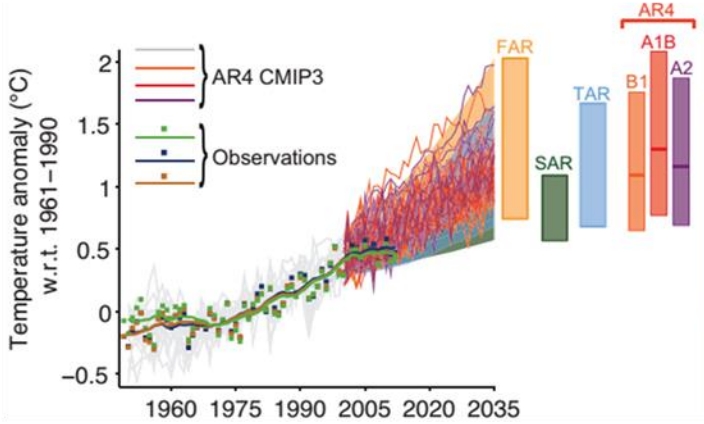
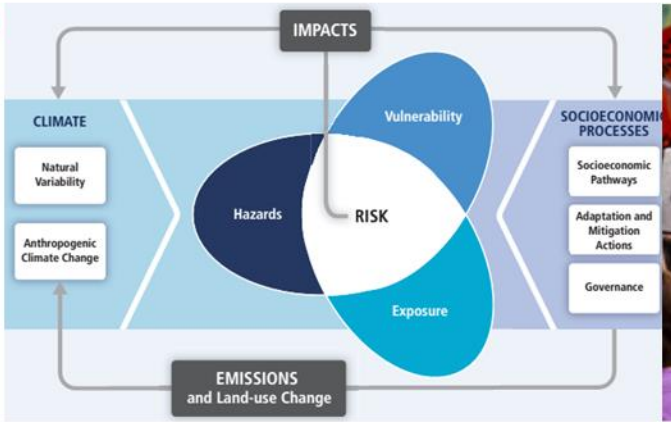




Energy Systems & Climate Change





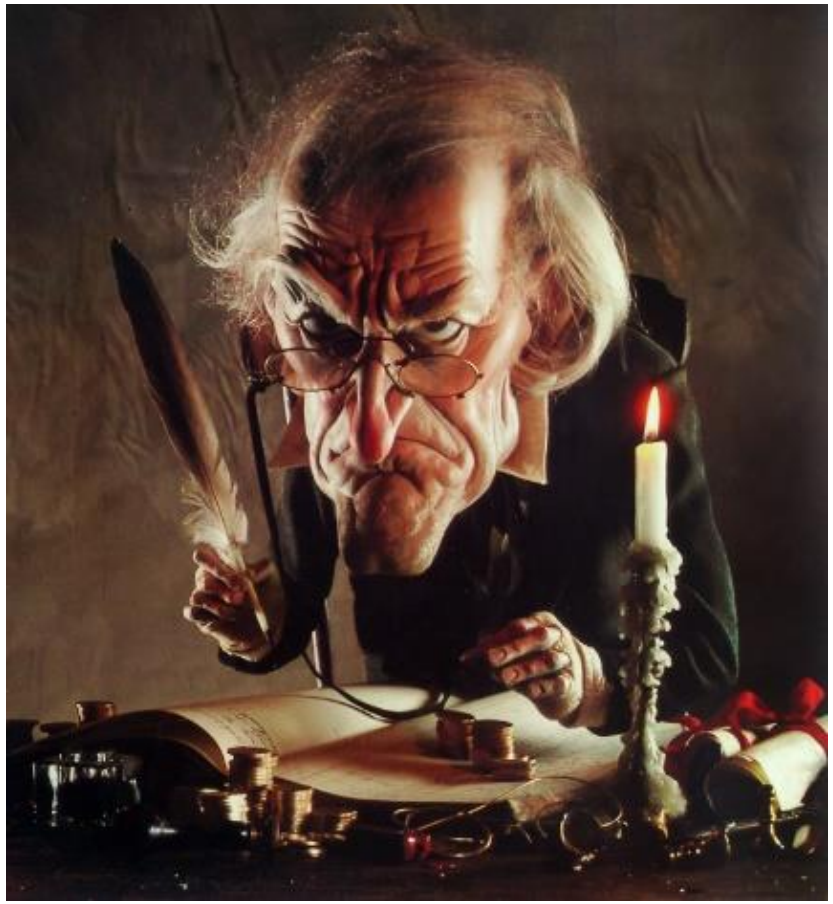
Energy efficiency - introduction

Energy efficiency

≠

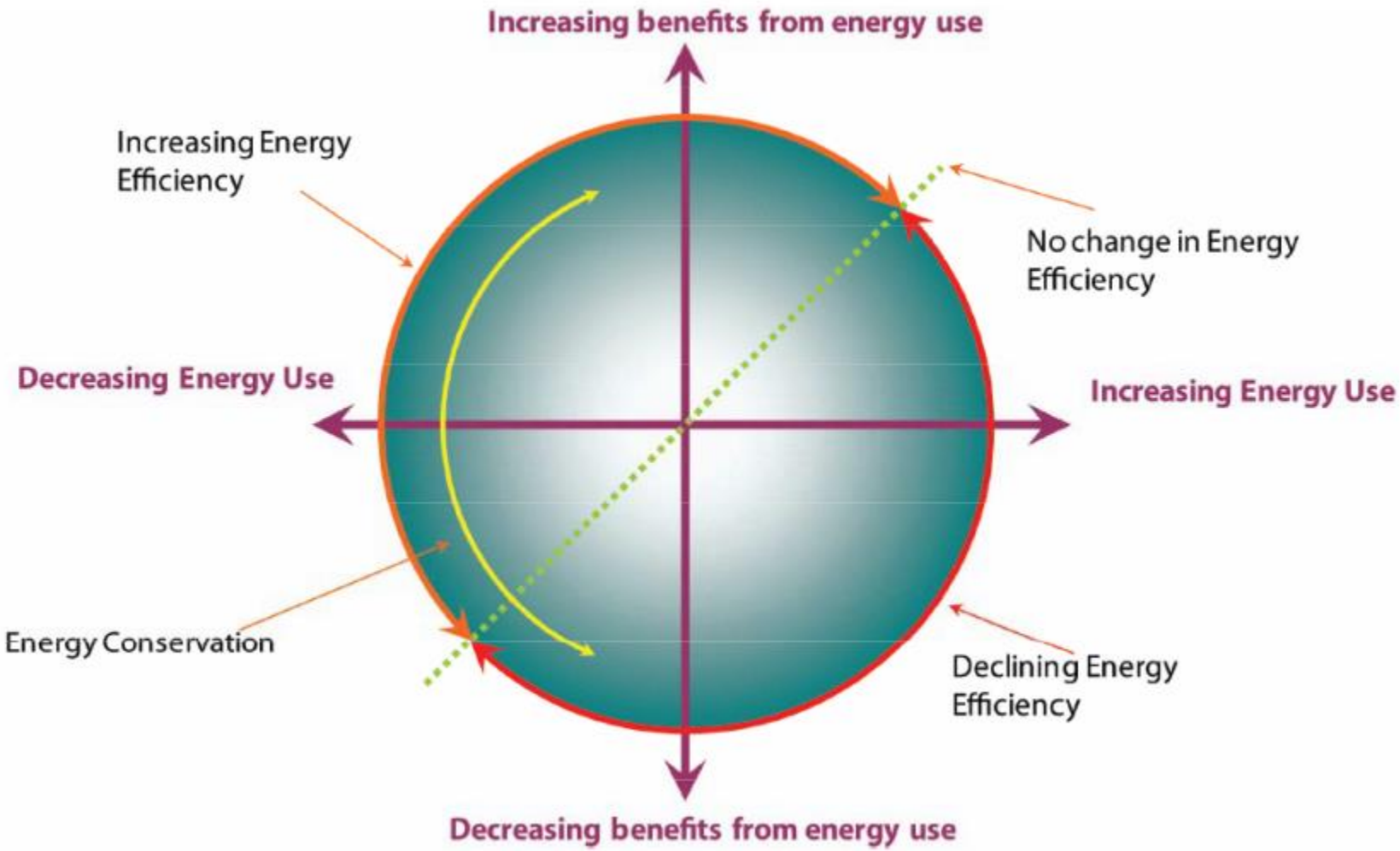
Energy conservation

- Same level of service
- Reduced energy input



- Reduced level of service

Energy efficiency versus energy conservation



Energy efficiency versus energy conservation

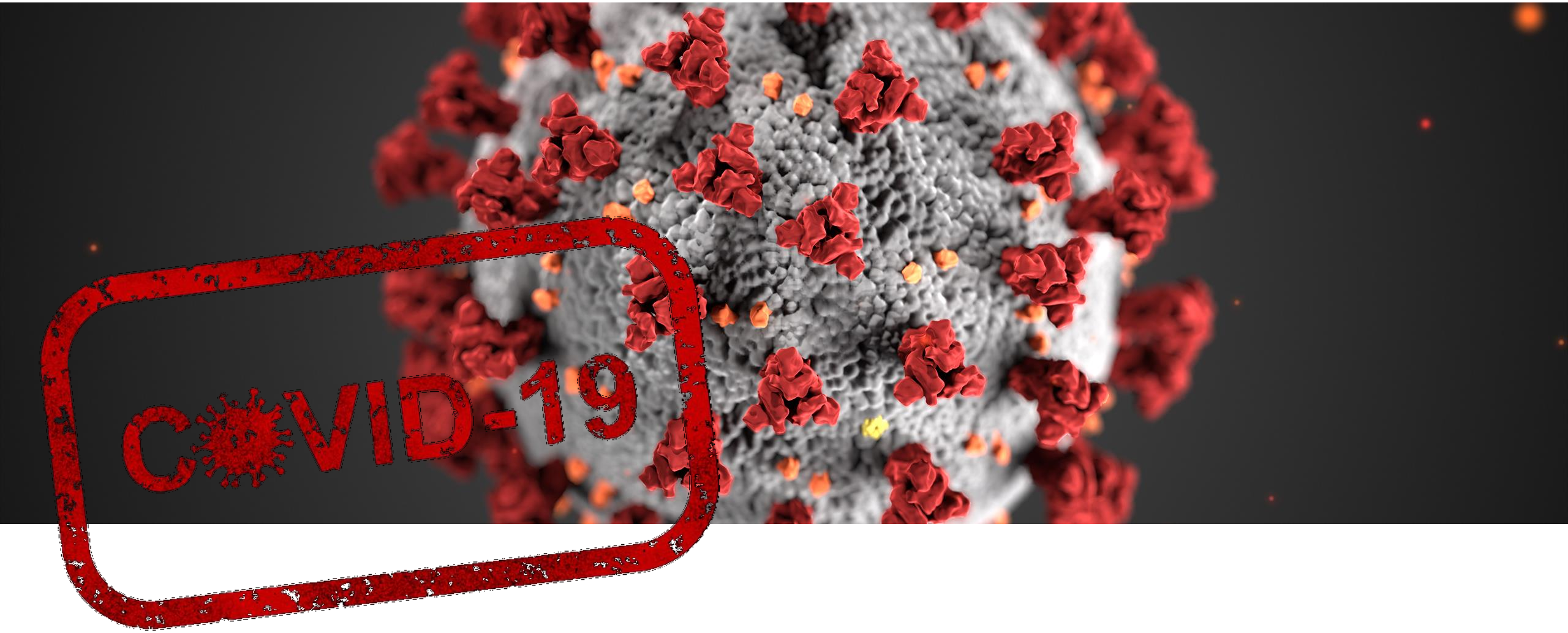
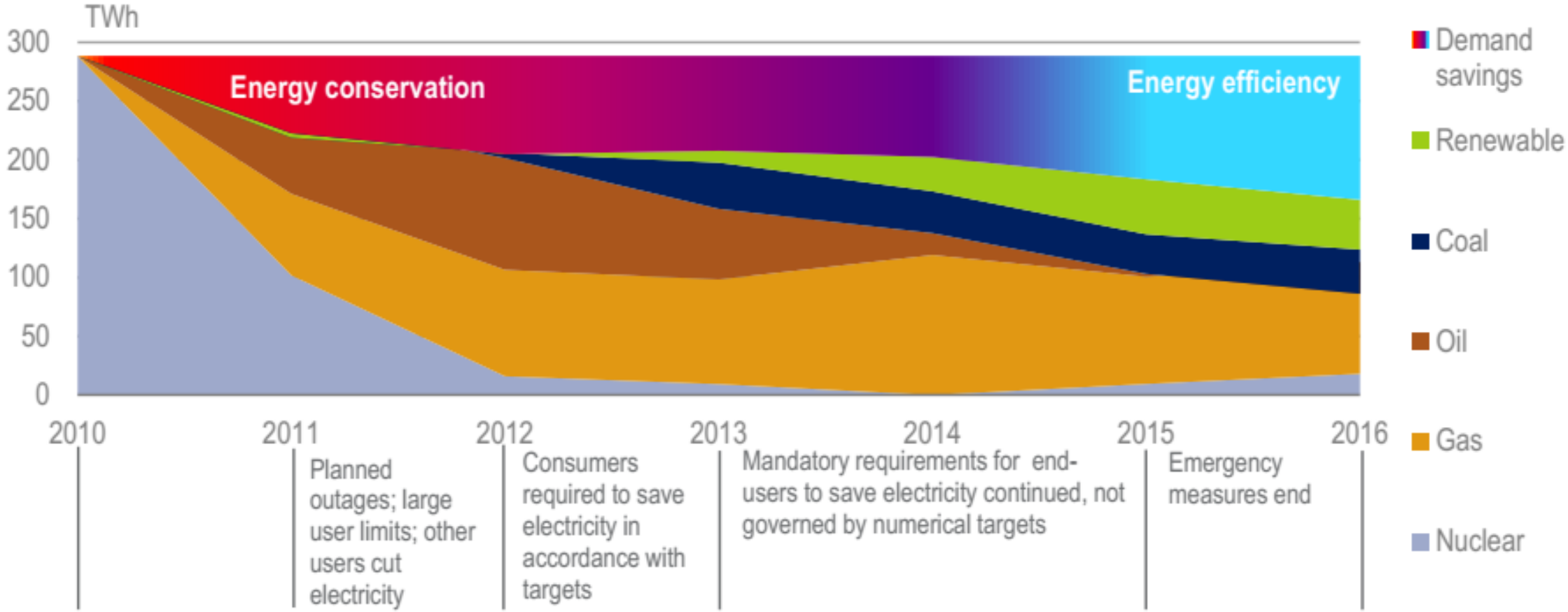


Figure 1.22 Replacement of nuclear electricity generation in Japan after shutdown



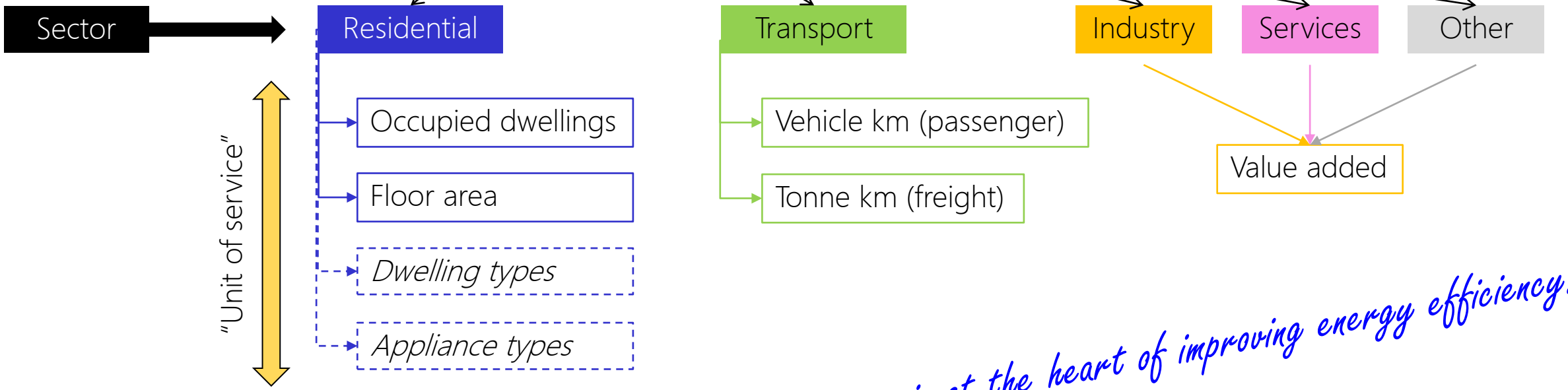
Source: Adapted from IEA (2017a), *World Energy Statistics and Balances 2017* (database), www.iea.org/statistics.

Source: Energy Efficiency Market Report 2017, IEA/OECD (2017)

Energy efficiency - introduction

Energy efficiency:

$$\frac{\text{Final energy consumed}}{\text{Unit of service delivered}}$$



Engineering is at the heart of improving energy efficiency.

Energy efficiency - introduction

Energy efficiency:

$$\frac{\text{Final energy consumed}}{\text{Unit of service delivered}}$$

⟷ What is a "unit of service"?

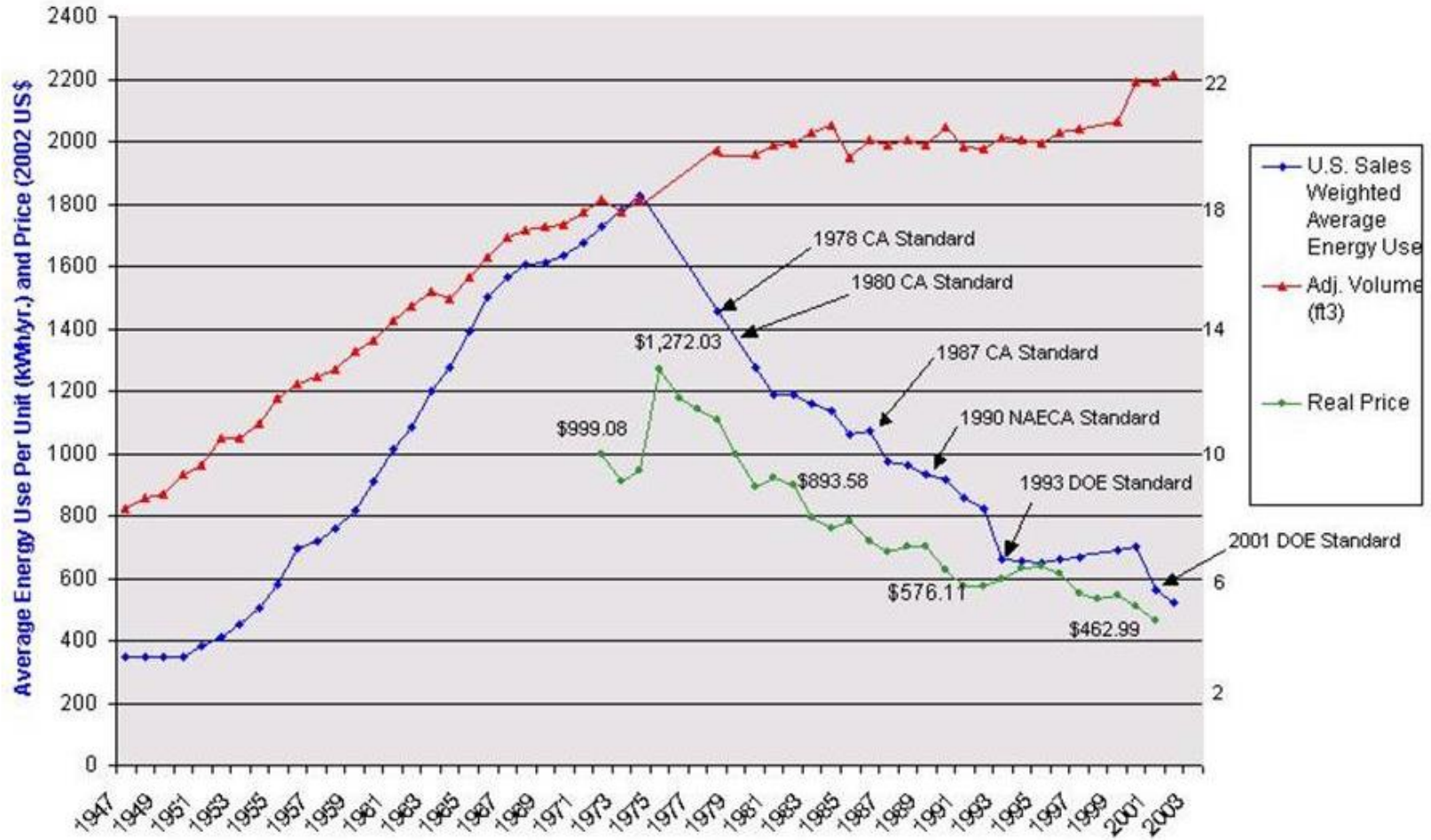
	House	Car	Factory	Data Centre	Fridge
Final energy	electricity + gas + oil + solid fuel	petrol + diesel + electricity	electricity + gas + oil + solid fuel	electricity	electricity
Unit of service	floor area	passenger km	items produced	data processed	food cooled
Complicating factors	*climate* *occupancy*	*climate* *driving style*	*nature of item* *automation*	*climate*	*climate* *door-open time*

Energy efficiency - introduction

Appliance example: Refrigerators

Note: level of service increased, energy consumption decreased

US refrigerators: size, energy consumption, and price vs time



Source: David Goldstein, LBNL

Energy efficiency - introduction

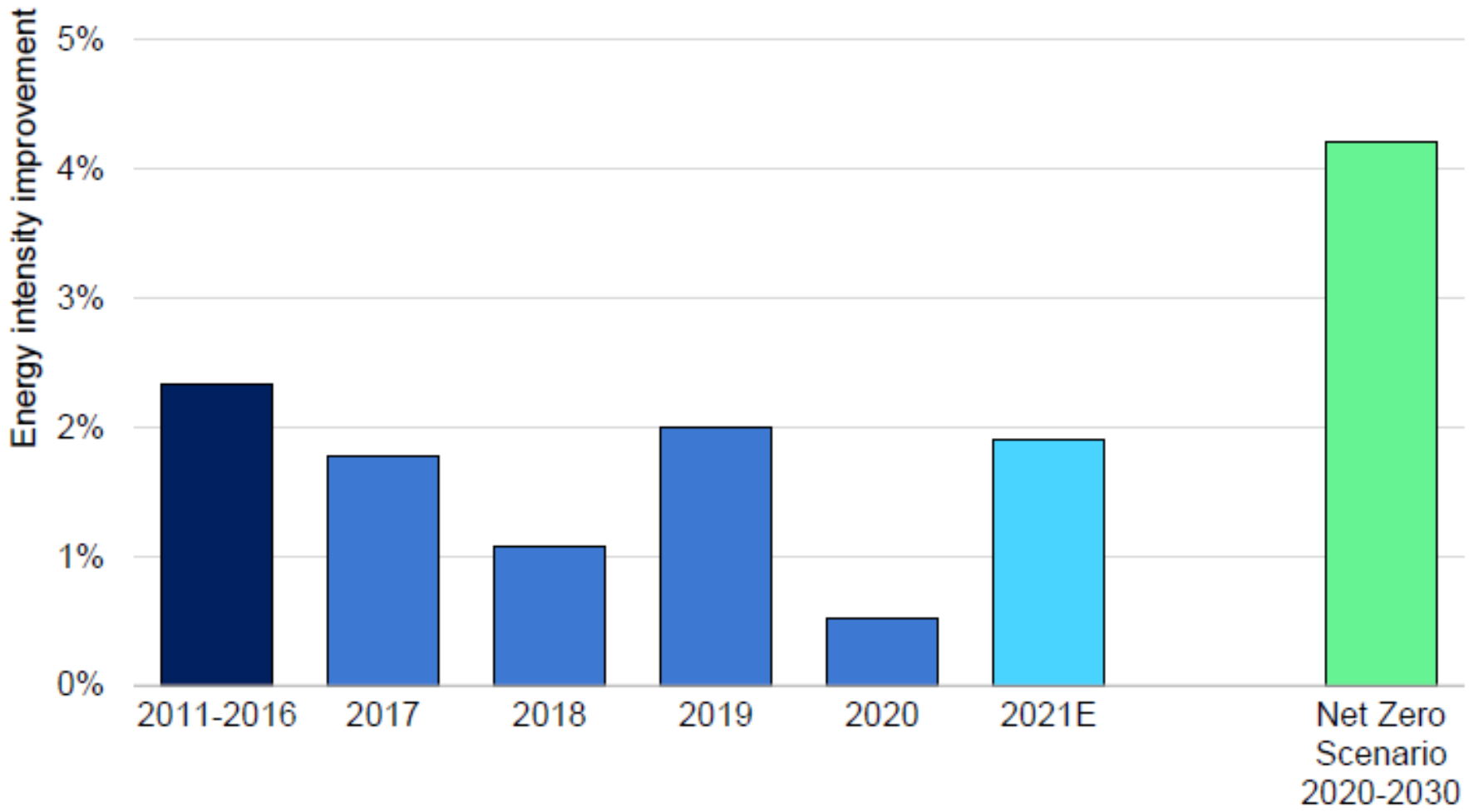
http://www.youtube.com/watch?v=olFdcvpwu_c

05:32 – 07:57

28:57 – 40:18

Energy intensity: $\frac{\text{(Primary or Final) energy consumed}}{\text{GDP generated}}$

Primary energy intensity improvement, 2011-2021 (Global)



Source: Energy Efficiency 2021. IEA/OECD (2021)

Energy efficiency - introduction

Energy efficiency:

$$\frac{\text{Final energy consumed}}{\text{Unit of service delivered}}$$

Energy intensity:

$$\frac{\text{(Primary or Final) energy consumed}}{\text{GDP generated}}$$

The amount of energy consumed (and the GDP generated) depend on many factors – not only on efficiency.

Energy efficiency - introduction

Changes in energy use: decomposition

Growth effect: ↔ Economic activity; Population; Transport

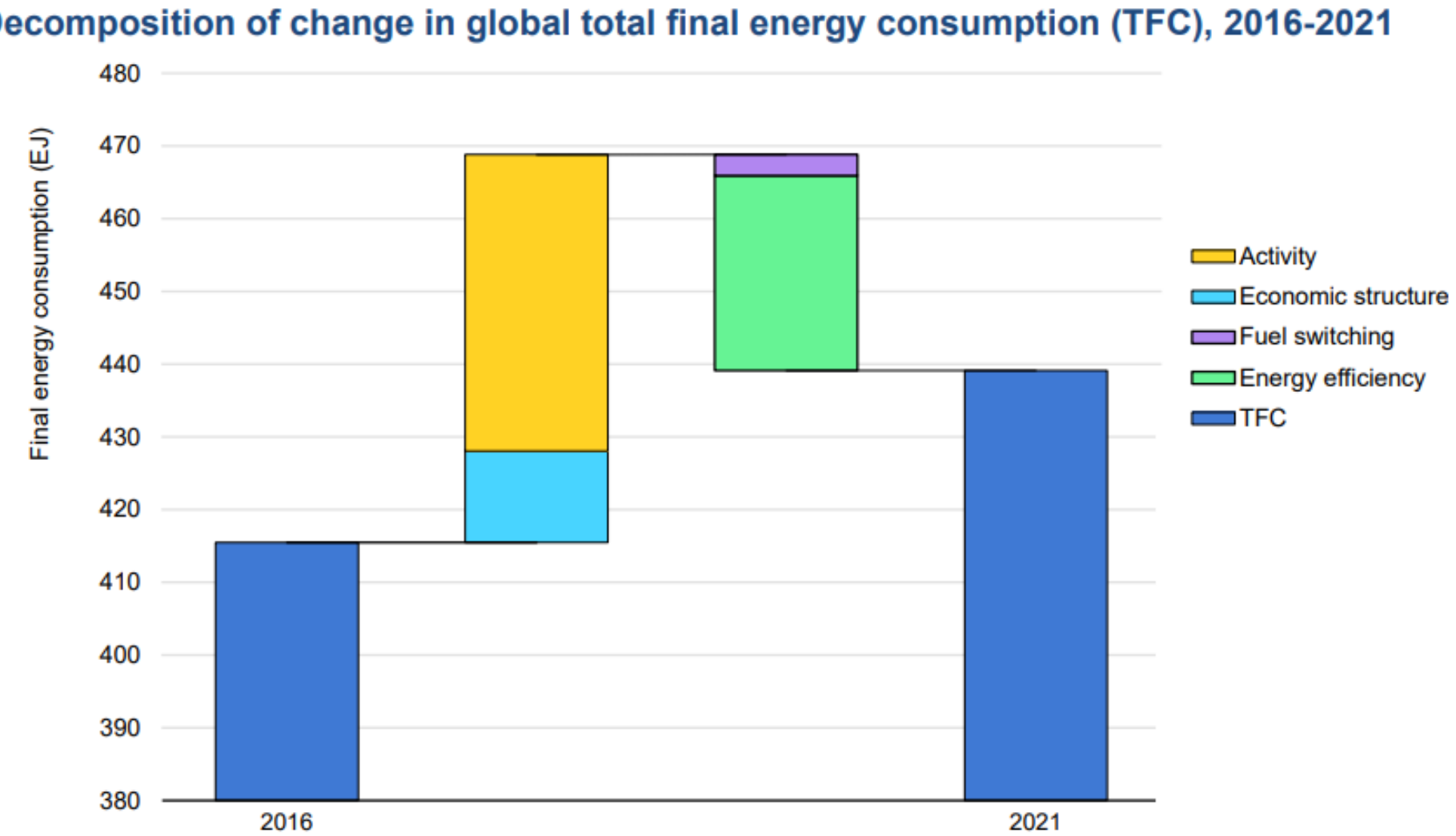
(how much we do; level of activity)

Structure effect: ↔ Industry types; Floor area per person; Appliance ownership rates; Transport modes, etc....

(what we do; types of activity)

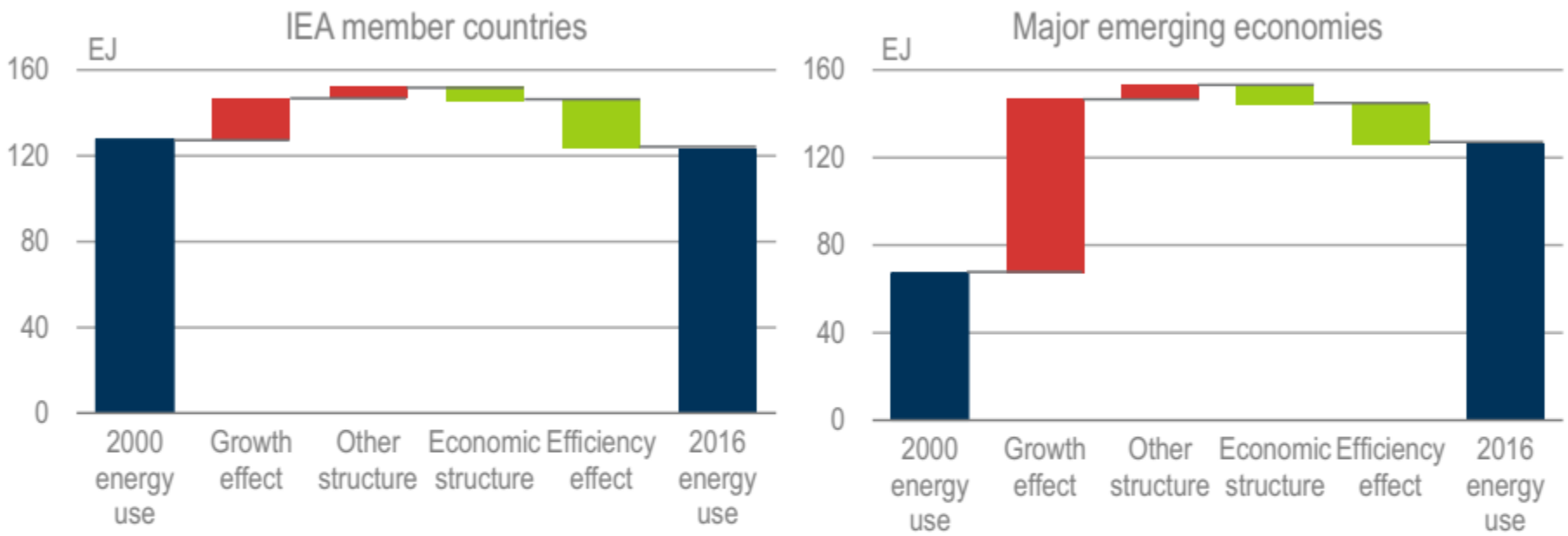
Efficiency effect: ↔ Energy consumed per unit of service delivered

(how efficiently we do it)



Source: Energy Efficiency 2022, IEA/OECD (2022)

Figure 1.8 Decomposition of final energy use in IEA member countries and major emerging economies

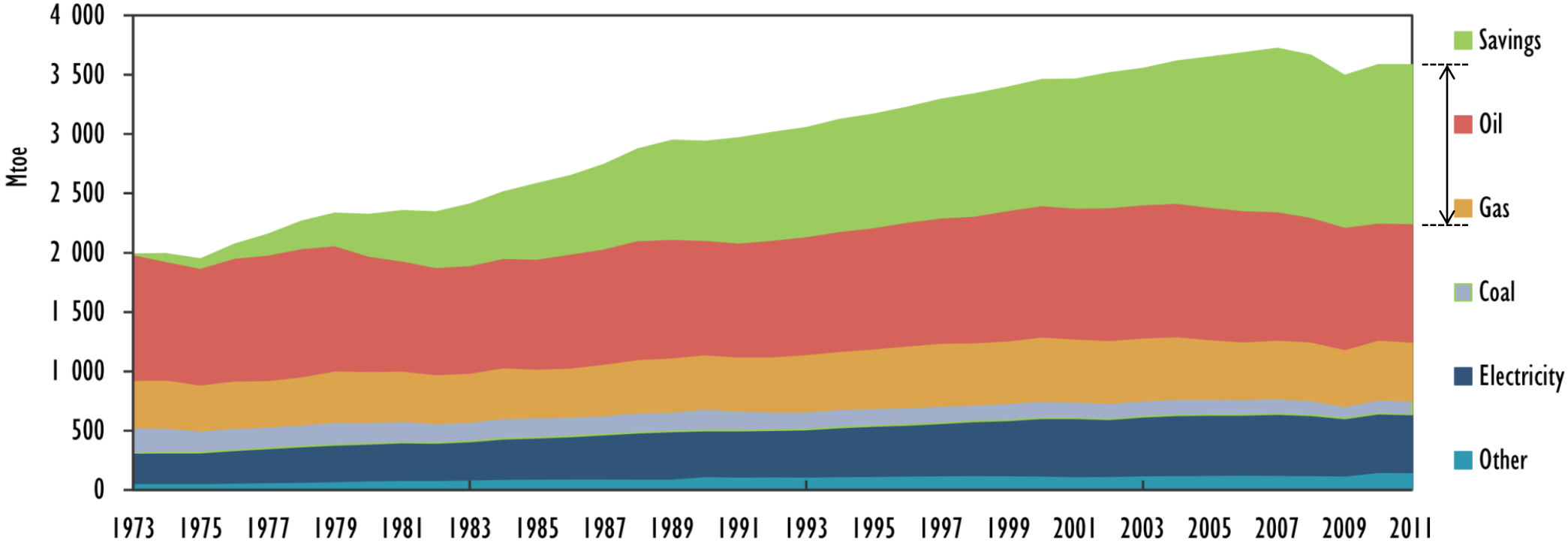


Notes: "Energy use" covers the residential, industry and services, passenger and freight transport sectors. It excludes non-energy and energy supply. "Other effects" include changes in residential dwellings, floor space and appliances per capita, and transport modal shifts. "Economic structure" reflects the movement from energy-intensive industry sectors to less intensive service sectors.

Sources: Adapted from IEA (2017e), *Energy Efficiency Indicators* (database), www.iea.org/statistics/topics/energyefficiency/; Timmer et al. (2015), *World Input Output Database* (database), www.wiod.org; IEA (2017c), *Mobility Model* (database), www.iea.org/etp/etpmodel/transport; IEA (2017d), *Energy Technology Perspectives 2017* (Residential Model); and IEA (2017a), *World Energy Statistics and Balances 2017* (database), www.iea.org/statistics.

Source: Energy Efficiency Market Report 2017, IEA/OECD (2017)

Figure 1.1 Energy savings from energy efficiency and energy consumption by energy source in 11 IEA member countries, 1973-2011

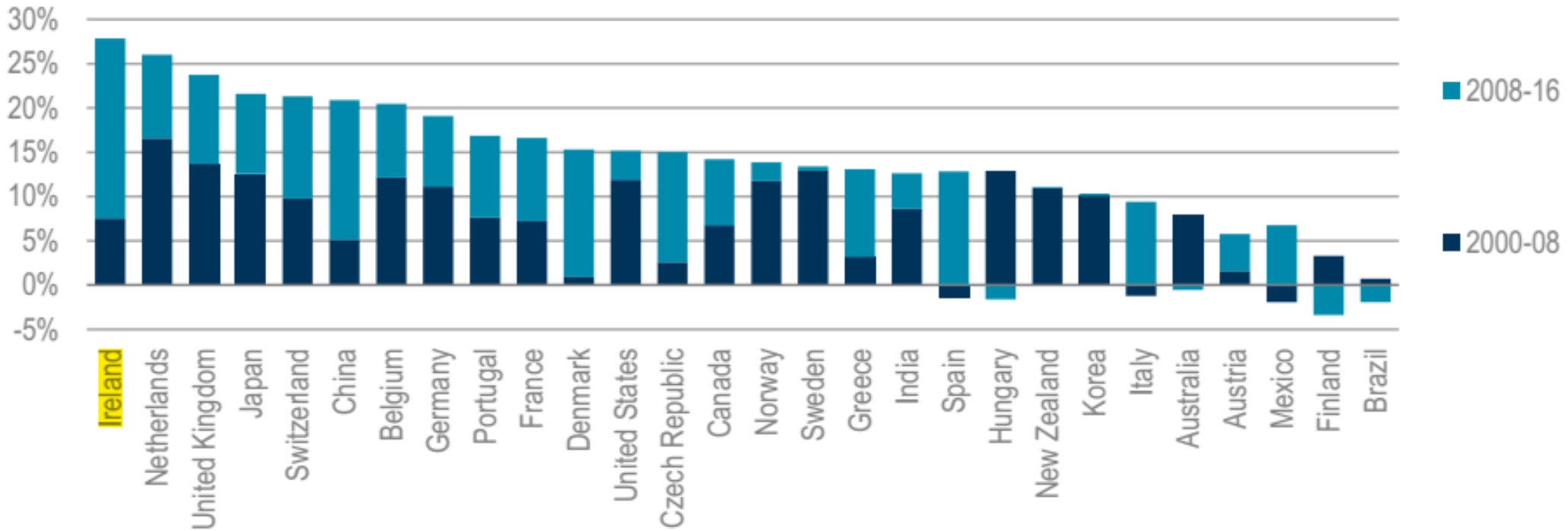


Notes: The 11 countries evaluated are Australia, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Sweden, the United Kingdom and the United States.

Source: Unless otherwise indicated, all tables and figures in this chapter derive from IEA data and analysis.

Source: Energy Efficiency Market Report 2014, IEA/OECD (2014)

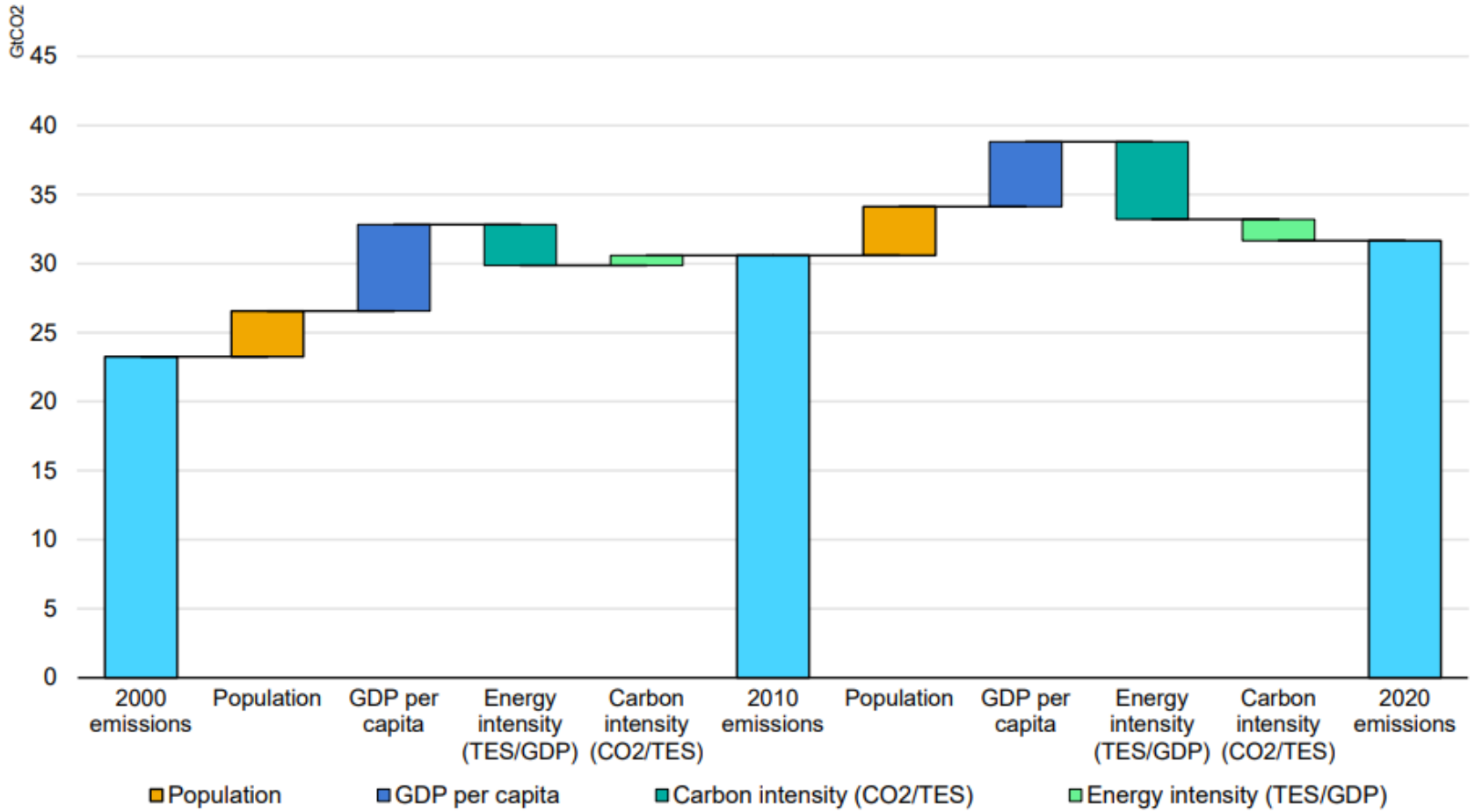
Figure 1.9 Percentage improvement in the efficiency effect for select countries, 2000-16



Sources: Adapted from IEA (2017e), *Energy Efficiency Indicators* (database), www.iea.org/statistics/topics/energyefficiency/; Timmer et al. (2015), *World Input Output Database* (database), www.wiod.org; IEA (2017c), *Mobility Model* (database), www.iea.org/etp/etpmodel/transport; IEA (2017d), *Energy Technology Perspectives 2017* (Residential Model); and IEA (2017a), *World Energy Statistics and Balances 2017* (database), www.iea.org/statistics.

Source: Energy Efficiency Market Report 2017, IEA/OECD (2017)

Global CO_2 emissions from fuel combustion and drivers, 2000-2020



Note: From 2019 to 2020 global CO_2 emissions fell by around 2 Gt CO_2 due to lower economic activity brought about by the Covid-19 pandemic.

Source: Energy Efficiency 2022, IEA/OECD (2022)

What's a Negawatt?

What's a negawatt?

A negawatt is a theoretical unit of avoided power demand.

Example:

Electricity demand (in some region) is expected to increase by 1 GW over the next 5 years: address the challenge.

Solution 1	Solution 2
• Buy a new 1 GW power station.	• Buy 1 GW of electricity-saving measures (negawatts).
• "Lock in" increased demand for primary energy.	• "Lock in" avoided demand for primary energy.

Energy efficiency - negawatts

energy consumption by residential appliances

Increasing global population

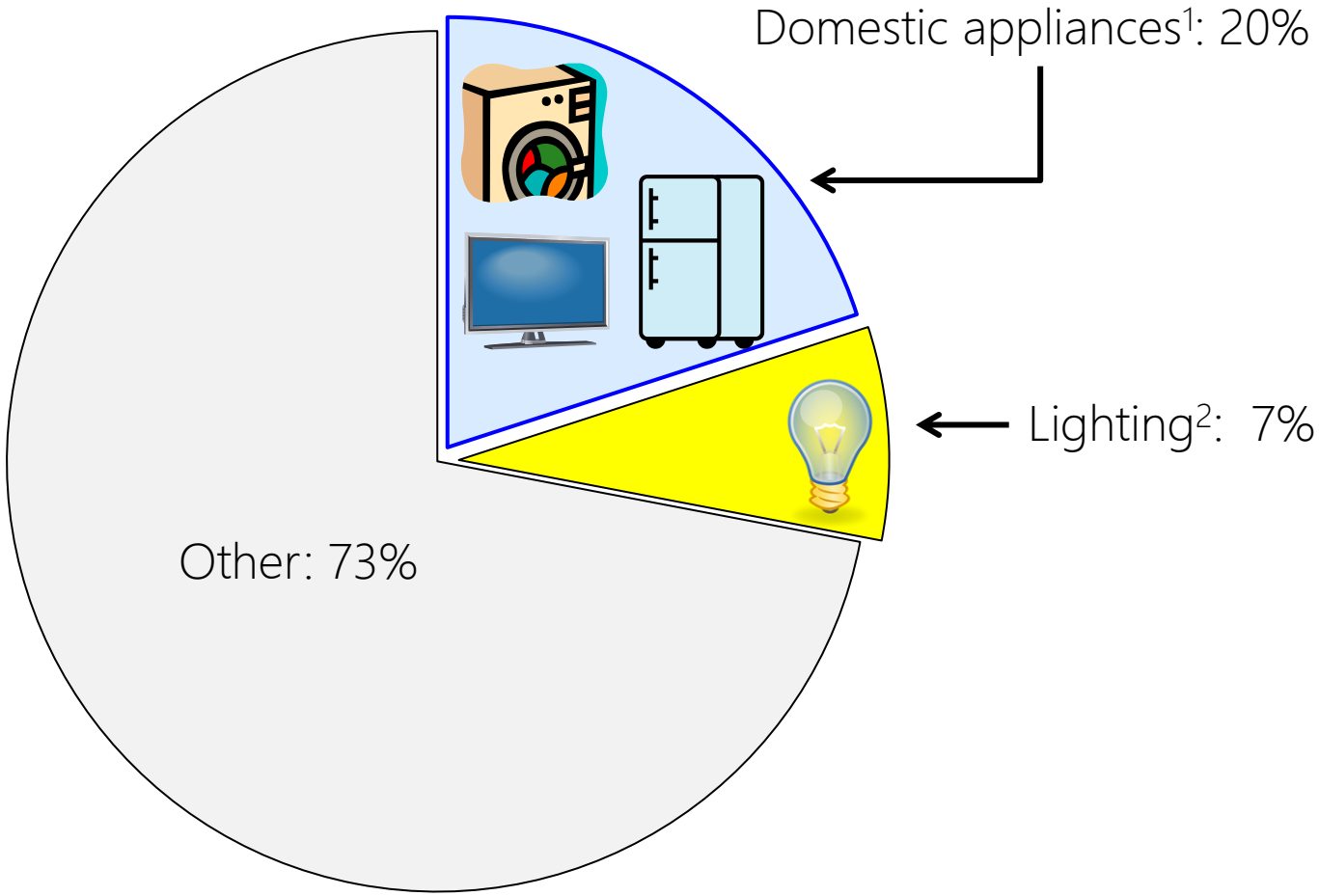
Urbanization
(rely more on appliances)

Smaller household sizes
(more households per person)

Increasing household wealth
(more appliances per household)

Appliance efficiency
(energy consumption per appliance)

Global electricity demand, by application

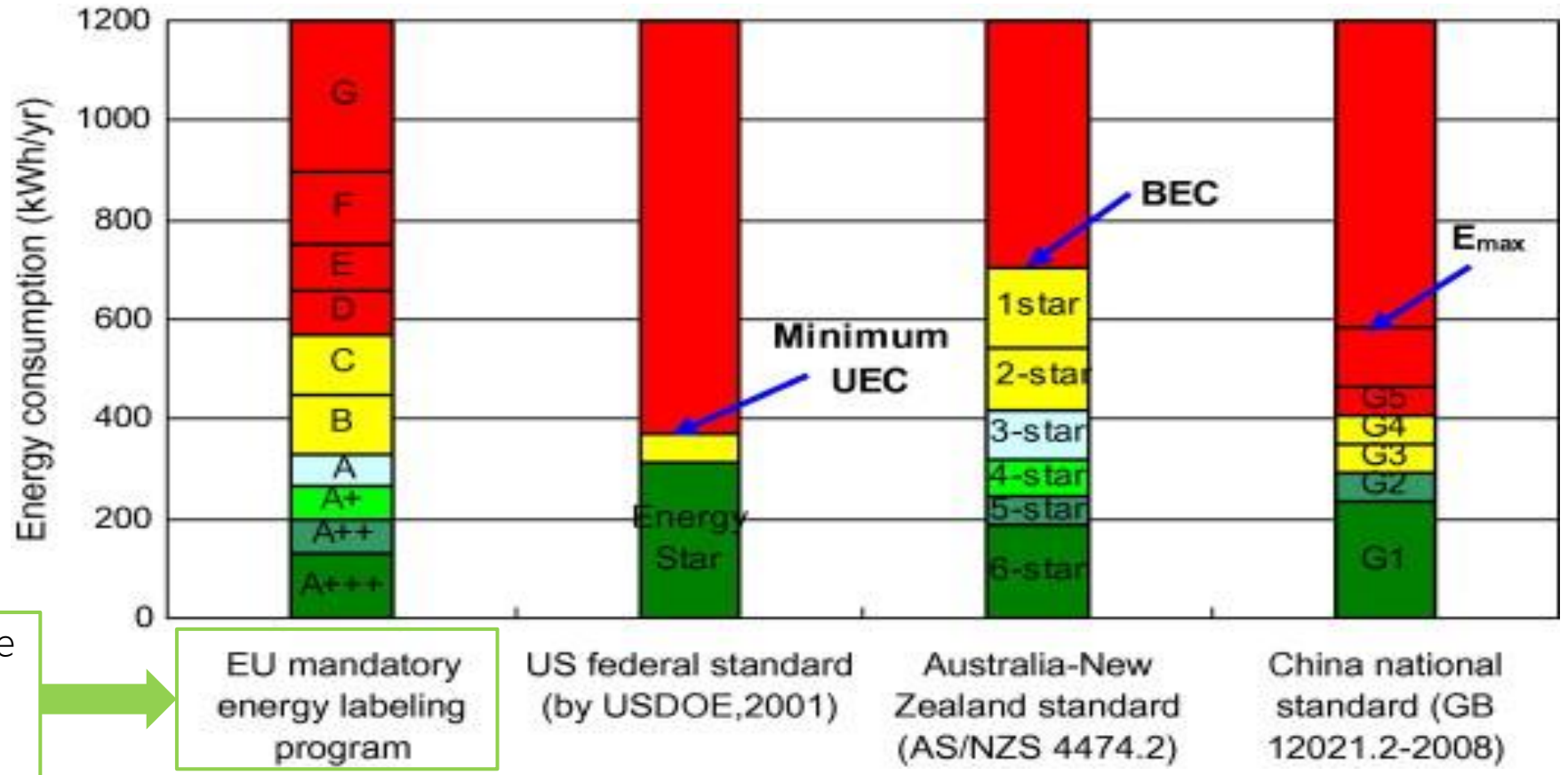


[1]Raw data: International Energy Agency (2022) (https://www.iea.org/reports/appliances-and-equipment)

[2]Raw data: International Energy Agency (2022) (https://www.iea.org/data-and-statistics/charts/global-electricity-consumption-by-lighting-in-the-net-zero-scenario-2010-2030)

Energy efficiency - negawatts

Appliance example: Refrigerators



These bands were changed in 2021.

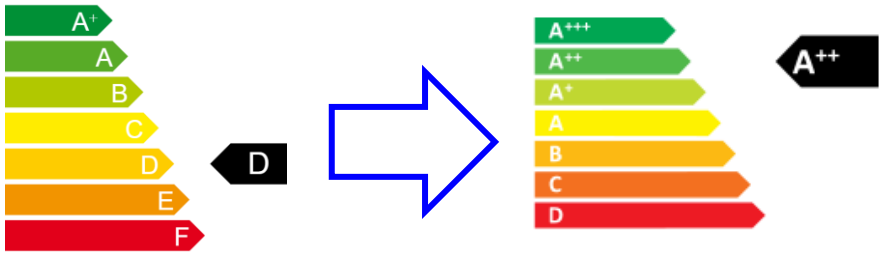
(200 kWh/a = D)

Comparison of international refrigerator energy efficiency standards on a selected model.

Jing Tao , Suiran Yu. **Implementation of energy efficiency standards of household refrigerator/freezer in China: Potential environmental and economic impacts.** Applied Energy Volume 88, Issue 5 2011 1890 – 1905.

Energy efficiency - negawatts

Appliance example: Refrigerators



China population: ~1.4 billion

China fridges: ~0.3 billion …?

Annual electricity consumption per fridge (D rated)*: ~600 kWh

Annual electricity consumption per fridge (A++ rated)*: ~200 kWh

Annual electricity saving per upgraded fridge (D to A++)*: ~400 kWh

Total annual electricity saved: ~120,000 GWh

*Based on pre-2021 EU energy ratings for fridge-freezer units

Energy efficiency - negawatts

China's Three Gorges Dam

22 GW_e (world's most powerful)

80,000 GWh_e per year

http://www.youtube.com/watch?v=sTAtTt32tMI

Lighting example: LED

Simple Payback Period: $\frac{\text{Cost}}{\text{Annual Savings}}$

Worked example:

An LED lamp, with a power draw of 5 W, delivers light equivalent to a 35 W halogen lamp. Given a price of €10 for the LED lamp, €0.40 per kWh for electricity, and assuming that the LED lamp is used for an average of 3 hours per day, calculate the simple payback period for the LED lamp.

Halogen lamp (35 W)

LED lamp (5 W)

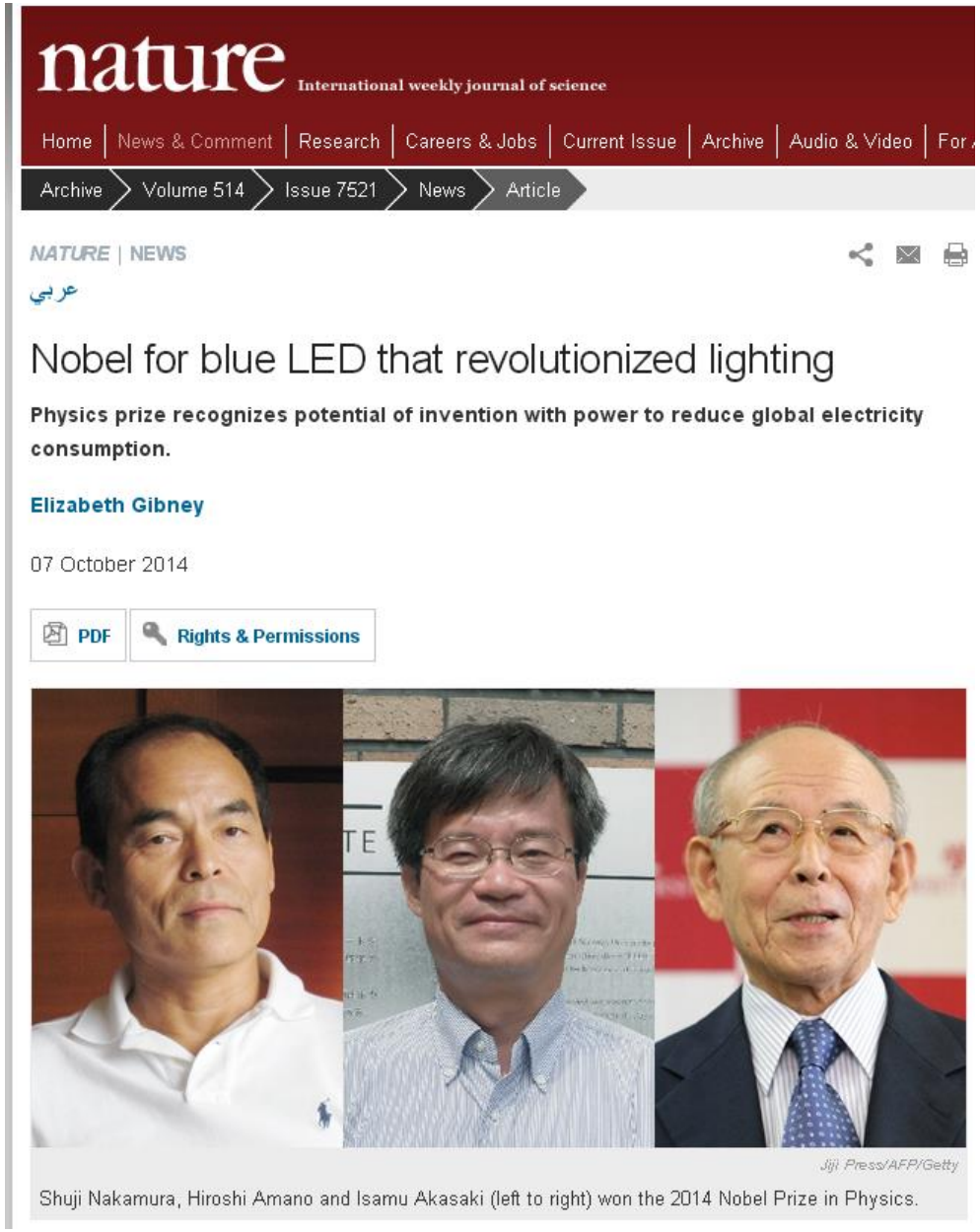
Energy efficiency - negawatts

Lighting example: LED

LED lighting *alone* could reduce global electricity demand by ~5%.

Roughly equivalent to the electricity consumption of EU-27…

Nobel Prize for Physics, 2014



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NATURE | NEWS

عربي

Nobel for blue LED that revolutionized lighting

Physics prize recognizes potential of invention with power to reduce global electricity consumption.

Elizabeth Gibney

07 October 2014

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Jiji Press/AFP/Getty

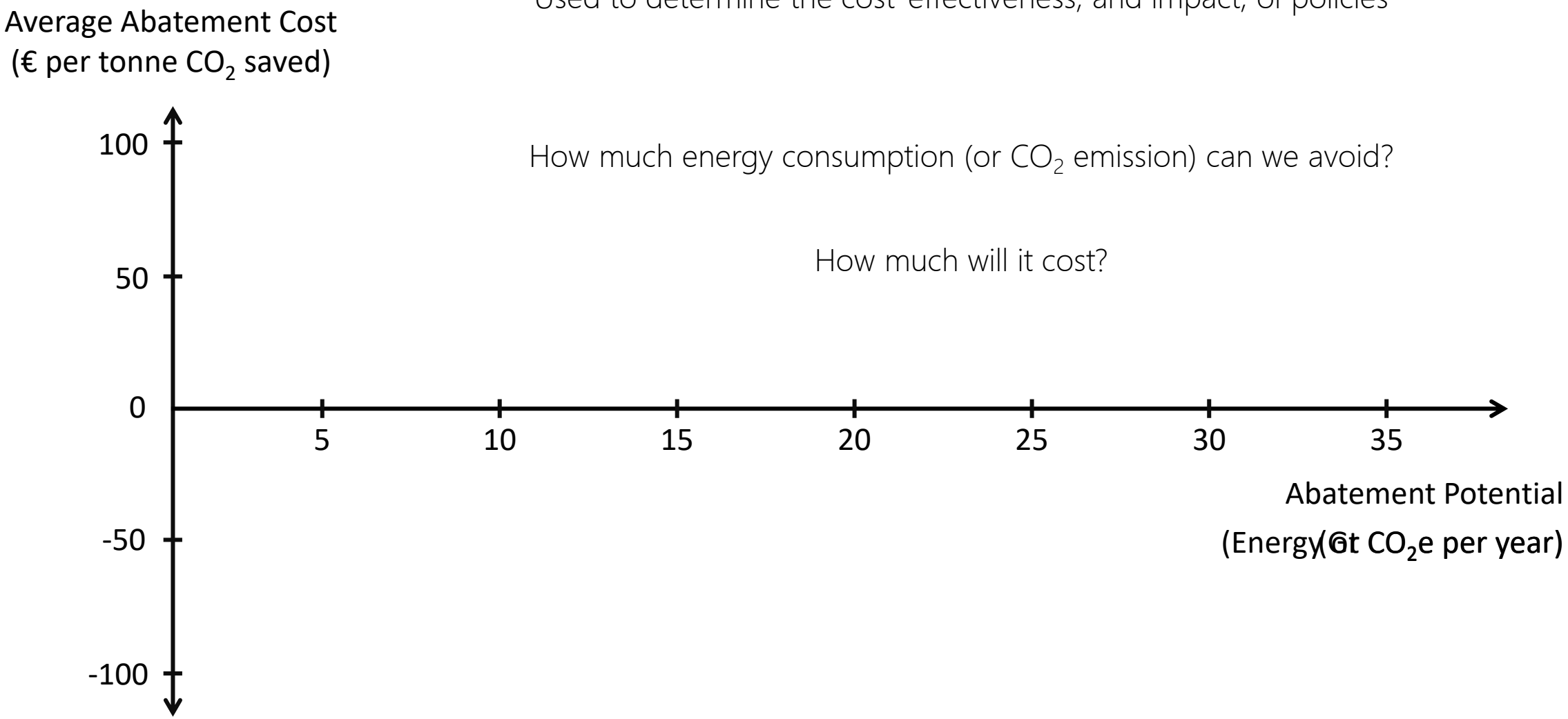
Shuji Nakamura, Hiroshi Amano and Isamu Akasaki (left to right) won the 2014 Nobel Prize in Physics.

MAC curves

Energy efficiency – how much?

Marginal abatement cost curves (MAC curves)

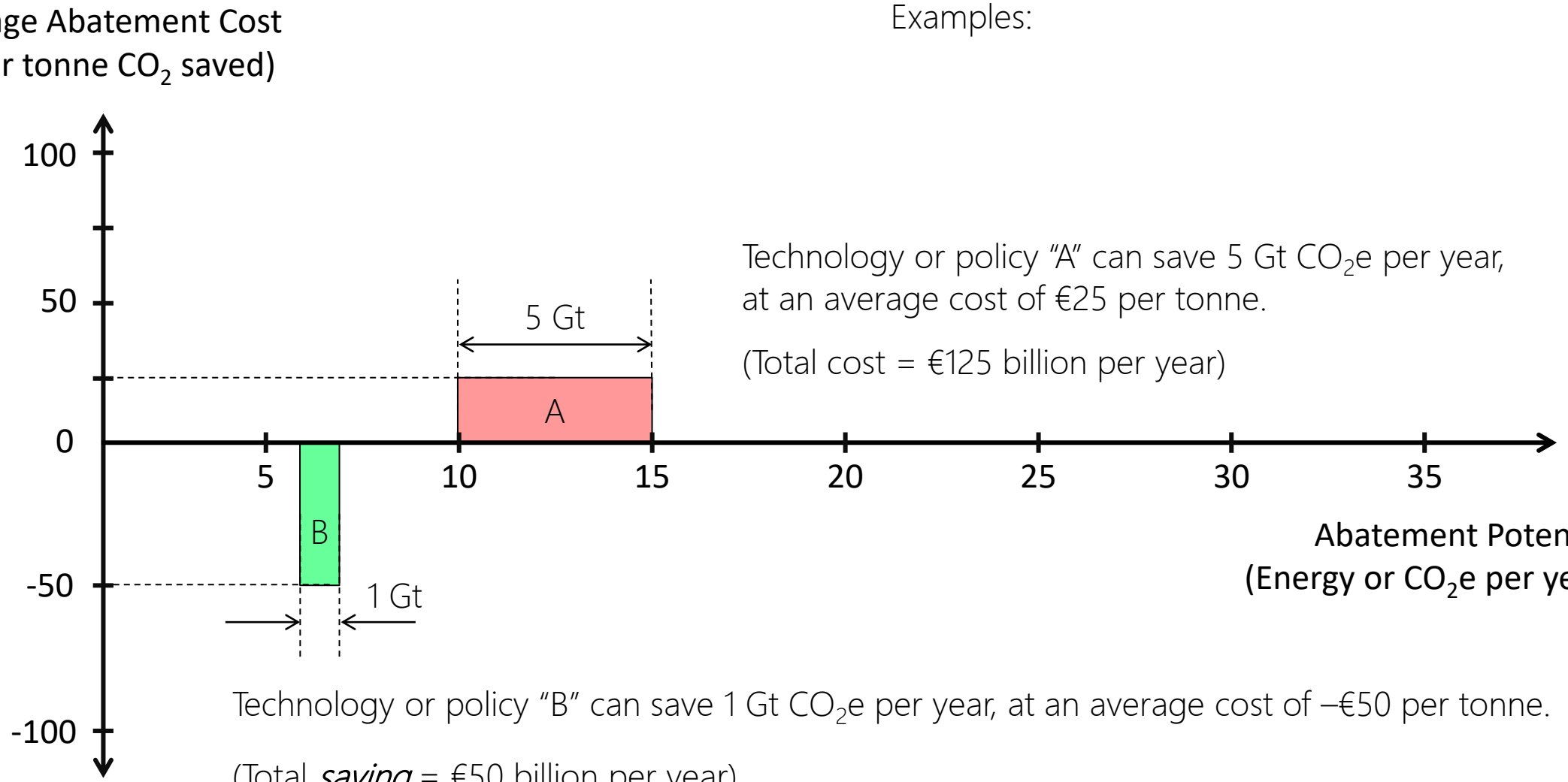
Used to determine the cost-effectiveness, and impact, of policies



How much energy consumption (or CO_2 emission) can we avoid?

How much will it cost?

Marginal abatement cost curves (MAC curves)



Examples:

Technology or policy "A" can save 5 Gt CO_2e per year, at an average cost of €25 per tonne.

(Total cost = €125 billion per year)

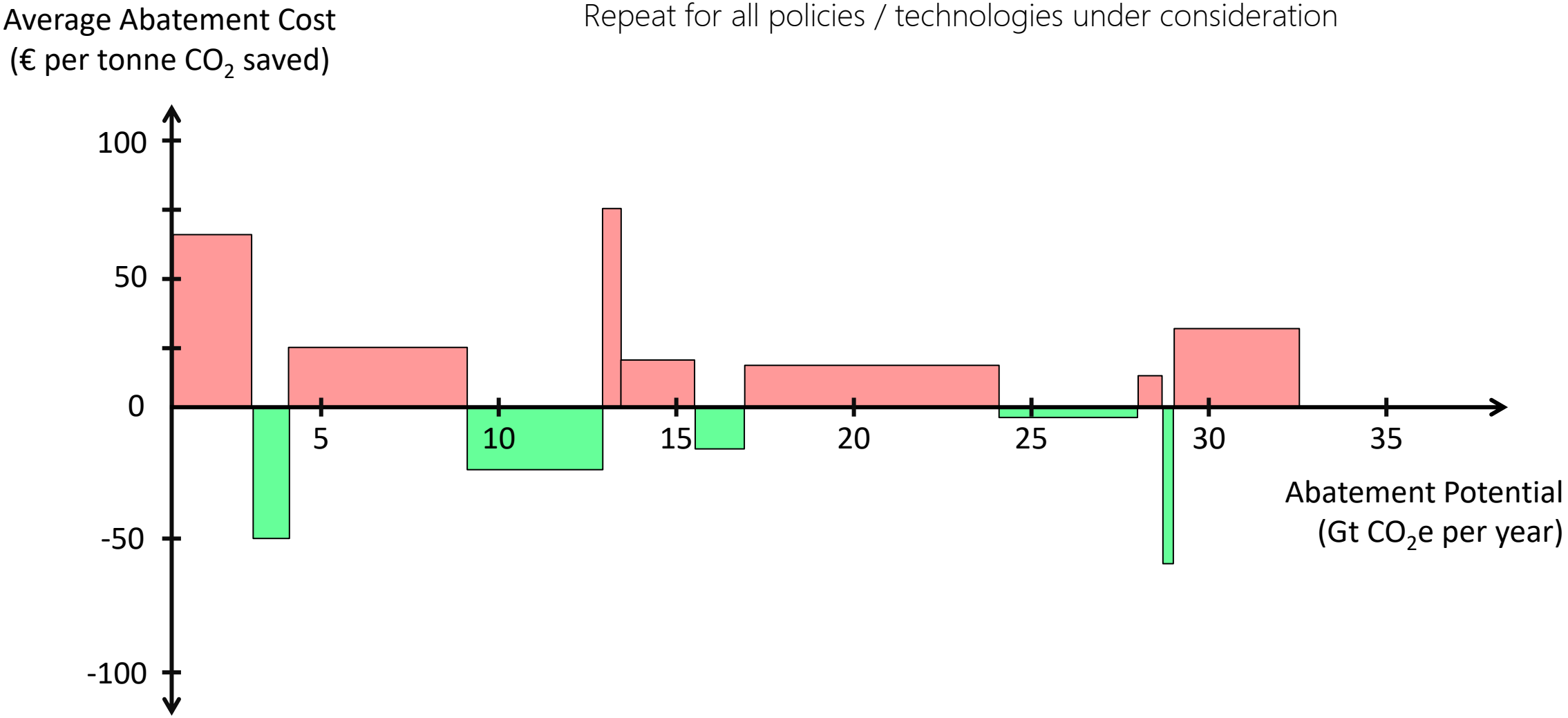
Technology or policy "B" can save 1 Gt CO_2e per year, at an average cost of –€50 per tonne.

(Total *saving* = €50 billion per year)

Energy efficiency – how much?

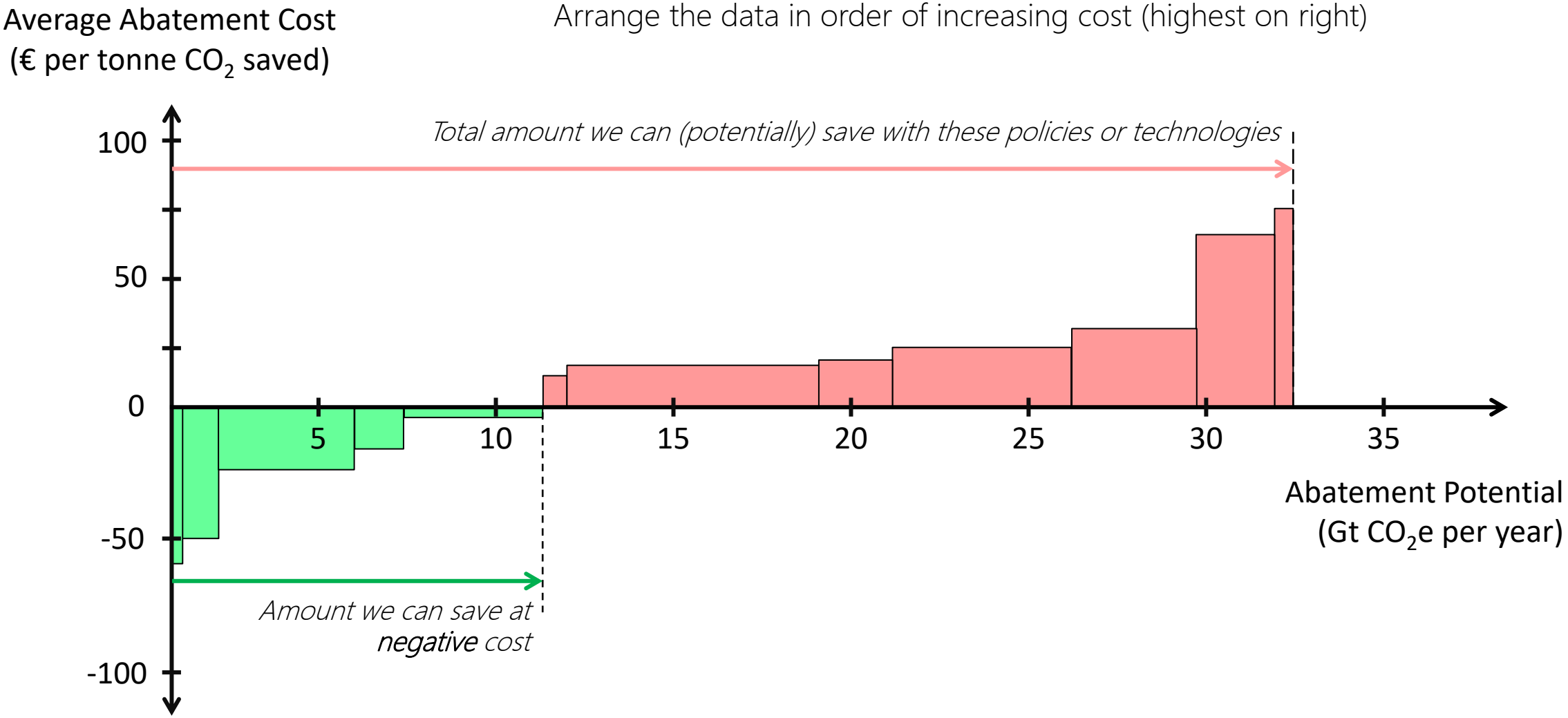
Marginal abatement cost curves (MAC curves)

Repeat for all policies / technologies under consideration



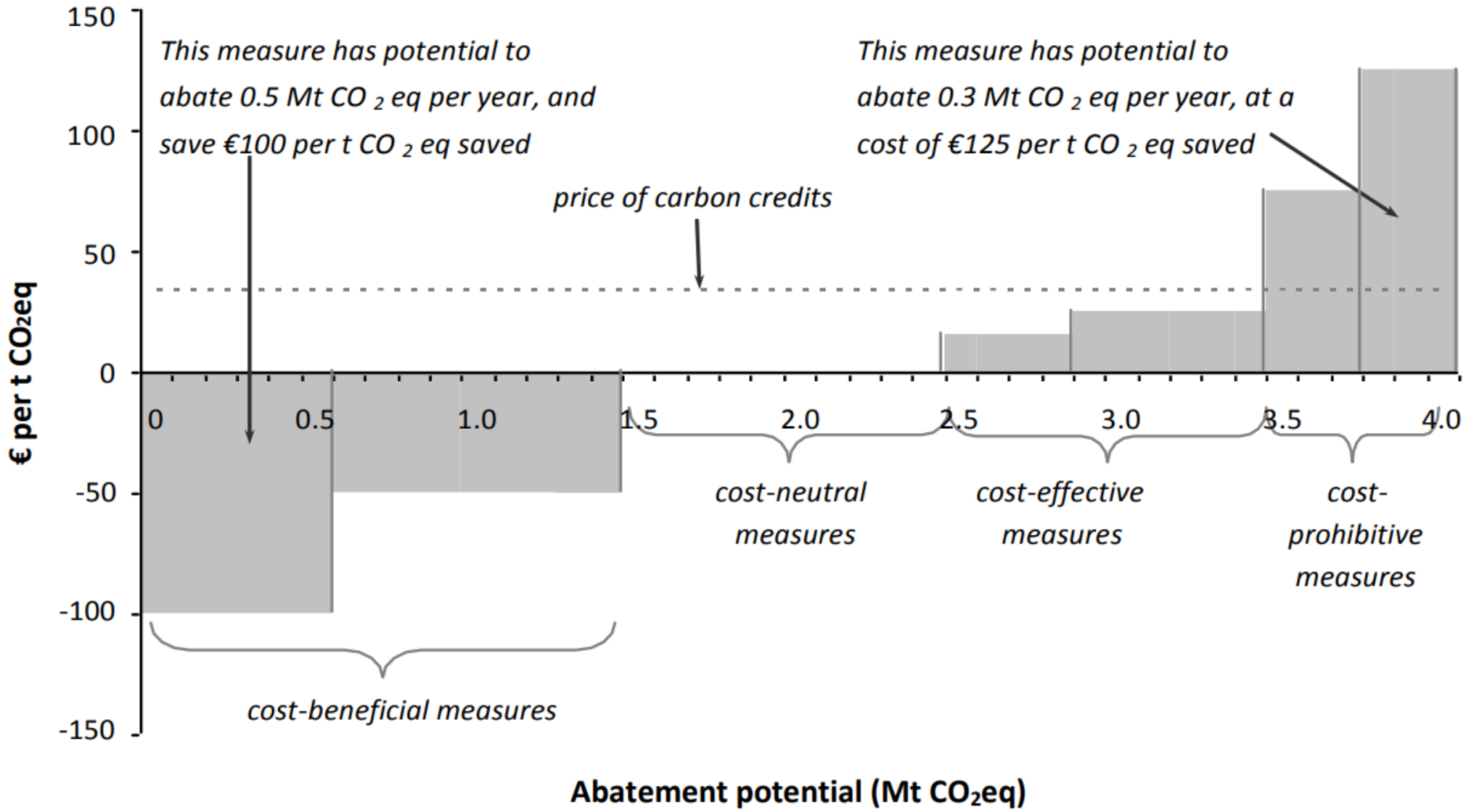
Marginal abatement cost curves (MAC curves)

Arrange the data in order of increasing cost (highest on right)



Energy efficiency – how much?

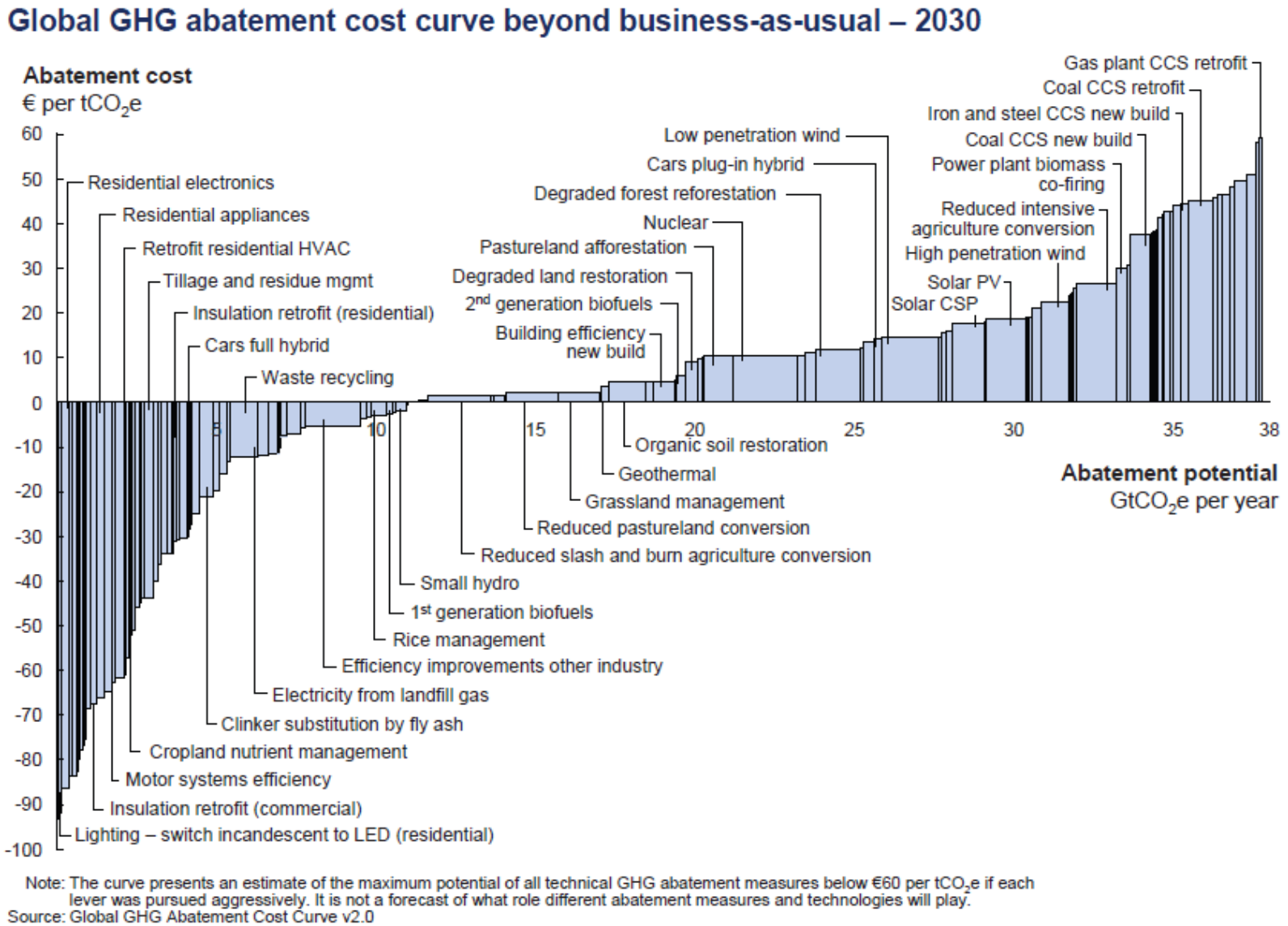
Marginal abatement cost curves (MAC curves)



Source: "An Analysis of Abatement Potential of Greenhouse Gas Emissions in Irish Agriculture 2021-2030", p10. Teagasc (2018)

Energy efficiency – how much?

Marginal abatement cost curves (MAC curves)

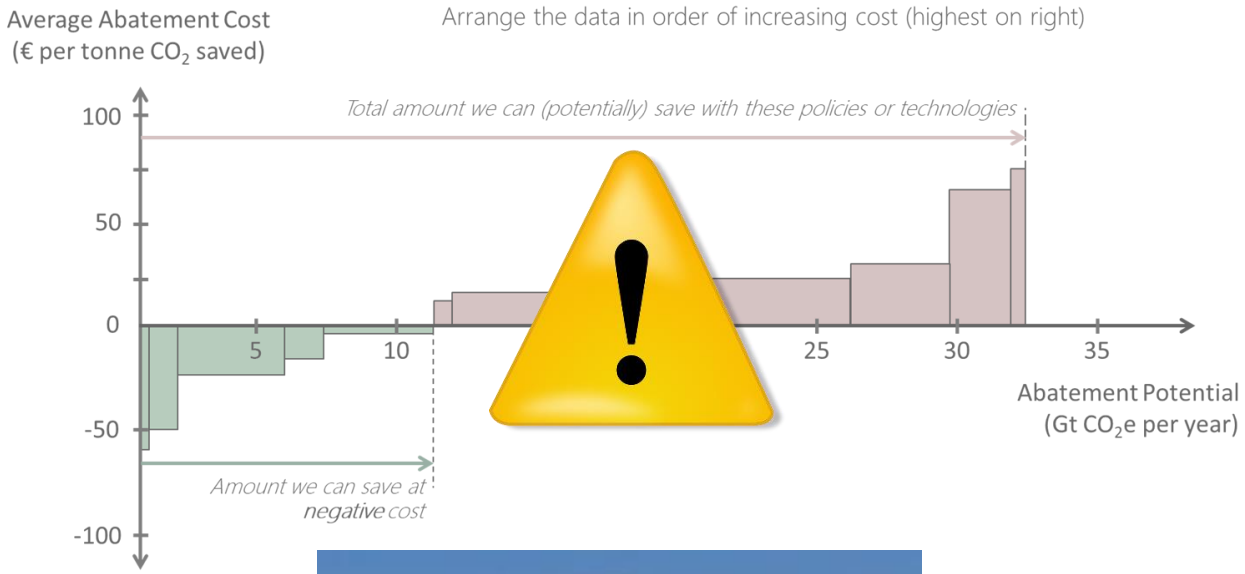


Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

Source: https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/greenhouse-gas-abatement-cost-curves

Energy efficiency – how much?

Marginal abatement cost curves (MAC curves)



Problems with MAC curves:

1. Estimates of both "abatement potential" and "average cost", are highly sensitive to the assumptions on which they are based.

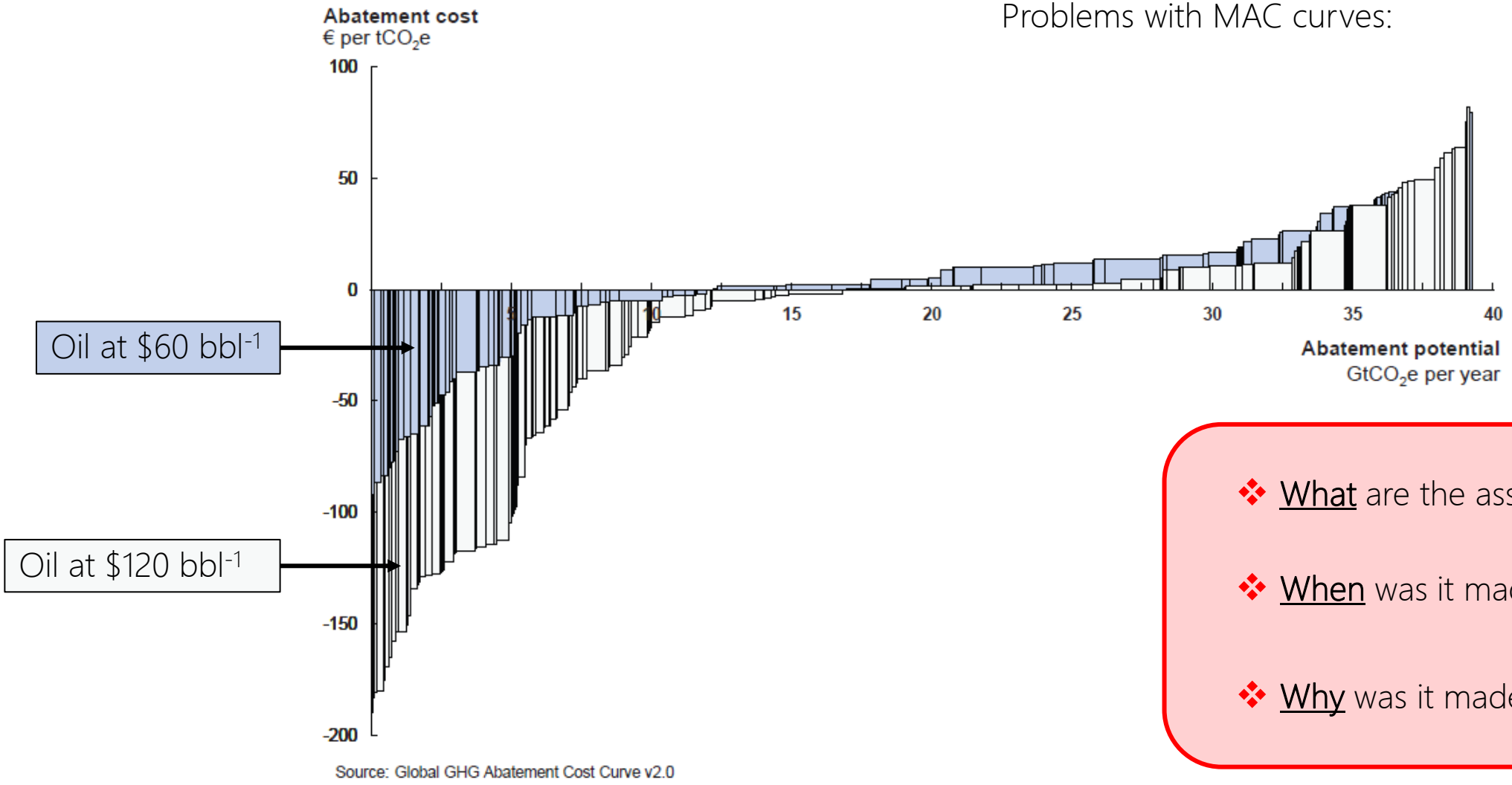
2. The estimates are a snapshot made at a single point in time – costs, and abatement potential, can change substantially over a few years.

3. Non-financial costs are excluded.

4. The clarity and simplicity of the graph can be very beguiling for policy-makers.

Energy efficiency – how much?

Marginal abatement cost curves (MAC curves)



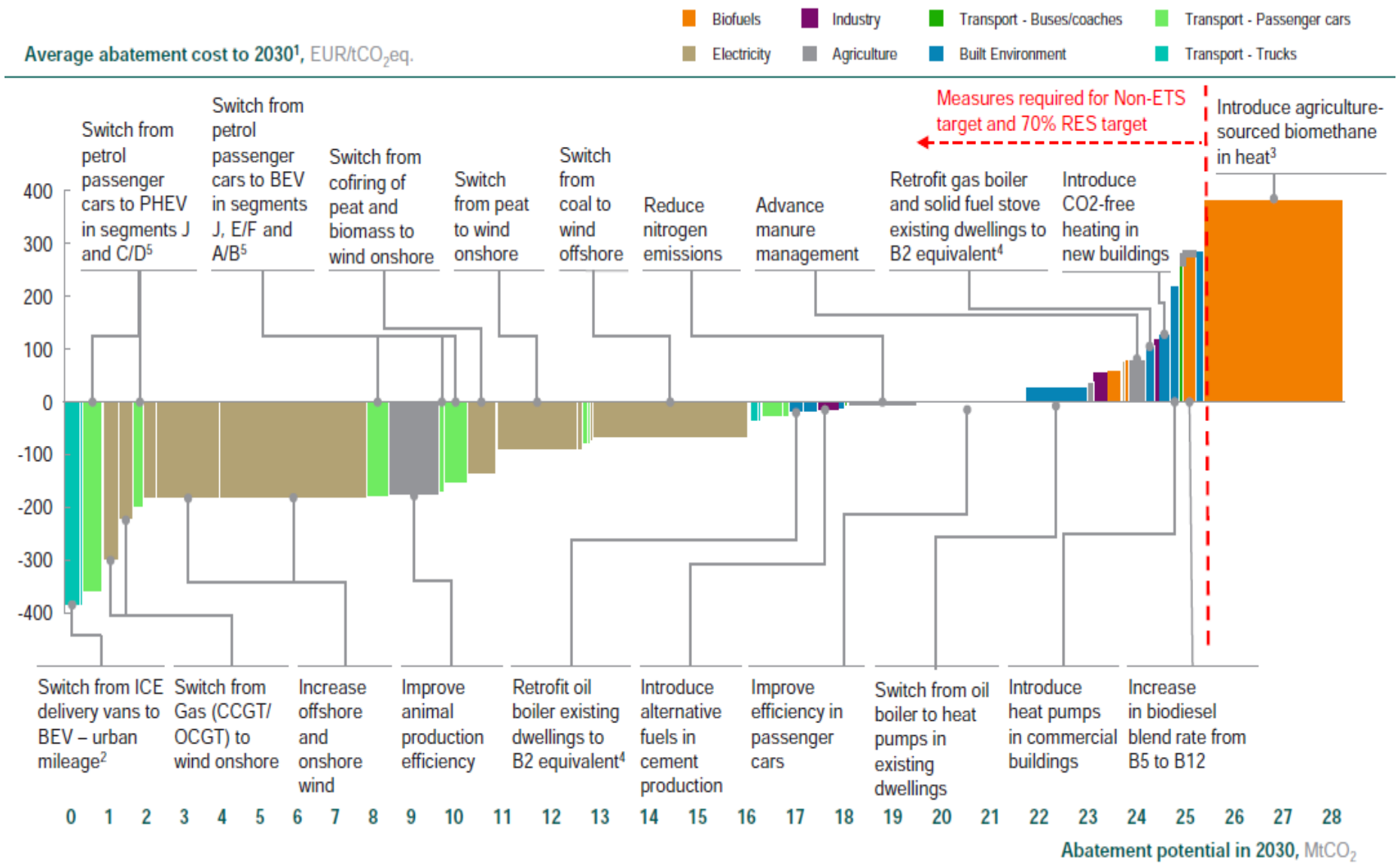
Problems with MAC curves:

- <u>What</u> are the assumptions?
- <u>When</u> was it made?
- <u>Why</u> was it made (who made it)?

Source: https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/greenhouse-gas-abatement-cost-curves

Energy efficiency – how much?

Ireland MAC curve, used to formulate the 2019 Climate Action Plan

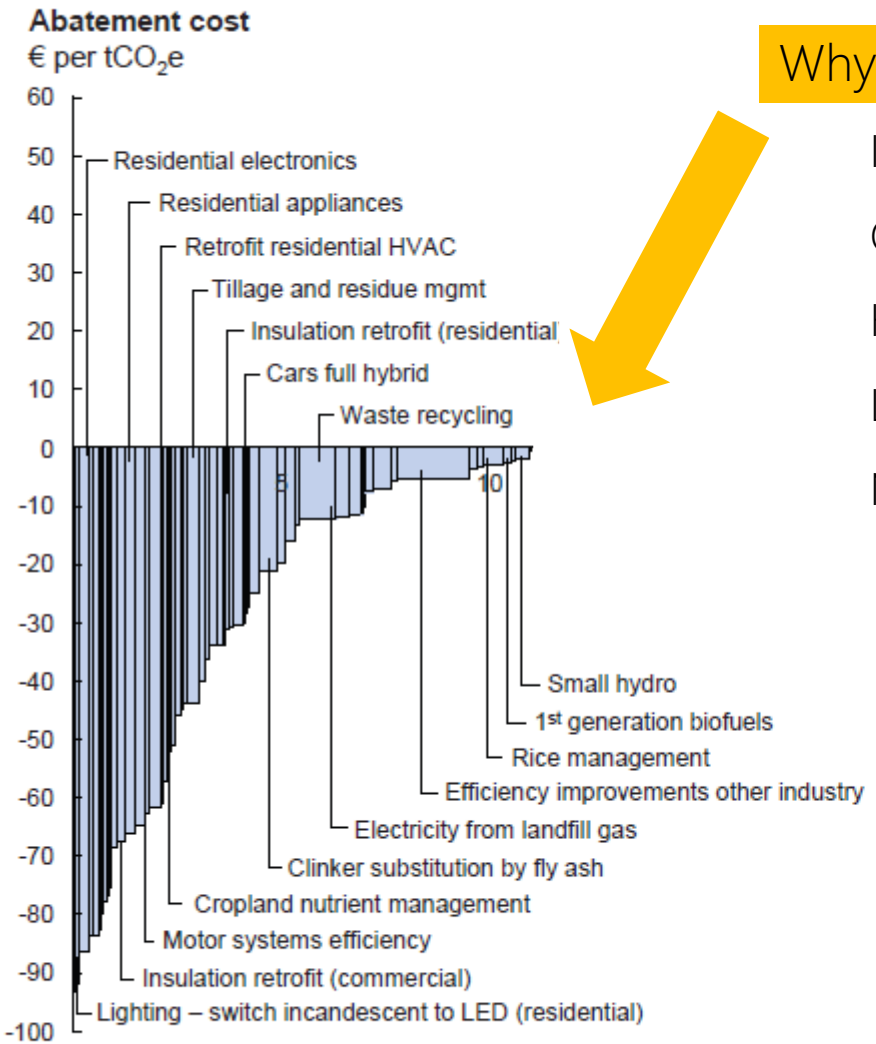


Source: Climate Action Plan 2019, p28. Government of Ireland (2019)

Energy efficiency – hurdles

Energy efficiency – hurdles

Global GHG abatement cost curve beyond business-as-usual – 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

Why not captured yet – if negative cost?

Information deficit – mainly consumers

Ownership issues (split incentives) – e.g. landlord / tenant

High upfront cost?

Long payback period

Market failures: policy distortions, subsidies etc.

Suggested actions to capture potential

Impose energy labelling requirement

Set energy efficiency standards – BER etc.

Finance energy efficiency upgrades

Eliminate policy distortions

Energy efficiency – pitfalls

Energy efficiency – hurdles

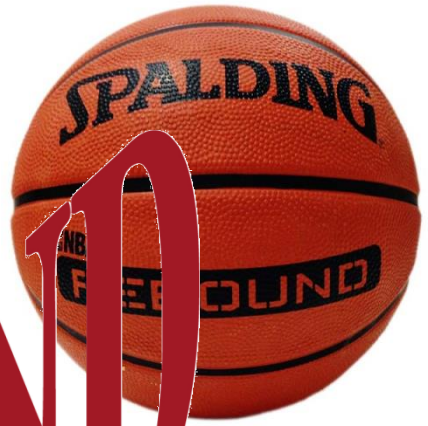
Potential pitfalls:

1. Shortfall

Energy efficiency – hurdles

Potential pitfalls:

2. Rebound



REBOUND®

Energy efficiency – hurdles

Potential pitfalls:

3. Backfire

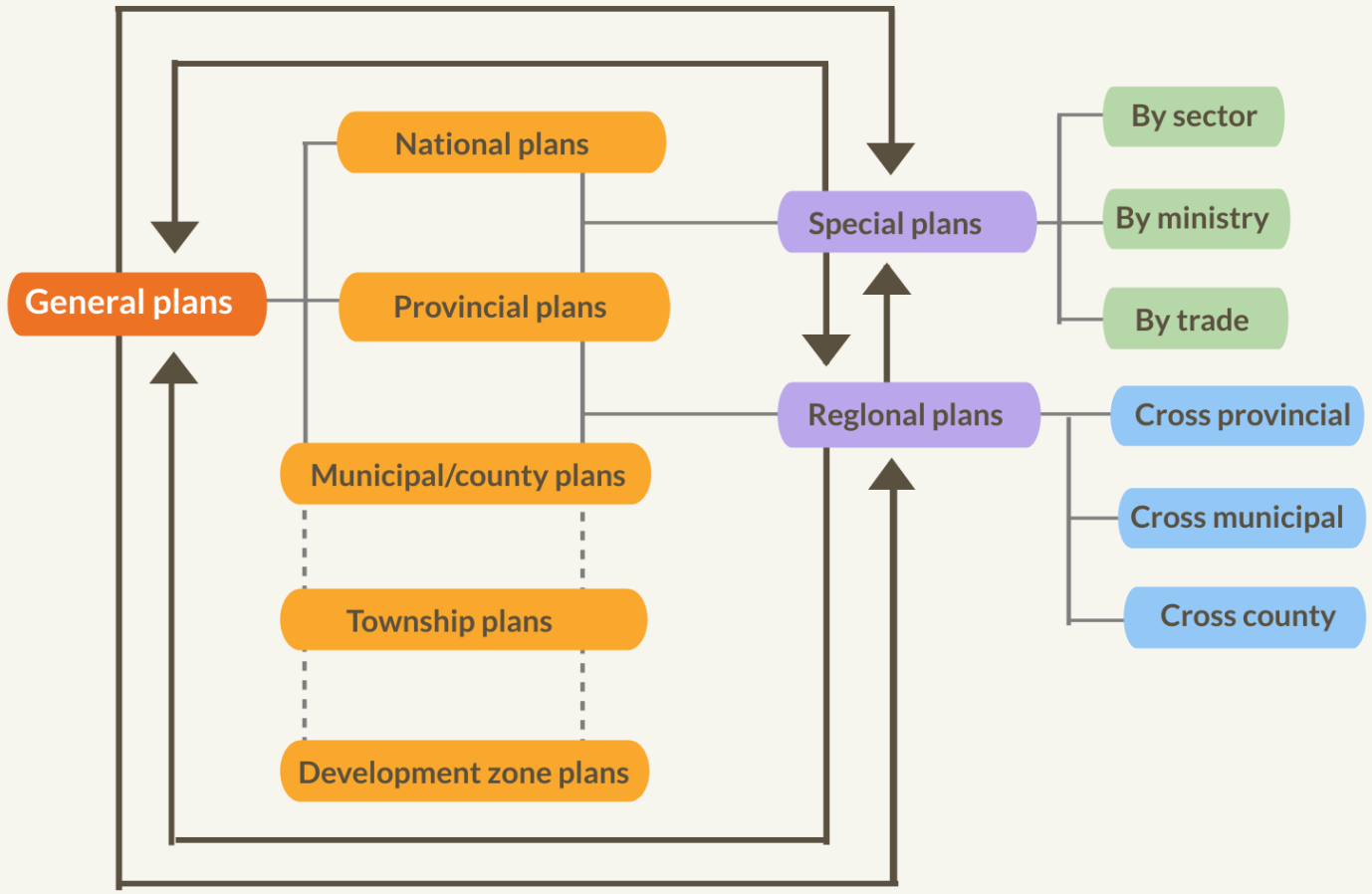
Energy efficiency: policy

Policy options:

- Performance standards (appliances, buildings, vehicles, etc.)
- EE Utilities (e.g. Efficiency Vermont, etc.)
- EE “obligations” (EED 1.5%, etc.)
- Energy labelling (appliances, buildings, vehicles, etc.)
- EE incentives (Tax relief, low-interest loans, grants, etc.)
- Energy taxes
- Support for EE R&D

Energy efficiency: policy

Flow chart of plan formulation in China



China's policies are formulated in 5-year plans.

Image source: https://chinadialogue.net/en/climate/9532-china-raises-its-low-carbon-ambitions-in-new-2-2-targets/

Energy efficiency: policy

12th Five-year Plan (2011-2015)

Target: Reduce energy-intensity of GDP by 16% (re 2010)

Outcome: Reduced by 18.2% [1]

13th Five-year Plan (2016-2020)

Two main EE objectives:

- Reduce energy-intensity of GDP by 15% by 2020 (re 2015); outcome: 14% reduction achieved[2]
- Cap PER at 5 Gtce (3.5 Gtoe) by 2020 (was 3.01 Gtoe in 2015); outcome: 5.1 Gtce[3]

14th Five-year Plan (2021-2025)

- Reduce energy-intensity of GDP by 13.5% by 2025 (re 2020)
- Tighter energy efficiency standards for energy-intensive industries
- Energy security is very important

[1] Source: e.g. http://www.lse.ac.uk/GranthamInstitute/law/13th-five-year-plan/

[2] Source: e.g. https://www.enerdata.net/china-institutions-and-energy-policy-energy-efficiency.html

[3] Source: Statistical Review of World Energy 2023

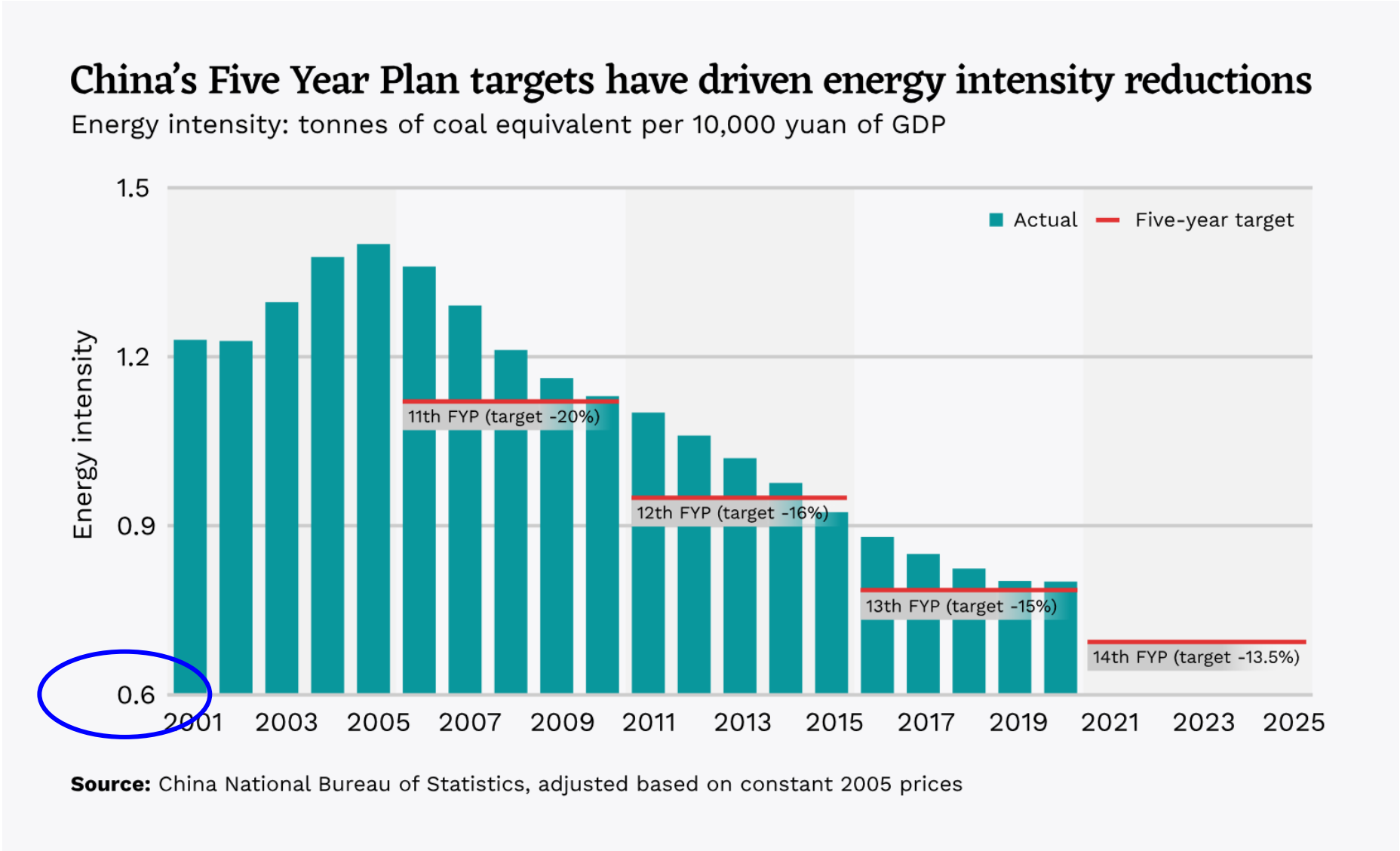
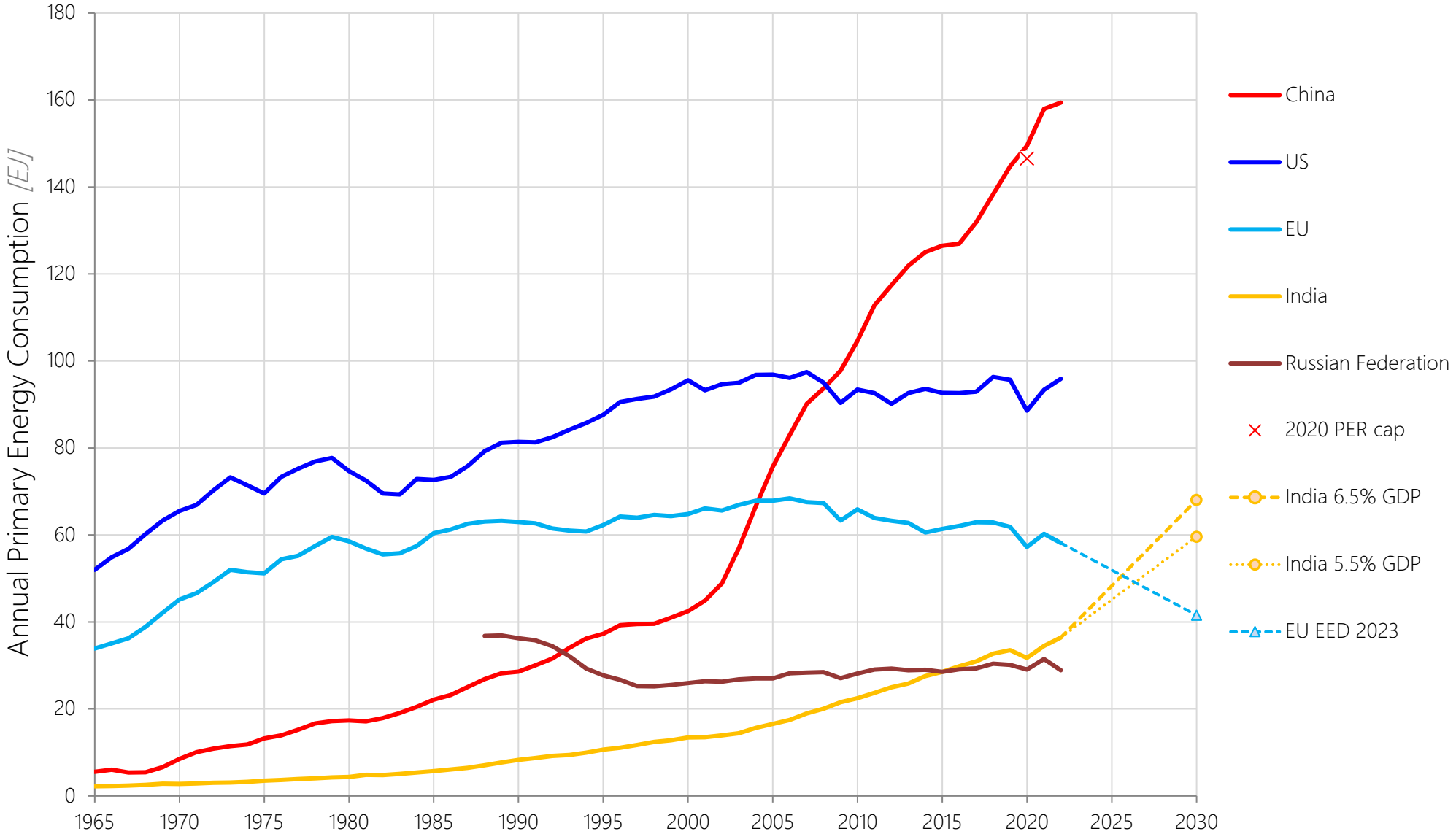


Image source: *https://chinadialogue.net/en/energy/will-recent-power-shortages-slow-chinas-progress-to-carbon-neutrality*

Energy efficiency: policy

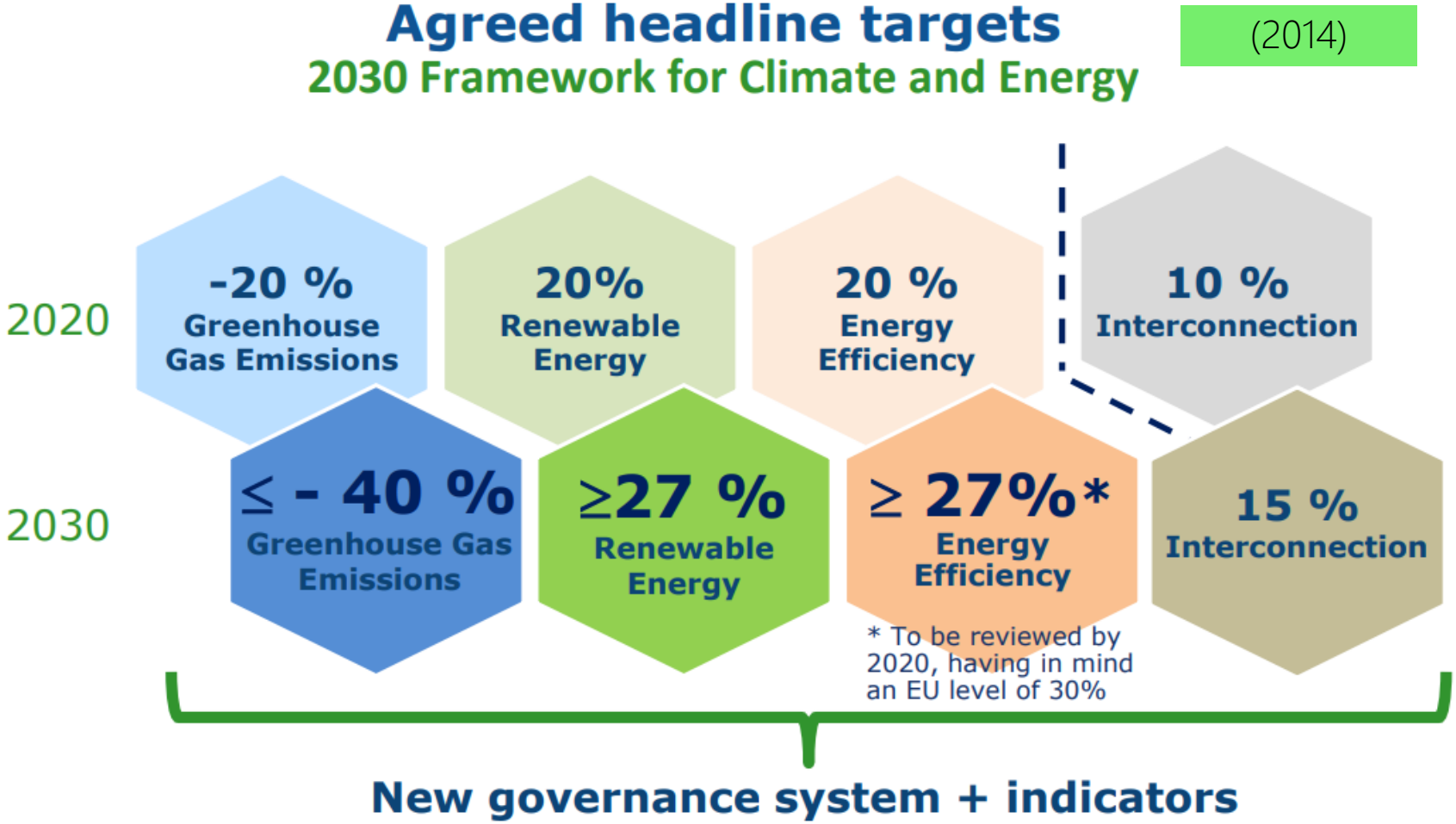


Sources – Historical data: BP Statistical Review of World Energy; Projections: W. Smith

Energy efficiency: policy

European Union

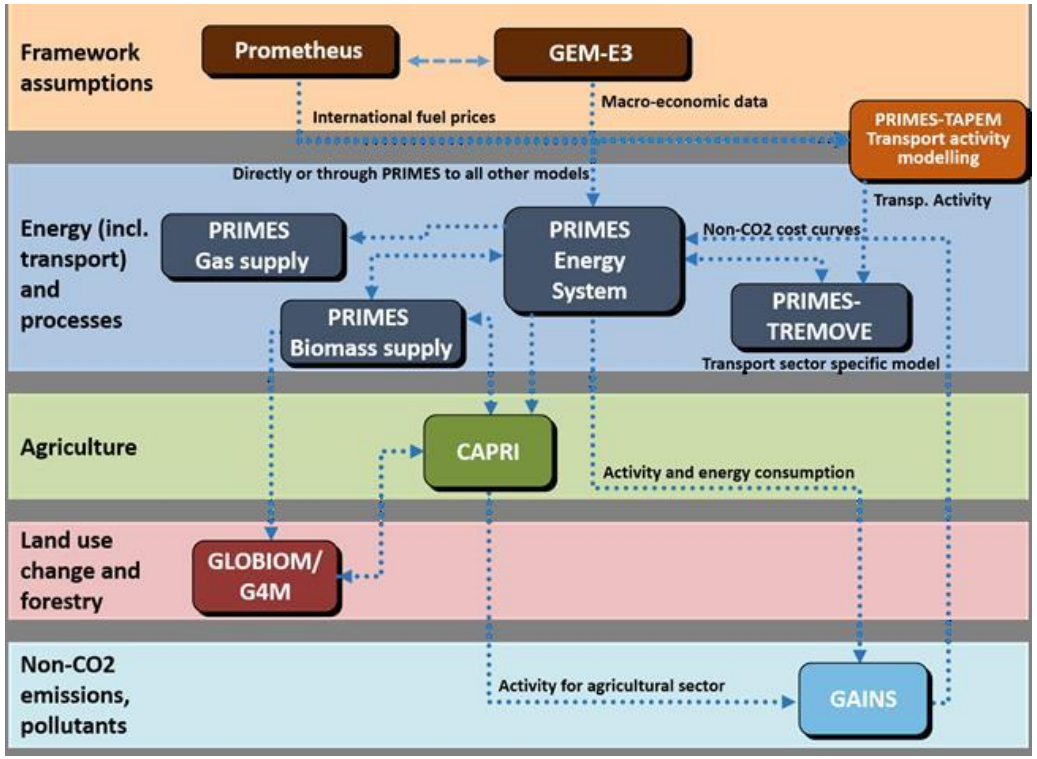
Looking towards 2030



Source: Outcome of the 2014 European Council *https://ec.europa.eu/clima/sites/clima/files/strategies/2030/docs/2030_euco_conclusions_en.pdf*

How is the EU energy efficiency target calculated?

- The target is defined as a reduction in (primary or final) energy consumption relative to "business as usual".
- "Business as usual" (BAU) is estimated using an energy-economic model to project future energy demand, assuming current policies etc.



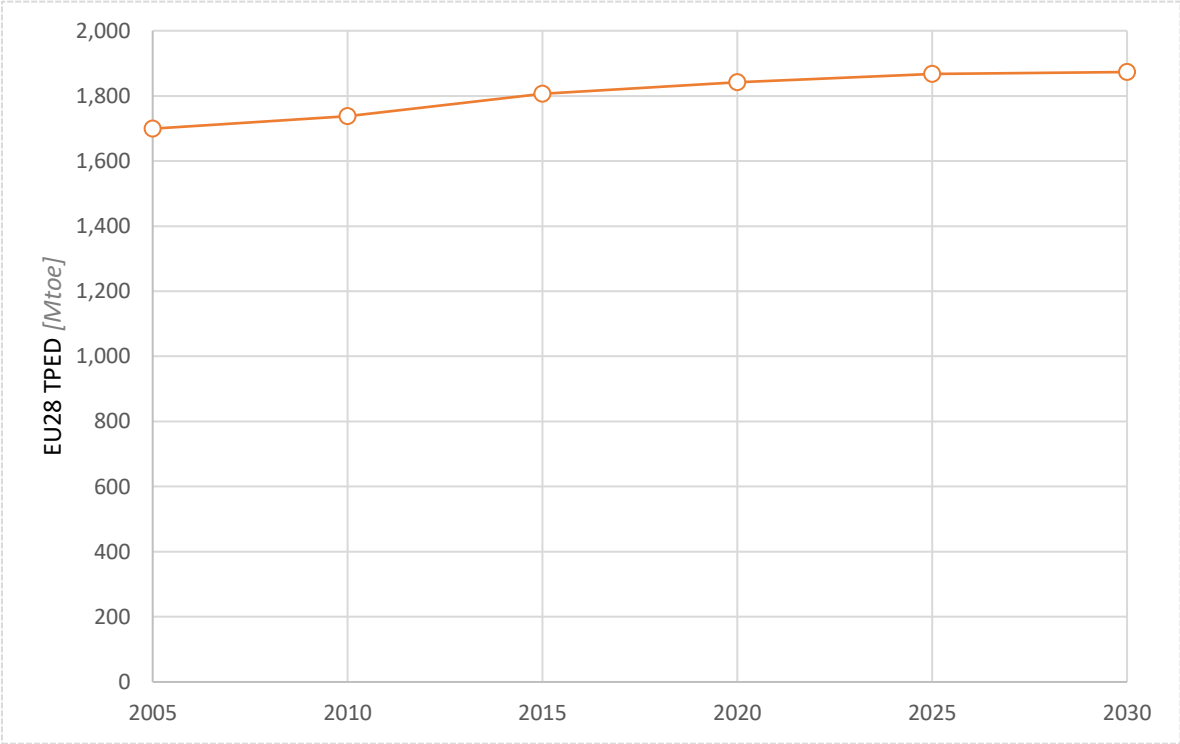
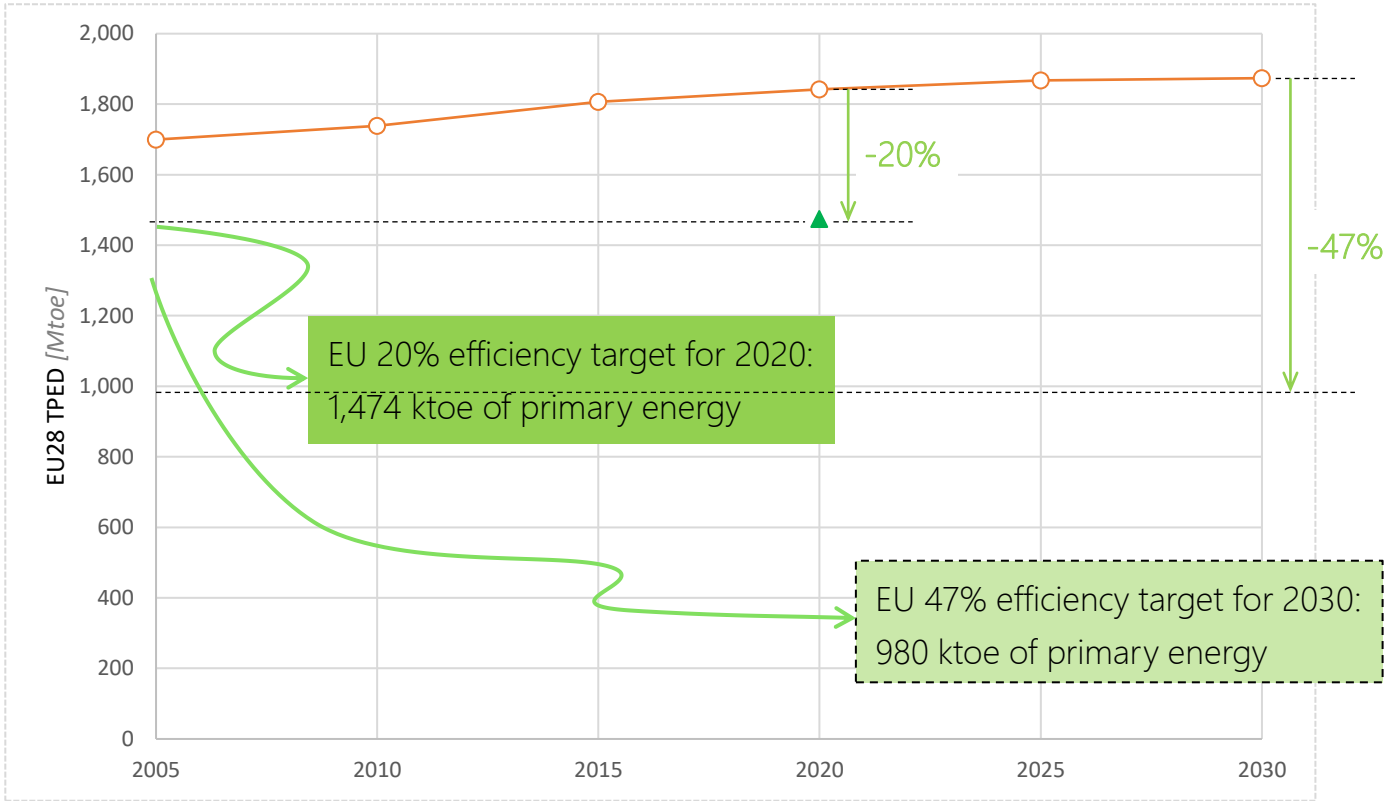


Image source: *https://ec.europa.eu/energy/en/data-analysis/energy-modelling/modellingfigure*

Energy efficiency: policy

How is the EU energy efficiency target calculated?

- The target is defined as a reduction in (primary or final) energy consumption relative to "business as usual".
- "Business as usual" (BAU) is estimated using an energy-economic model to project future energy demand, assuming current policies etc.
- The projected energy demand in 2020 or 2030 is then reduced by "x" %.
- These projections were run in 2007…
- …updates run in 2020



Source: *https://ec.europa.eu/energy/en/data-analysis/energy-modelling/modellingfigure*

Evolution of EU energy efficiency targets

2007: European Council proposes 2020 Targets (20-20-20 by 2020)

- EE target: reduce EU energy consumption in 2020 by 20%, relative to business as usual (BAU) expectation.

2007-09:

- Financial crisis and economic stagnation
- Russia-Ukraine gas dispute

} Renewed interest in energy efficiency.

2014: European Council proposes 2030 Targets: EE target of ≥ 27% (relative to 2007 BAU expectation for 2030)

2016: "Winter Energy Package"[1] proposes increasing 2030 EE target to 30%

2018: Agreement to increase 2030 EE target to 32.5%[2]

2021: "Fit for 55" strategy increases 2030 EE target to 46% (PER), 44% (TFC)

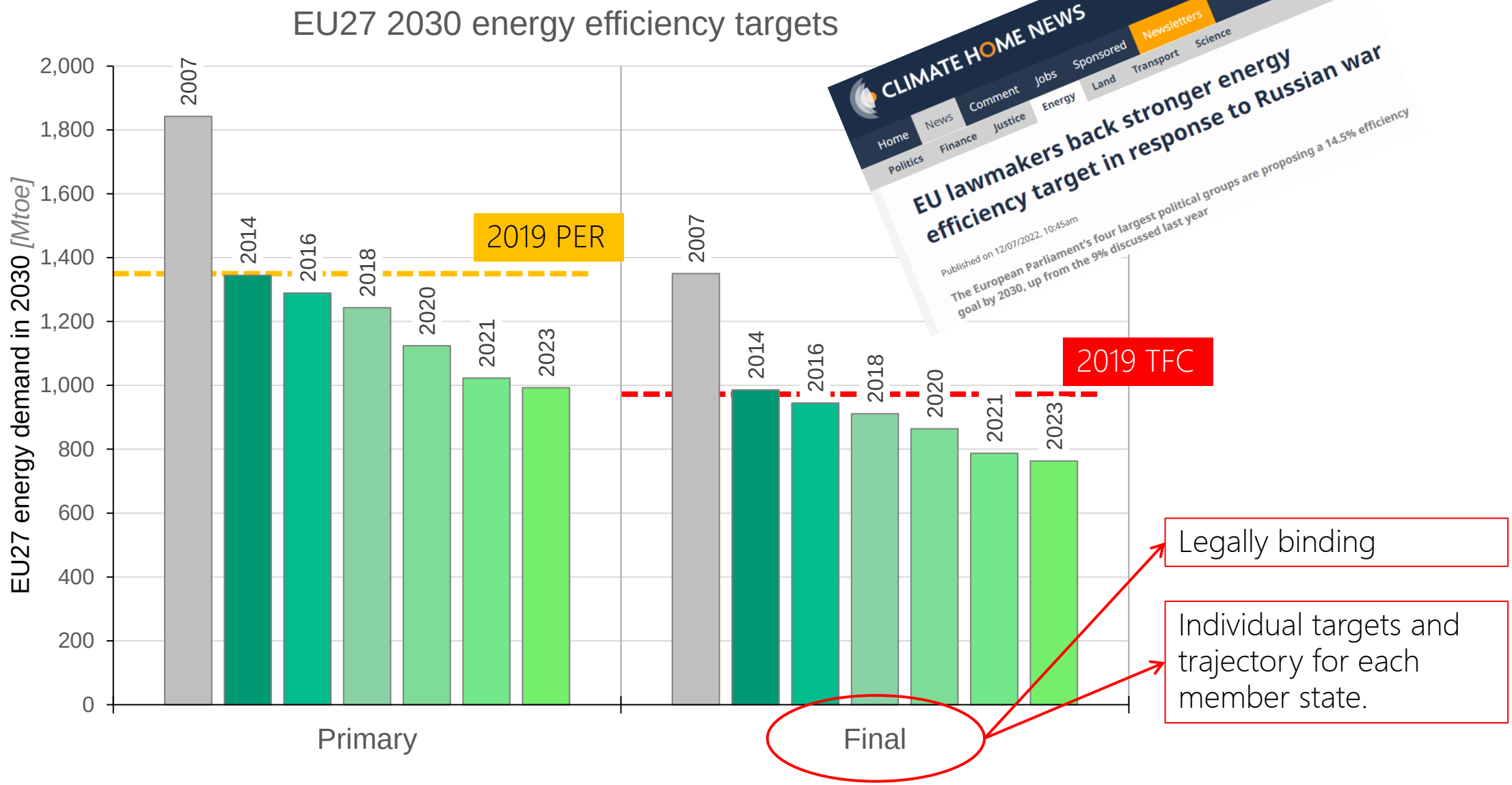
2022: "REPowerEU" plan increase 2030 EE target to 48% (PER), 47% (TFC)

EED 2023 targets reduce:
TPED to 992.5 Mtoe *(47%)*
TFC to 763 Mtoe *(46%)*

[1] *https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans*

[2] *http://europa.eu/rapid/press-release_STATEMENT-18-3997_en.htm*

Evolution of EU energy efficiency targets



What policies and measures are in place to achieve these targets?

- EcoDesign Directive (2009/125/EC) ….defines minimum standards for appliances
  (new regulations, from March 2021, include repairability and recyclability)

- Energy Labelling Regulation (EU) 2017/1369 ….appliances must be labelled
  (new format and scaling, from March 2021)

- Energy Performance of Buildings Directive (2010/31/EU) ….standards and certification (e.g. BER)

- Energy Efficiency Directive (EU 2023/1791)
  - National Energy Efficiency Targets
  - National Energy and Climate Plans (NECPs) – updated every 2 years from 2023-4
  - Energy companies to sell energy savings of 1.5% per year

- Energy Star Programme (2013, with USA)….identifies most-energy-efficient office equipment

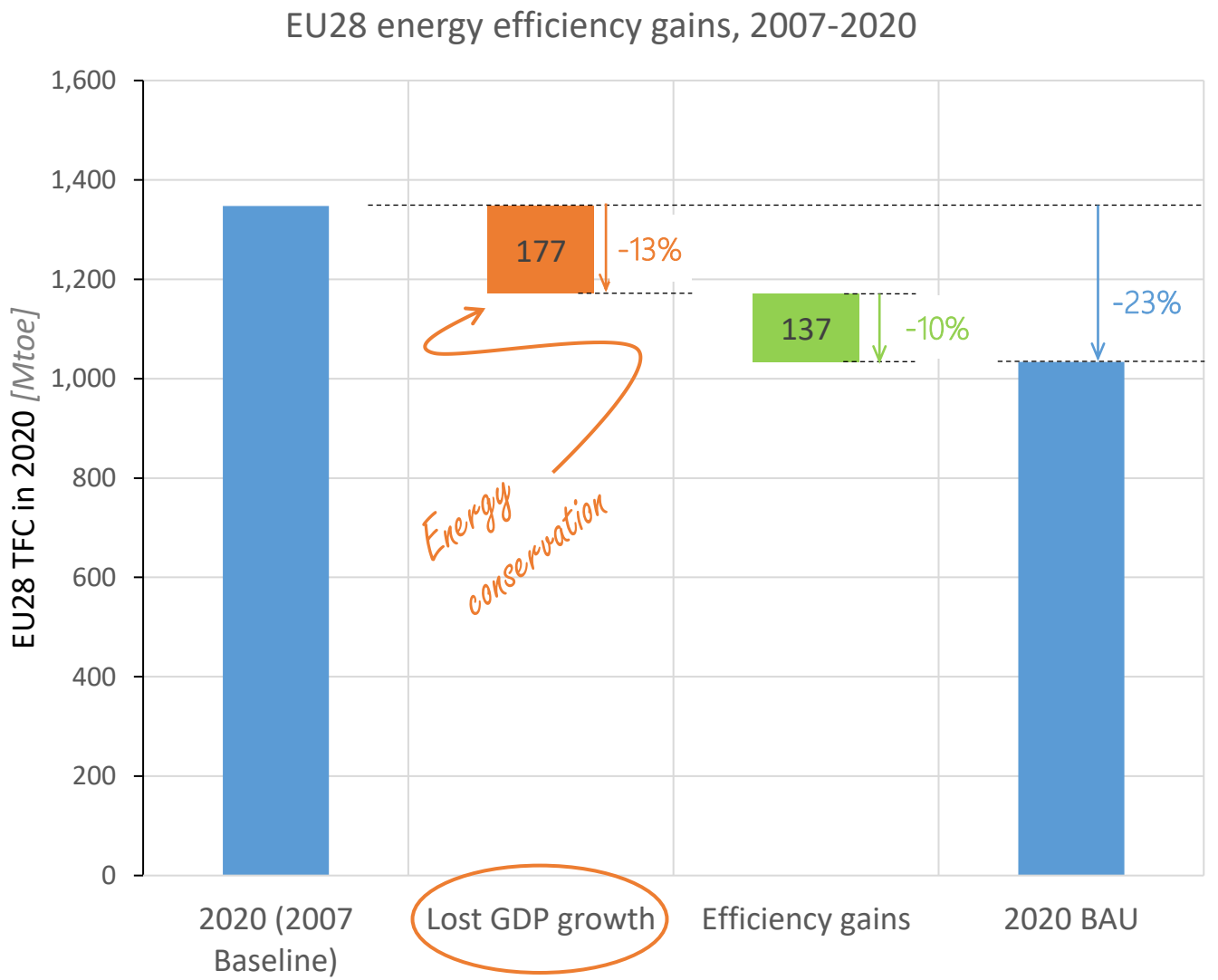
Energy efficiency: policy

What policies and measures are in place to achieve these targets?

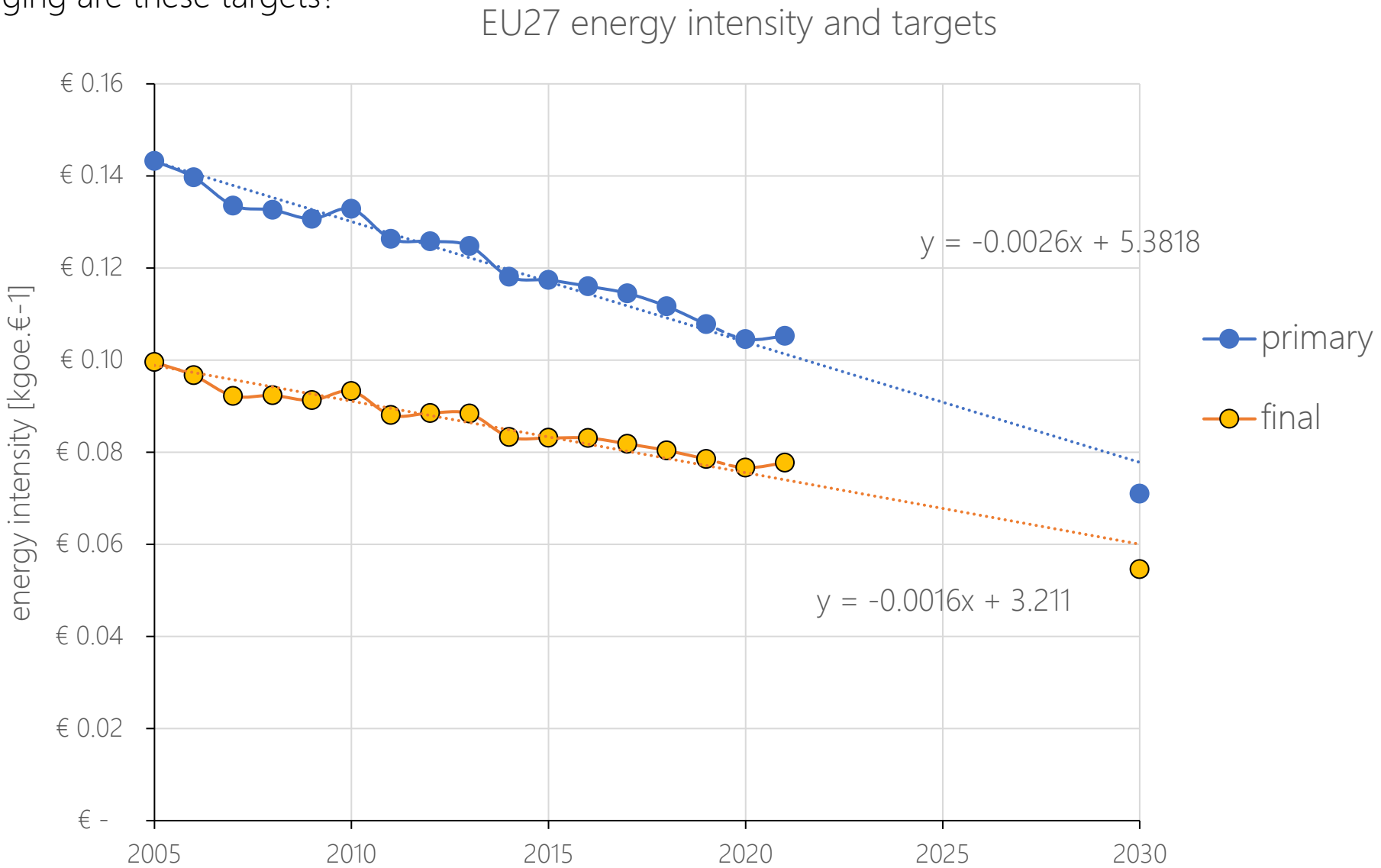
Additional measures adopted by the EU to improve energy efficiency include:

- energy efficient renovations must be carried out to at least 3% of buildings owned and occupied by central governments each year
- planned rollout of ~200 million smart meters for electricity, and 45 million for gas, by 2020 (…now 2024)
- large companies must conduct energy audits at least every four years
- promotion of cogeneration of heat and power (CHP)
- launch of an EU strategy on heating & cooling
- protecting the rights of consumers to receive easy and free access to data on real-time and historical energy consumption
- CO_2 emission standards for cars and vans

How challenging are these targets?



How challenging are these targets?



EU energy efficiency summary

- EU is a net importer of primary energy.
- Energy efficiency addresses all three pillars of EU energy policy:
  - Securability
  - Affordability
  - Sustainability
- Strong support from MEPs for ambitious energy-efficiency targets.

However:

- The way in which the EE target has traditionally been specified is complicated, abstract, and inflexible.
- Impact of financial crisis on historical energy consumption may be under-appreciated.





Energy Systems & Climate Change