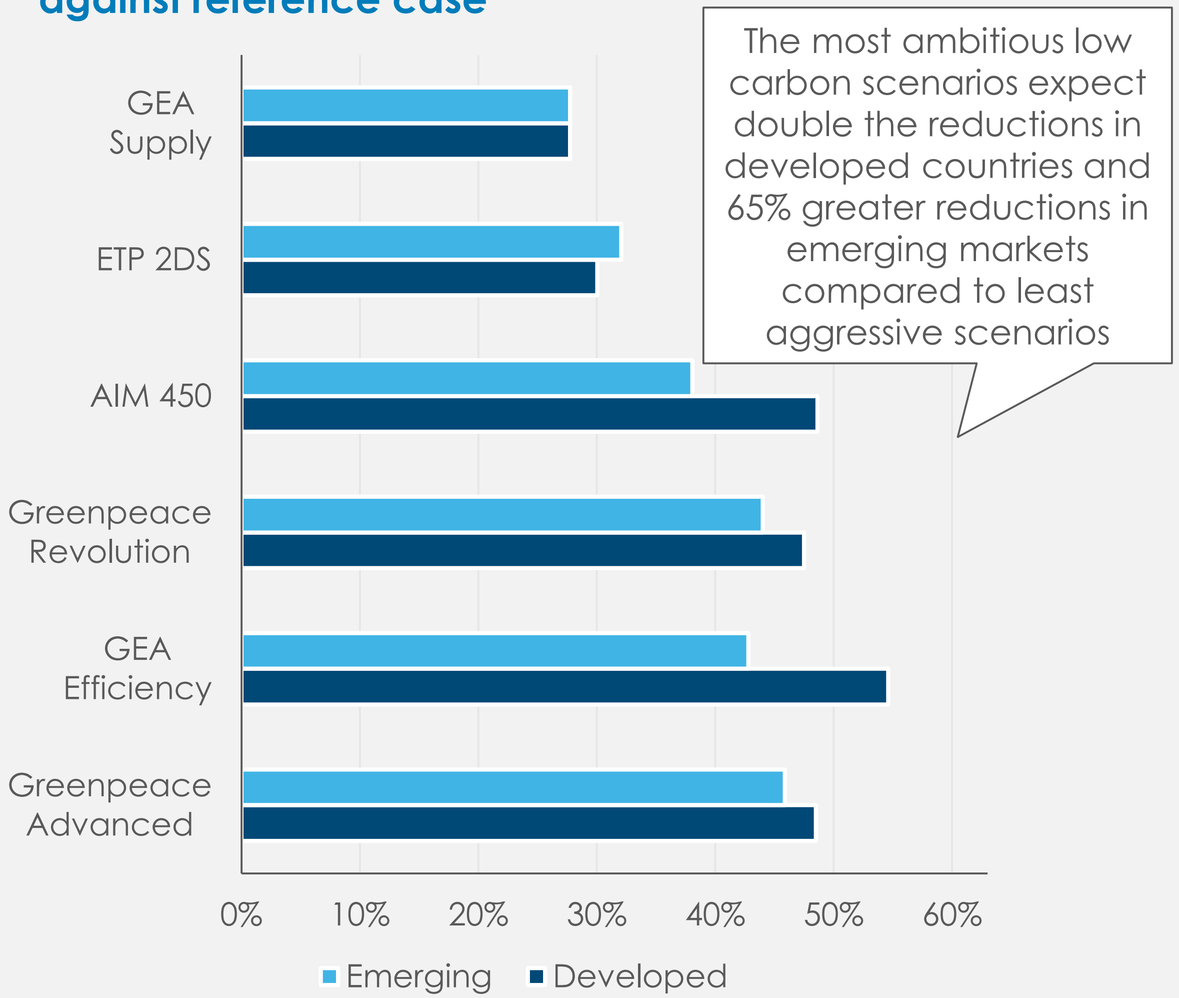
Stretching energy productivity ambitions is key to a low carbon pathway: Low carbon scenarios include on average a 2.5% annual improvement and a "stretch" scenario would achieve 3.5%



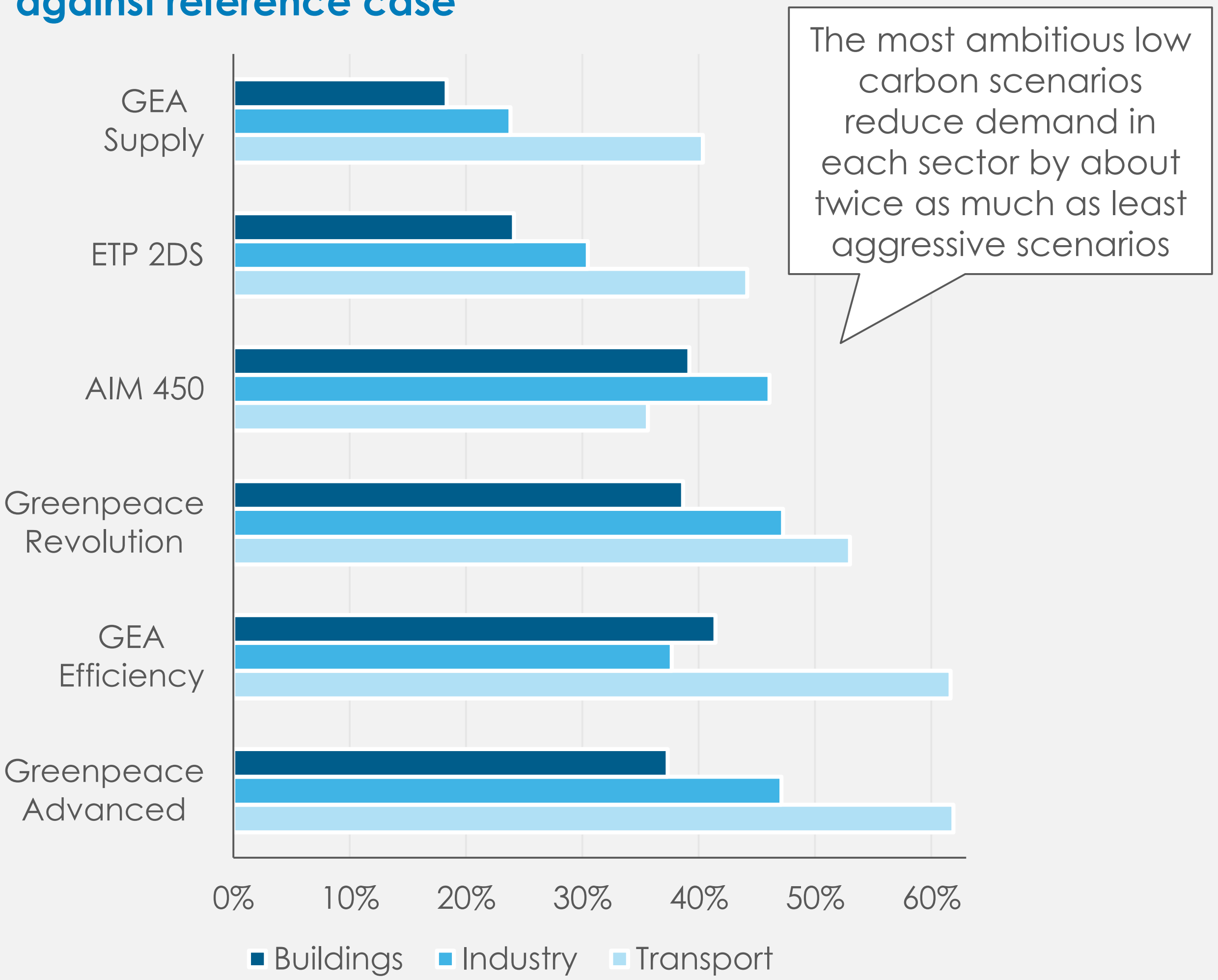
Note: ETC energy productivity benchmark is based on primary energy demand improvements other figures are based on final energy demand.

Low carbon scenarios with ambitious energy productivity improvements achieve 50-100% greater demand reductions than less aggressive scenarios across regions and sectors

Reduction in energy demand by region against reference case



Reduction in energy demand by sector against reference case



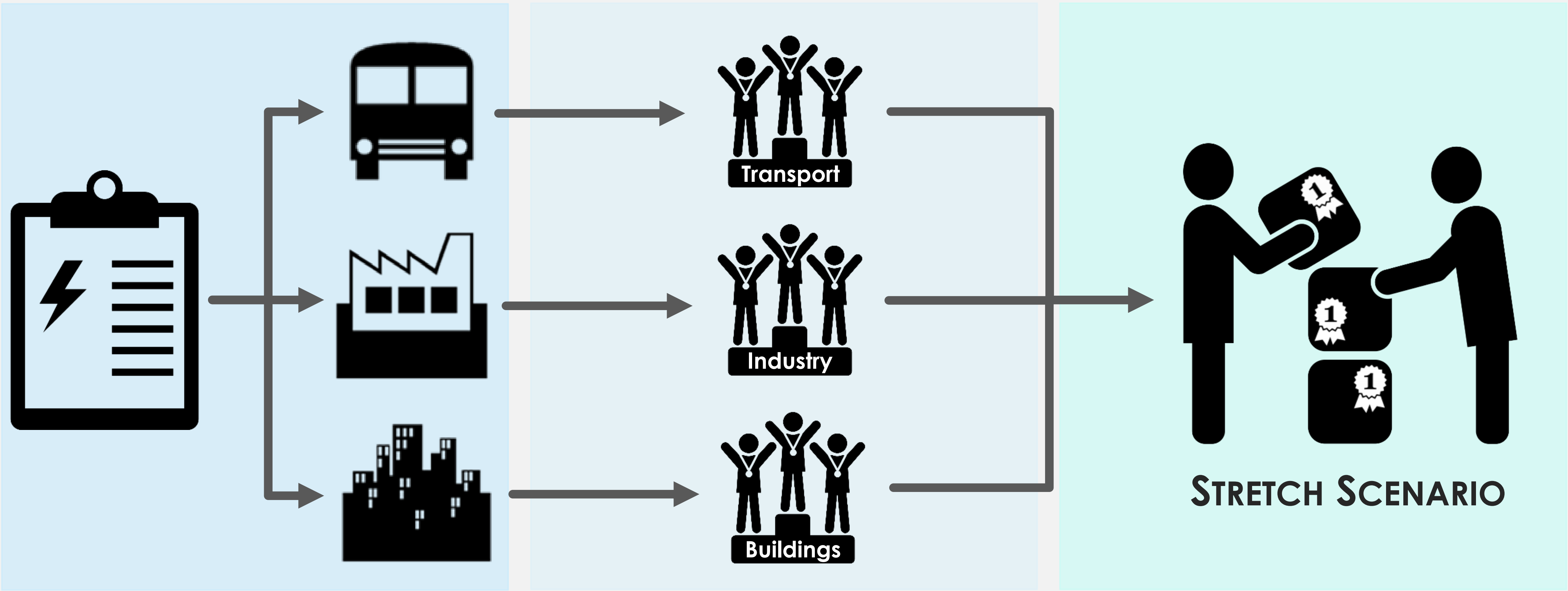
Note: Comparison made to models' internal reference case

Combining best performance across existing low carbon scenarios leads to an ambitious “stretch” scenario

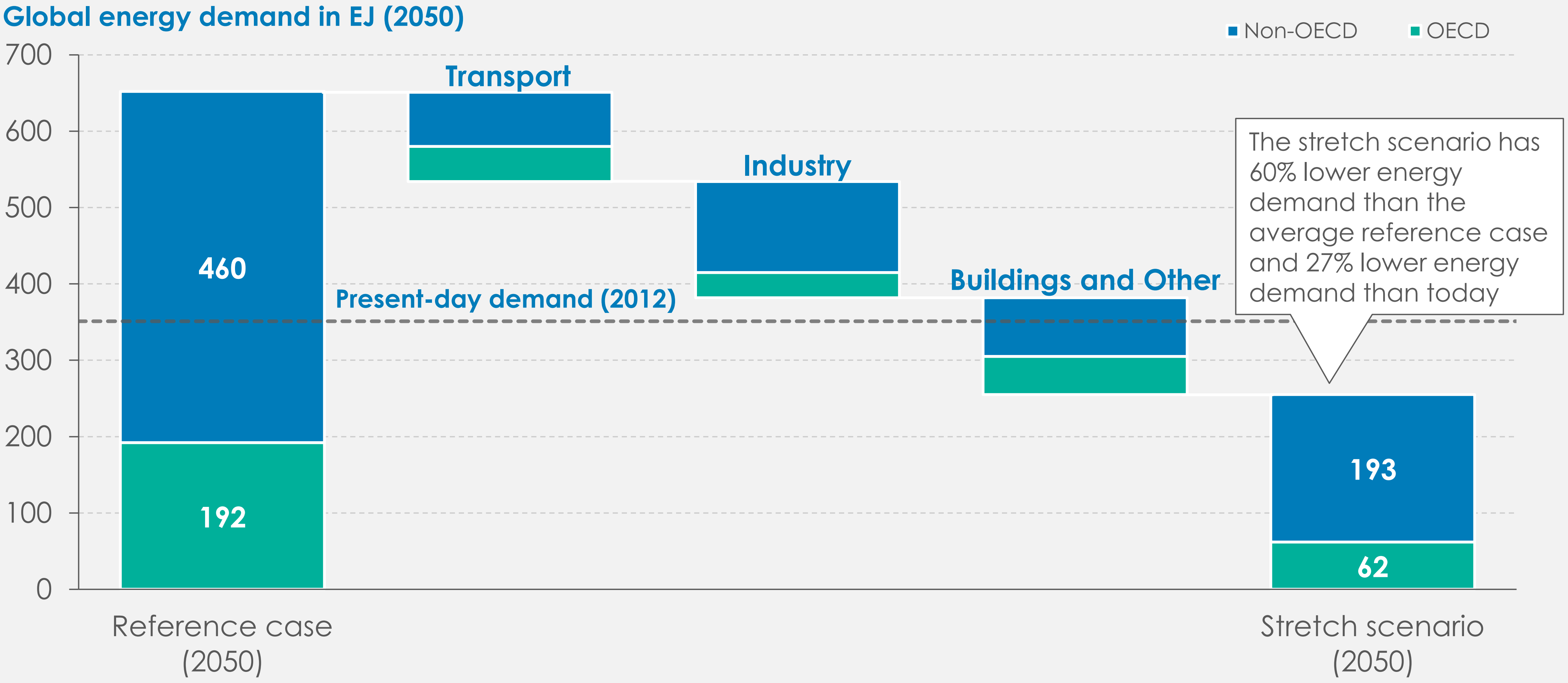
1. Decompose low carbon scenarios into their sectorial subcomponents

2. Within sectors rank scenarios according to lowest energy demand

3. Combine best performances to construct the “stretch” scenario



In a “stretch” scenario, global energy demand is 60% lower than in the reference case – with roughly equal reductions coming from each sector – and 27% lower than present-day demand



Note: The reference case is the average of ETP 6DS, AIM Reference, Greenpeace Reference, and GEA Reference. The lowest energy demand scenario is based on a combination of GEA Efficiency, Greenpeace Revolution and Greenpeace Advanced.

Scenarios rely primarily on energy efficiency to achieve energy demand reductions, although structural changes in energy services can unlock further improvements

$$\frac{GDP}{Energy} = \frac{Service\ level}{Energy} \times \frac{GDP}{Service\ level}$$

Energy efficiency of services:

Energy is converted into services, such as mobility in transport, comfort in buildings or tonnes of steel in industry

Technological improvements (e.g. more efficient vehicles) or modal shifts (e.g. switching to rail freight over road freight) provide a greater level of service for a particular quantity of energy (e.g. fewer joules per mile travelled)

GDP productivity of services:

Services across the transport, buildings and industry sectors are in turn used to generate economic activity

Structural changes (e.g. denser urban forms) and behavioural changes (e.g. remote working) enable more economic activity to be generated with a given level of services (e.g. fewer commuting miles for same level of economic activity)

Transport

- Energy demand from transport today
- Energy demand from transport by 2050
- Energy productivity improvements in transport – Examples
- Key drivers of energy productivity improvements in transport
- The role of electrification and alternative fuels in driving energy efficiency in transport
- How policy can drive energy efficiency improvements in transport – Examples

Transport accounts for 26% of current global final energy demand, with light road passenger vehicles and heavy road freight together constituting two thirds of transport energy demand

Transport

Present-day (2013)

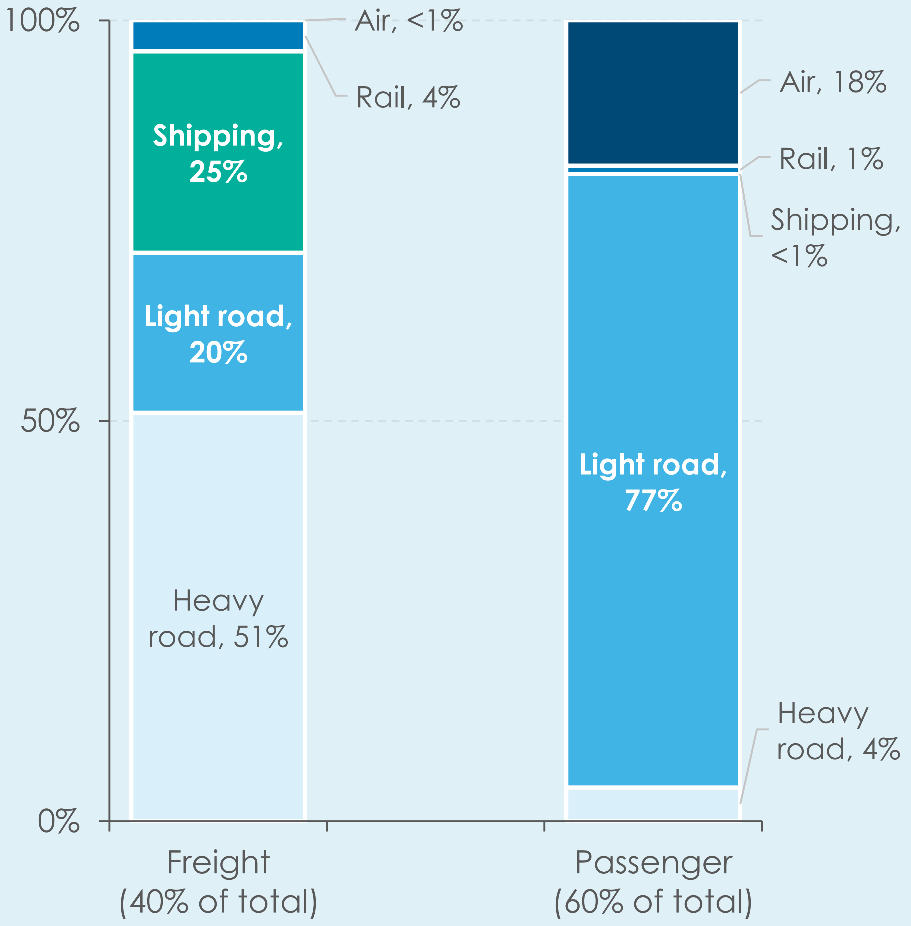
105EJ

26% of global final energy demand

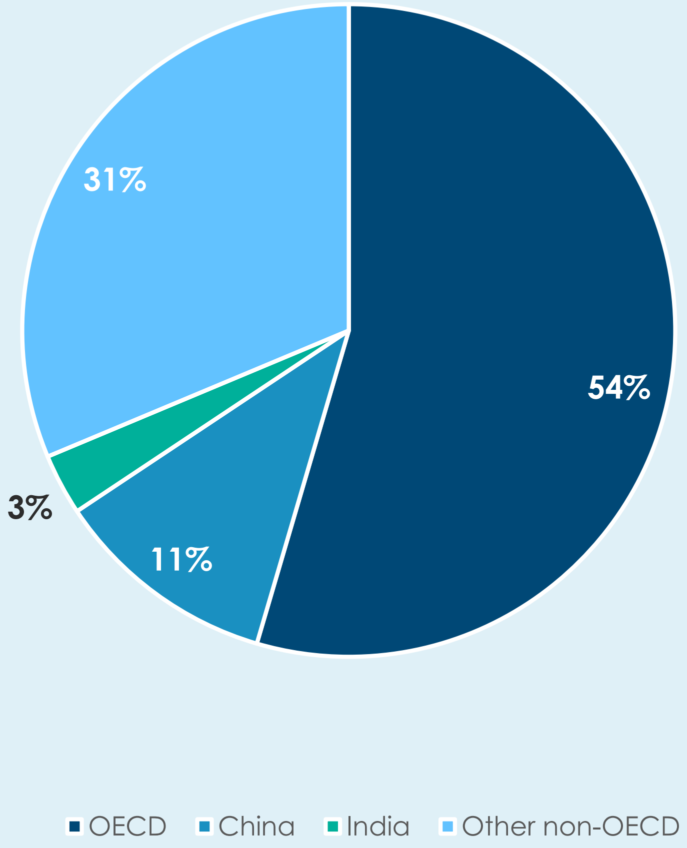
7,430MT CO_2[1]

22% of total carbon emissions

Energy demand by mode (2013)



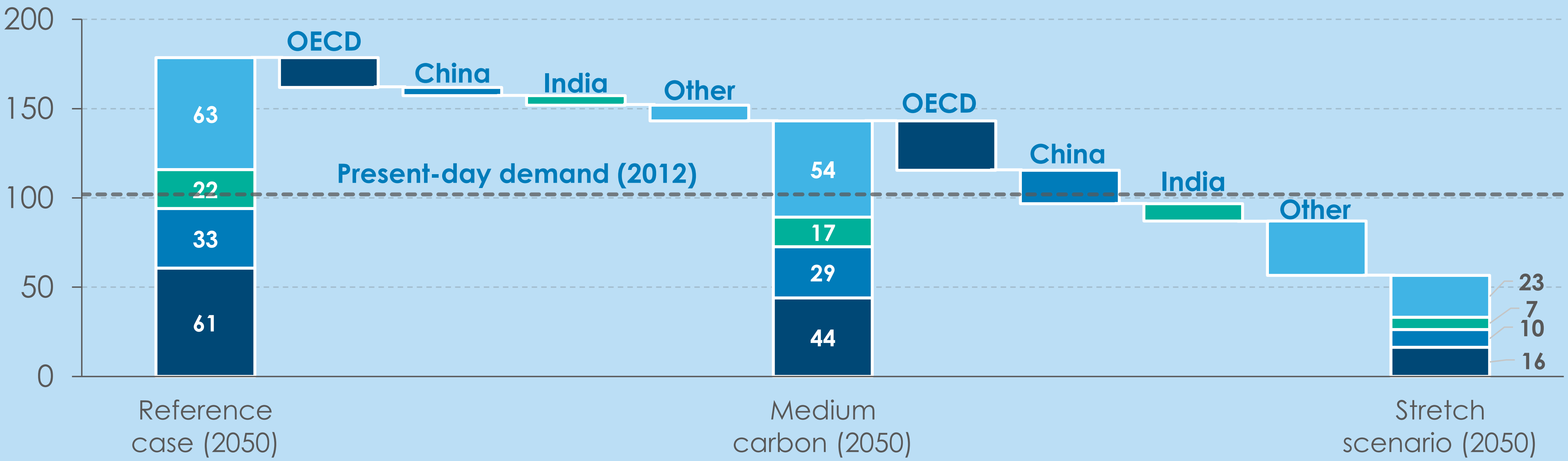
Energy demand by region (2013)

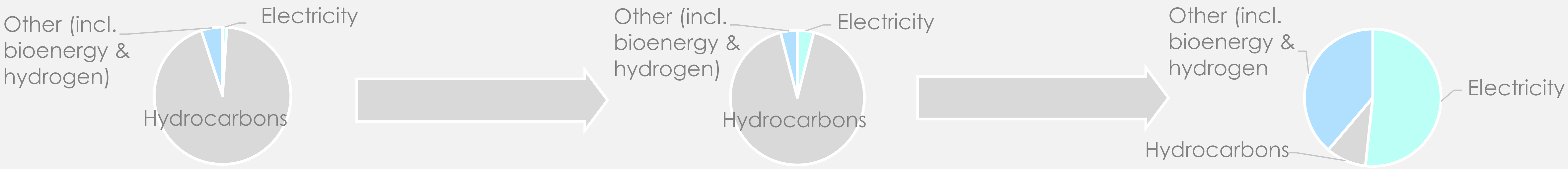


1 Total carbon emissions include both direct emissions and emissions from the generation of energy inputs used in the sector. Figures are based on the ETP 2016 estimates.

In the stretch scenario transport energy demand falls by ~70% versus the reference case, with two thirds of reductions in non-OECD economies

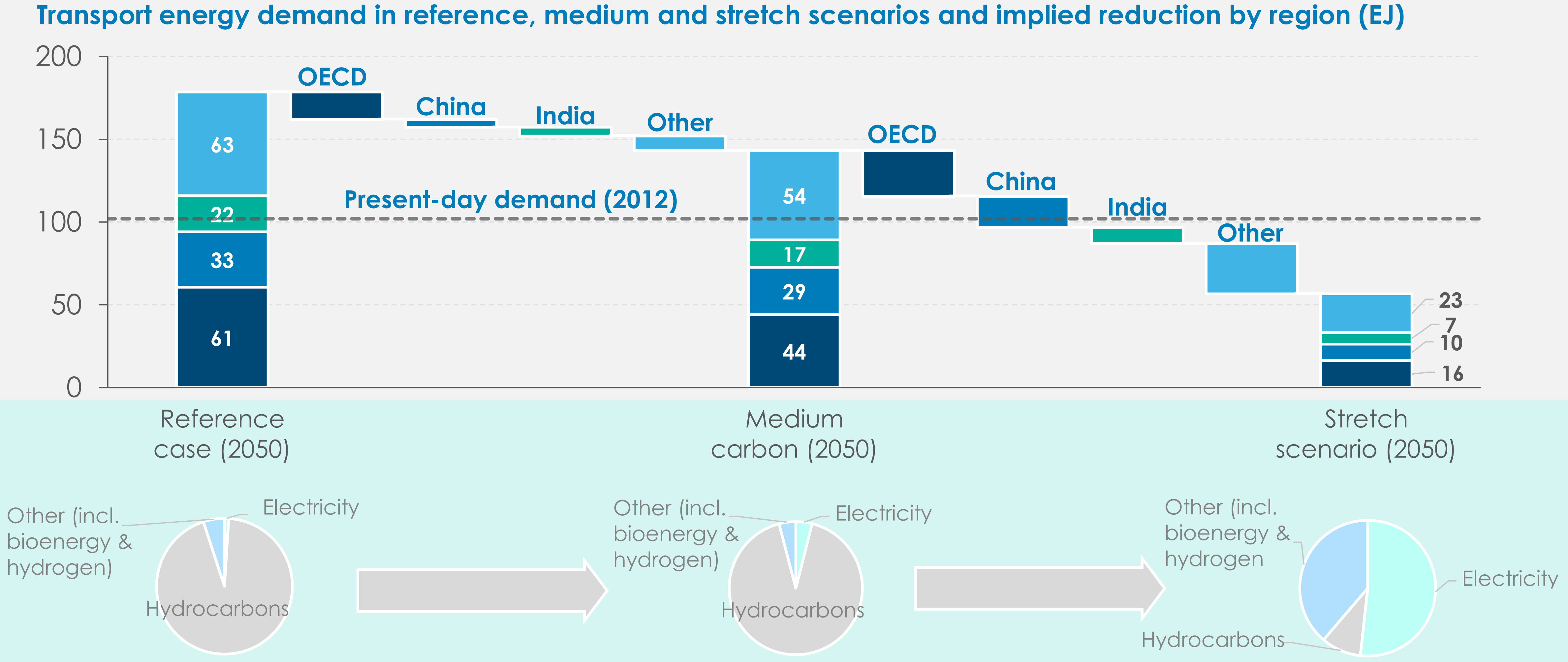
Transport energy demand in reference, medium and stretch scenarios and implied reduction by region (EJ)





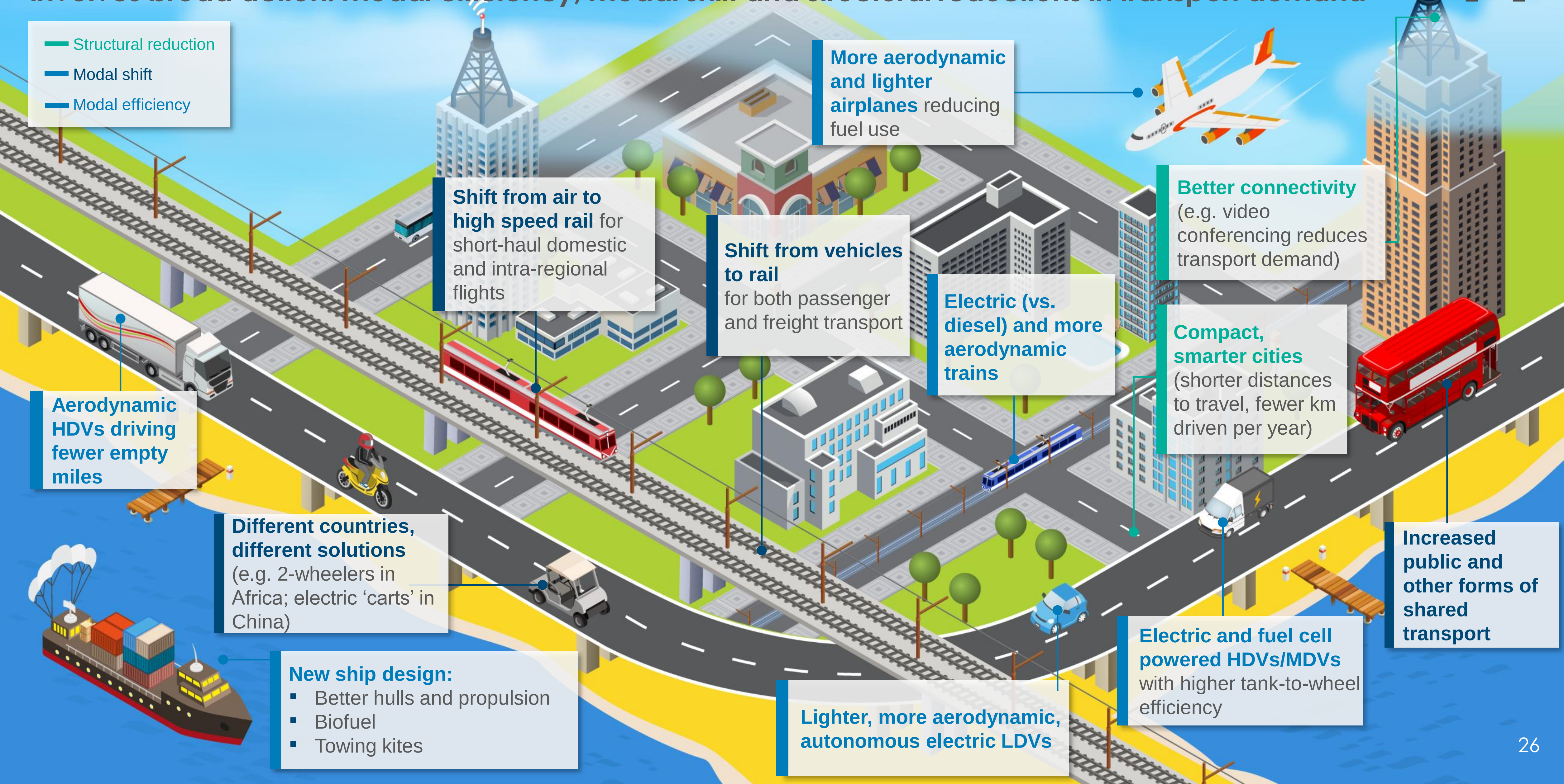
Note: Reference case is ETP 6DS; Medium carbon is the average of ETP 2DS, McKinsey BAU, Shell Ocean and Shell Mountains; Stretch scenario is Greenpeace Adv.

The stretch scenario implies fuel switching in the transport sector, with electricity and alternative fuels jointly accounting for 90% of energy demand compared to 6% in the reference case



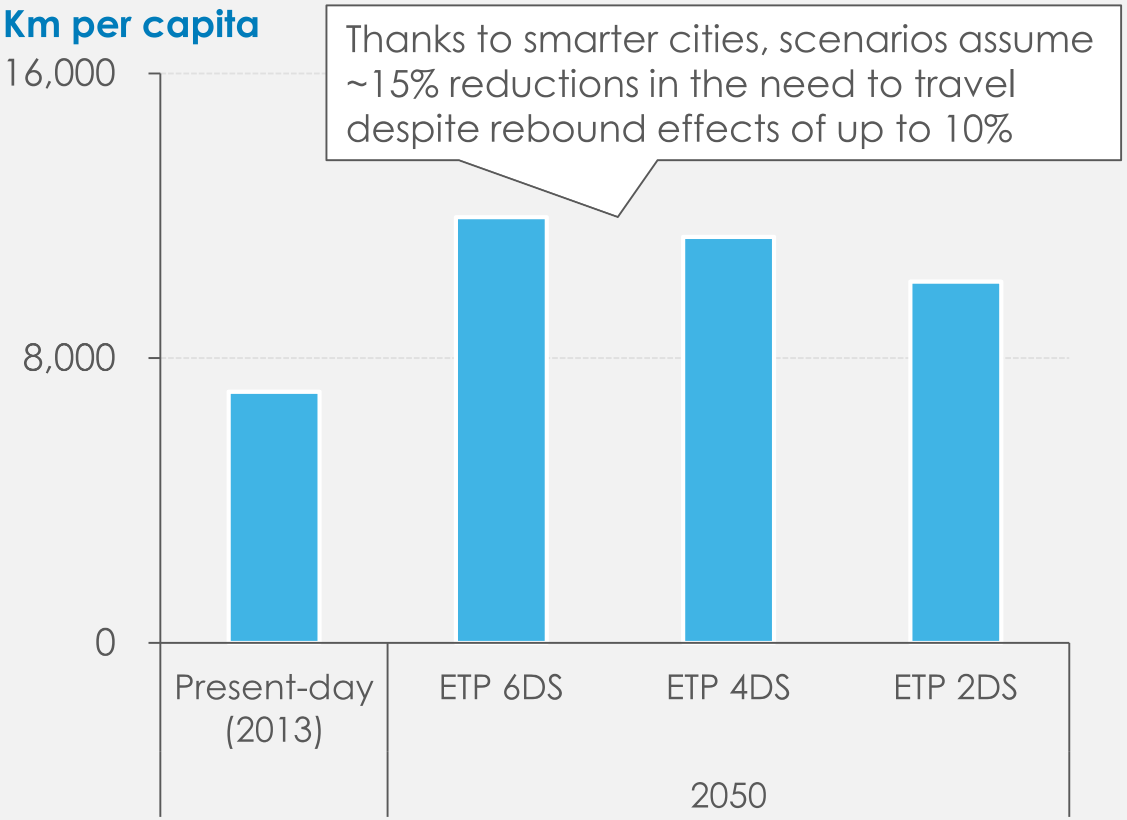
Note: Reference case is ETP 6DS; Medium carbon is the average of ETP 2DS, McKinsey BAU, Shell Ocean and Shell Mountains; Stretch scenario is Greenpeace Adv.

Achieving the depth of transport energy demand reductions envisioned in the stretch scenario involves broad action: modal efficiency, modal shift and structural reductions in transport demand

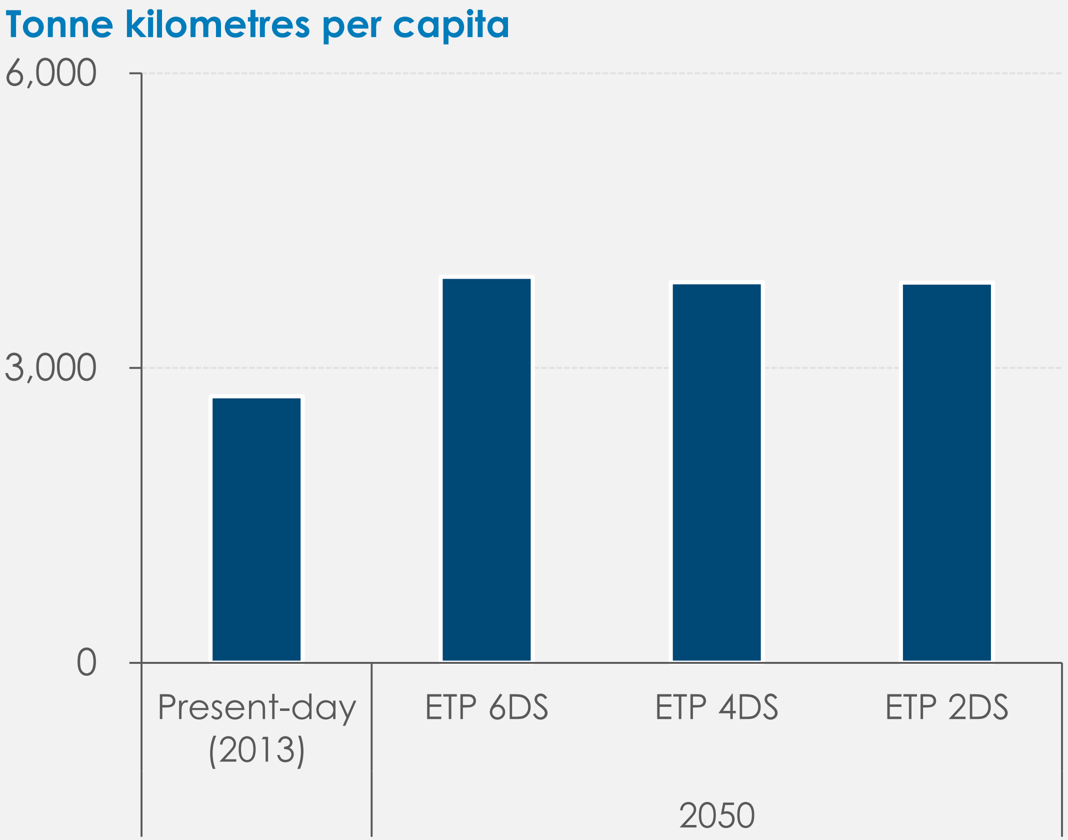


Moderate reductions in miles travelled are achieved in passenger transport, as structural changes allow people to travel less, while miles travelled in freight transport remain stable

Passenger transport



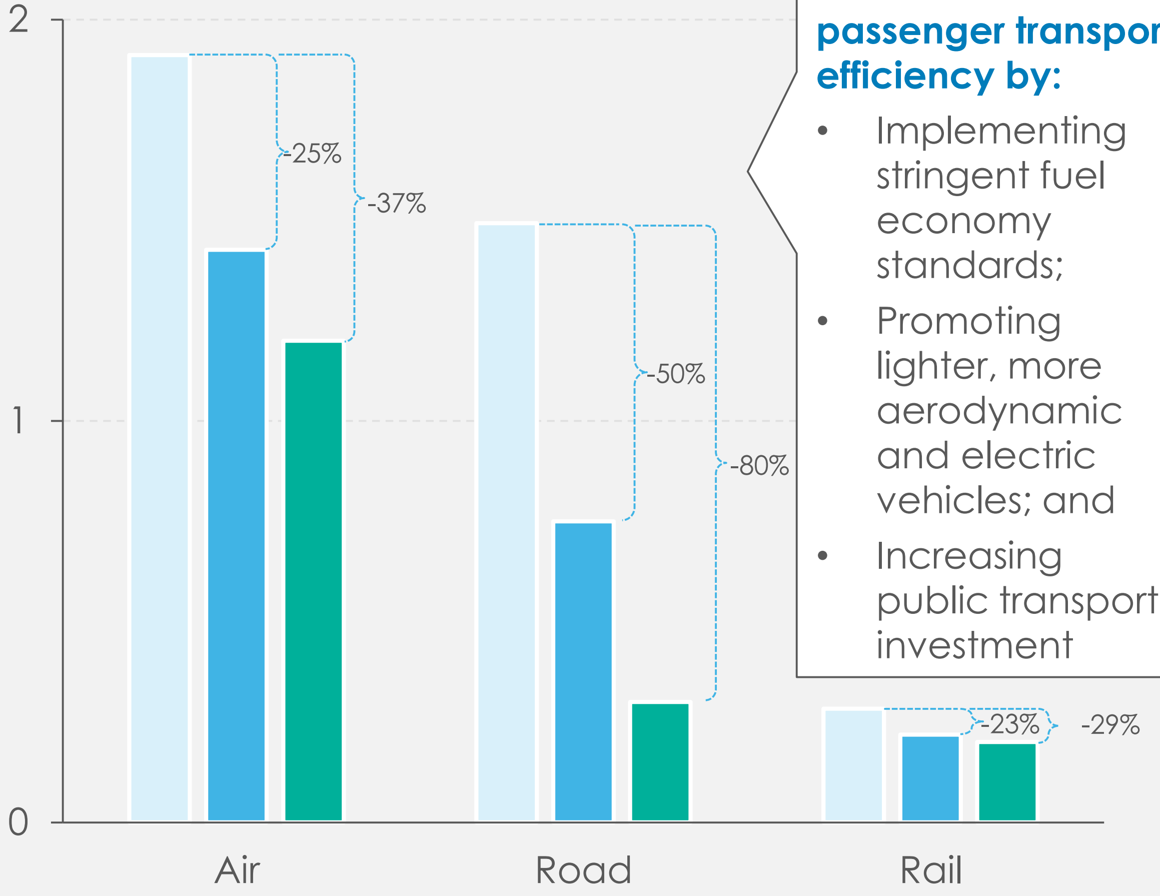
Freight transport



Note: The figures above only include transport with air, rail, and light and heavy road

Energy efficiency improvements drive the majority of transport energy demand reductions, either through switching between modes or within-mode efficiency improvements

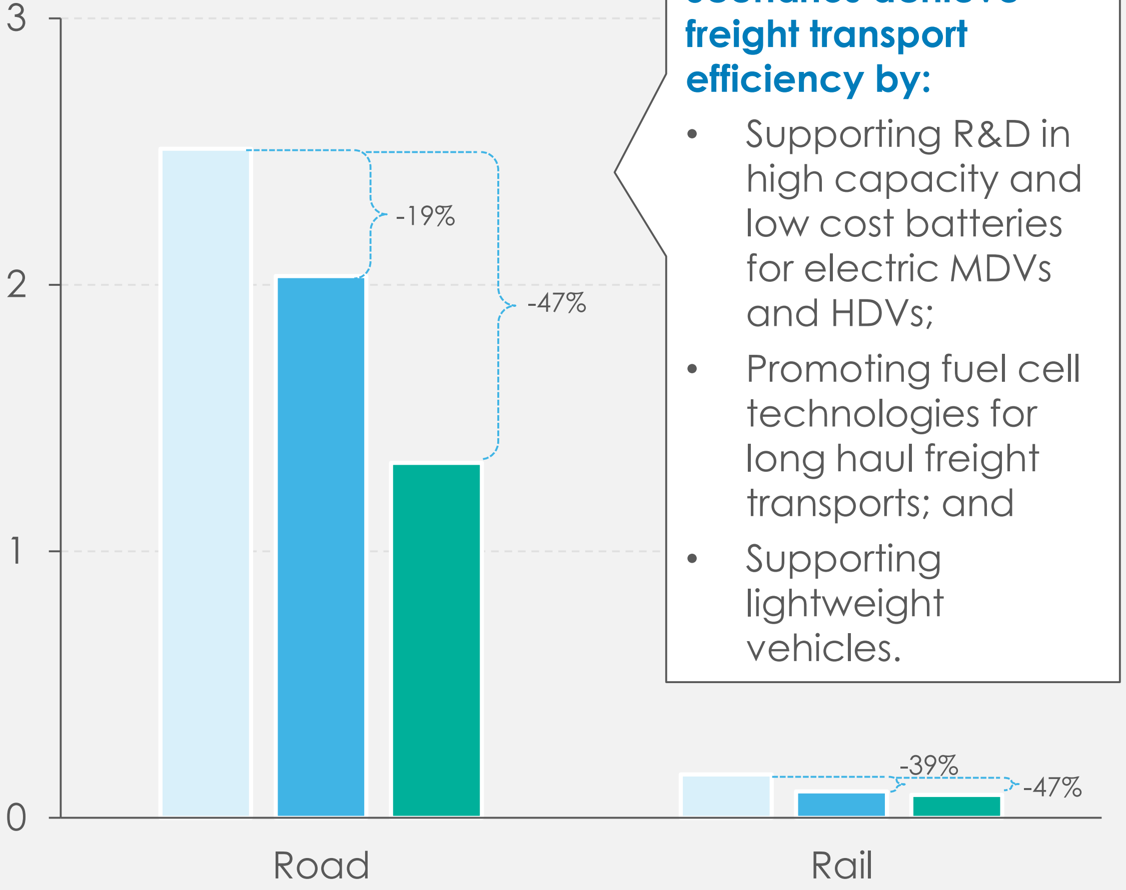
Passenger transport



Scenarios achieve passenger transport efficiency by:

- Implementing stringent fuel economy standards;
- Promoting lighter, more aerodynamic and electric vehicles; and
- Increasing public transport investment

Freight transport



Scenarios achieve freight transport efficiency by:

- Supporting R&D in high capacity and low cost batteries for electric MDVs and HDVs;
- Promoting fuel cell technologies for long haul freight transports; and
- Supporting lightweight vehicles.

□ Present-day (2010) ■ Shell Mountains (2050) ■ Stretch scenario (2050)

Modal shifting plays a role in reducing transport energy demand, especially through a shift to public transport for passenger travel and a shift to rail for freight travel

Shift from car to bus and rail

- 25% reduction in kilometres driven due to a shift to bus and rail

→ 40-50% reduction in energy per kilometre travelled

Shift from larger to smaller cars

- 10% shift from large sized to small-medium sized vehicles

→ 10-20% reduction in energy per kilometre travelled

Shift from air to rail

- 33% of short-haul air travel shifted to rail

→ ~80% reduction in energy per kilometre travelled

Shift from freight lorry to rail

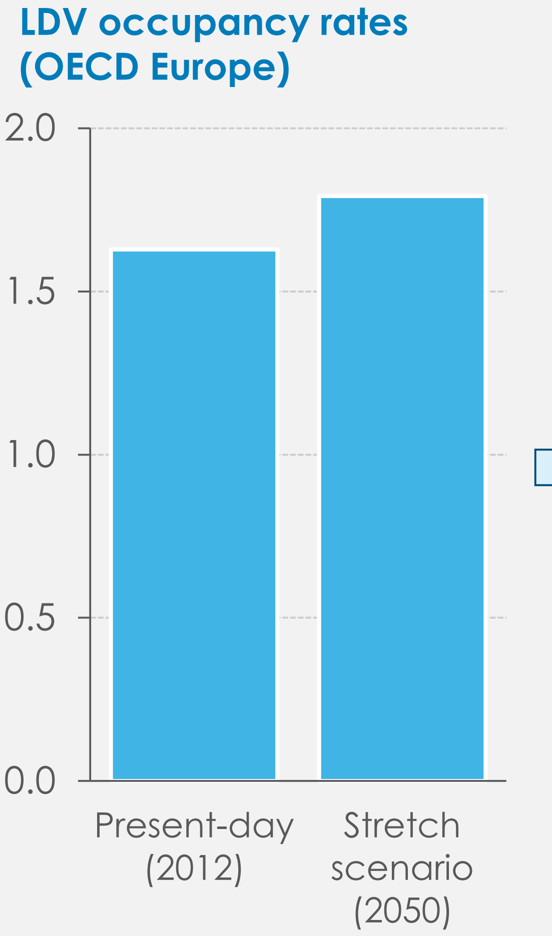
- 25% of heavy road freight shifted to rail

→ 80-90% reduction in energy per kilometre travelled

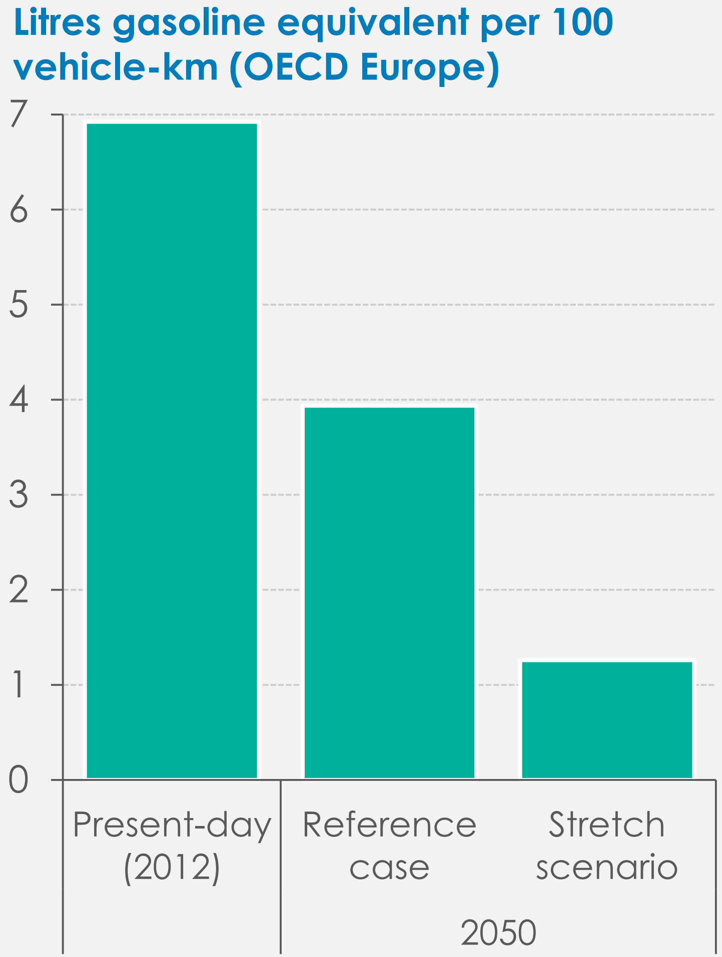
Estimates suggest that these four major modal shifts would reduce total transport energy demand by roughly 10%

Within-mode efficiency improvements can halve transport energy demand, through moderate gains in occupancy rates combined with large improvements in vehicle efficiency

Increased occupancy



Improved conversion



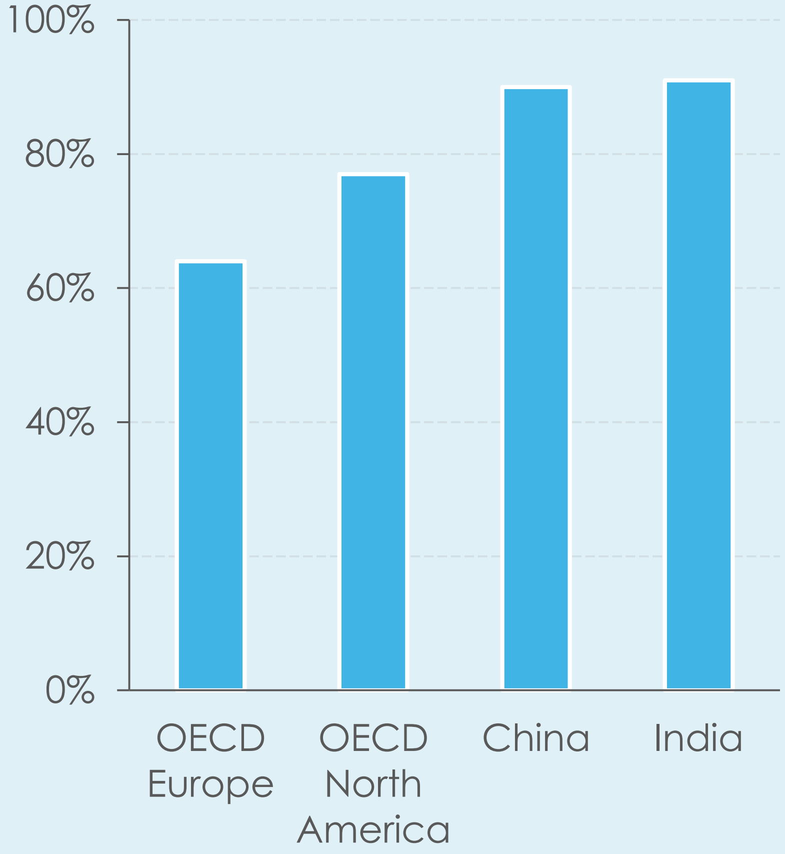
Estimates suggest that improvements in within-mode efficiency improvements could reduce total transport energy demand by approximately 50%

Note: Stretch scenario is Greenpeace Rev.

A large proportion of passenger vehicle efficiency improvements is driven by electrification, with a smaller contribution from mechanical efficiency

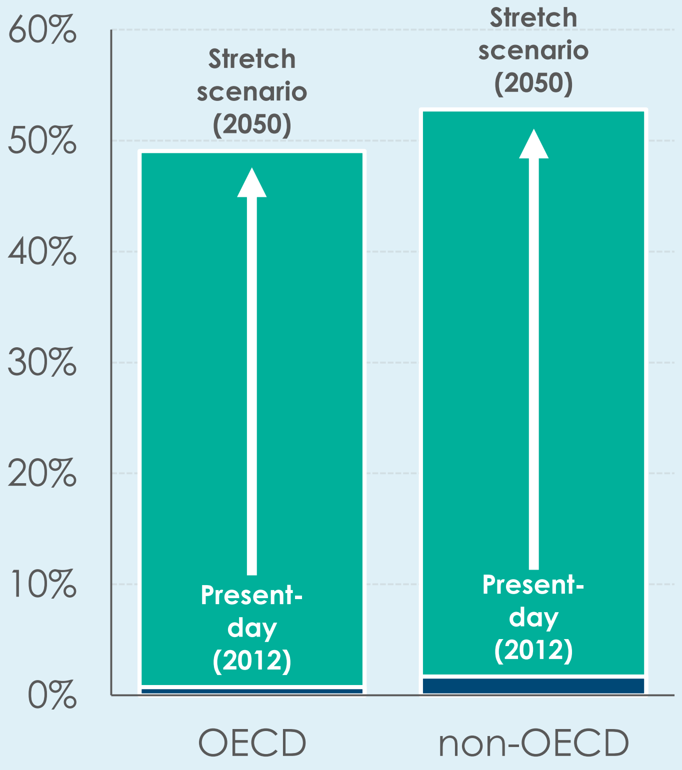
High share of EVs

EVs as a share of total vehicle sales in 2050 in the stretch scenario



High electrification

Electricity as share of transport energy demand in 2050 in the stretch scenario



Improved technical efficiency

Fuel-in-tank vehicle

100% fuel in 'tank' (gasoline)

Tank to wheel efficiency:

- **Internal combustion engine = 15%**
- **Hybrid electric vehicle = 22-29%**

Electric vehicle

100% fuel in 'tank' electricity

Tank to wheel efficiency:

- **Battery electric vehicle (low) = 67%**
- **Battery electric vehicle (high) = 81%**

Estimates suggest that efficiency gains due to electrification represent ~60-75% of the passenger vehicle efficiency gains in the stretch scenario, with the remainder due to mechanical efficiency

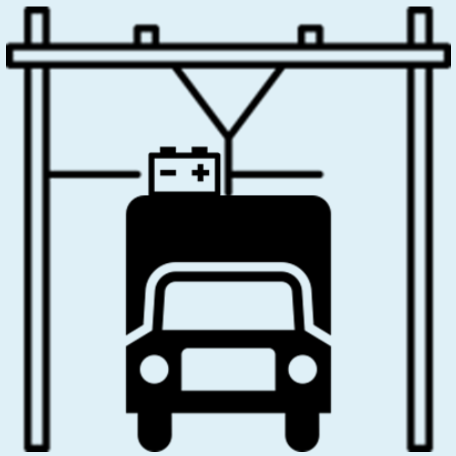
Note: Stretch scenario is Greenpeace Adv.

Radical innovation is required to drive heavy duty vehicle efficiency through fuel switching, as freight transport has limited fuel alternatives to date

Limits for electrification of long-haul freight

There are extra difficulties in electrifying long-haul road freight because:

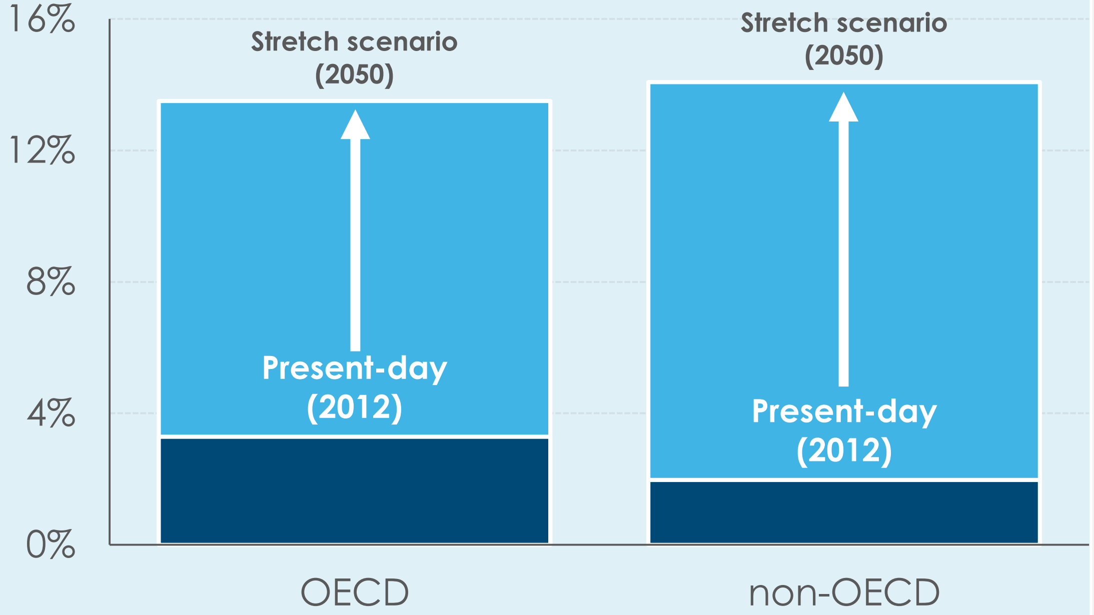
- the driving ranges of electric vehicles are limited due to battery constraints, and
- overhead catenary lines are not practical for long distance travel or in certain areas



A role for biofuels and potentially hydrogen

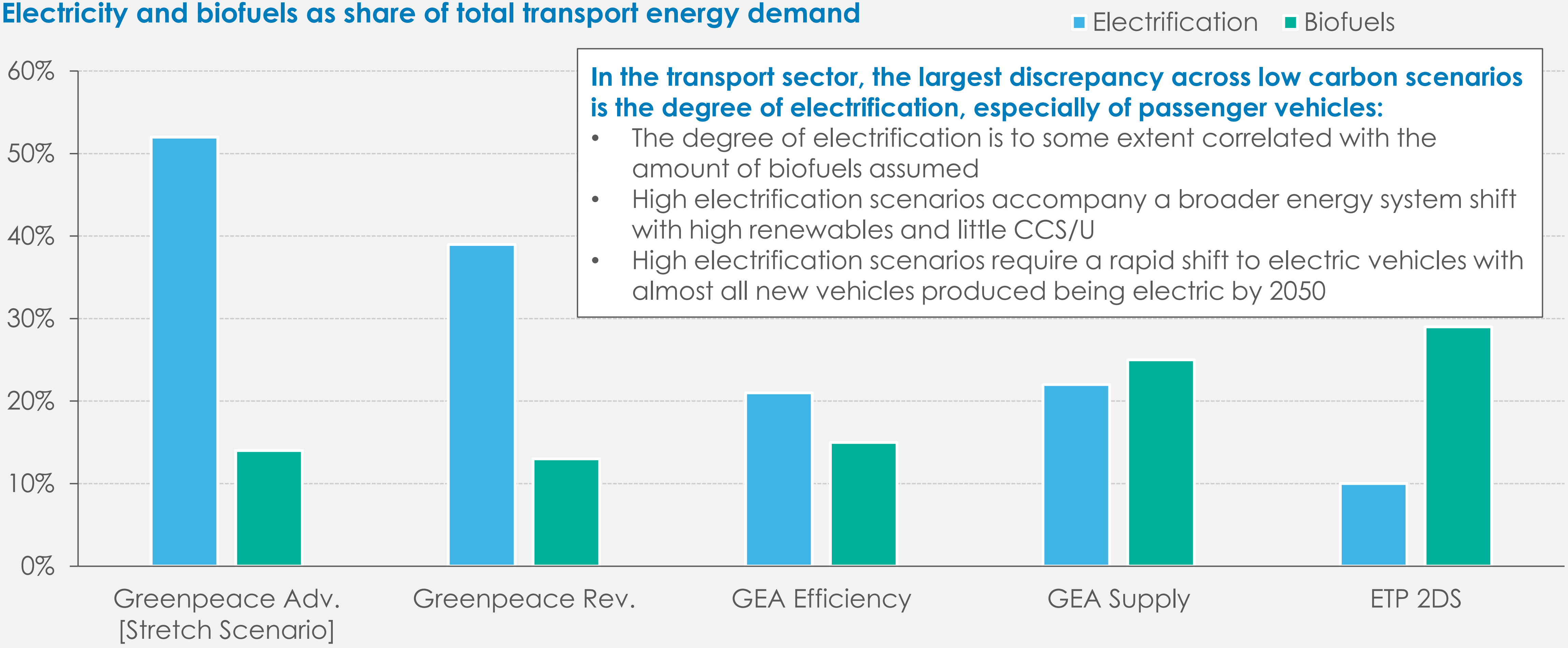
Hence, the use of hydrogen fuel cells and biofuels become of greater importance as hydrocarbons are phased out

Bioenergy as share of transport energy demand in 2050 in the stretch scenario



Low carbon scenarios differ significantly in the degree of electrification and the amount of biofuels assumed in 2050, resulting in different total transport energy demand levels

Electricity and biofuels as share of total transport energy demand



In the transport sector, the largest discrepancy across low carbon scenarios is the degree of electrification, especially of passenger vehicles:

- The degree of electrification is to some extent correlated with the amount of biofuels assumed
- High electrification scenarios accompany a broader energy system shift with high renewables and little CCS/U
- High electrification scenarios require a rapid shift to electric vehicles with almost all new vehicles produced being electric by 2050

	Greenpeace Adv. [Stretch Scenario]	Greenpeace Rev.	GEA Efficiency	GEA Supply	ETP 2DS
Total transport energy demand in 2050 (EJ)	**57**	**70**	**89**	**138**	**100**

Urban planning and infrastructure, incentives to behaviour changes, vehicles standards and targeted support to innovation can drive transport energy demand reductions

			Rough share of reduction potential[1]:
Structural reduction in transport demand and modal shift	**Compact and connected cities**	▪ Urban planning and zoning regulations that create greater density and reduce transit needs ▪ Reduction of explicit or implicit subsidies for urban sprawl through service pricing and land taxes that reflect the public cost ▪ Incentives for technology alternatives to travel (e.g. teleconferencing or home working)	**20-40%** The impact of compact and connected cities is not well modelled in scenarios
	Shift to public transport	▪ Increased investment in integrated, efficient public transit systems (from first to last mile) ▪ Incentives to shifts towards more efficient modes of transport (e.g. subsidised public transport, congestion charges, pricing of parking)	
	Shift to more efficient vehicles	▪ Price and tax incentives to support shift to most efficient options (e.g. small over large vehicles, EV vehicles over ICE vehicles, rail over air transport) ▪ Support to the development of enabling infrastructure where necessary (e.g. charging network, improved rail network)	
Technical efficiency	**Fuel economy standards**	▪ Implementation of more stringent fuel economy standards ▪ Improved compliance with existing standards	**60-80%** … of which roughly half comes from electrification
	Low carbon fuels (carbon efficiency)	▪ Targeted support for low carbon fuels including synthetic fuels, biofuels and hydrogen, in particular to target relatively inflexible sources of demand (e.g. aviation or sparsely populated rural regions)	
	Technology innovation	▪ Targeted R&D support programmes to accelerate commercialisation and deployment of enabling technologies (e.g. high capacity and low cost batteries for electric vehicles, lighter and more aerodynamic vehicle design)	

1 Very roughly estimated for illustrative purposes, using data from across scenarios and from supplemental sources

Industry

Industry accounts for 32% of current global final energy demand, with heavy industries (such as chemicals, cement, iron and steel) constituting the majority of energy consumption in the sector

Industry

Present-day (2013)

127EJ[1]

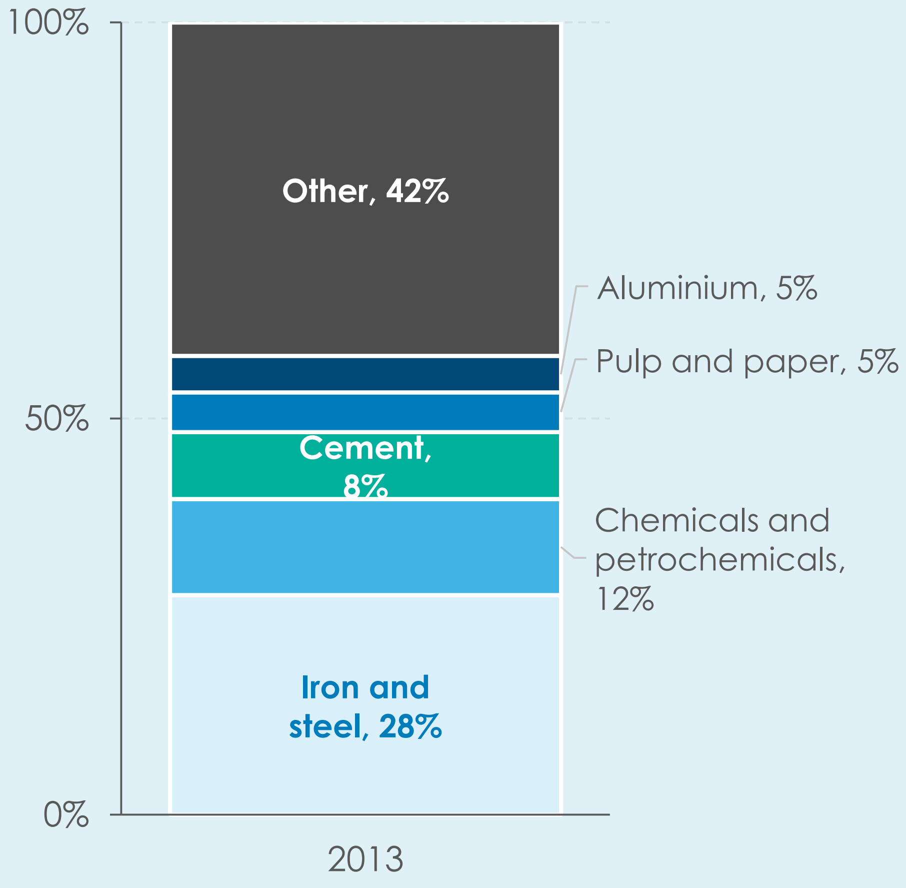
32% of global final energy demand

14,515MT CO_2[2]

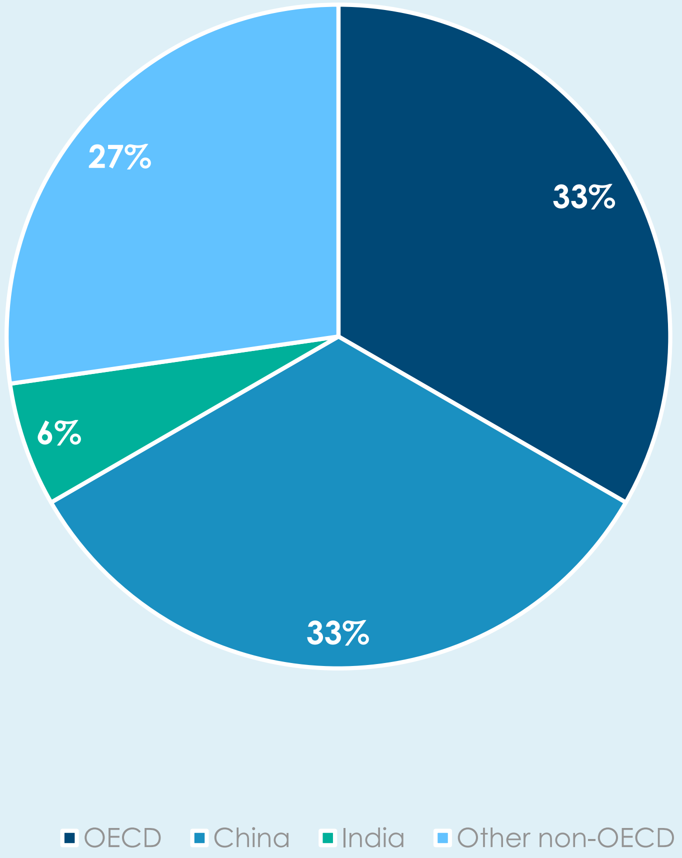
43% of total carbon emissions

- *Approx. 2,700MT are process emissions[2]*

Energy demand by industry (2013)[3]

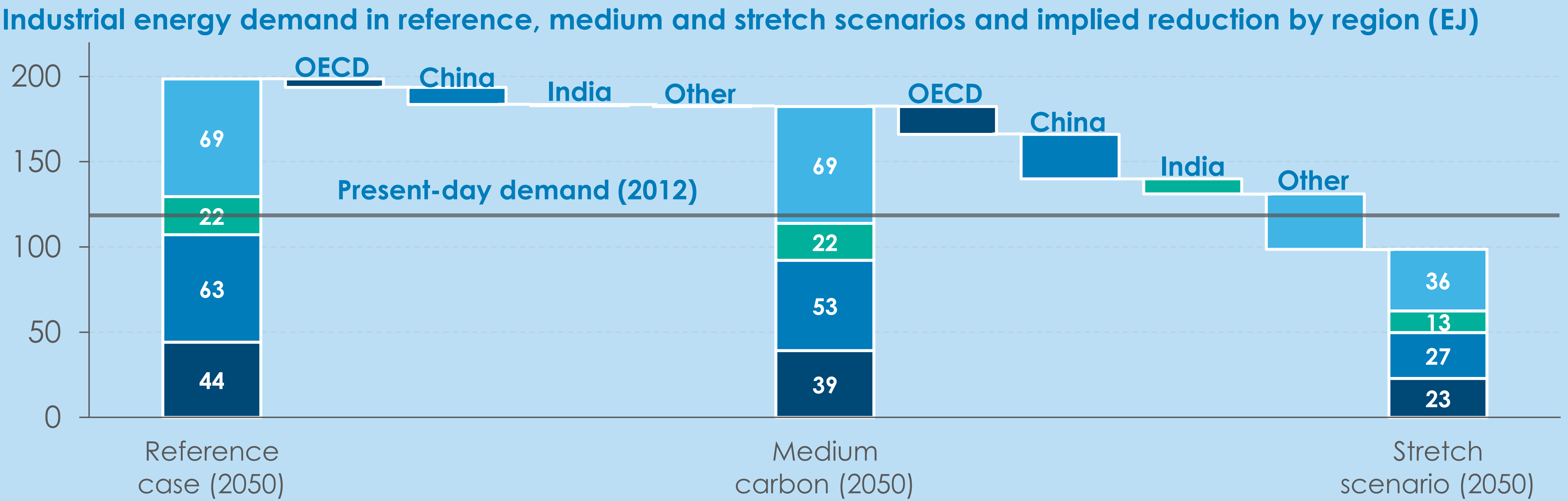


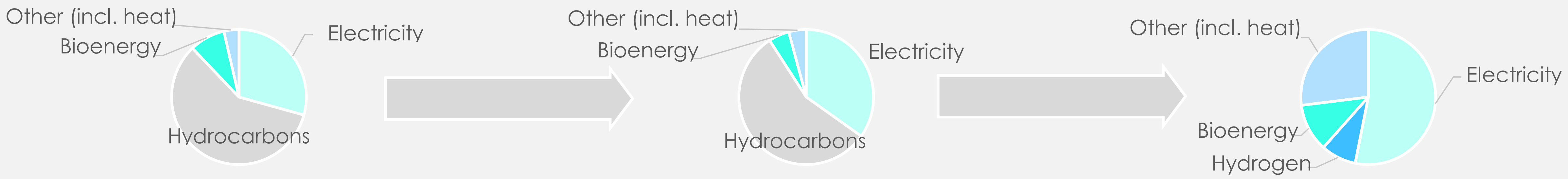
Energy demand by region (2013)[4]



Note: 1 Excl. energy content of chemical feedstock
3 Excl. chemical feedstock
2 Total carbon emissions include process emission, direct emissions and emissions from the generation of energy inputs
4 Incl. chemical feedstock. – Figures are based on the ETP 2016 estimates.

In the stretch scenario, industrial energy demand is lower by a factor 2 versus the reference case, with 36% of reductions coming from China and one third from other non-OECD countries

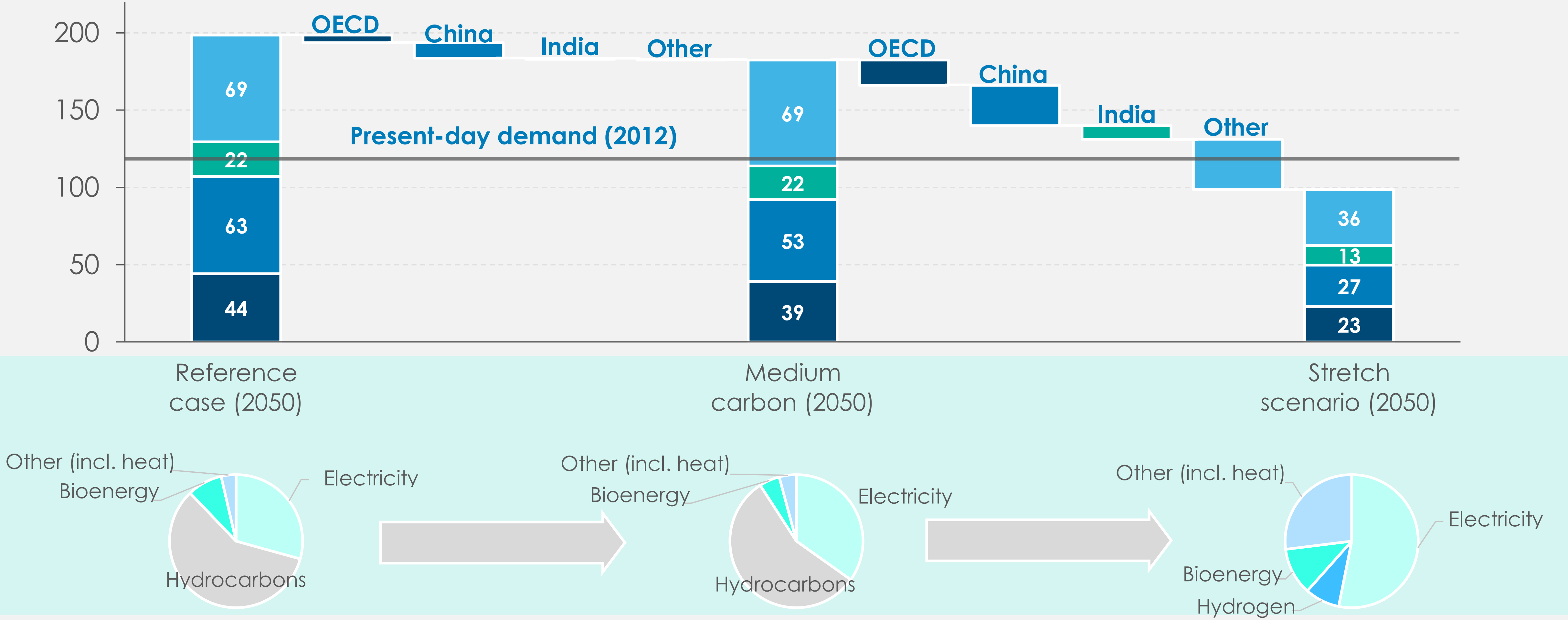




Note: Reference case is ETP 6DS; Medium carbon is the average of ETP 2DS, McKinsey BAU, Shell Ocean and Shell Mountains; Stretch scenario is Greenpeace Adv.

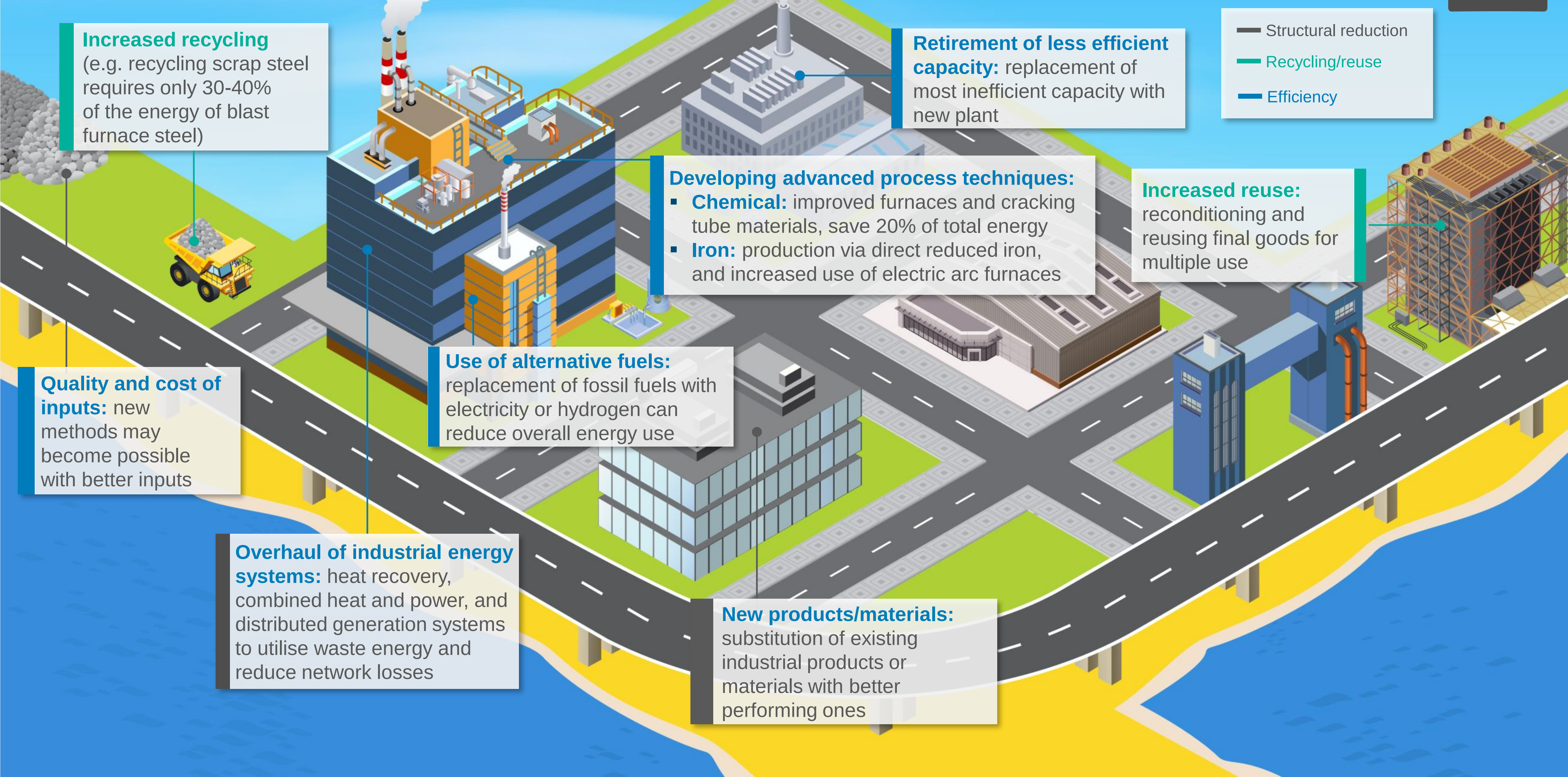
The stretch scenario implies a full substitution of hydrocarbons in the industrial sector, with electricity accounting for 53% of energy demand and alternative fuels for the remaining 47%

Industrial energy demand in reference, medium and stretch scenarios and implied reduction by region (EJ)



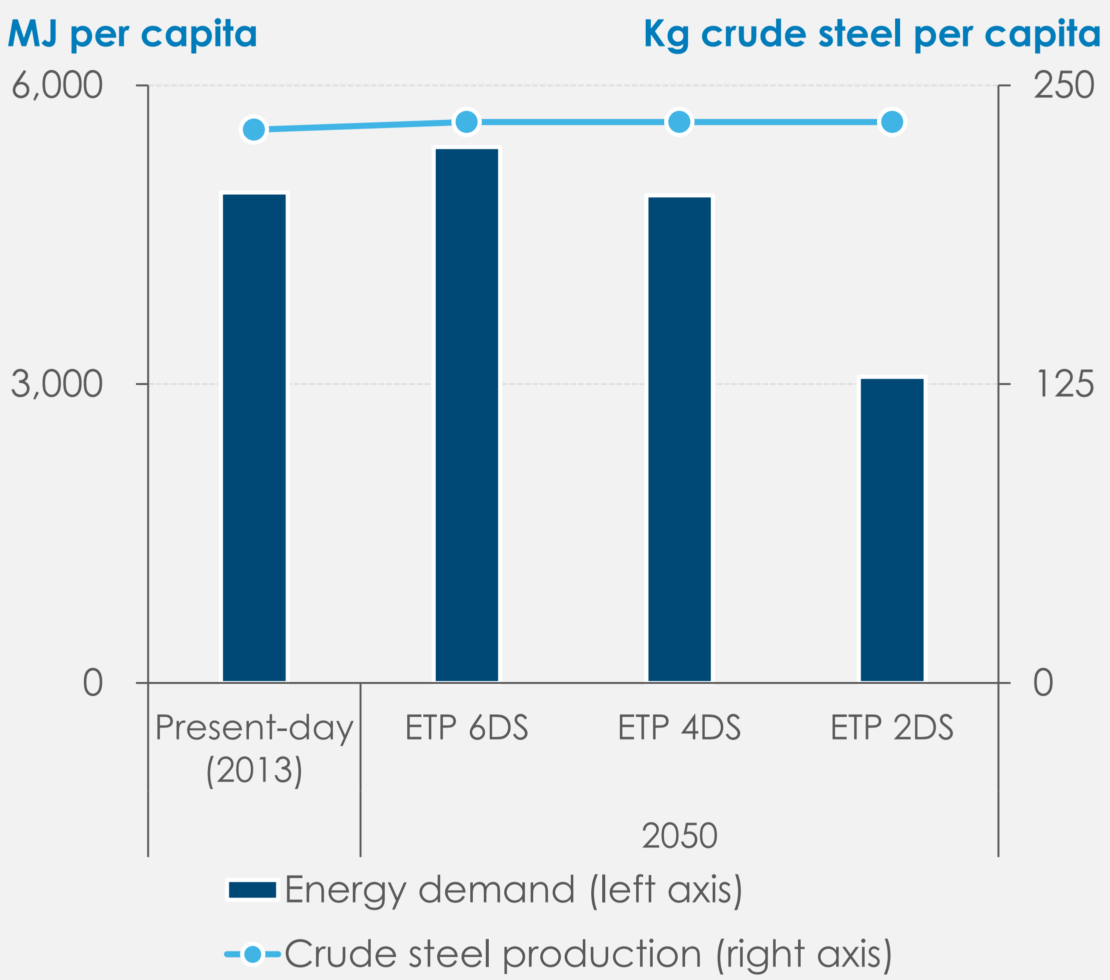
Note: Reference case is ETP 6DS; Medium carbon is the average of ETP 2DS, McKinsey BAU, Shell Ocean and Shell Mountains; Stretch scenario is Greenpeace Adv.

The stretch scenario relies mostly on efficiency measures to achieve reductions in industrial energy demand, but structural reductions can unlock additional potential

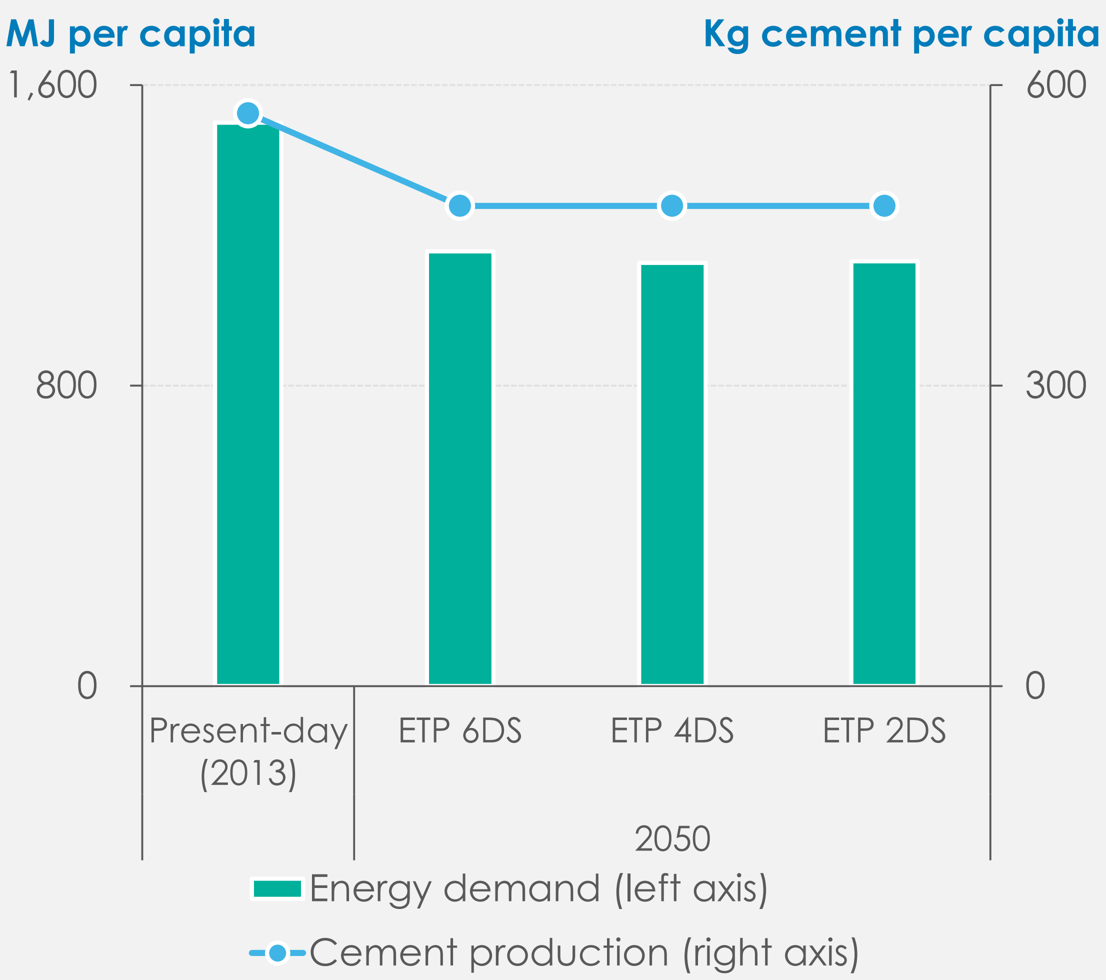


Across low carbon scenarios, industrial energy demand per capita falls due to increased efficiency rather than to lower resource use: Production per capita remains relatively stable

Iron and steel production



Cement production



Note: For iron and steel, final energy consumption includes blast furnaces and coke ovens.

Improved processes and retirement of less efficient capacity alone result in a 50% reduction in industrial energy demand: Additional gains from structural changes are not well modelled

Retirement of less efficient capacity

- Replacing old plant with a typical new plant can reduce energy demand by 30-45%

Improved process efficiency

- Over the next two decades, advanced process efficiency could reduce energy demand by 20-30% in some cases

Greater waste heat recovery

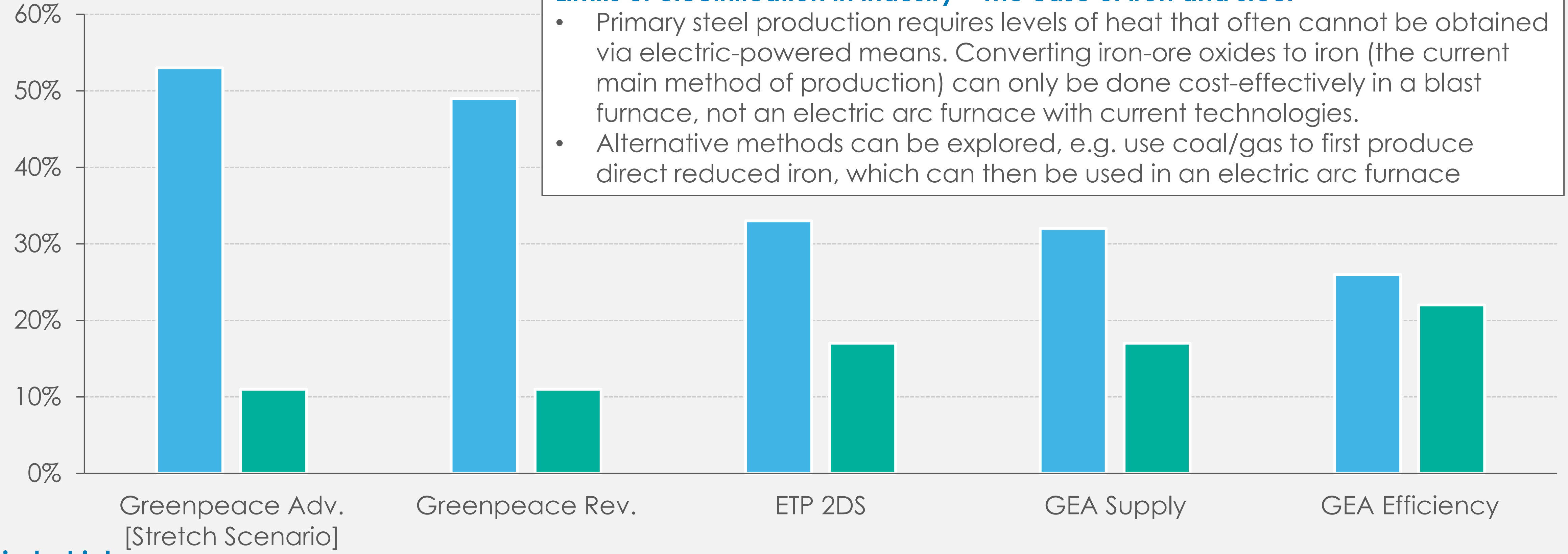
- Combined heat and power systems with use of waste heat could reduce energy demand by 10-50% in some cases

- **These three overarching shifts are responsible for almost the entire 50% reduction in industrial energy demand envisioned in the stretch scenario**
- **Other potential levers, such as the development of a more circular economy, are not deeply considered in scenarios**

Note: Modelling teams did not provide detailed information about the assumptions made, but available references and overall improvements achieved in the most ambitious scenarios point to this scale of improvements.

Low carbon scenarios differ significantly in the degree of electrification and the amount of biofuels assumed in 2050, resulting in different total industrial energy demand levels

Electricity and biofuels as share of total industrial energy demand



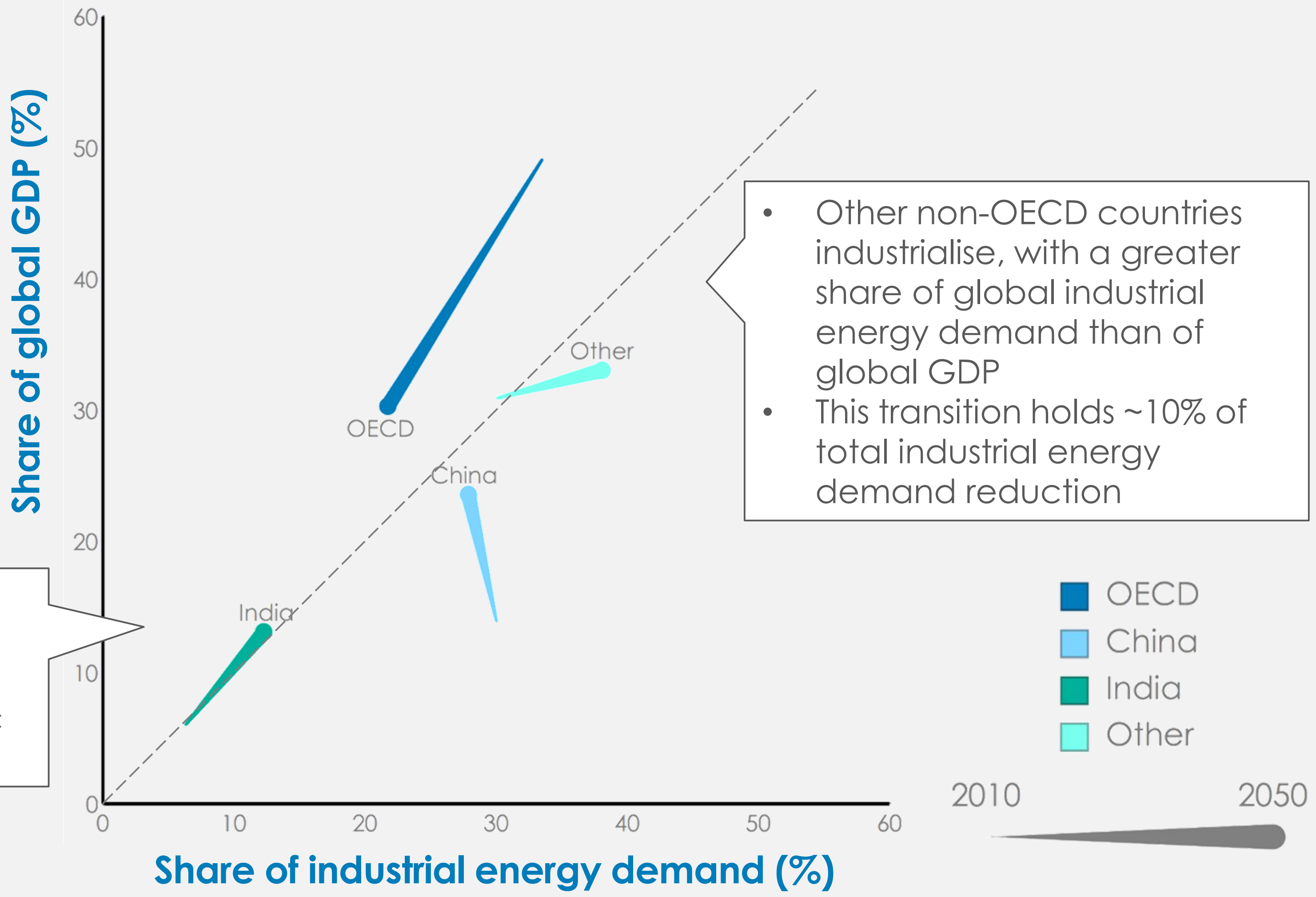
Limits of electrification in industry – The case of iron and steel

- Primary steel production requires levels of heat that often cannot be obtained via electric-powered means. Converting iron-ore oxides to iron (the current main method of production) can only be done cost-effectively in a blast furnace, not an electric arc furnace with current technologies.
- Alternative methods can be explored, e.g. use coal/gas to first produce direct reduced iron, which can then be used in an electric arc furnace

Total industrial energy demand in 2050 (EJ)	Greenpeace Adv. [Stretch Scenario]	Greenpeace Rev.	ETP 2DS	GEA Supply	GEA Efficiency
	99	**98**	**138**	**255**	**209**

Industrial energy use shifts out of China into other, newly industrialising, non-OECD countries:

New industrial capacity offers an opportunity for deployment of efficient technologies

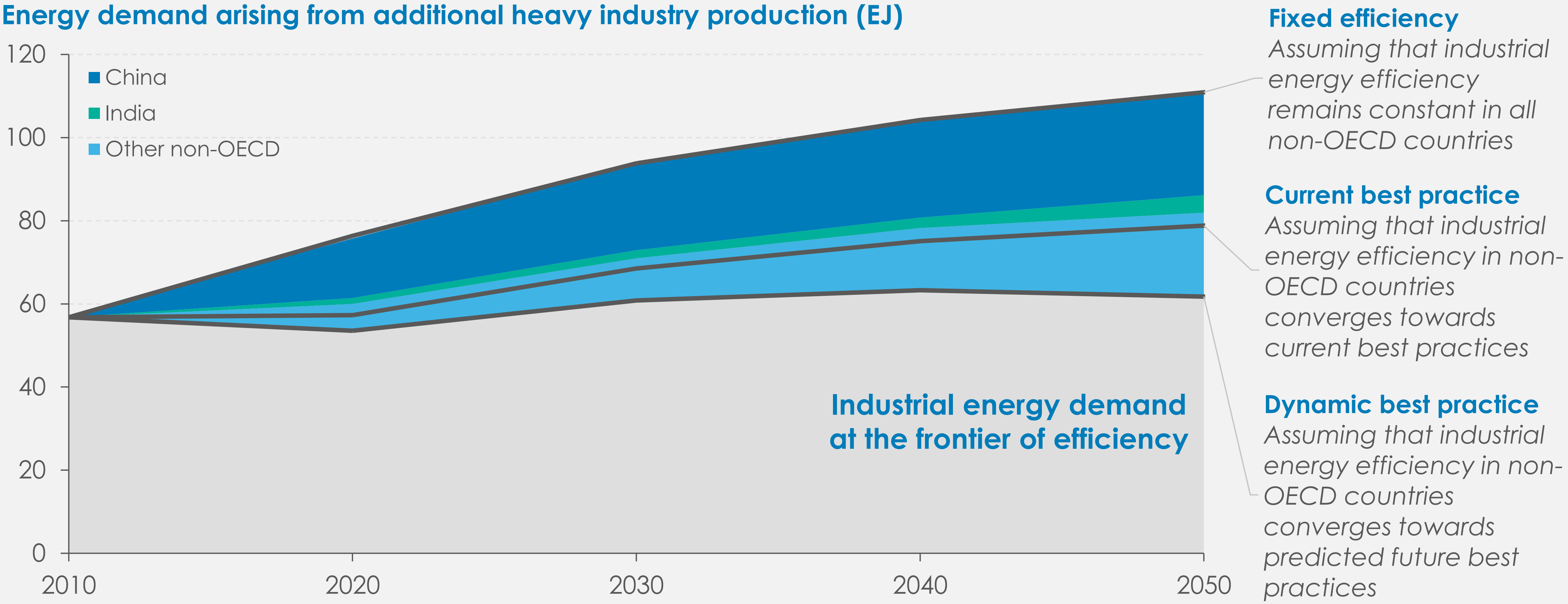


India industrialises rapidly, but this appears to be in line with domestic GDP needs

- Other non-OECD countries industrialise, with a greater share of global industrial energy demand than of global GDP
- This transition holds ~10% of total industrial energy demand reduction

Note: Shares are averaged across all scenarios, as shares are relatively constant across scenario types, i.e. share of industrial energy demand in regions does not vary significantly depending on whether scenario is low carbon, medium carbon or reference

Energy demand from heavy industry can remain stable if emergent Best Available Techniques are disseminated, whereas absence of best practice roll-out would lead to a 95% increase



Note: Based on Shell Mountains

A range of price and tax incentives combined with targeted RD&D and support to the roll-out of Best Available Technologies can drive industrial energy demand reductions

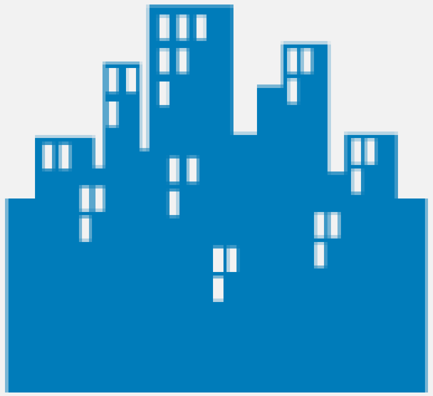
			Rough share of reduction potential[1]:
Structural reduction	Shift to lower-energy products	▪ Incentives to shift industrial product demand to lower energy (and lower carbon) substitutes ▪ RD&D support to develop new industrial products involving the use of less energy	**5-10%** Not well estimated in scenarios
	Improved industrial energy systems	▪ Tax incentives and subsidies for the fitting of high-temperature heat recovery in plant design and retrofit to reduce wasted energy ▪ Support for distributed on-site renewable co-generation can further improve energy efficiency by capturing waste heat for low temperature processes and reducing network losses	
Recycling and reuse	Increased recycling	▪ Waste fees levied on consumers to increase rates of recycling of materials at product end-of-life ▪ Subsidies to producers to incentivise the use of recycled materials over new raw materials ▪ Support to information/labelling programmes to increase the consumption of goods with recycled inputs ▪ RD&D for products that enable greater recycling of materials at low costs	**N/A** Not explicitly estimated in scenarios
	Increased reuse	▪ Waste fees levied on consumers to increase rates of refurbishment at product end-of-life ▪ Subsidies to producers to incentivise the supply of refurbished products over new ones ▪ Support to information/labelling programs to increase reuse ▪ RD&D for product development that enables easy repair and refurbishment	
Efficiency	Advanced techniques	▪ RD&D to accelerate the commercialisation and diffusion of technologies needed to reduce energy intensity of industrial processes, including electrification of processes where possible	**90-95%** … of which about half from transferring BAT to emerging markets
	Uptake of Best Available Technologies	▪ Standards and incentives to integrate Best Available Technologies in design and construction to reduce lock in of inefficient performance over long asset lifetimes ▪ Support to technology transfer and capacity building for emerging economies to enable efficient new plant as demand shifts to these regions ▪ Incentives for the retirement or significant retrofit of less efficient plant prior to end of full life	
	Alternative fuels	▪ RD&D to develop industrial applications for hydrogen and other synthetic high energy density fuels where electrification is not possible or desirable	

1 Very roughly estimated for illustrative purposes, using data from across scenarios and from supplemental sources

Buildings

Buildings account for one third of current global final energy demand, with space heating constituting one third of energy consumption in the sector

Buildings



Present-day (2013)

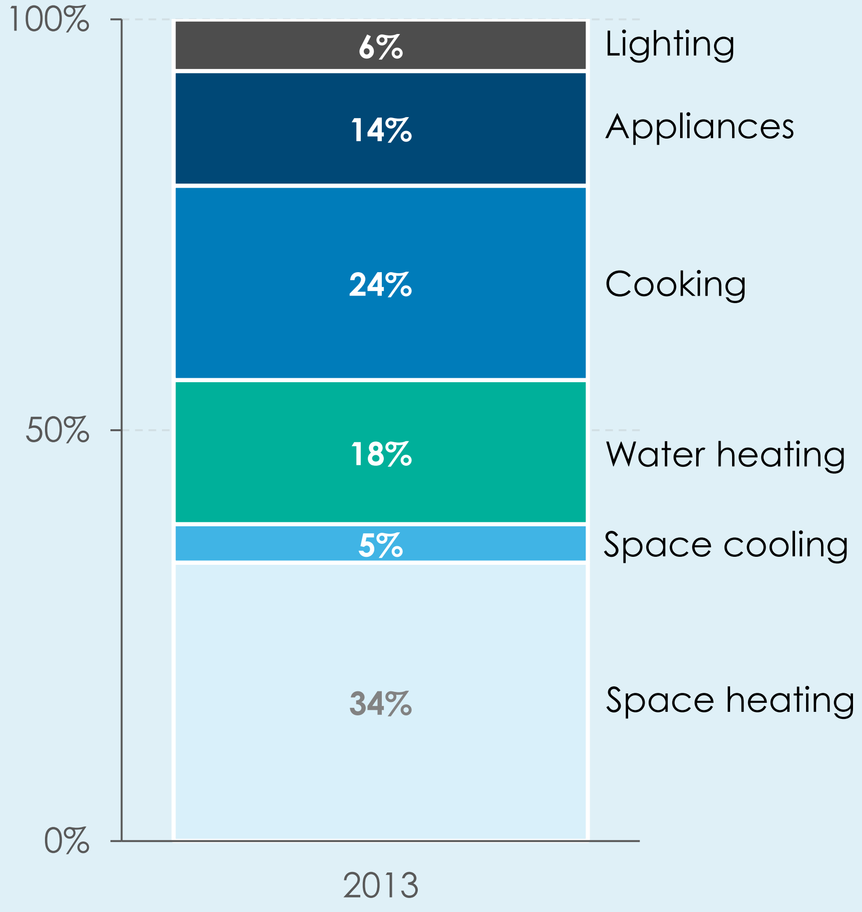
135EJ[1]

34% of global final energy demand

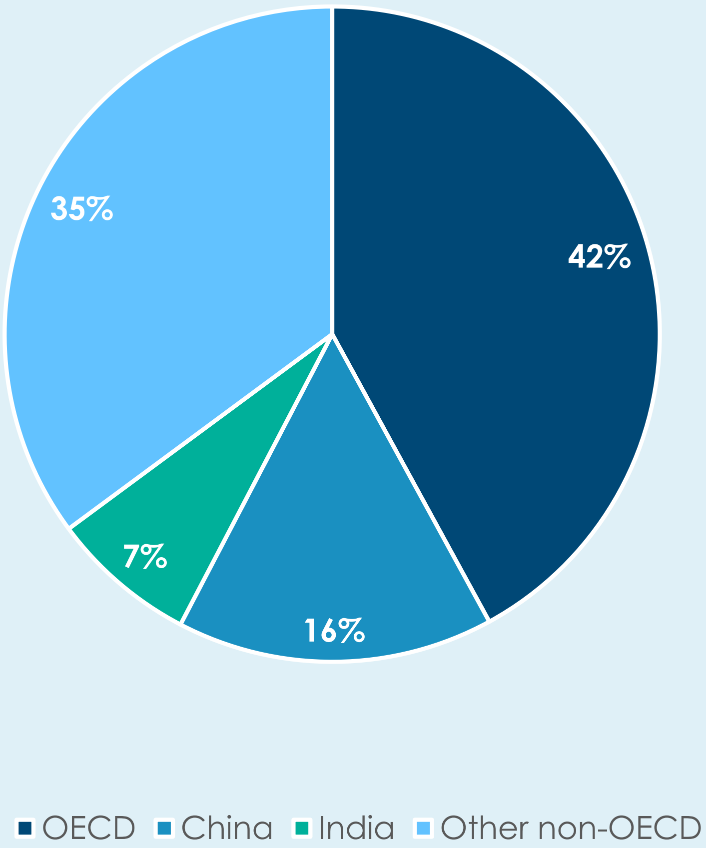
11,915MT CO_2[2]

35% of total carbon emissions

Energy demand by type (2013)[3]



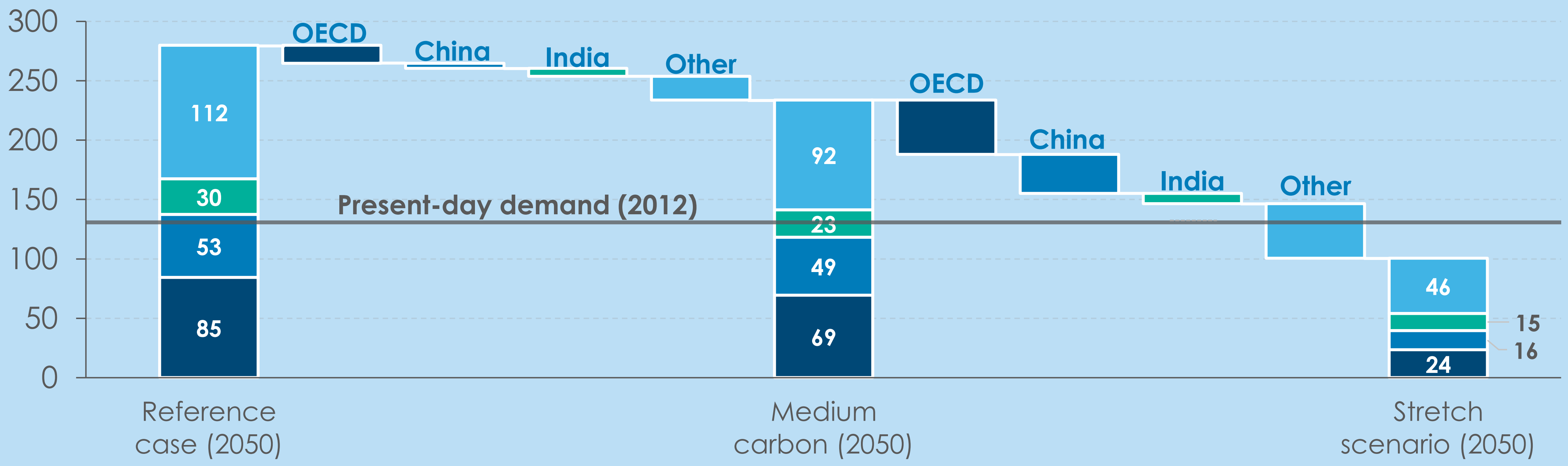
Energy demand by region (2013)[3]

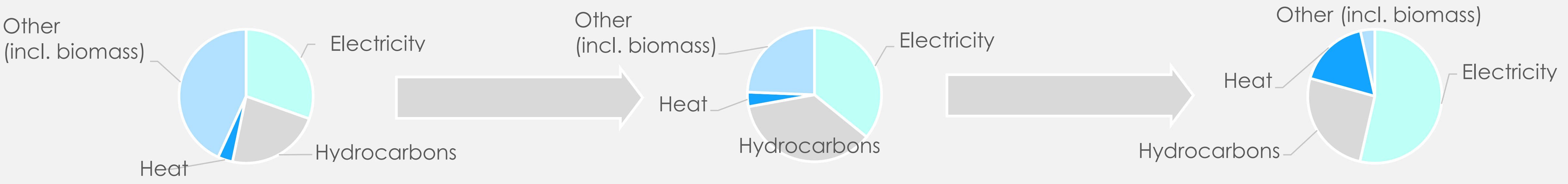


Note: 1 Based on the sector category buildings and other which includes agriculture 2 Total carbon emissions include all energy related emissions including emissions from electricity used in buildings 3 Excl. energy demand in agriculture, fishing and non-specified other. – Figures are based on the ETP 2016 estimates.

In the stretch scenario, buildings energy demand is lower by a factor 3 versus the reference case, with 34% of reductions coming from the OECD

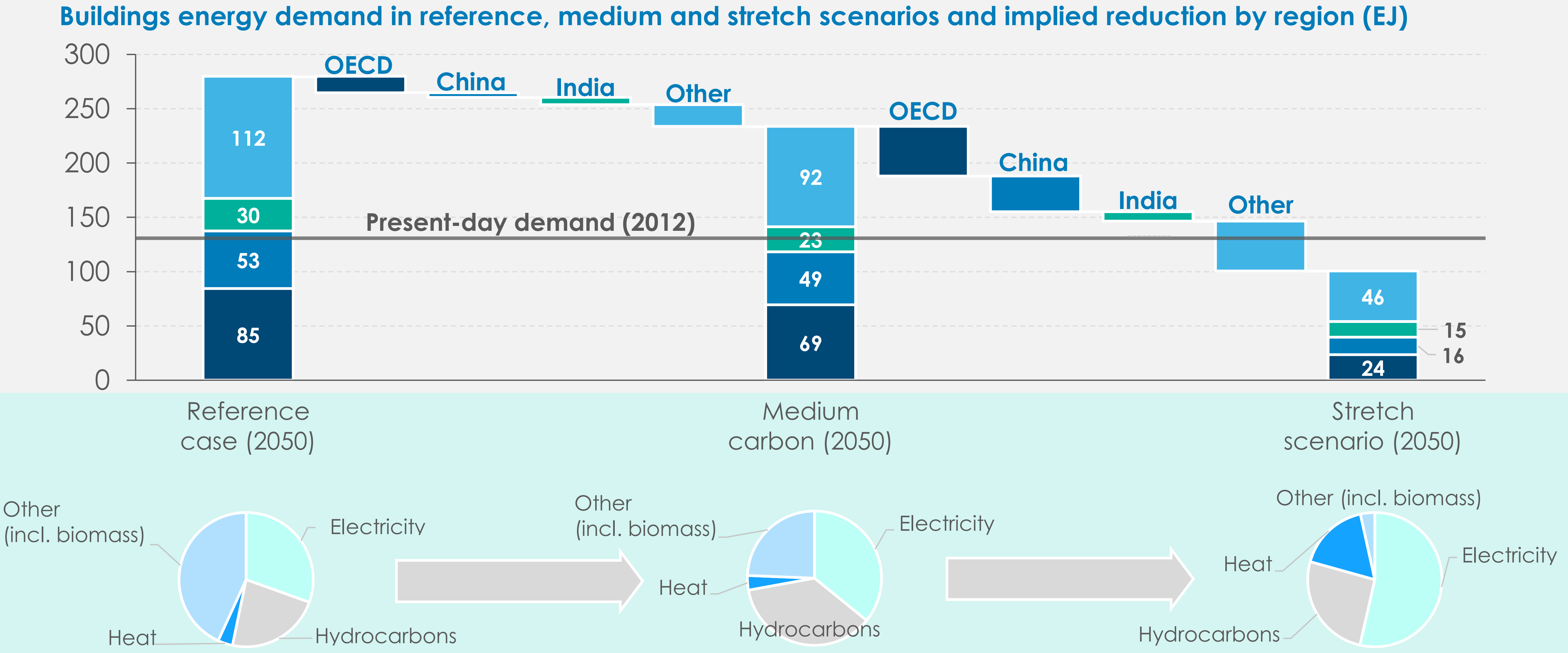
Buildings energy demand in reference, medium and stretch scenarios and implied reduction by region (EJ)





Note: Energy demand figures are based on the sector category buildings and other which includes agriculture. The reference case is ETP 6DS; Medium carbon is the average of ETP 2DS, McKinsey BAU, Shell Ocean and Shell Mountains; Stretch scenario is Greenpeace Adv. Other fuels include bioenergy, hydrogen and other.

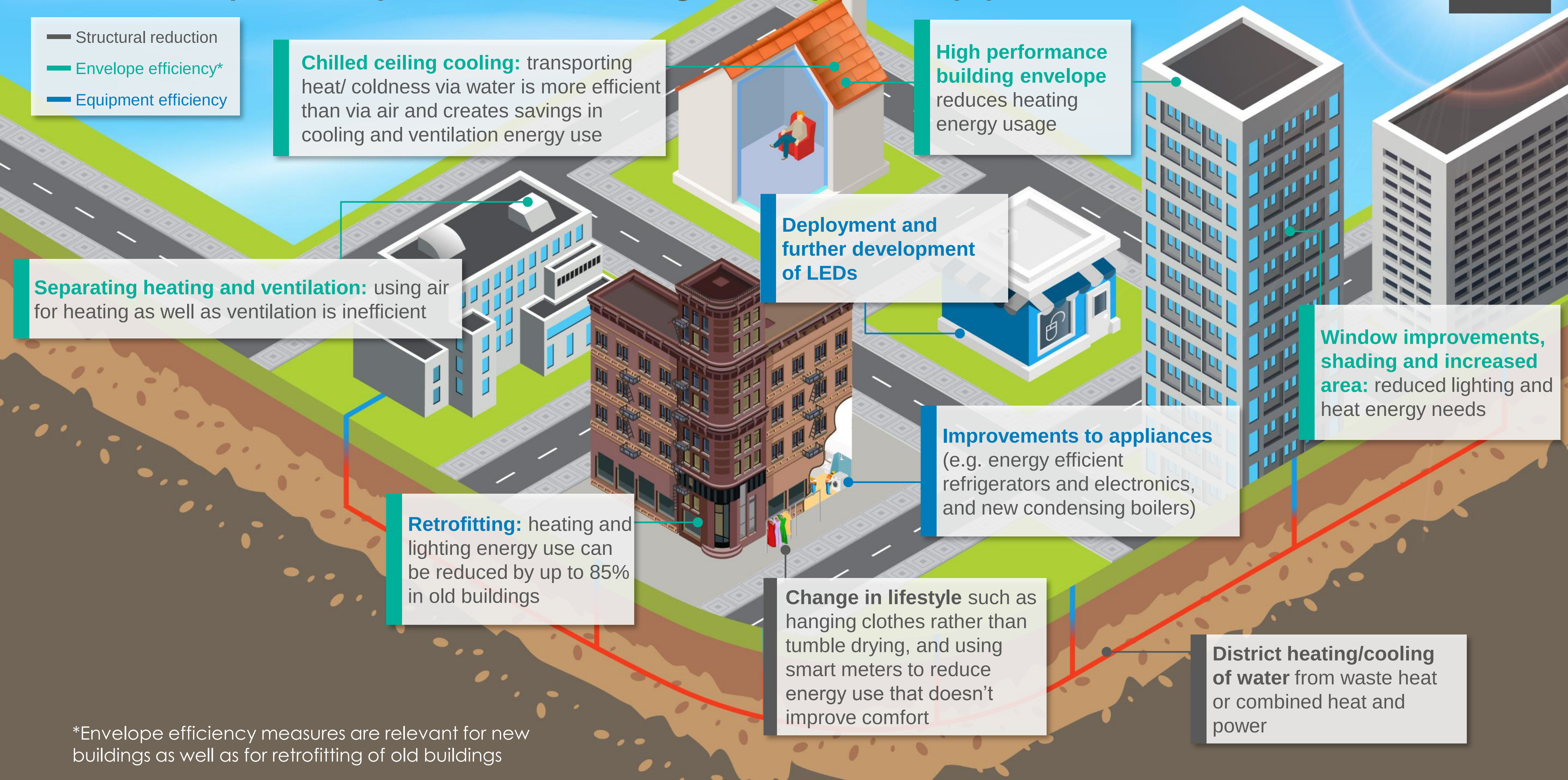
The stretch scenario implies a shift in the energy mix of the buildings sector, with a higher share of electricity (54%) and heat (17%) and a lower share of biomass (3%)



Note: Energy demand figures are based on the sector category buildings and other which includes agriculture. The reference case is ETP 6DS; Medium carbon is the average of ETP 2DS, McKinsey BAU, Shell Ocean and Shell Mountains; Stretch scenario is Greenpeace Adv. Other fuels include bioenergy, hydrogen and other.

ENERGY PRODUCTIVITY IMPROVEMENTS IN BUILDINGS – EXAMPLES

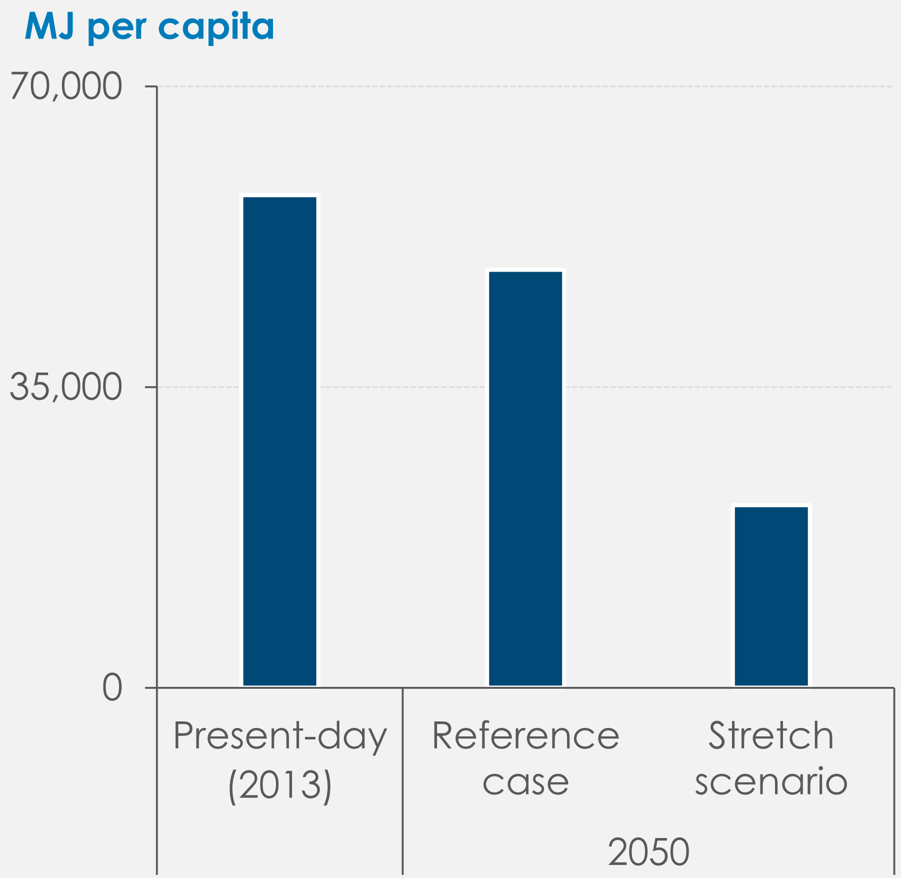
Achieving the depth of reductions in buildings energy demand envisioned by the stretch scenario involves mostly efficiency measures in buildings envelope and equipment



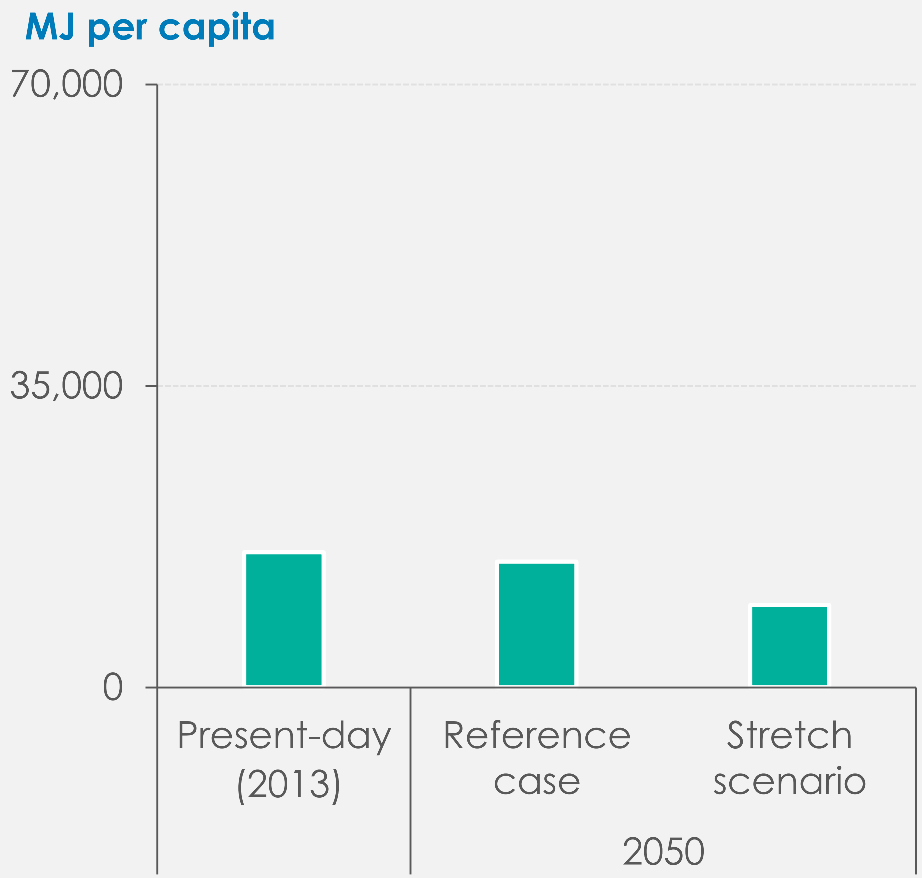
*Envelope efficiency measures are relevant for new buildings as well as for retrofitting of old buildings

Buildings energy demand per capita is reduced by half in industrialised economies and one third in developing ones but remains significantly higher in industrialised economies

OECD buildings



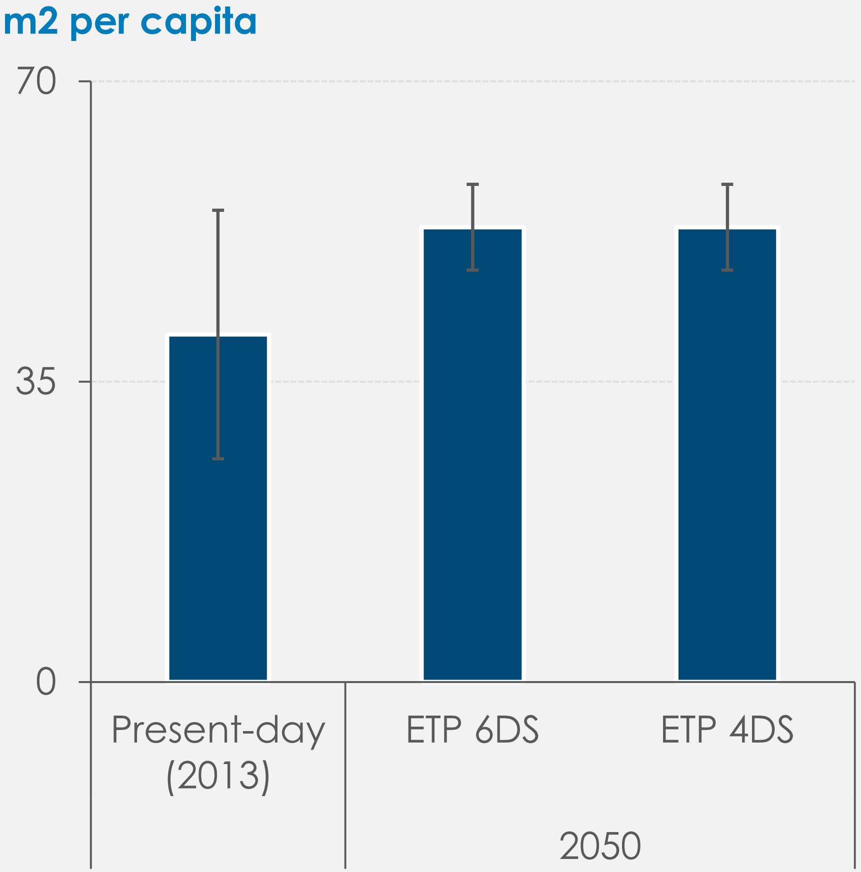
Non-OECD buildings



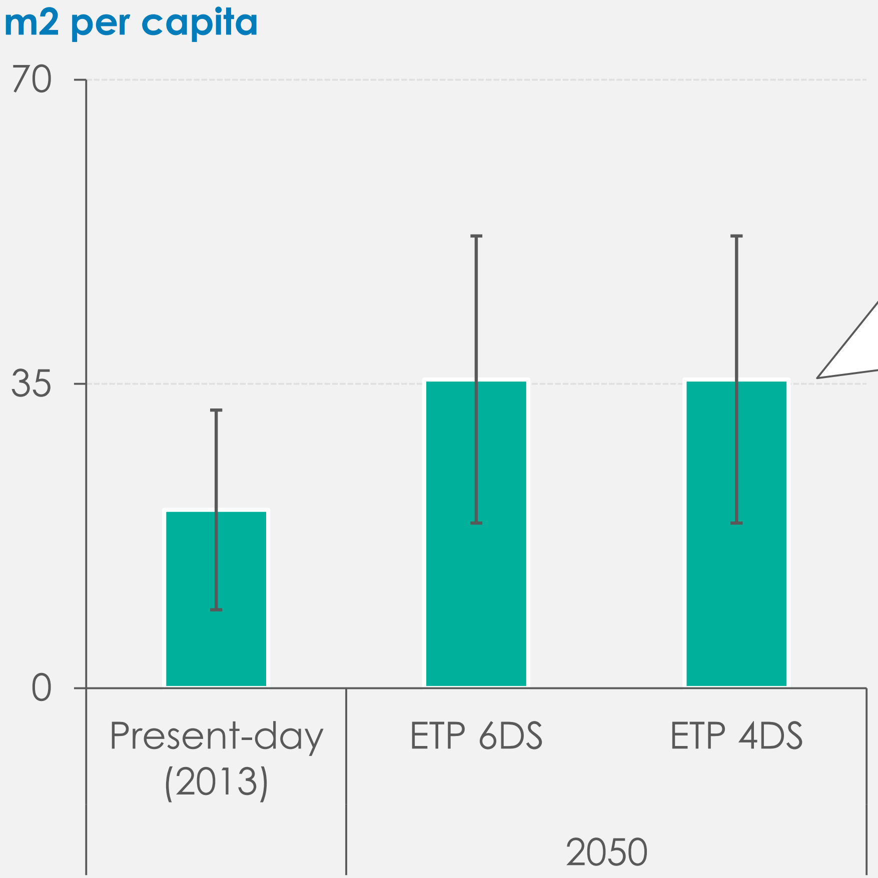
Note: OECD energy demand is used as representative for industrialised economies while non-OECD energy demand is used as representative for developing economies. The Reference case is GEA Ref. and the Stretch scenario is GEA efficiency.

Reductions in buildings energy demand do not come from reductions in comfort levels or any changes in lifestyle choices: Space per capita increases in reference and low carbon scenarios

OECD buildings



Non-OECD buildings

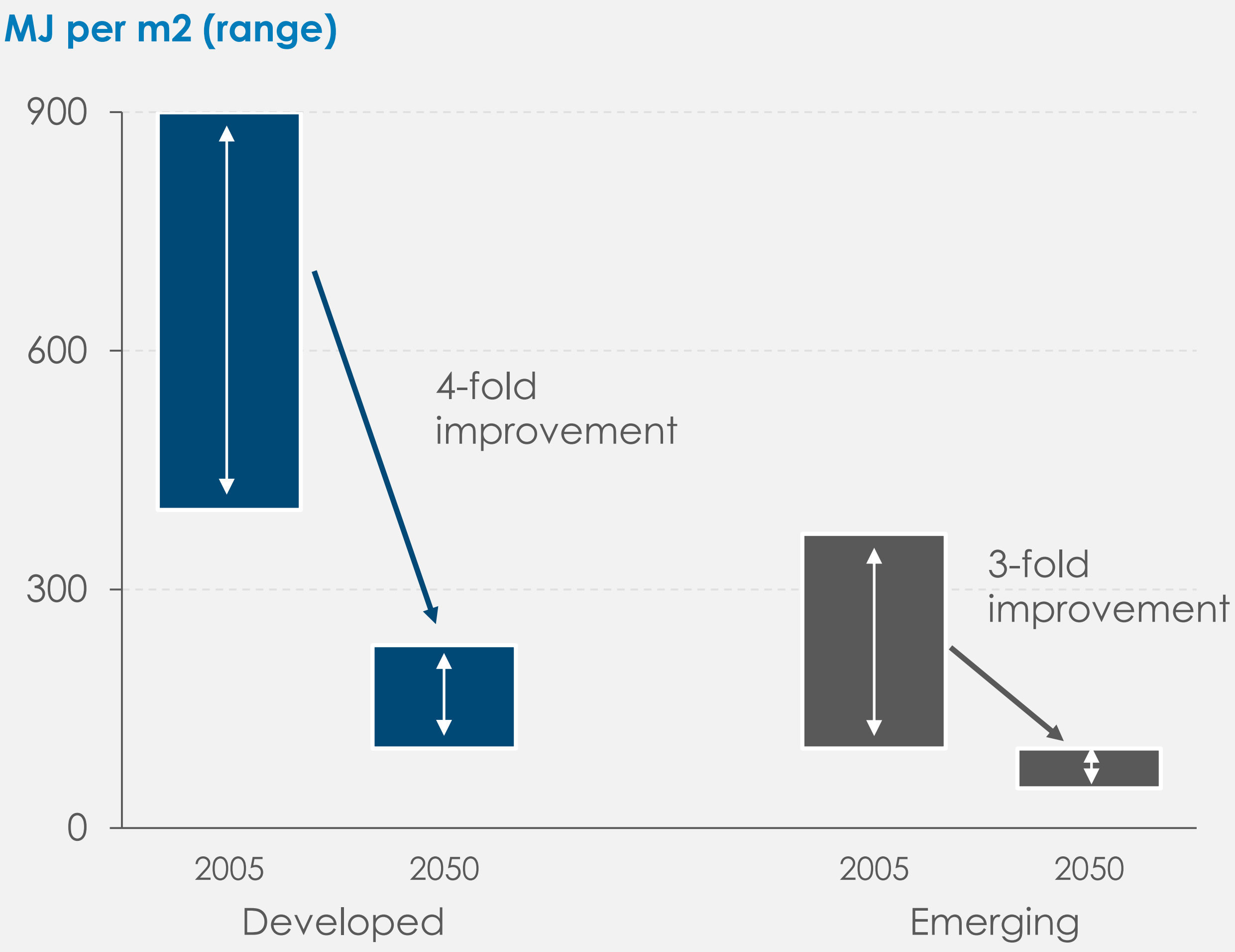


- Scenarios do not assume a decrease in space per capita in low carbon vs. reference cases
- Although evidence varies, reductions of at least a few percentage points would seem feasible

Note: OECD energy demand is used as representative for industrialised economies while non-OECD energy demand is used as representative for developing economies. The Reference case is GEA Ref. and the Stretch scenario is GEA Efficiency.

Reductions in buildings energy demand are driven by significant decreases in energy use per unit of space in both developed and emerging countries

Enhanced efficiency

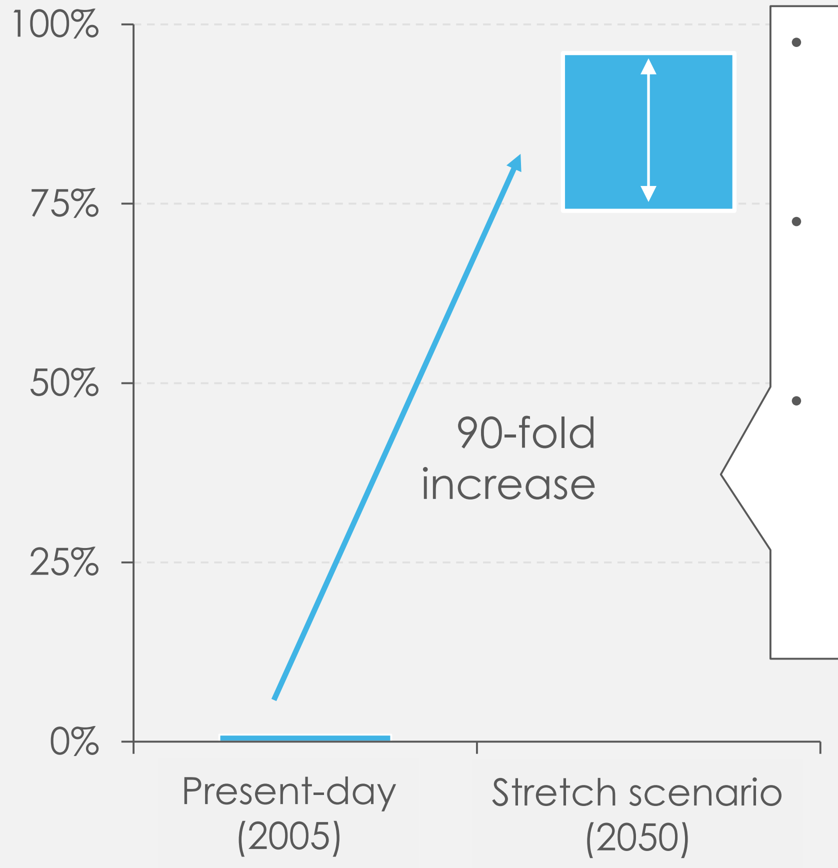


Note: All figures above are based on the stretch scenario (GEA efficiency).

Large reductions in buildings energy use come from improvements to the building envelope, driven by improved new building codes and acceleration of refurbishment

Improved building codes

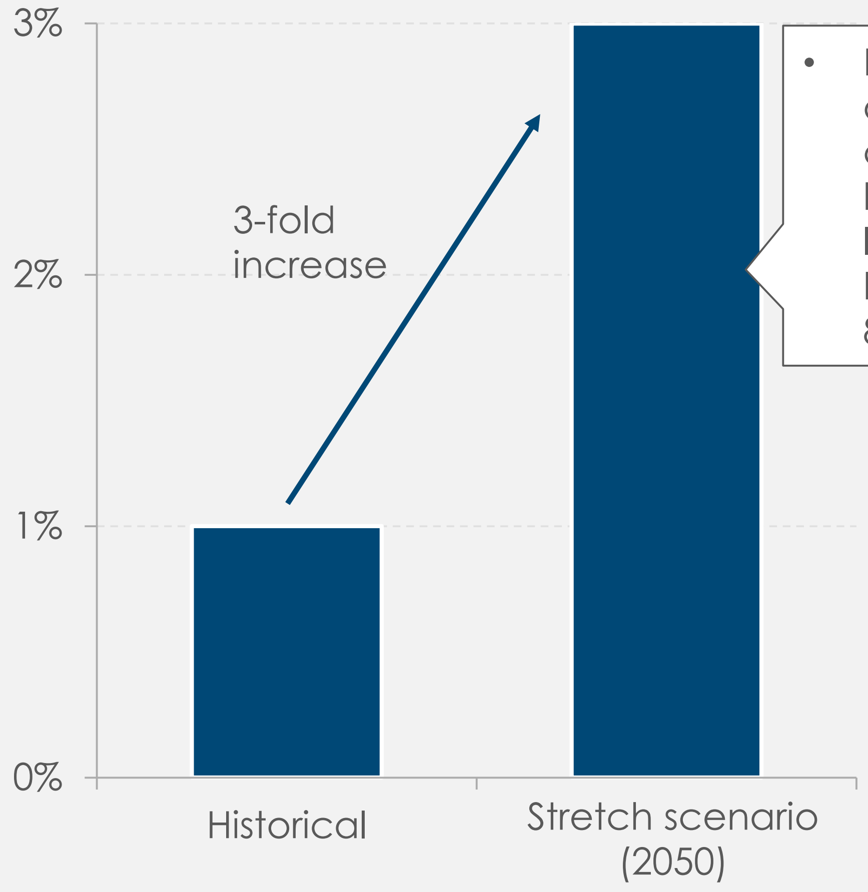
Share of building stock with advanced technology (range)



- High performance building envelope can reduce heating by 75-90%
- Chilled ceiling cooling can save 30-60% in cooling and ventilation
- Window improvements can reduce lighting costs by 30-80% and heating by 40-75%

Increased refurbishment

Retrofits per annum

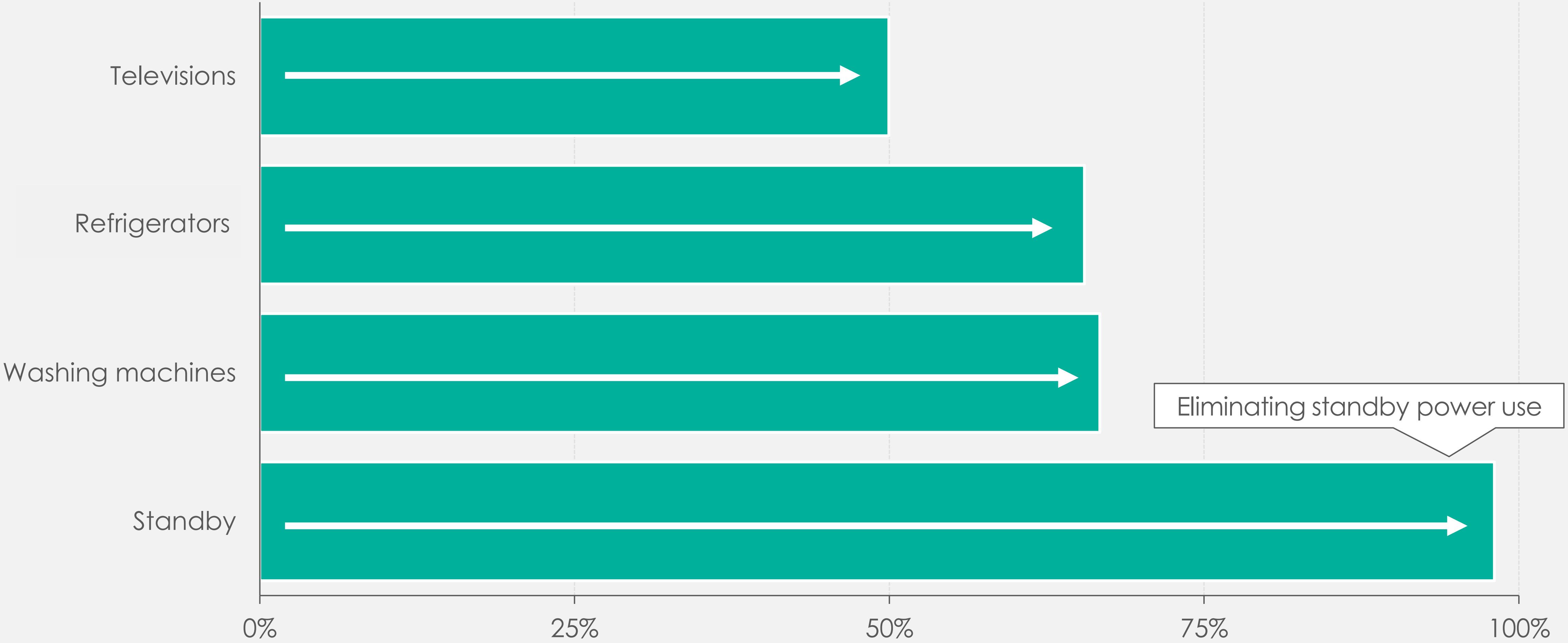


- Retrofitting old buildings can reduce heating and lighting use by up to 85%

Note: All figures above are based on the stretch scenario GEA efficiency.

Improved appliance efficiency levels also generate significant reductions in buildings energy use: Potential savings on selected appliances range from 50% to nearly 100%

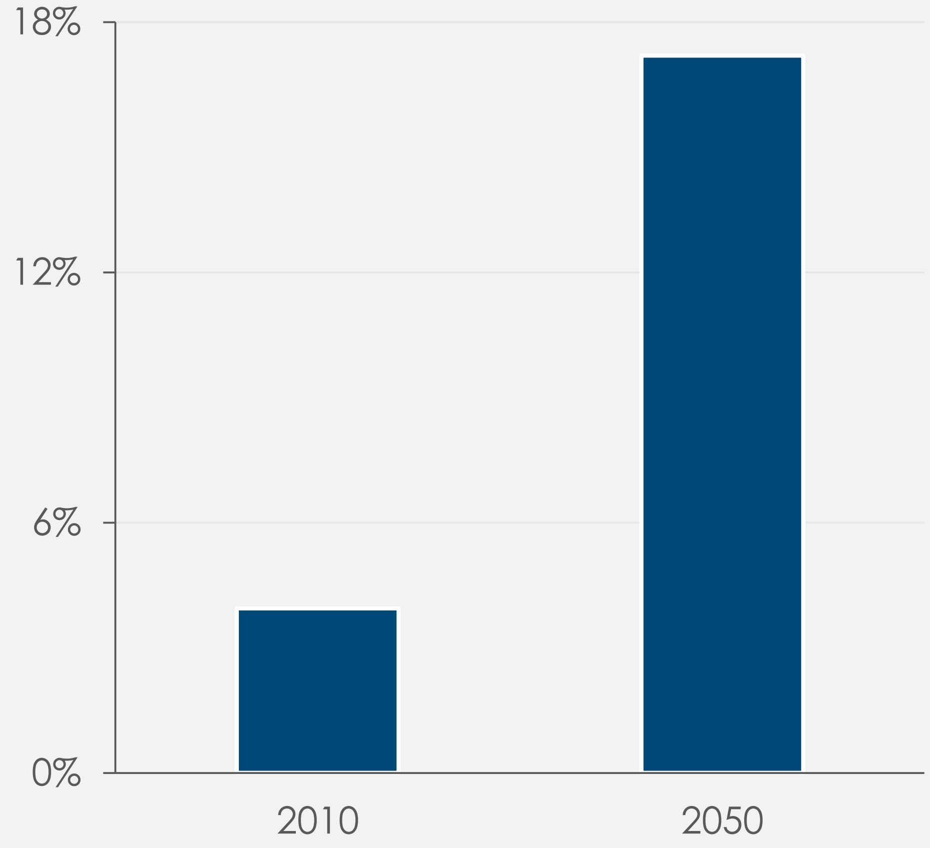
Assumed savings on selected appliances in the stretch scenario



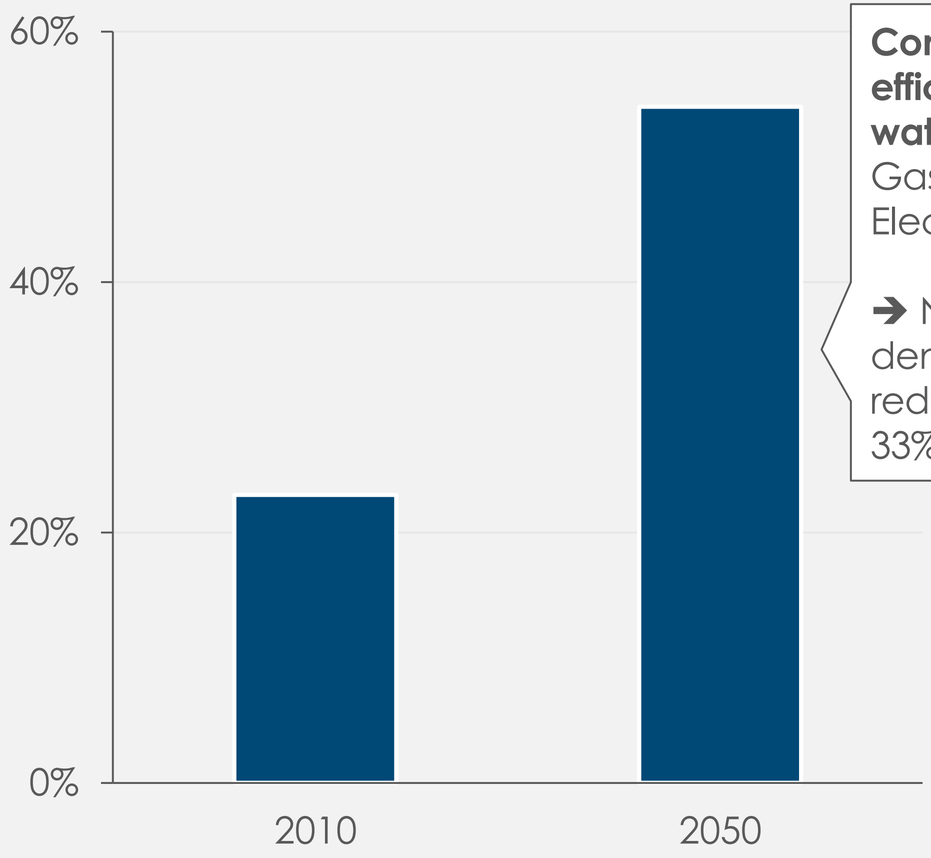
Note: All figures above are based on the stretch scenario (GEA efficiency).

Fuel switching makes a substantial contribution to reduced buildings energy demand, through both the development of district heating and significant electrification

Share of energy demand in buildings – Reused heat



Share of energy demand in buildings – Electricity



Conversion efficiency for water heating:
Gas: 60%
Electric: 90%

➔ Net energy demand reduction of 33%

Note: All figures above are based on the stretch scenario (GEA efficiency).

Development and enforcement of stringent standards for envelope and equipment, targeted RD&D support and price incentives can drive buildings energy demand reductions

			Rough share of reduction potential[1]:
Structural reduction	**Lifestyle changes & smart management**	▪ Support to programmes providing information and behavioural nudges to consumers on energy use ▪ Support to the roll-out and use of smart meters ▪ Cross cutting policies to support awareness of and demand for energy saving opportunities	**20-30%** Lifestyle changes and smart management not clearly modelled in scenarios
	District heat	▪ National and municipal policies to support the development and deployment of modern district heating networks	
	Distributed generation	▪ Incentives for increased self-generation e.g. tax rebates or feed-in tariffs, where demand savings are achieved through lower network losses	
Envelope efficiency	**Renovation**	▪ Tax incentives, subsidies and support to neighbourhood-scale coordination to increase rates of retrofitting, especially in developed economies ▪ Stringent retrofit standards and targeted incentives to prioritise energy saving measures	**20-30%**
	New build	▪ More stringent building codes requiring improved building envelopes, including thermal insulation, windows with high U-values and mandatory air sealing, as well as outcome based codes ▪ Improved monitoring and verification to increase compliance, especially in emerging economies	
	Technical capacity	▪ Policies that support technical capabilities building of installers, especially in emerging economies ▪ Support for RD&D of new technologies and buildings systems, e.g. passive ventilation	
Equipment efficiency	**Lighting and Appliances**	▪ Labelling and minimum energy performance standards for new lighting and appliances ▪ Incentives to remove aging inefficient lighting and appliances from the market	**40-60%** … of which roughly one-third comes from electrification
	Heating and Cooling	▪ Incentives to switch to heat pumps, high-efficiency cooling systems, etc. ▪ Support for RD&D around thermal storage and renewable cooling ▪ Support for RD&D around heating and cooling technologies adapted to different climates	
	Electrification	▪ Support for infrastructure and devices that enable a switch to electrified technologies for heating, cooling and appliances, including smart grid, home demand management systems, etc.	

1 Very roughly estimated for illustrative purposes, using data from across scenarios and from supplemental sources

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