School of Earth & Environment
FACULTY OF ENVIRONMENT

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Paper session 2.00-3.30pm Mon 13 Sept 2021: Distributional impacts and behavioural change in energy efficiency

Rebound effects may erode half the energy savings from improved energy efficiency: Implications for the Paris Agreement

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Co-authors: Steve Sorrell; Gregor Semieniuk; Matthew Heun; Victor Court.
BIEE Energy for a Net Zero Society Conference, 13-14 Sept 2021
Mon 13th Sept 2021

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Large rebound effects & implications for Paris

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This presentation outlines the paper published in RSER March 2021

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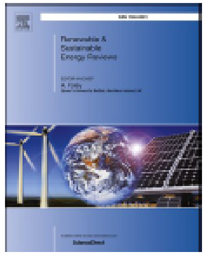

Check for updates

Energy efficiency and economy-wide rebound effects: A review of the evidence and its implications

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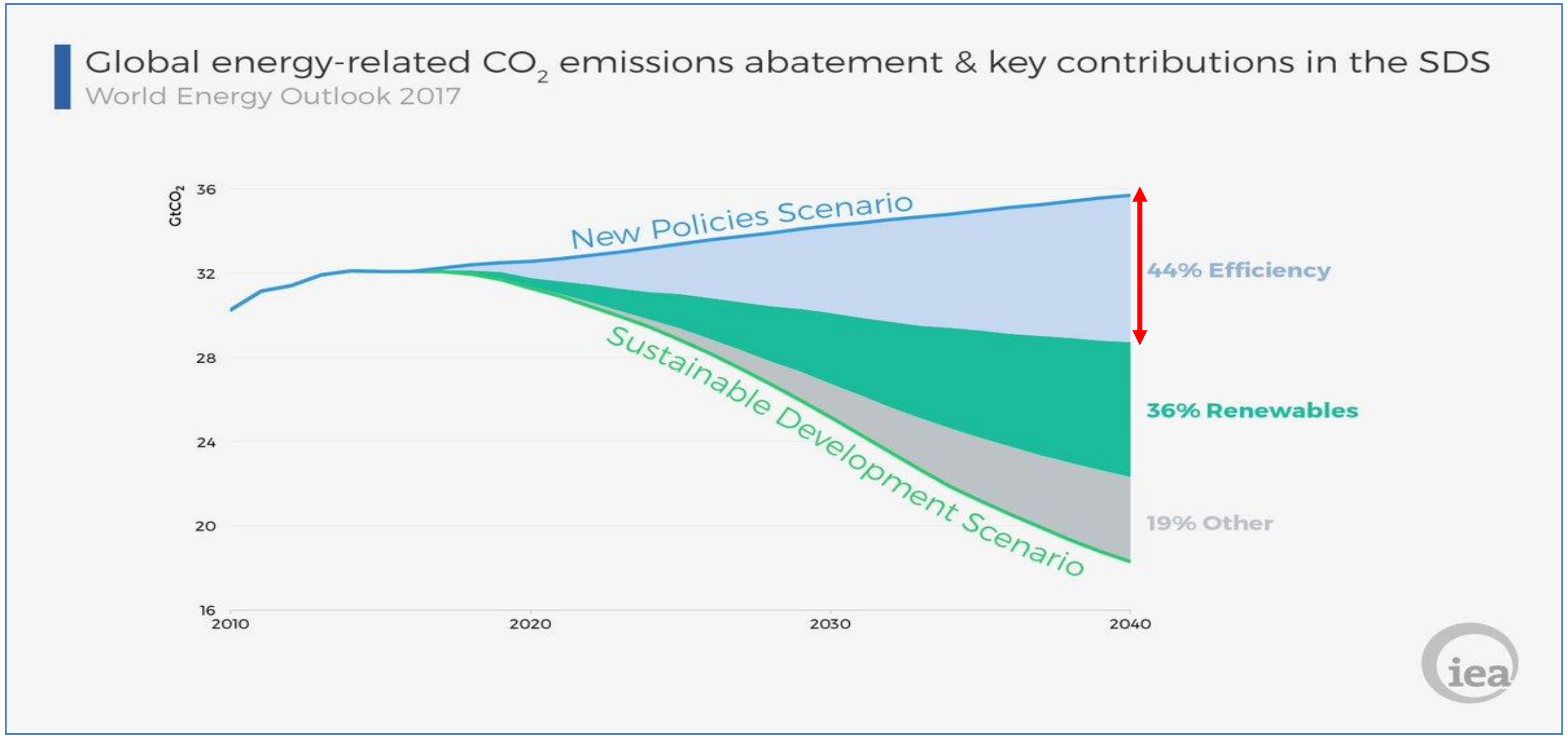
Presentation outline

Background: a big reliance on energy efficiency to help meet Paris



Source: IEA (2017) World Energy Outlook 2017

Future energy use scenarios feature near-to **absolute** decoupling

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Meeting a 1.5ºC Paris target: IEA 2021

Source: Net Zero by 2050 – IEA available at https://www.iea.org/reports/net-zero-by-2050

But the historical record is very different: absolute global decoupling has NOT occurred

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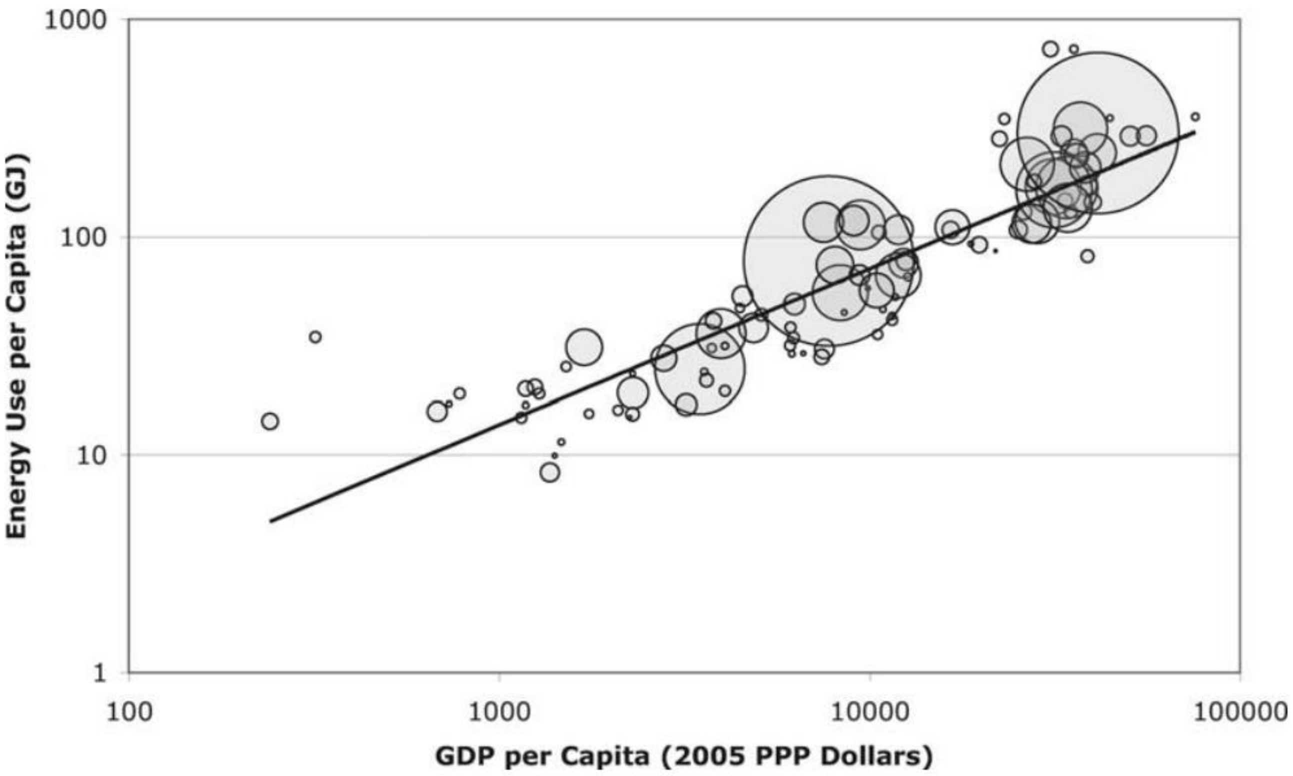
In fact, there is a tight coupling between energy-GDP

Figure 2: Energy Consumption per Capita vs. GDP per Capita, 2010



Source: Csereklyei et al (2016)

But the historical record is very different: absolute global decoupling has NOT occurred

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Only GHG/CO_2 have shown signs of absolute decoupling (due to lots of renewables..)

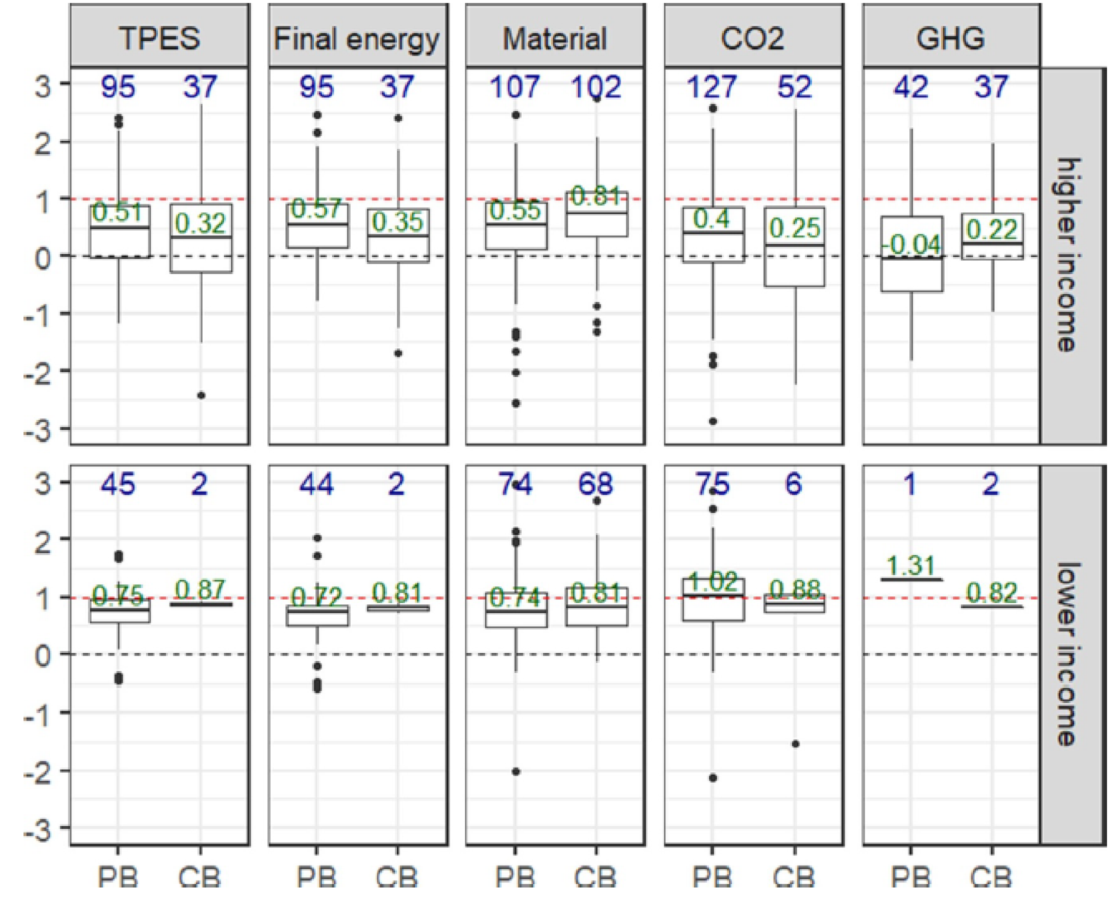

Figure 2. Resource and emission elasticities of GDP in two classes of higher income and lower income countries in the last 10 years. Box plots show medians, quartiles and ranges of elasticities (% change in resource use or emissions per % change in real

Haberl, H., et al. (2020) A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, Part II: synthesizing the insights. *Environmental Research Letters*. Available at: https://doi.org/10.1088/1748-9326/ab842a

- Study screened 10,000 initial papers down to final 835 papers in a systematic review
  - "The analyzed literature provides ample evidence that a **continuation of past trends will not yield absolute reductions** of resource use or GHG emissions."
  - "So far, **environment and climate policies have at best achieved relative decoupling** between GDP and resource use respectively**.**"

Source: Haberl et al, (2020), *ERL*

Presentation outline

Background: a big reliance on energy efficiency to help meet Paris

1. RSER Paper - The energy-GDP disconnect

Part 1: Setting out the past-vs-future energy-GDP disconnect

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Increasingly models show energy-GDP pathways tending towards absolute decoupling

P.E. Brockway et al. *Renewable and Sustainable Energy Reviews 141 (2021) 110781*

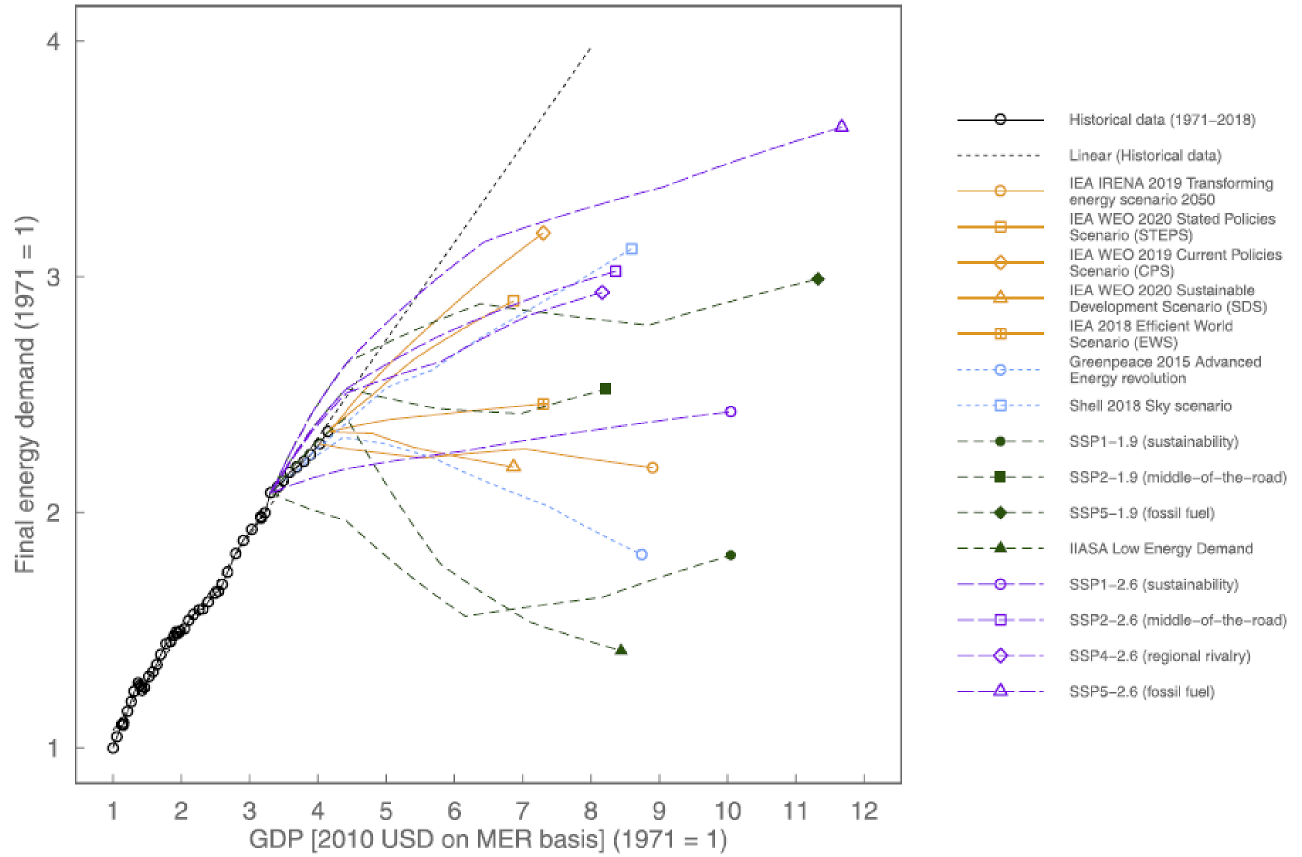

Fig. 1. Historical trends and future scenarios for global final energy use and GDP (1971–2050). *Notes:* Scenario plots are in four groups: orange (IEA models); green (1.5 °C IAMs); purple (2.0 °C IAMs) and blue (other models). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Source: Brockway et al. (2021)

Part 1: Setting out the past-vs-future energy-GDP disconnect

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Increasingly models show a tightening assumption towards absolute decoupling

P.E. Brockway et al. *Renewable and Sustainable Energy Reviews 141 (2021) 110781*

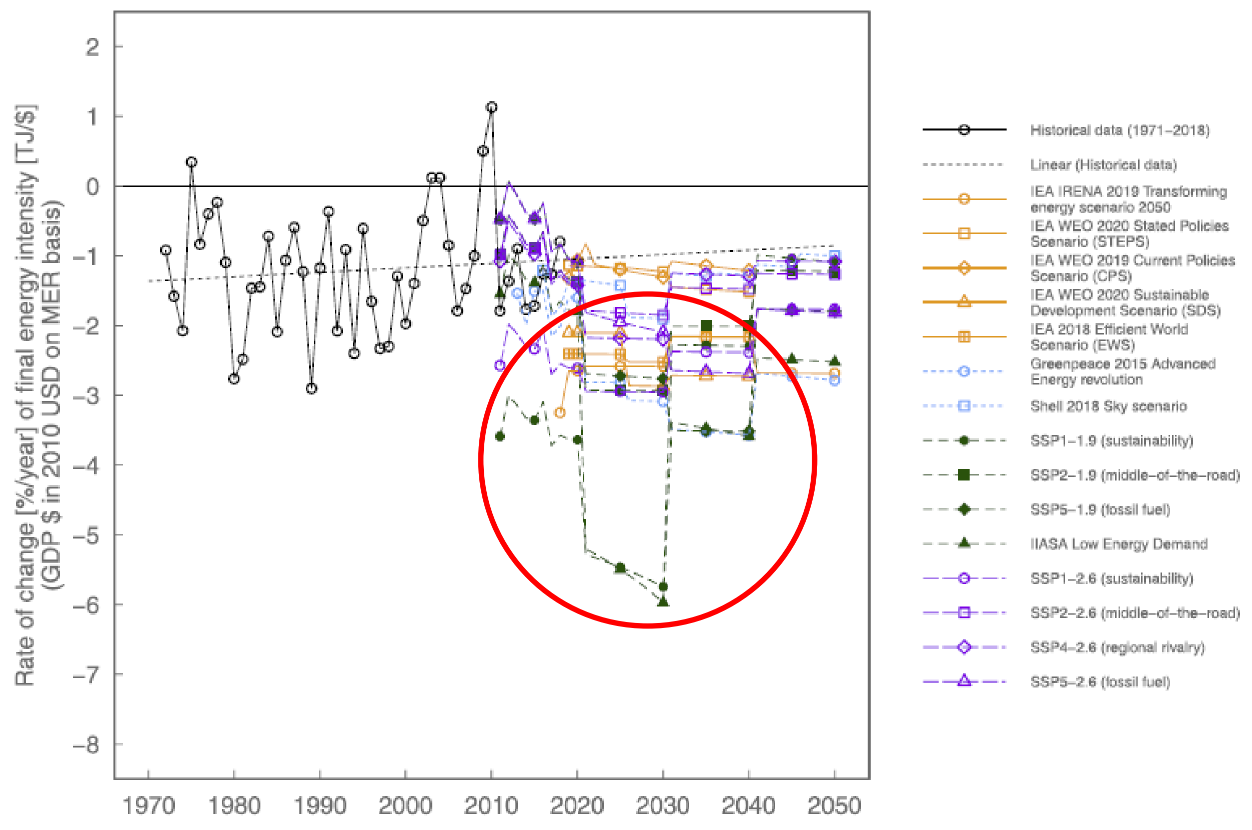


Fig. 2. Historical trends and future scenarios for annual change in final energy intensity (1971–2050). *Notes:* Annual percentage change in global final energy intensity (plotted annually for the historical trend, and as a decadal average for each scenario). Black dotted line is linear regression/projection of historical trends. The scenario plots are in four groups: orange (IEA models); green (1.5 °C IAMs); purple (2.0 °C IAMs) and blue (other models). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

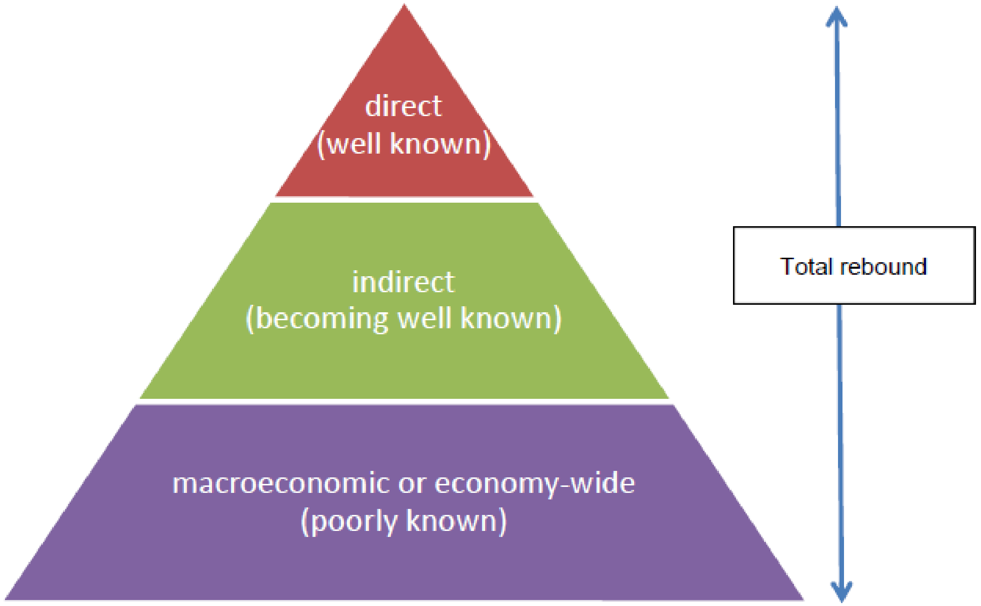
Source: Brockway et al. (2021)

Presentation outline

Background: a big reliance on energy efficiency to help meet Paris

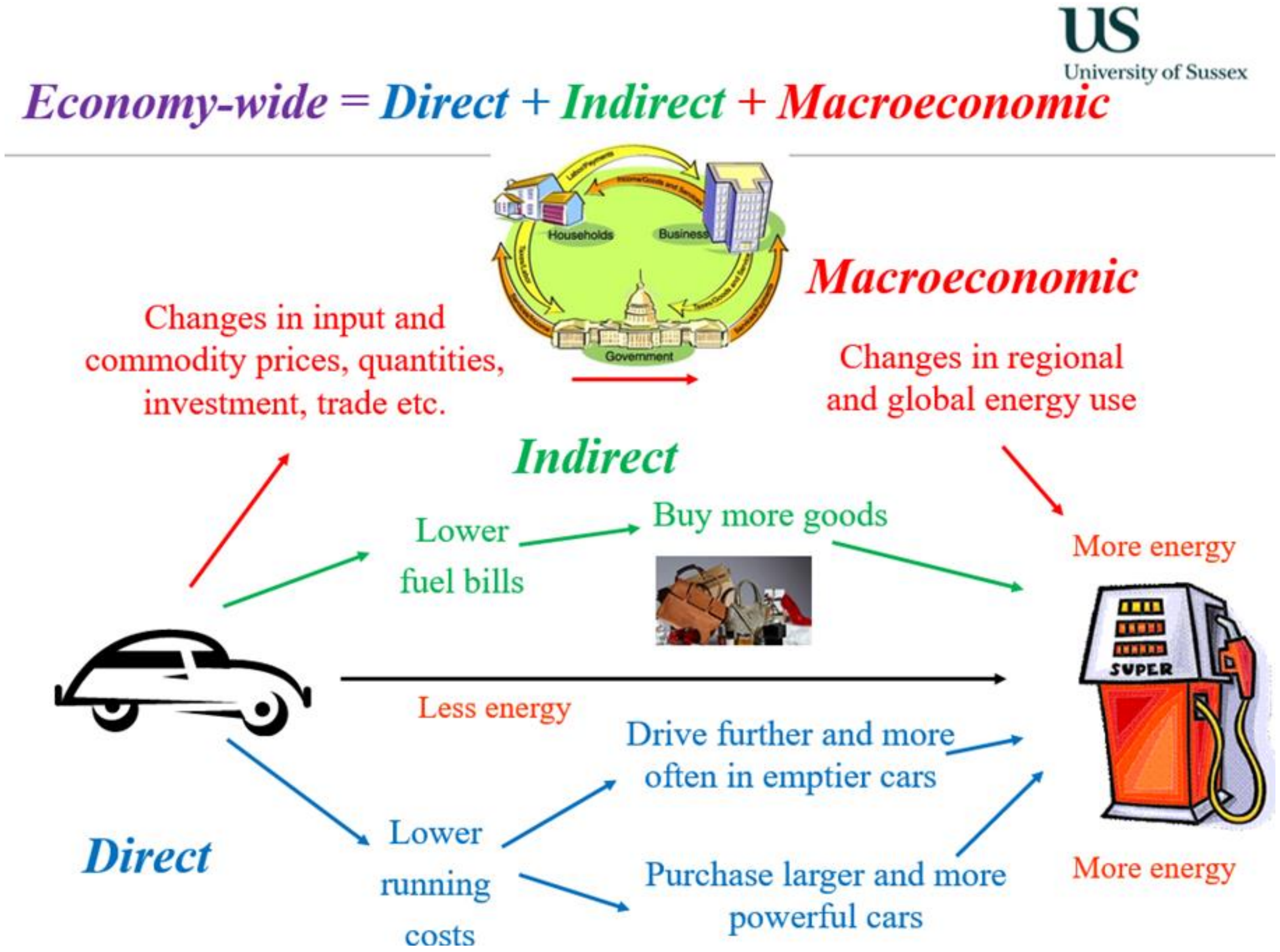
1. RSER Paper - The energy-GDP disconnect

2. RSER Paper - The evidence for large, economy-wide rebound



Rebound effects are complex

Economy-wide rebound = sum of micro (direct + indirect) + macroeconomic effects



Source: courtesy of Steve Sorrell

Part 2: literature survey: large economy-wide rebound may be a plausible explanation for energy-GDP coupling

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21 CGE models surveyed

P.E. Brockway et al. *Renewable and Sustainable Energy Reviews 141 (2021) 110781*

Table 2
Estimates of long-run, economy-wide rebound effects from 21 CGE modelling studies.

Source	Region	Model Type	Modelled energy efficiency improvement(s)	Baseline estimate of long-run, economy-wide rebound effect	Range of estimates in sensitivity tests
Vikström [75]	Sweden	Dynamic	15% (12%) in non-energy (energy) sectors.	60%	60%
Grepperud *et al.* [76];	Norway	Dynamic	Doubling growth rate of electricity productivity in paper, metals, chemicals & finance (in turn), and growth rate of oil productivity in fisheries and road transport (in turn)	Not quantified but modest in fisheries and road transport, larger in paper and chemicals, and >100% in metals	
Allan *et al.* [77]	UK	Dynamic	5% in all production sectors	Elec = 27%; Non-elec = 31%	Elec = 12%–58%; Non-elec = 13%–67%
Hanley *et al.* [78]	Scotland	Dynamic	5% in all production sectors	Elec = 131%; Non-elec = 134%	Elec = 41%–250% Non-Elec = 35%–244%
Anson *et al.* [79]	UK	Dynamic	5% in commercial transport sector	39%	37%–105%
Guerra *et al.* [60]	Spain	Static	5% in all production sectors	87%	15%–230%
Broberg *et al.* [80]	Sweden	Dynamic	5% in: 1) all production sectors; 2) non-energy sectors; 3) energy-intensive sectors	1) All sectors = 73% 2) Non-energy = 69% 3) Energy-intensive = 78%	41%–81%

Source: Brockway et al. (2021)

Part 2: literature survey: large economy-wide rebound may be a plausible explanation for energy-GDP coupling

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12 other models/studies surveyed

P.E. Brockway et al.

Table 2
Estimates of long-run, economy-wide reb

Source	Region	Model Type
Vikström [75]	Sweden	Dynamic
Grepperud et al. [76];	Norway	Dynamic
Allan et al. [77]	UK	Dynamic
Hanley et al. [78]	Scotland	Dynamic
Anson et al. [79]	UK	Dynamic
Guerra et al. [60]	Spain	Static
Broberg et al. [80]	Sweden	Dynamic

Table 3
Estimates of economy-wide rebound effects from a selection of non-CGE studies.

Category	Source	Region, Period	Model structure	Specification of energy efficiency	Method of estimating economy-wide rebound effect	Baseline estimate of economy-wide rebound effect
Macroeconomic models	Saunders [26]	Sweden, 1850–2000	Solow growth model with a (KL, E), CES aggregate production function incorporating energy-augmenting technical change	Energy-augmenting technical change (τ)	Ratio of modelled actual energy savings to modelled potential energy savings	50–60%
	Barker et al. [94]	Global 2010–2030	41-sector, 20-region macro-econometric model of the global economy (E3MG)	Energy efficiency policies included in the 2006 IEA World Energy Outlook	Direct rebound effect assumed. Indirect and macroeconomic effects estimated from ratio of modelled actual energy savings to modelled potential energy savings	52%
	Lemoine [95]	Non-specific, but cost share and elasticity data from US	General equilibrium model with N production sectors and an energy sector	Energy-augmenting technical change (τ)	Analytical expressions decomposing the rebound into a number of partial and general equilibrium effects	38% 80% energy sector 28% other sectors
	Rausch and Schwerin [96]	US 1960–2011	Two sector (production and consumption) general equilibrium model with different vintages of energy-using capital	Energy-augmenting technical change (τ)	Ratio of modelled actual energy savings to modelled potential energy savings	102%
Econometric analysis	Adetutu et al. [97]	55 countries 1980–2010	Stochastic frontier analysis to estimate energy efficiency. Autoregressive, dynamic panel model to estimate efficiency elasticity of energy demand	Distance to frontier in a panel of 55 countries	Efficiency elasticity of energy demand	90% (short term) −36% (long term)

Source: Brockway et al. (2021)

Part 2: literature survey: large economy-wide rebound may be a plausible explanation for energy-GDP coupling

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Large rebound ~60% average

CGE studies (21 NO.)
As a crude indicator, **the mean (median), baseline estimate of economy-wide rebound effects from the 21 studies is 58% (55%) –** with a mean of 65% (60%) from the 14 producer studies and 55% (50%) from the 7 consumer studies.

..the evidence from CGE studies broadly suggests that **economy-wide rebound effects may erode more than half of the energy savings from improved energy efficiency**.

Other studies (12 NO.)
As a crude indicator, **the mean estimate of economy-wide rebound effects from the 12 studies is 71%** – with a mean of 62% from the macroeconomic models, 104% from the econometric studies, and 46% from the growth accounting studies.

… the results broadly reinforce the conclusion from the review of CGE studies, namely that **economy-wide rebound effects may erode more than half of the energy savings from improved energy efficiency**

Source: Brockway et al. (2021)

Presentation outline

Background: a big reliance on energy efficiency to help meet Paris

1. RSER Paper - The energy-GDP disconnect
2. RSER Paper - The evidence for large rebound
3. RSER Paper - What's under the bonnet of the models?

Part 3: could a lack of energy rebound in energy models could explain future absolute decoupling projections?

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Energy rebound is only partly included, and GDP tends to be exogenous

Table 4
Modelling of rebound effects in four Integrated Assessment Models.

Integrated Assessment Model	Type	Regions	Modelling of the macro-economy	Modelling of energy demand and improved energy efficiency	Modelling of rebound effects
IMAGE	Partial equilibrium Recursive dynamic	26	Limited economic modelling. Exogenous assumptions for population, per-capita GDP and other variables	IMAGE model energy demand for a range of end-use functions in six sectors, including industry [115], transport [116], and residential [117]. The end-use functions (such as lighting, heating, cooling, hot water and appliances in the residential sector) are represented on the basis of relationships with economic activity levels that physical activity indicators (such as tonnes of steel, passenger kilometers per transport mode), structural change and both autonomous energy efficiency improvements (AEEI) and price induced energy efficiency improvements (PIEEI).	**Direct**: several. Decreasing costs of energy supply in response to efficiency measures can lead to increases in activity levels (such as transport activity) or reduction of investments in efficiency. **Indirect**: Several. Decreasing costs of energy supply in response to efficiency measures in one sector, can significantly impact measures in other sectors. Similar holds for measures to reduce costs of energy supply. **Macroeconomic**: Energy market effect (lower price of energy induces greater demand).

Source: Brockway et al. (2021)

Part 3: could a lack of energy rebound in energy models could explain future absolute decoupling projections?

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Table 5
Inclusion of rebound effects in a selection of global energy models.

Global energy model	Modelling of the macro-economy	Modelling of rebound effects
Global modelling for BP Energy Outlook	Exogenous, via regional projections of population, per-capita GDP, energy intensity and other variables	Direct: included via assumptions for the own-price elasticity of some energy services. Indirect none Macroeconomic: energy market effect.
Shell World Energy Model	Exogenous, via regional projections of population and per-capita GDP	Direct: included via assumptions for the own-price elasticity of energy services, together with an 'energy ladder' effect for energy services in developing countries. Indirect: none. Macroeconomic: energy market effect

Source: Brockway et al. (2021)

Presentation outline

Background: a big reliance on energy efficiency to help meet Paris

1. RSER Paper - The energy-GDP disconnect
2. RSER Paper - The evidence for large rebound
3. RSER Paper - What's under the bonnet of the models?
4. RSER Paper - Implications for modelling, policy and Paris

Part 4: Implication for Paris: meeting 1.5-2’C targets is likely going to get harder

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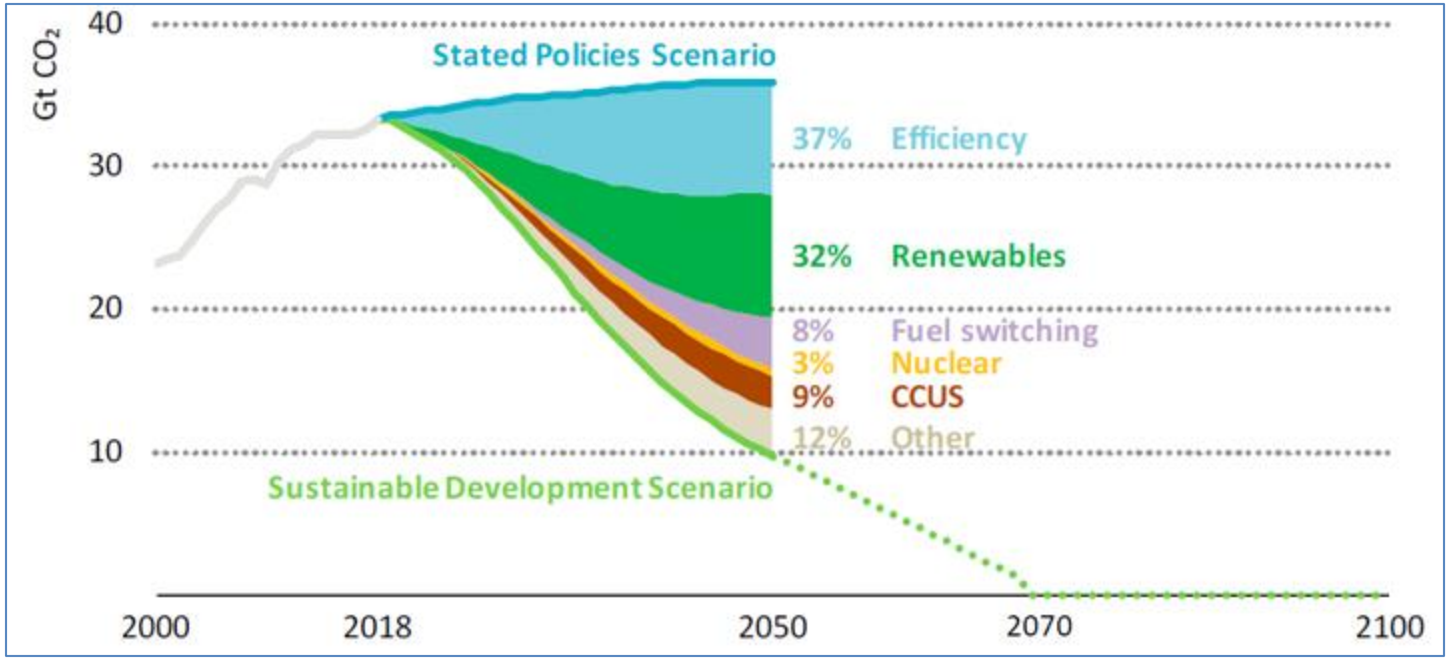
Responses

1. **Try to fix the efficiency/rebound dial**
   - Improve modelling
     - Short term: Develop future/IPCC scenarios without strong energy-GDP decoupling
     - Longer term: Deep inclusion of efficiency and rebound into energy-economy models
   - Account for rebound into efficiency policy
     - Higher efficiency targets
     - Carbon taxes
2. **Turn other key policy dials further**
   - Renewables
   - Carbon capture & storage (BECCS/DACS)
   - Post-growth economic policies (see Hickel et al, 2021)



IEA (2019) World Energy Outlook Figure 2.1: Energy-related CO2 emissions and reductions by source in the Sustainable Development Scenario

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Thanks for listening!

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Visit our exergy economics website:

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Follow my decoupling project:

- https://www.researchgate.net/project/Applying-thermodynamic-laws-to-the-energy-GDP-decoupling-problem