SOUTH ASIA SUBREGIONAL WORKSHOP

Frontier Technologies: Techno-Economic and Socio-Technical Challenges

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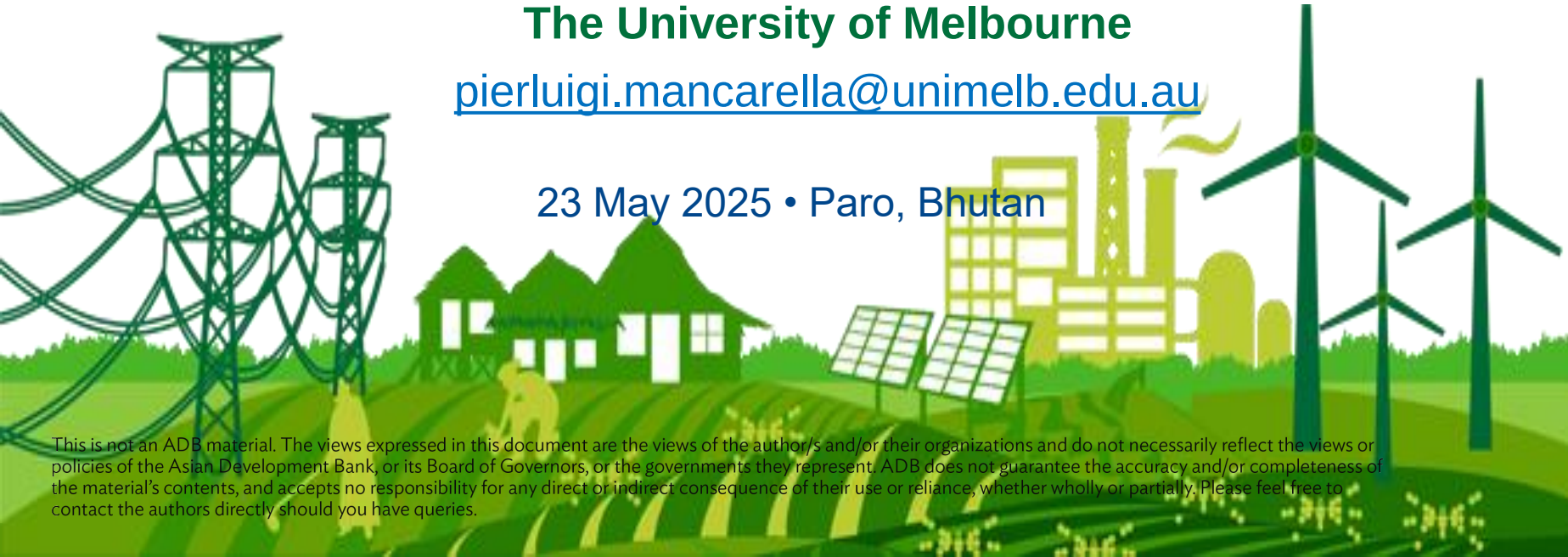
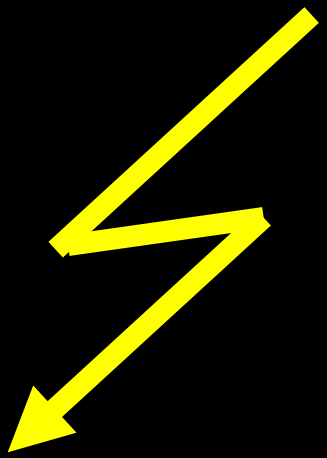
23 May 2025 • Paro, Bhutan



Classical power system drivers: the *energy* ***dilemma***

Then something else came up…



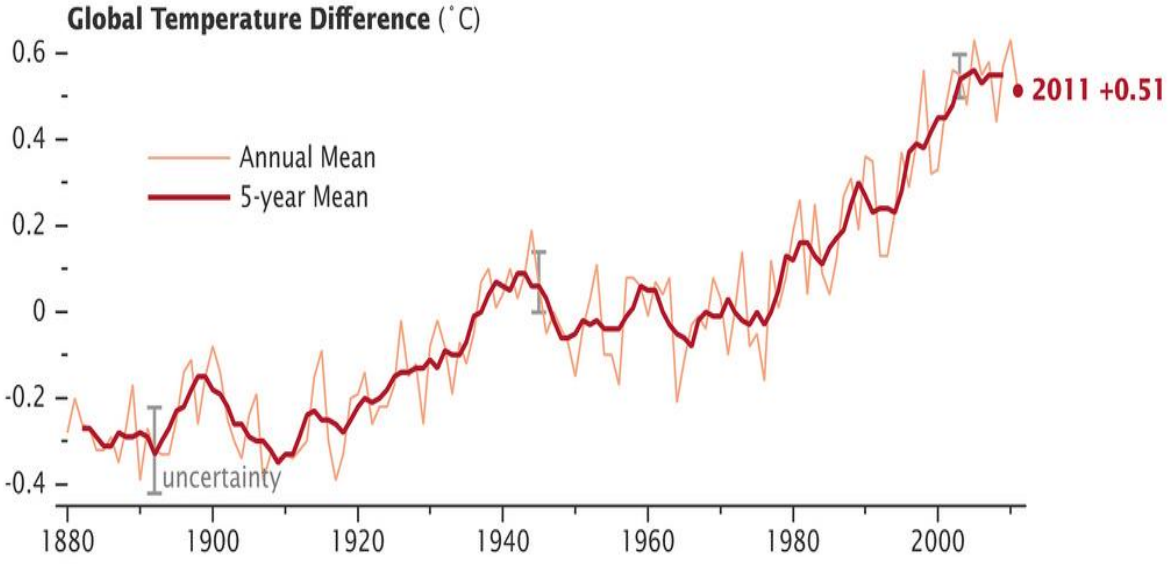
Fear

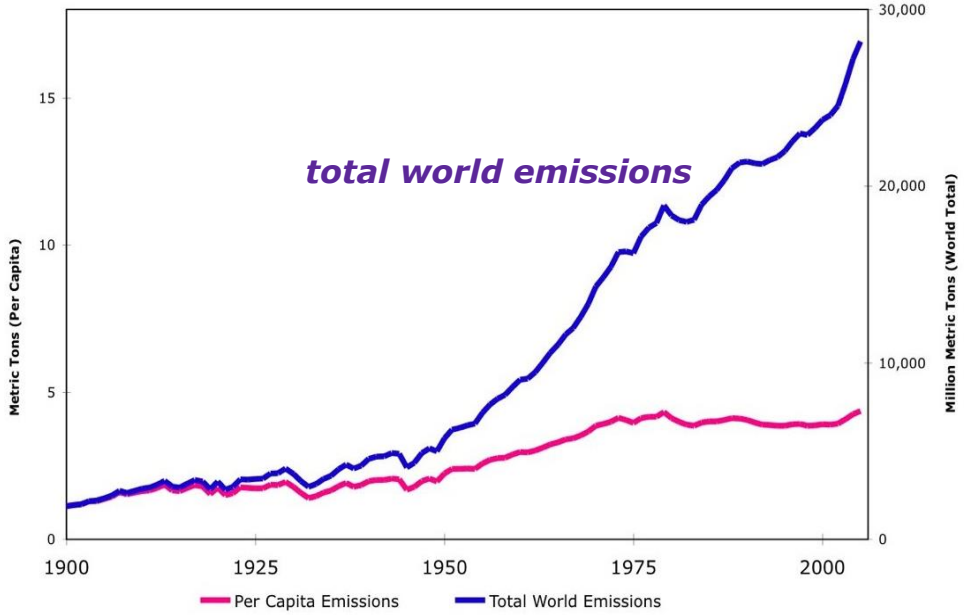
- Keep the Lights On
- Security

Greed

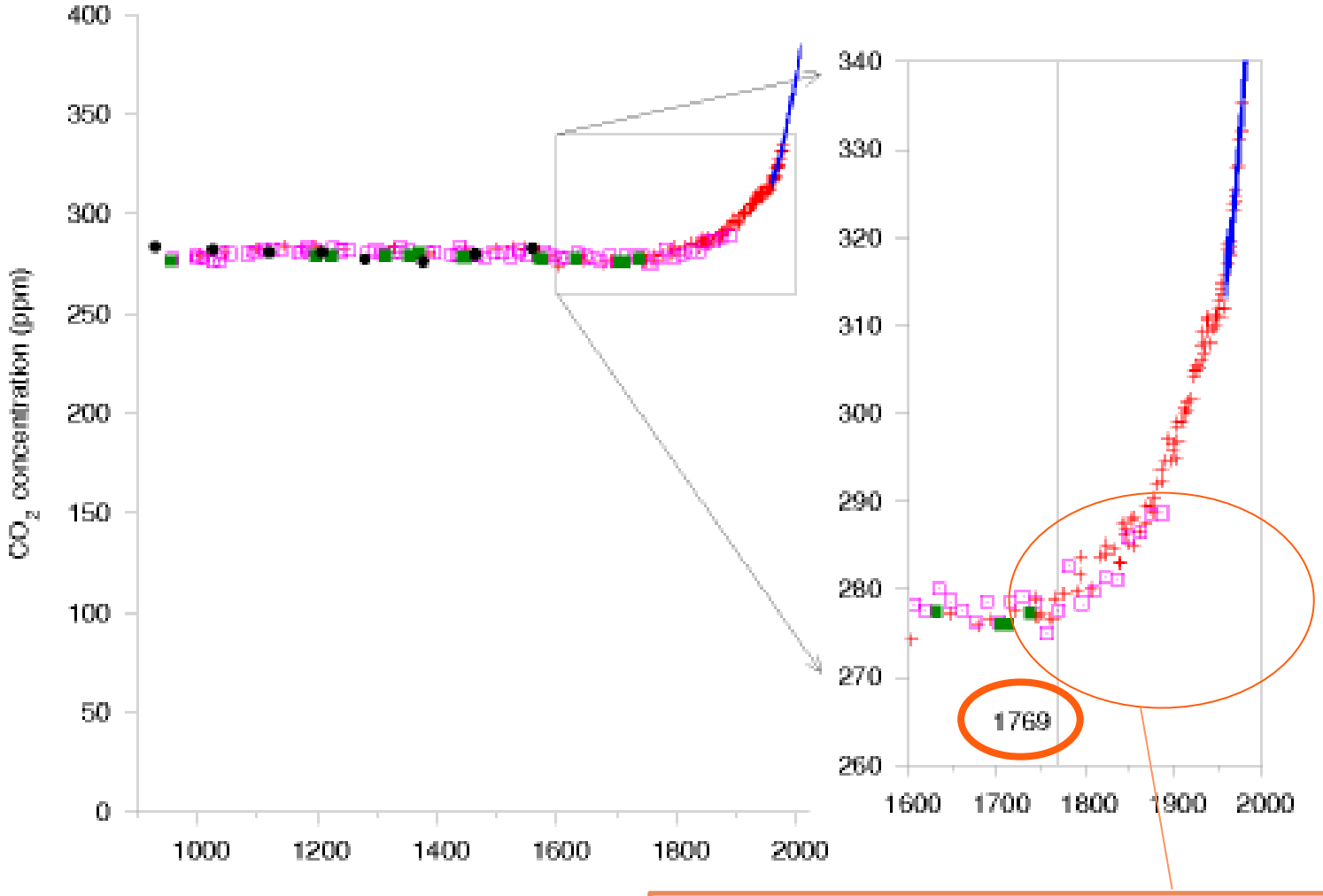
- Minimise Costs
- Economics

Global temperature trends and CO_2 emissions in the last century





CO_2 concentrations for the last 1000 years

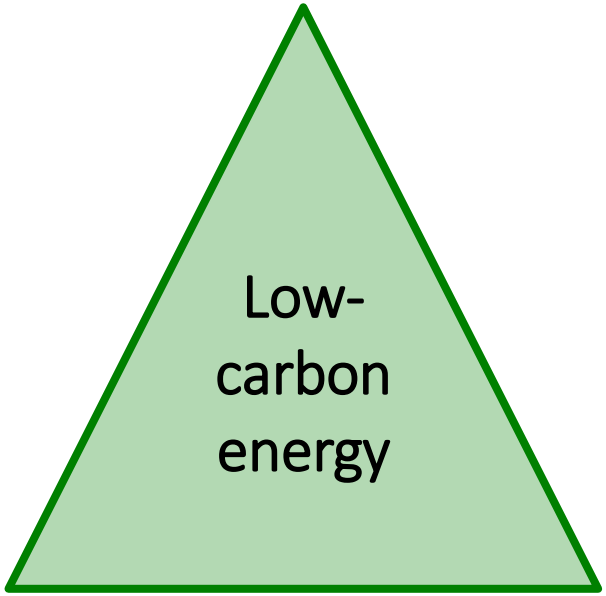


Do you think that something **new** may have happened between 1800 and 2000?

Source: D. MacKay, "Sustainable energy - without the Hot Air"

The *energy* *trilemma*

Affordability

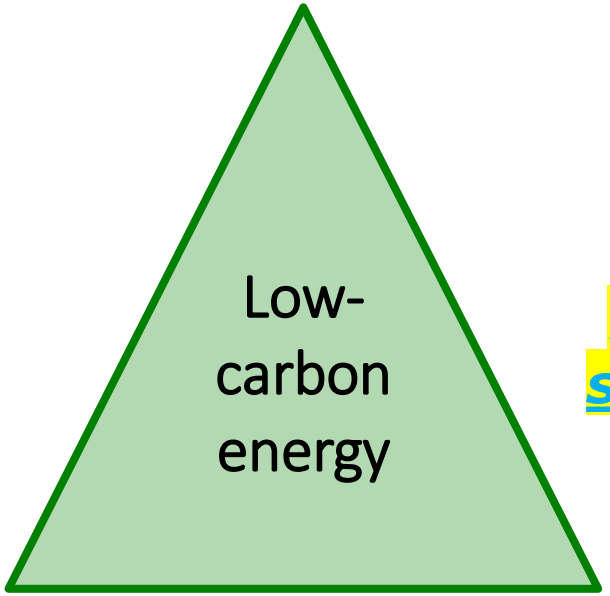


Reliability/Resilience

Decarbonisation

The *energy* *trilemma*

Affordability



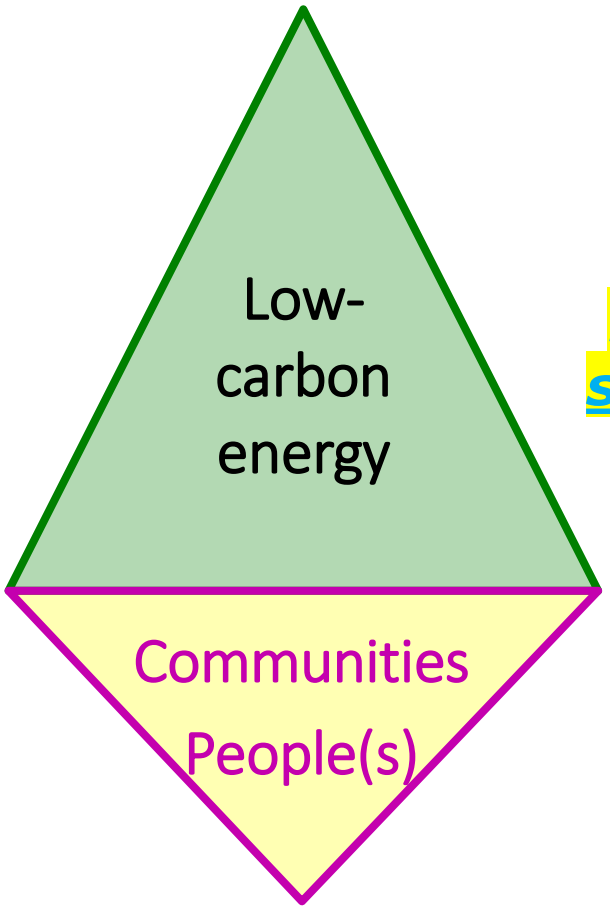
How do we ensure sustainability of the energy transition?

Reliability/Resilience

Decarbonisation

The *energy* *trilemma*

Affordability



Reliability/Resilience

Social aspects

How do we ensure sustainability of the energy transition?

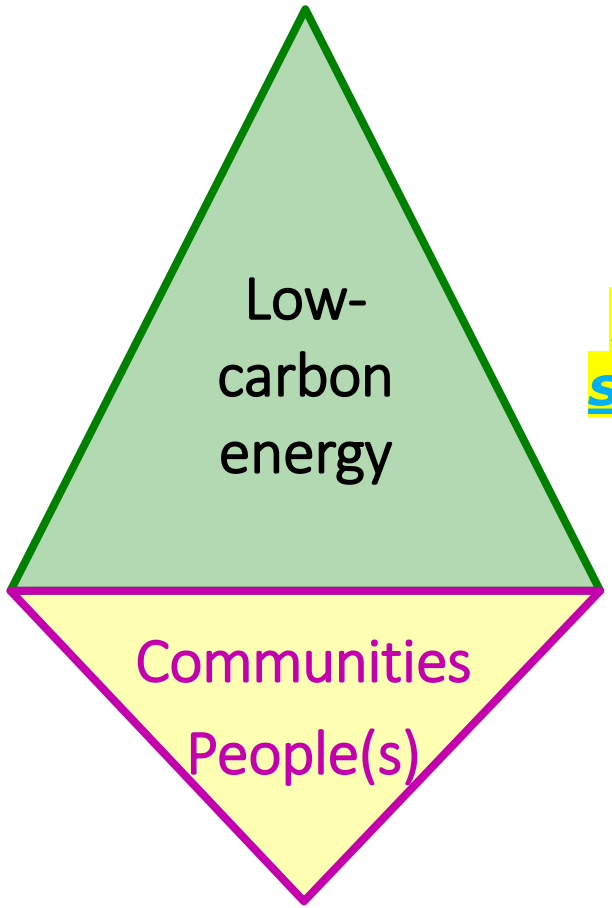
Decarbonisation

Between countries across the world

Within countries

How do we ensure a fair and just energy transition?

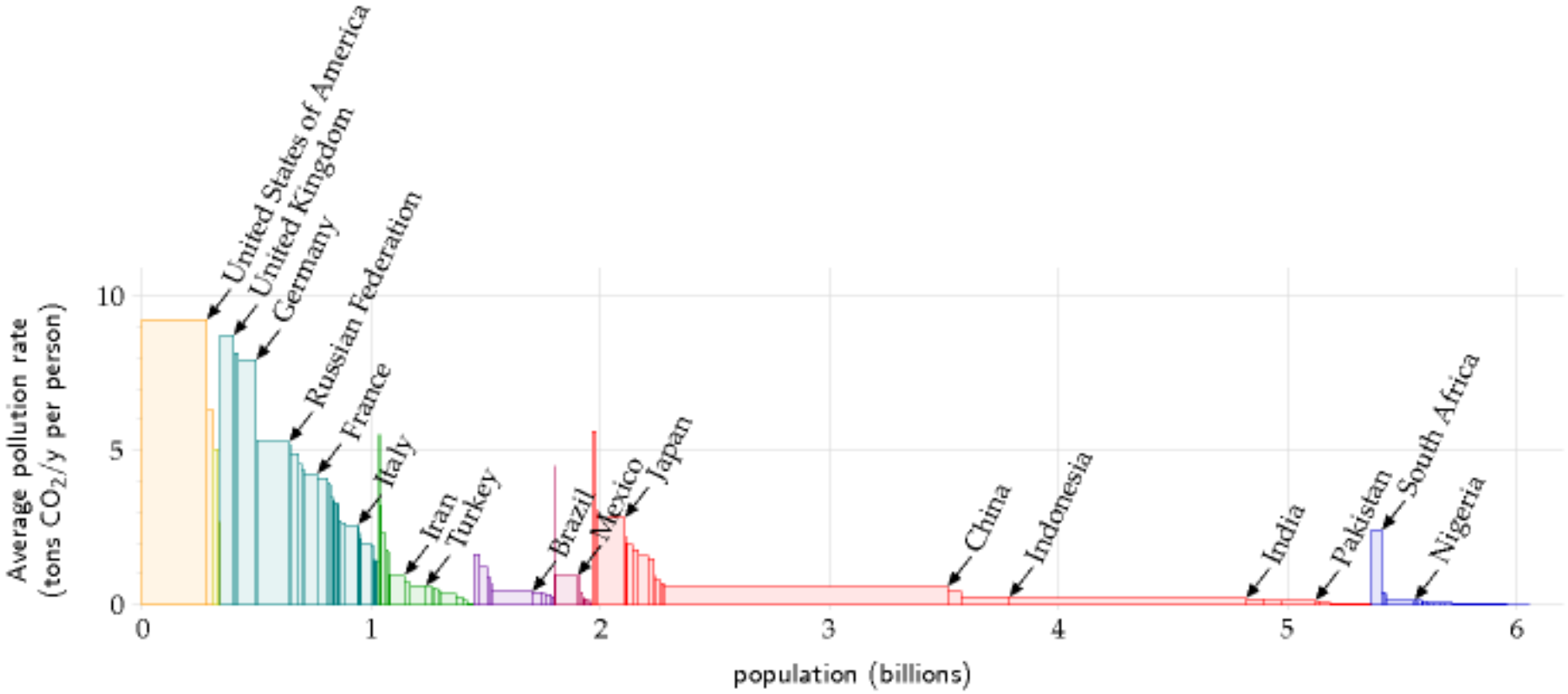
Or rather a *quadrilemma*!



How do we ensure sustainability of the energy transition?

How do we ensure a fair and just energy transition?

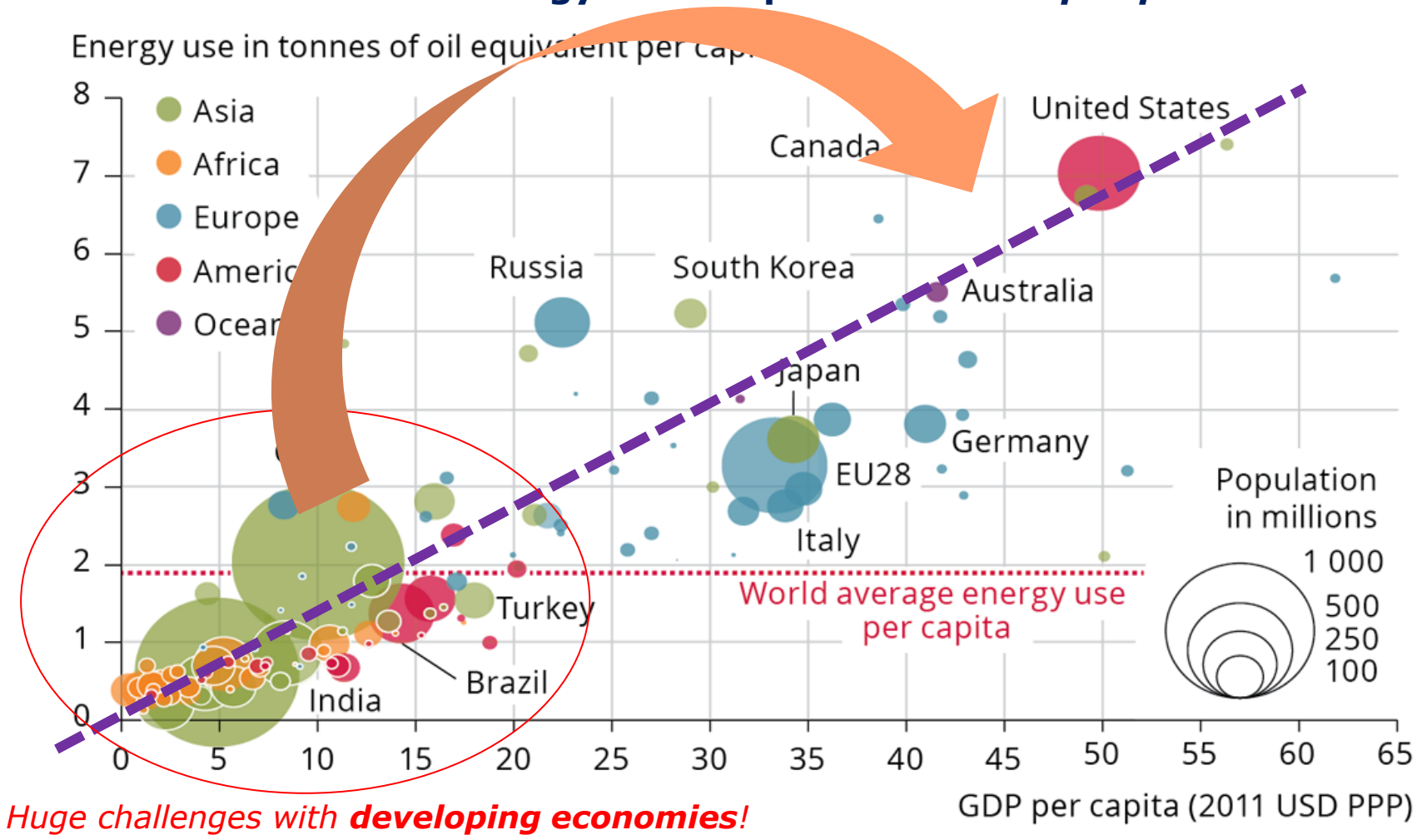
A fair transition across countries: historical perspectives



Source: D. MacKay, "Sustainable energy - without the Hot Air"

Electricity as humanity's socio-economic engine

Correlation of energy consumption and GDP *per person*



*Huge challenges with **developing economies**!*

Source: European Commission, European Environment Agency, https://www.eea.europa.eu/data-and-maps/figures/correlation-of-per-capita-energy

Decoupling growth from emissions

- **Limiting growth**?
  - **Politically untenable** and/or **unfair proposition**
- How to **decouple growth from energy (and emissions)**?
  - **Energy conservation**, **energy efficiency**, **zero-carbon energy**

- Fortunately, we are on the **right direction** in many countries…

"Between 1990 and 2016 the European Union's economy grew by more than 50%, while CO2 emissions fell by 25%" *

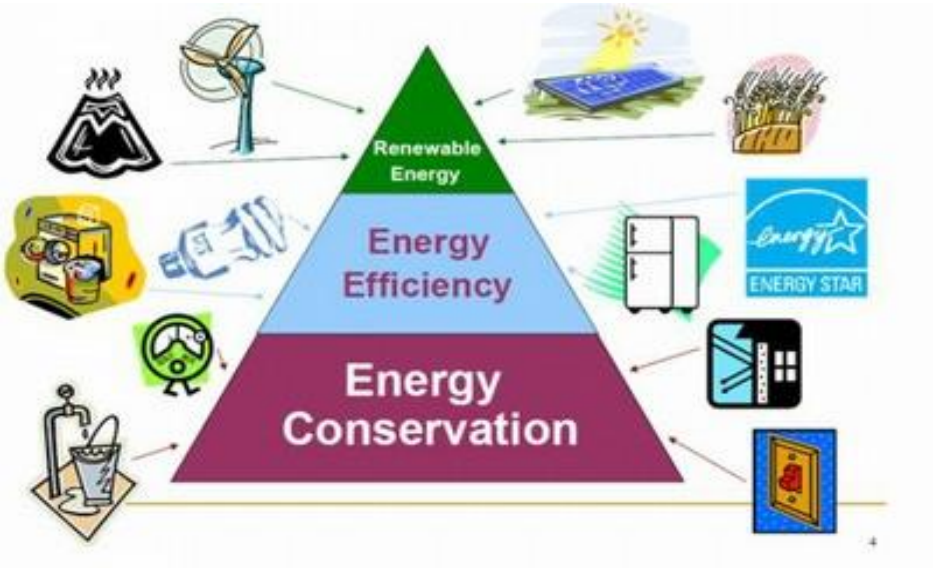
- … but there's still **a long way to go**, especially for developing economies

IEA: *"Global energy-related CO2 emissions rose to record high in 2021"*[x]

* Source: https://academic.oup.com/ooenergy/advance-article/doi/10.1093/ooenergy/oiac005/6550337?login=false

[x] Source: https://www.reuters.com/business/energy/global-energy-related-carbon-emissions-rose-6-2021-new-record-high-iea-2022-03-08/

"Classical" view on sustainability:
Decouple growth from energy consumption

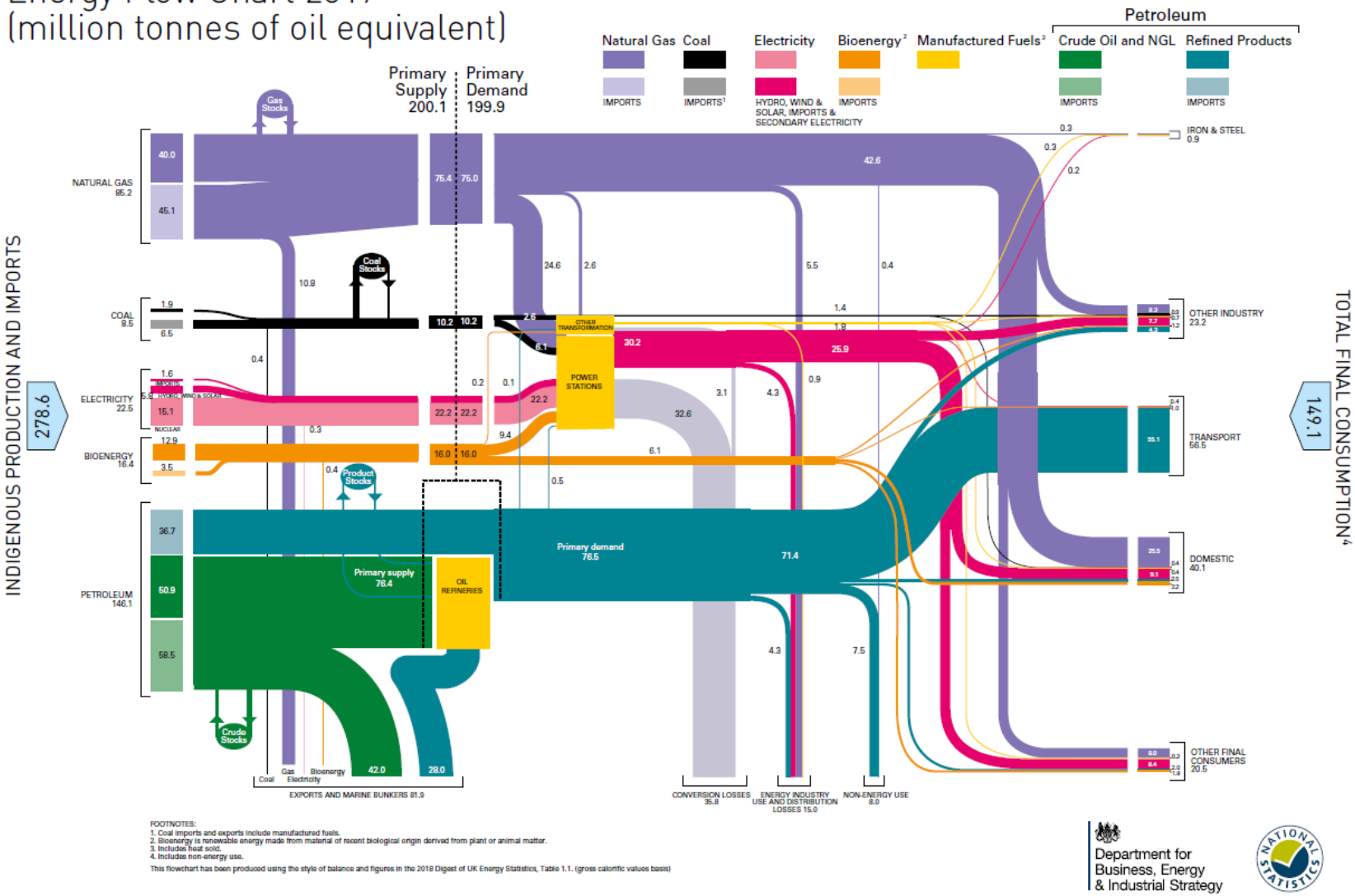


- **Energy conservation**
  - Reduce demand ("nega-watts")
- **Energy efficiency**
  - Reduce losses, improve transformation efficiency, integrate systems
- **Zero-carbon electricity**
  - Wind, solar, hydro, nuclear, etc.

"Fabric first"

Not only electricity!

Solution: Electrify EVERYTHING you can!

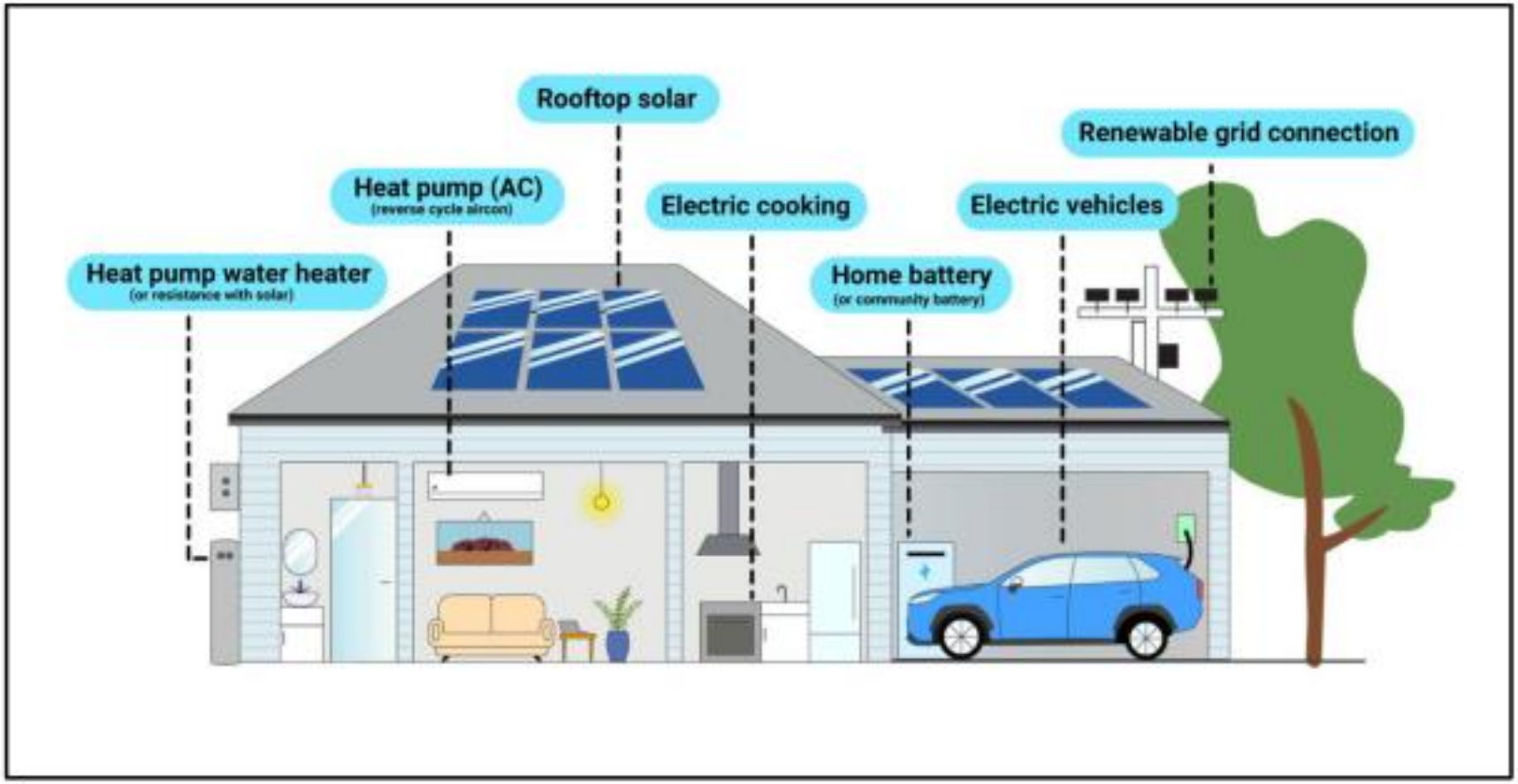


FOOTNOTES:
1. Coal imports and exports include manufactured fuels.
2. Bioenergy is renewable energy made from material of recent biological origin derived from plant or animal matter.
3. Includes heat sold.
4. Includes non-energy use.

This flowchart has been produced using the style of balance and figures in the 2018 Digest of UK Energy Statistics, Table 1.1. (gross calorific values basis)

Department for Business, Energy & Industrial Strategy

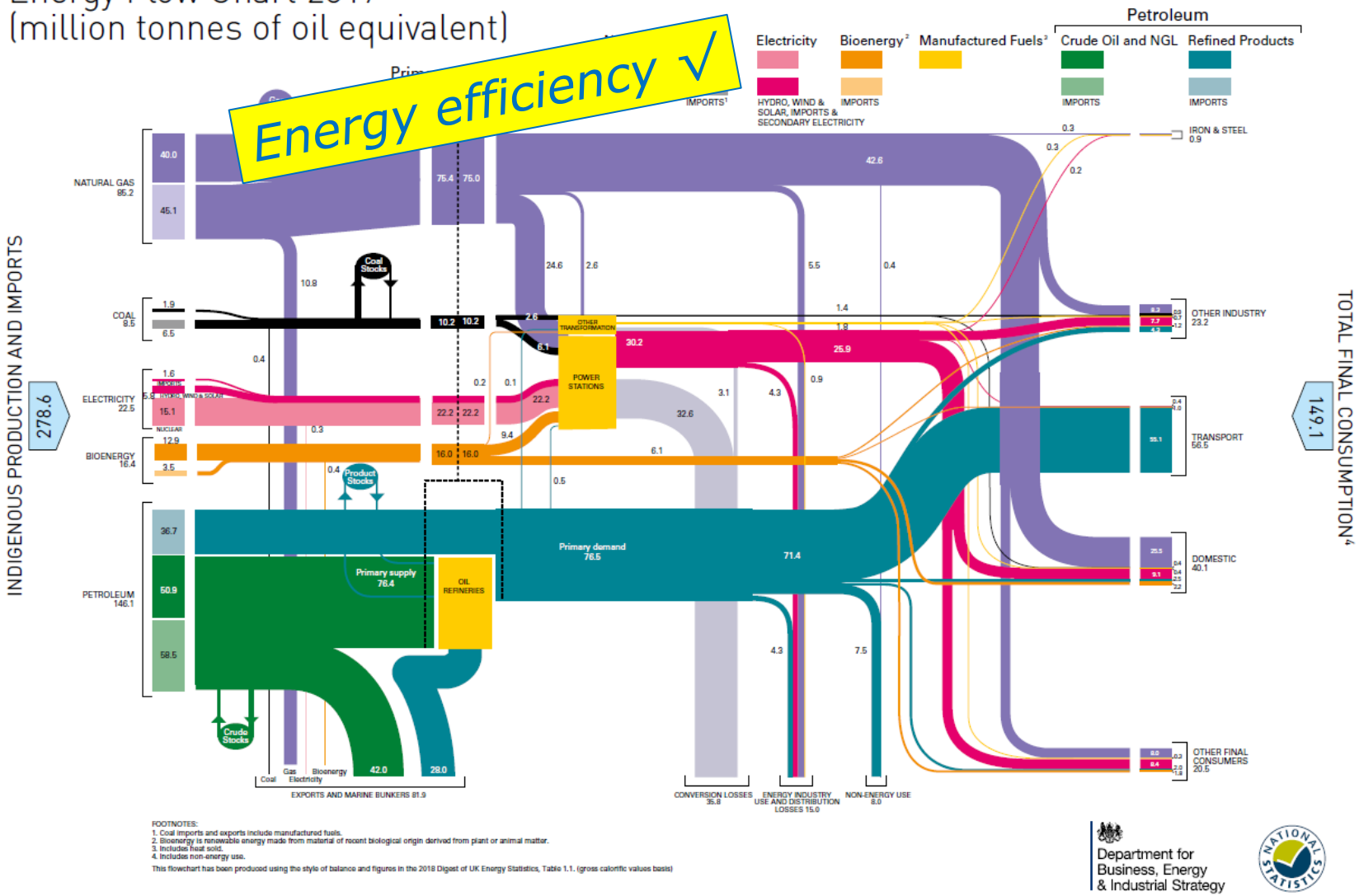
Tomorrow's all-electric homes



Source: Rewiring Australia, Submission to the Senate Inquiry on Residential Electrification 2023

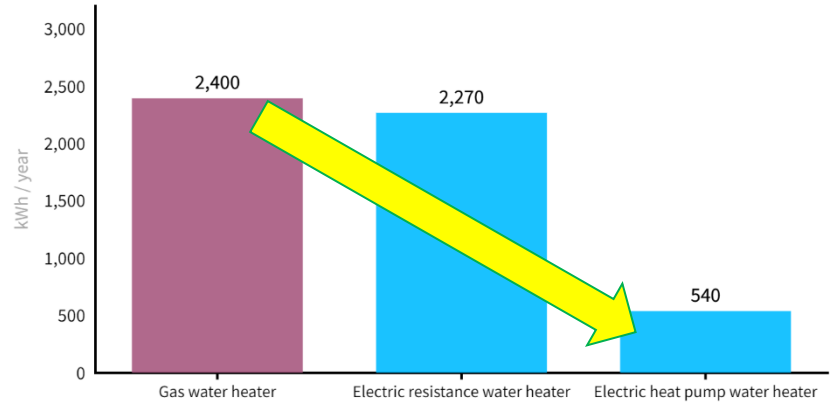
Not only electricity!

Electrify everything!



Energy efficiency gains in all-electric households and businesses

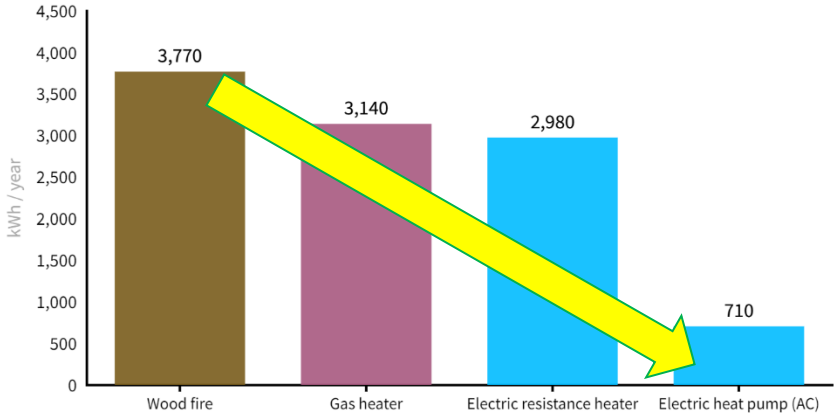
Water heaters | Average yearly energy use in kWh



Based on average Australian water heating energy needs of 2156 kWh per year. Solar capacity factor of 17.14%. Heat pump COP 4.0. Electric resistance COP 0.95. Gas COP 0.9.

Rewiring Australia

Space heaters | Average yearly energy use in kWh

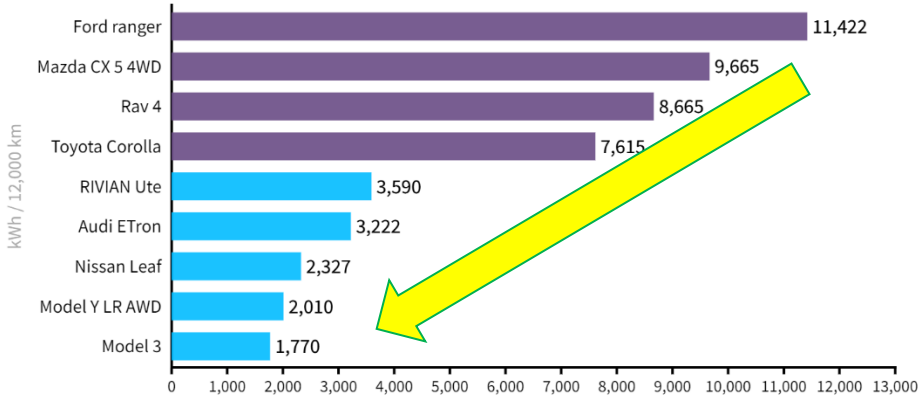


Based on average Australian water heating energy needs of 2828 kWh per year. Solar capacity factor of 17.14%. Heat pump COP 4.0. Electric resistance COP 0.95. Gas COP 0.9. Wood COP 0.75.

Rewiring Australia

Energy efficiency comes from electrification!

Vehicles | Yearly energy use comparison in kWh



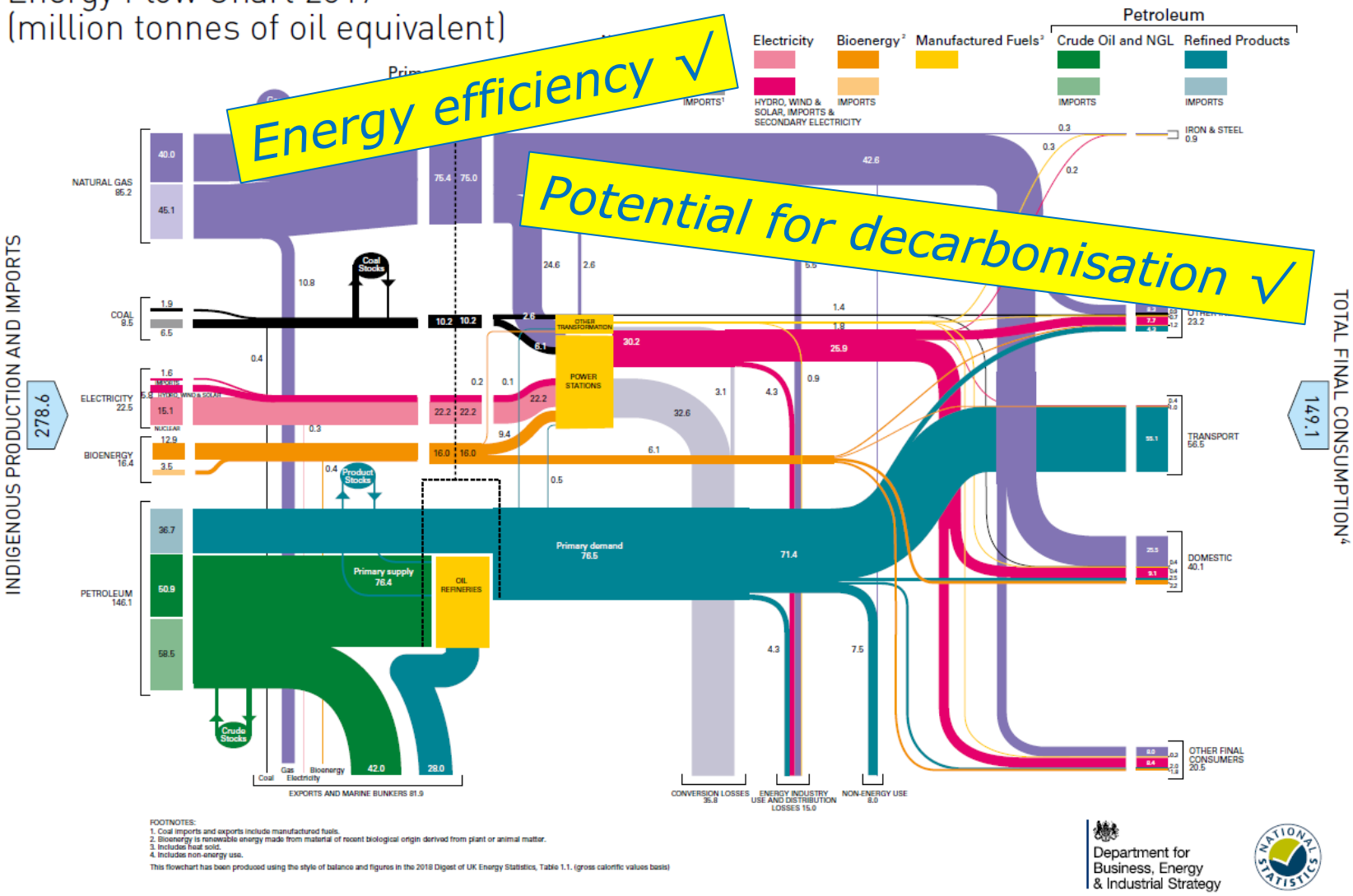
Based on average driving of 12,000 Km per year. EPA MPG comparison of vehicles.

Rewiring Australia

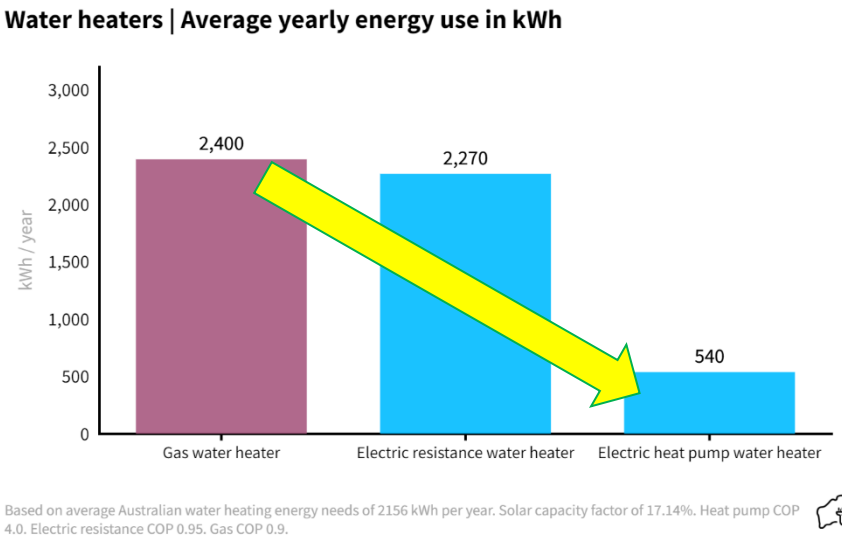
Source: https://www.rewiringaustralia.org/

Not only electricity!

Electrify everything!



Energy efficiency gains in all-electric households and businesses



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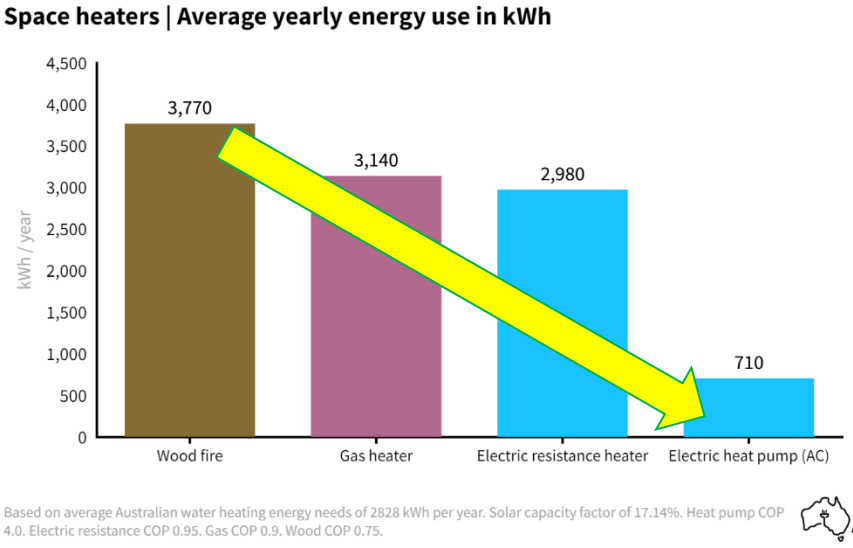

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Rewiring Australia

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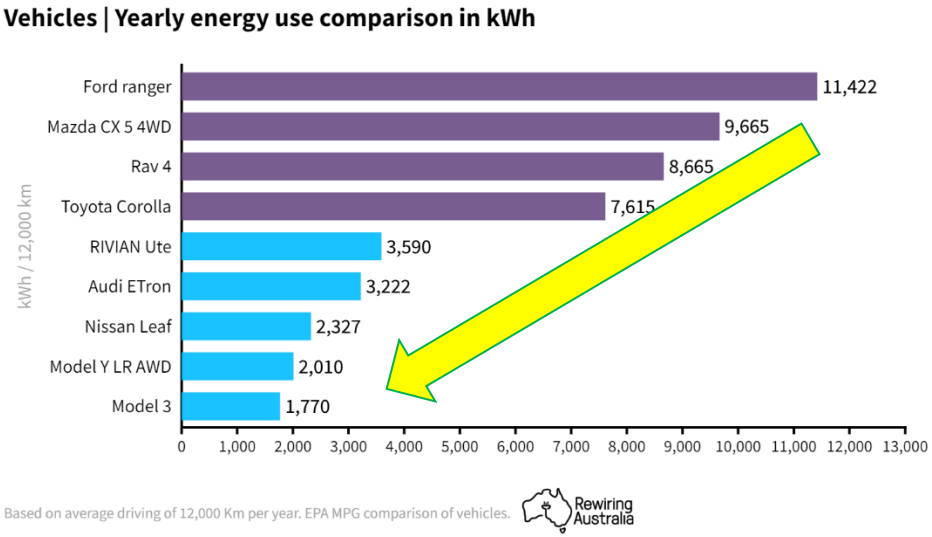


Based on average driving of 12,000 Km per year. EPA MPG comparison of vehicles.

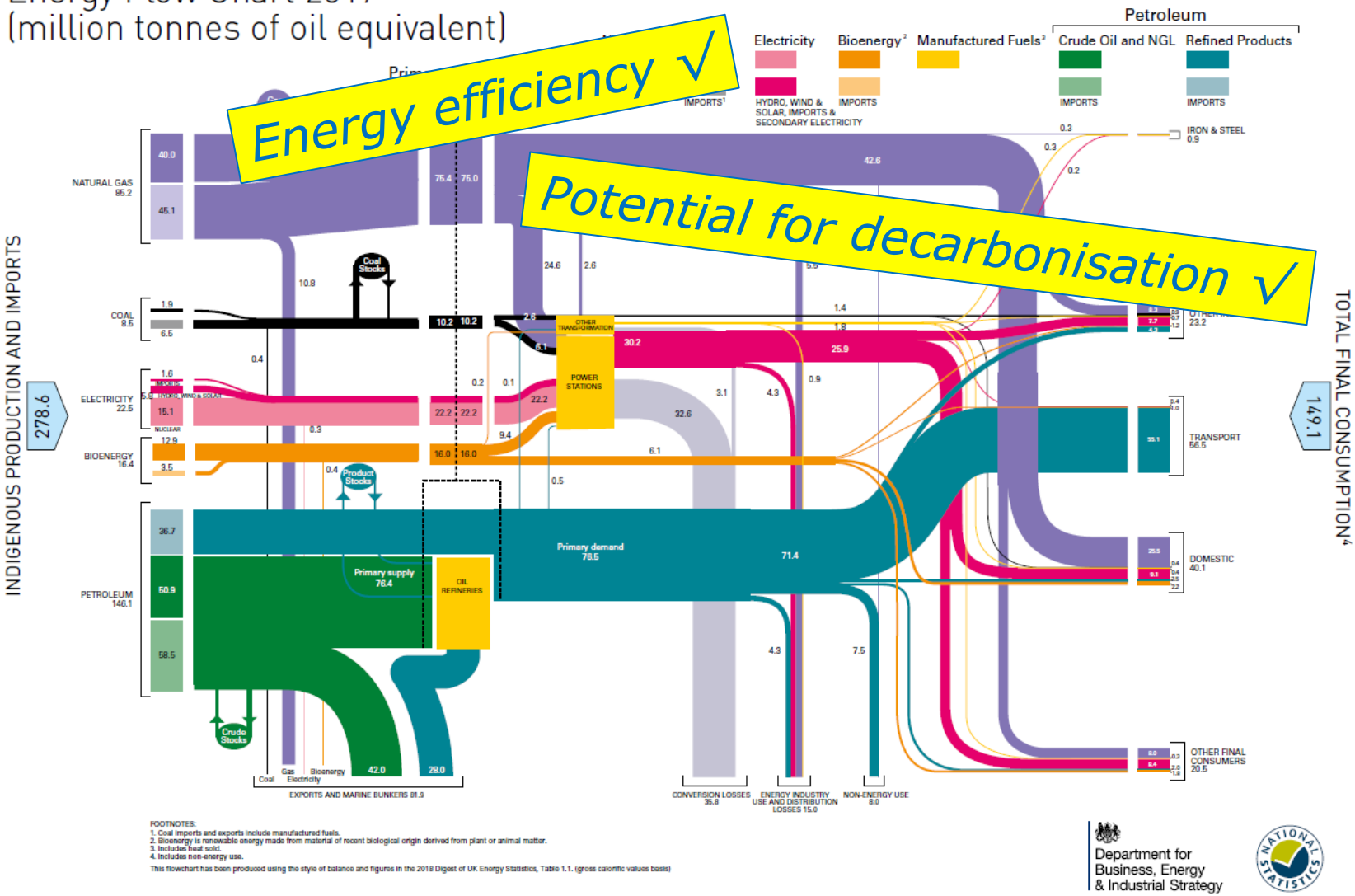
Rewiring Australia

Electrification may also eventually mean decarbonisation!

... regardless of whether it is based on renewables or nuclear ☺

Source: https://www.rewiringaustralia.org/

Electrify! Electrify! Electrify!



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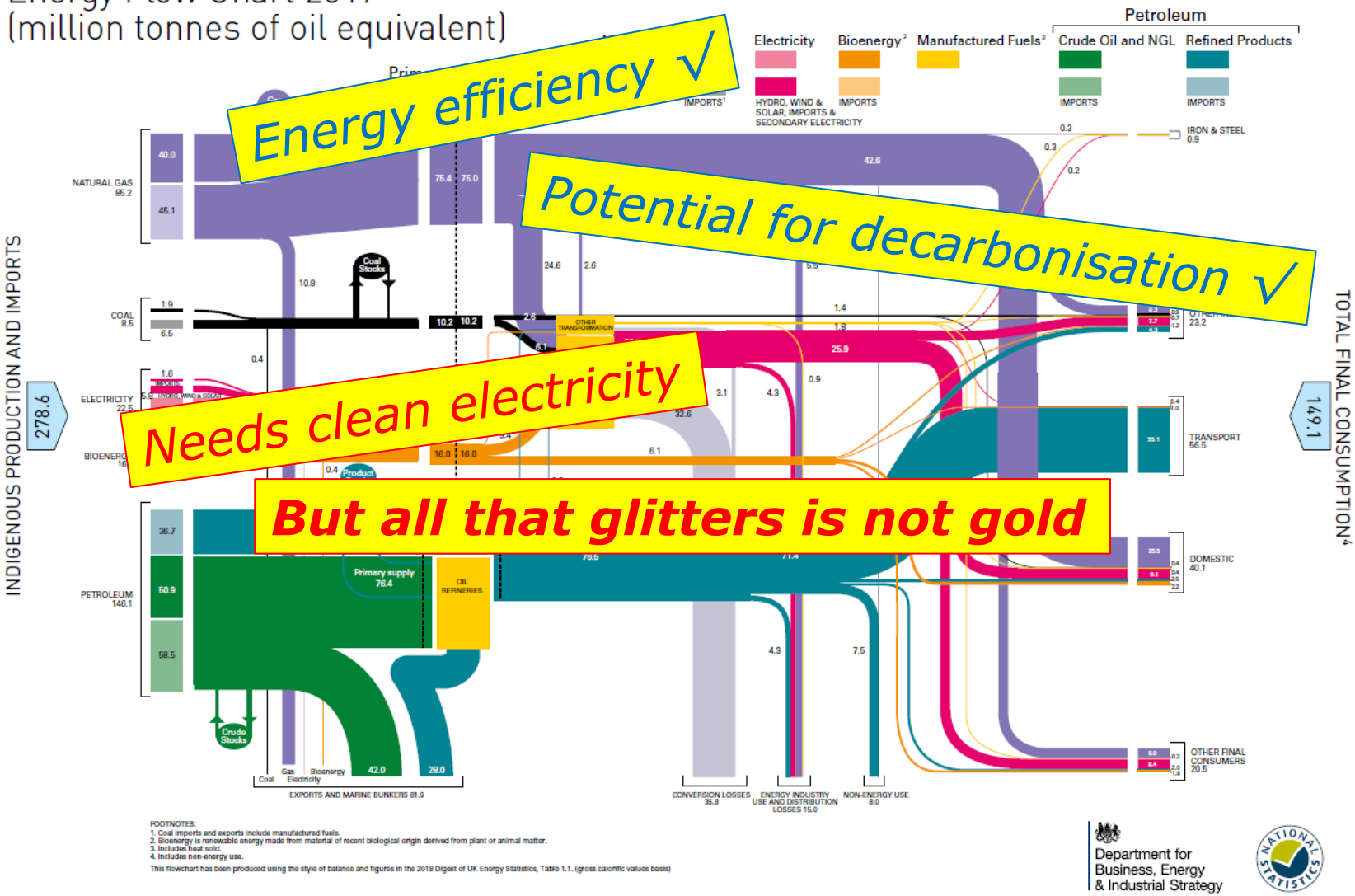
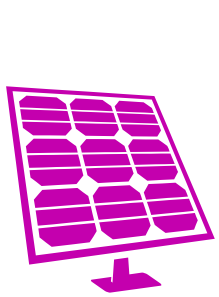
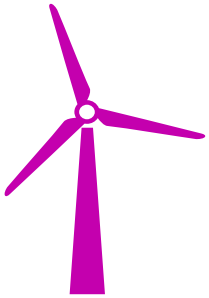


What technologies?

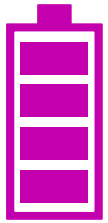
Technology cost decline since 2010



85%



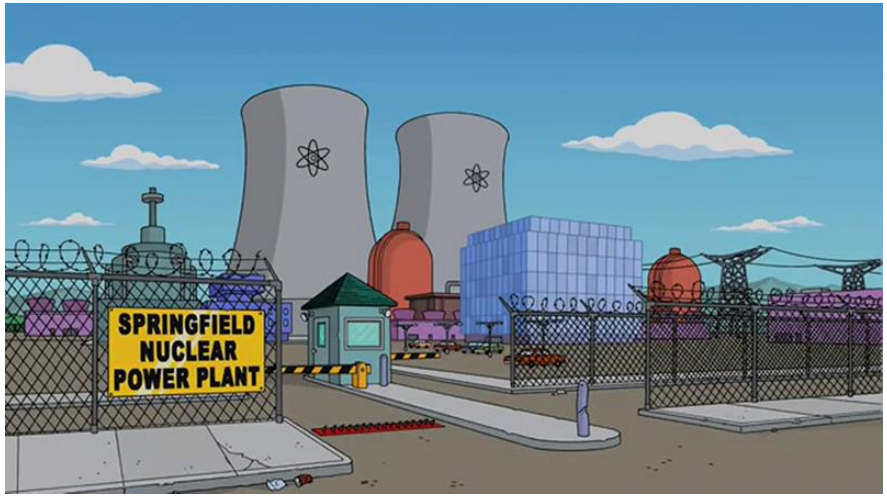
49%



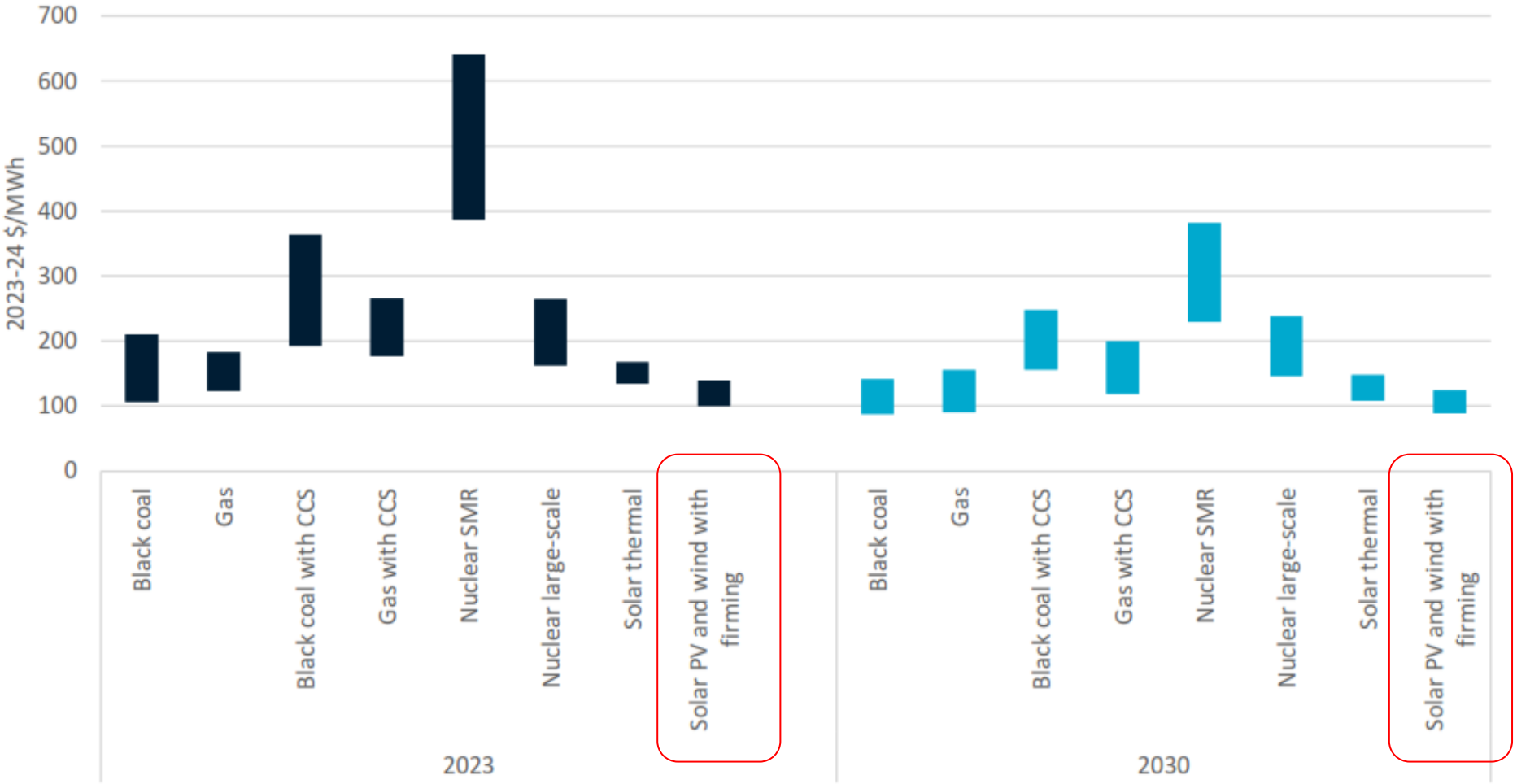
85%

Source: Bloomberg New Energy Finance **2019**, https://about.bnef.com/new-energy-outlook/#toc-download

What technologies?

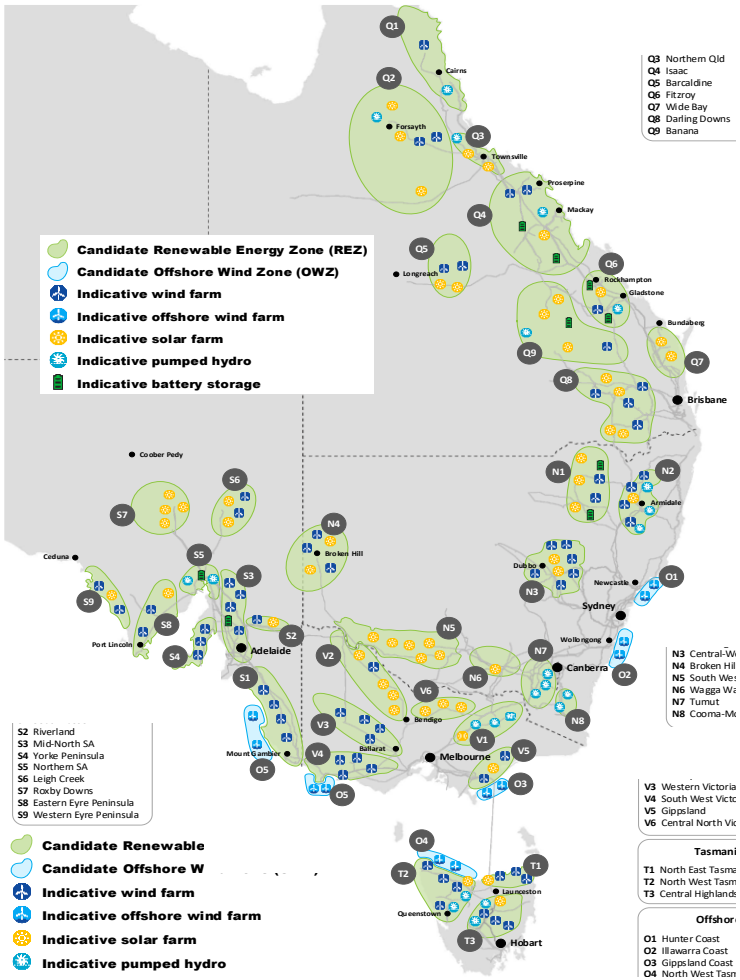


CSIRO's GenCost report

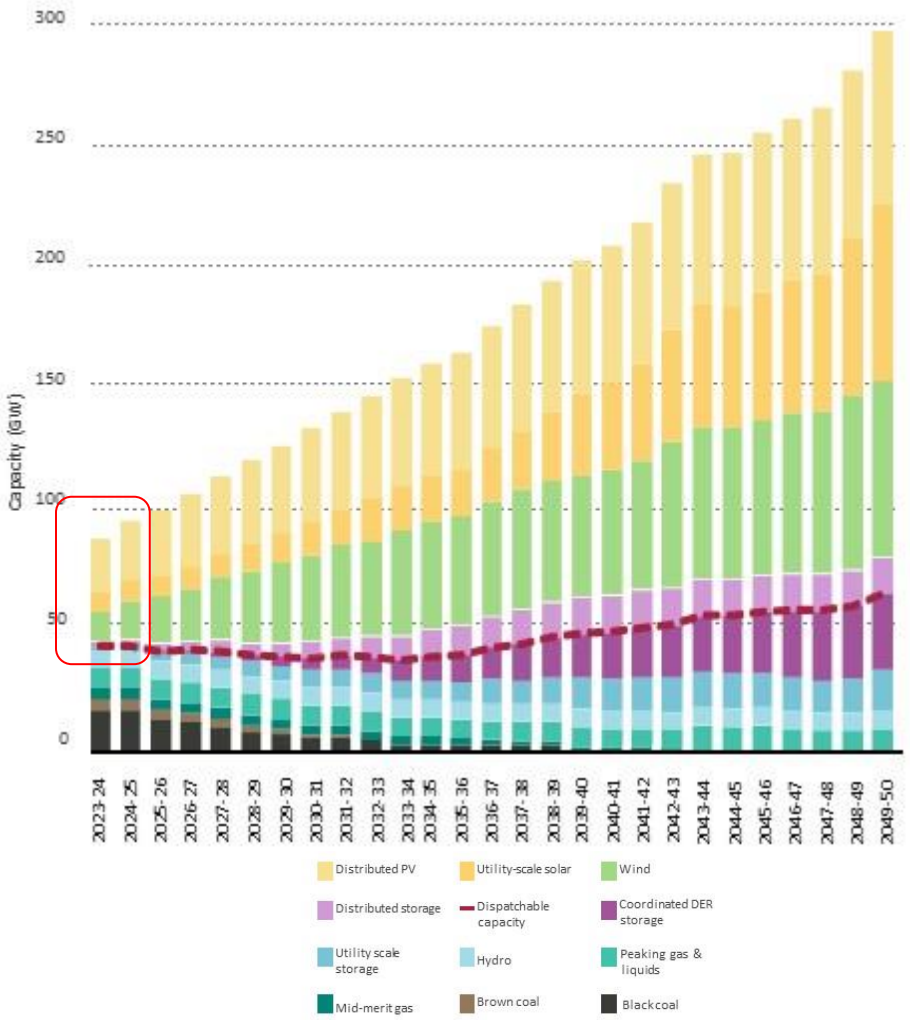


GenCost, Executive Summary, https://www.csiro.au/en/research/technology-space/energy/gencost

Future power system in Australia



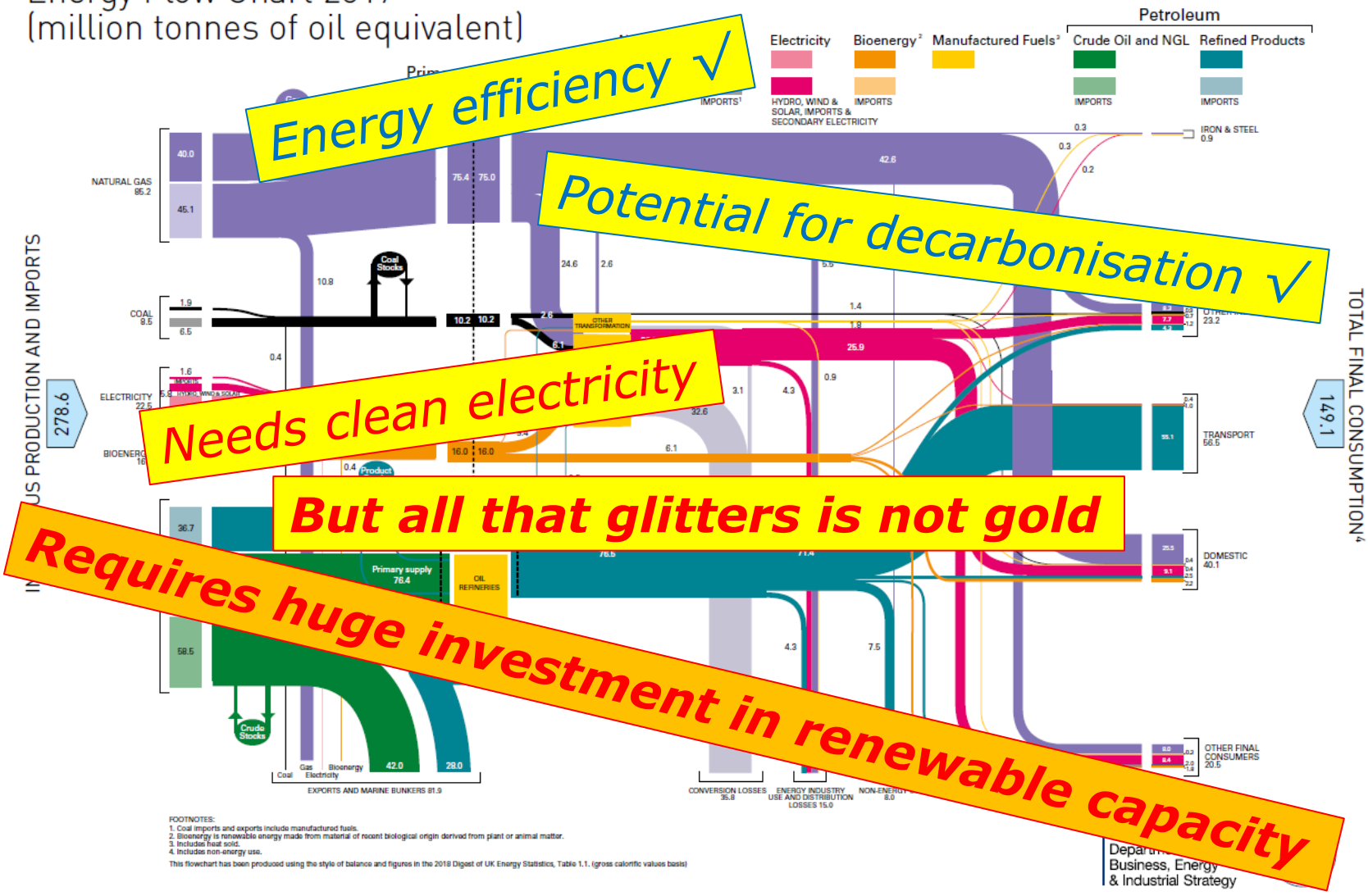
Installed capacity in ISP 2022 "step" scenario



Closure of coal fleet anticipated before 2033

AEMO - 2023 Electricity Statement of Opportunities; AEMO - ISP 2022

Electrify! Electrify! Electrify!



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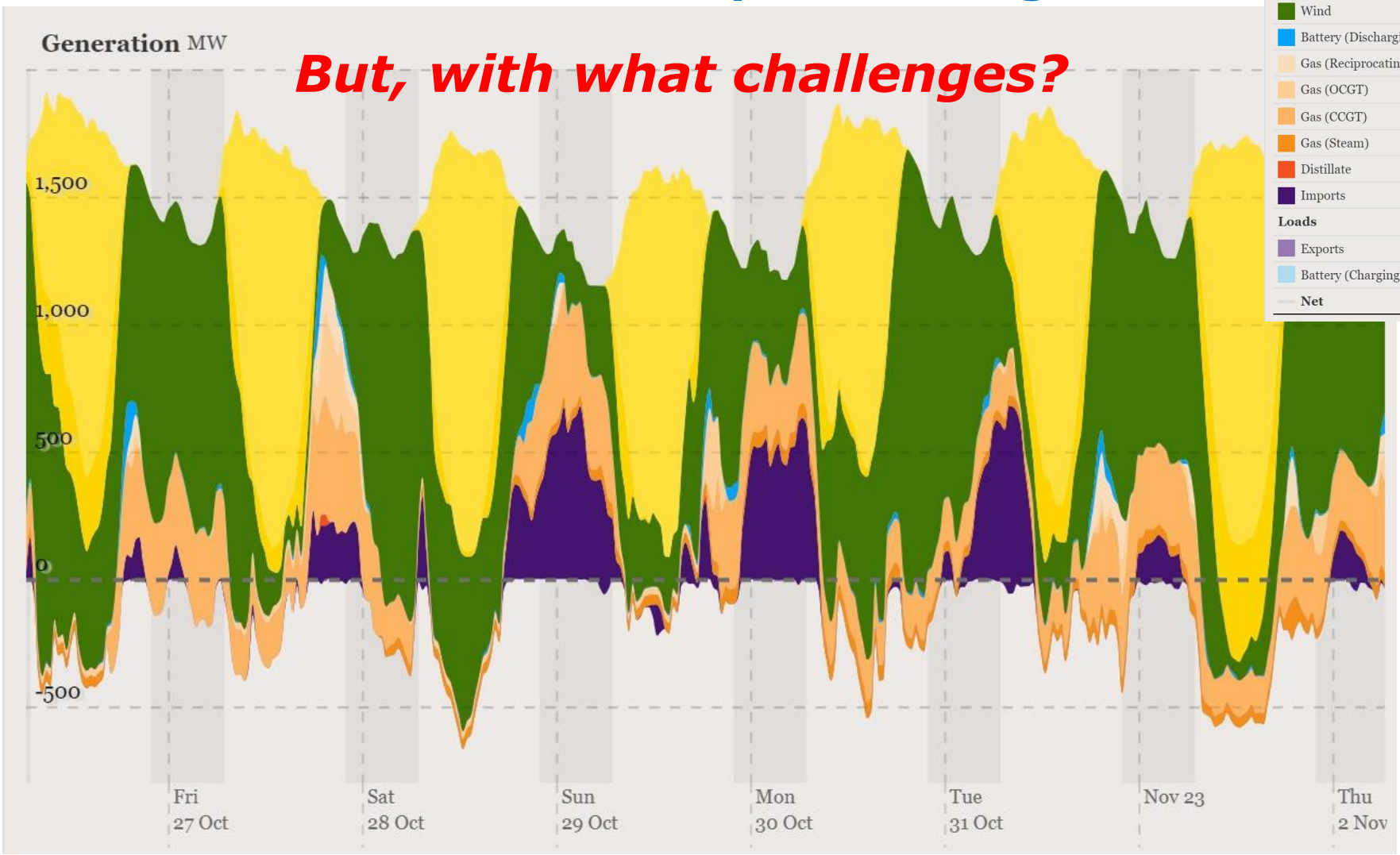
This flowchart has been produced using the style of balance and figures in the 2018 Digest of UK Energy Statistics, Table 1.1. (gross calorific values basis)

A typical week in South Australia…

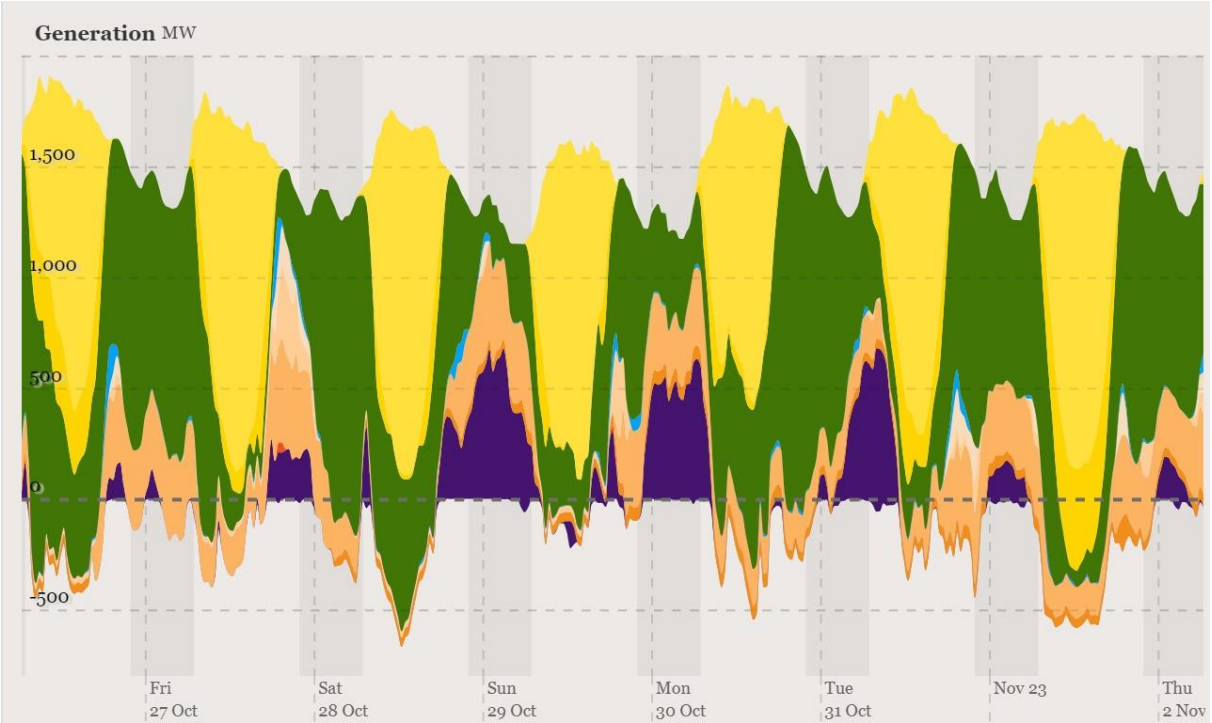
Sun down, wind up… like magic!

But, with what challenges?



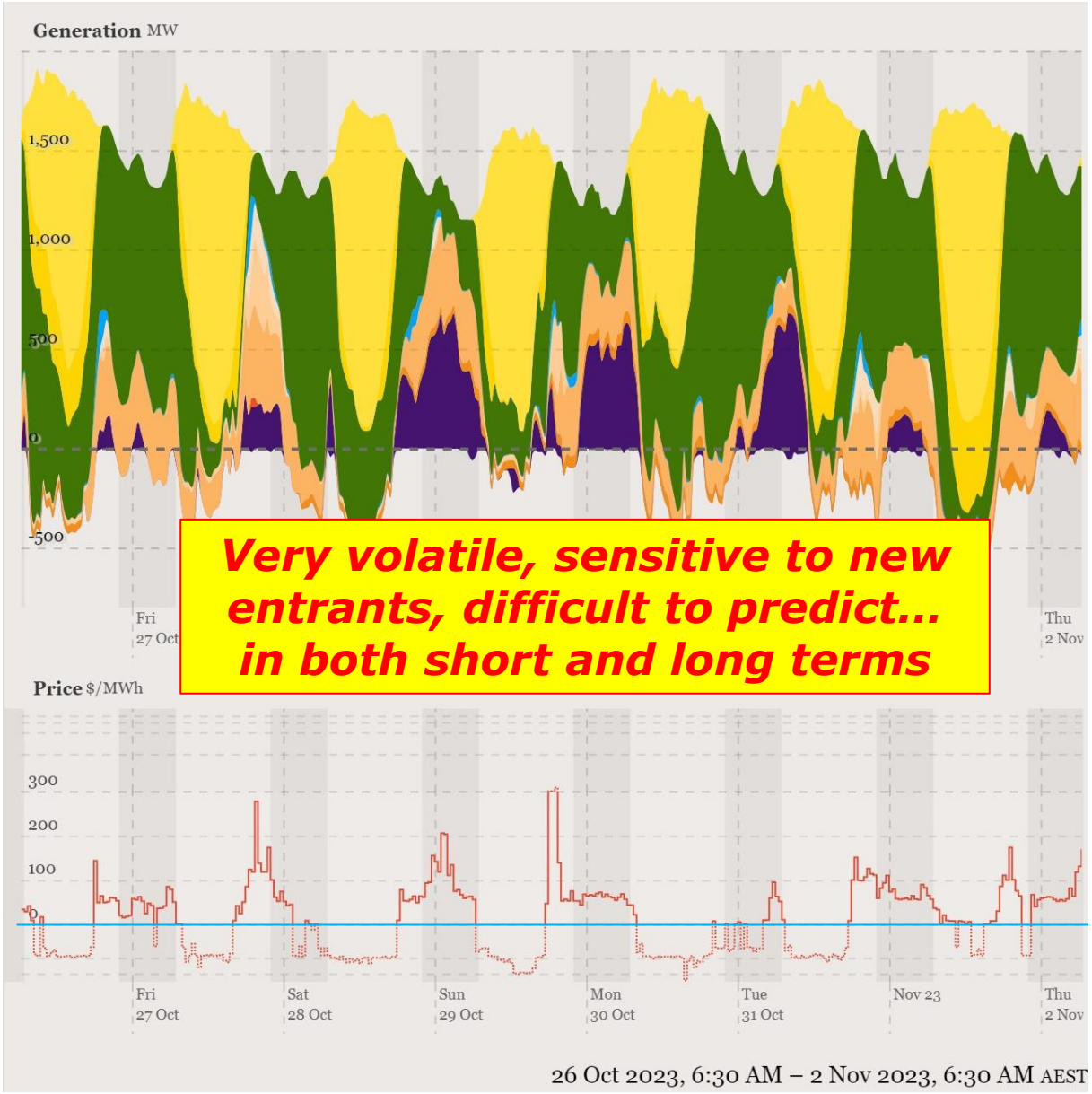
Source: AEMO and OpenNEM

System balancing…

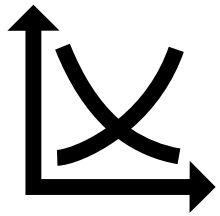


Source: AEMO and OpenNEM

… and electricity prices…



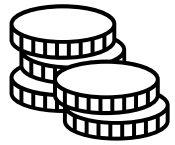
Very volatile, sensitive to new entrants, difficult to predict… in both short and long terms



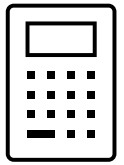
Source: AEMO and OpenNEM

Techno-economic issues with renewables

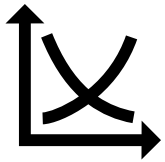
- ***Lower cost of production doesn't mean higher profit!***
  - Electricity generation is a very competitive space
  - Very low barriers to entry
  - Savings eventually passed over to customers



- **Uncertainty in revenues and profits** is significant
  - Variable and volatile prices mean variable and volatile profits!
  - Higher hedging costs, premiums, and desired returns
  - **Financing riskier and more complicated**



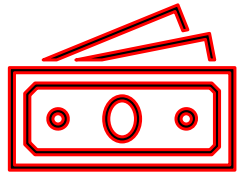
- **Governments** worldwide seem to have **passed** the ball **to the private sector**
  - Either because of competitive markets
  - Or because unable to pick up the check!



From economy of operation to economy of investment

- ***Investment cost dominating*** *means* ***cost of capital dominating***
- Access to cheap and stable financing essential!

- But **who is going to finance** these new power plants and the required infrastructure?



More markets?

More incentives?

Government takeover?

Noting that **nuclear** suffers from high cost, financing issues, and finally socially acceptability too

Resource inadequacy may be catastrophic!

*A mix of **technical and economic factors** caused unprecedented adequacy issues*

... and, by the way, not really to do with renewables!

Prices typically average around $A80/MWh (per megawatt hour), but can vary between -$1000/MWh (where generators actually pay to stay online) and $15,100/MWh.

Over the past week, wholesale prices surged due to two main factors: high coal and gas prices (driven by the Russian invasion of Ukraine) and roughly 25% of coal power stations being out of action because of maintenance as well as the sudden exit of 3,000 MW of power due to breakdowns (unplanned outages).

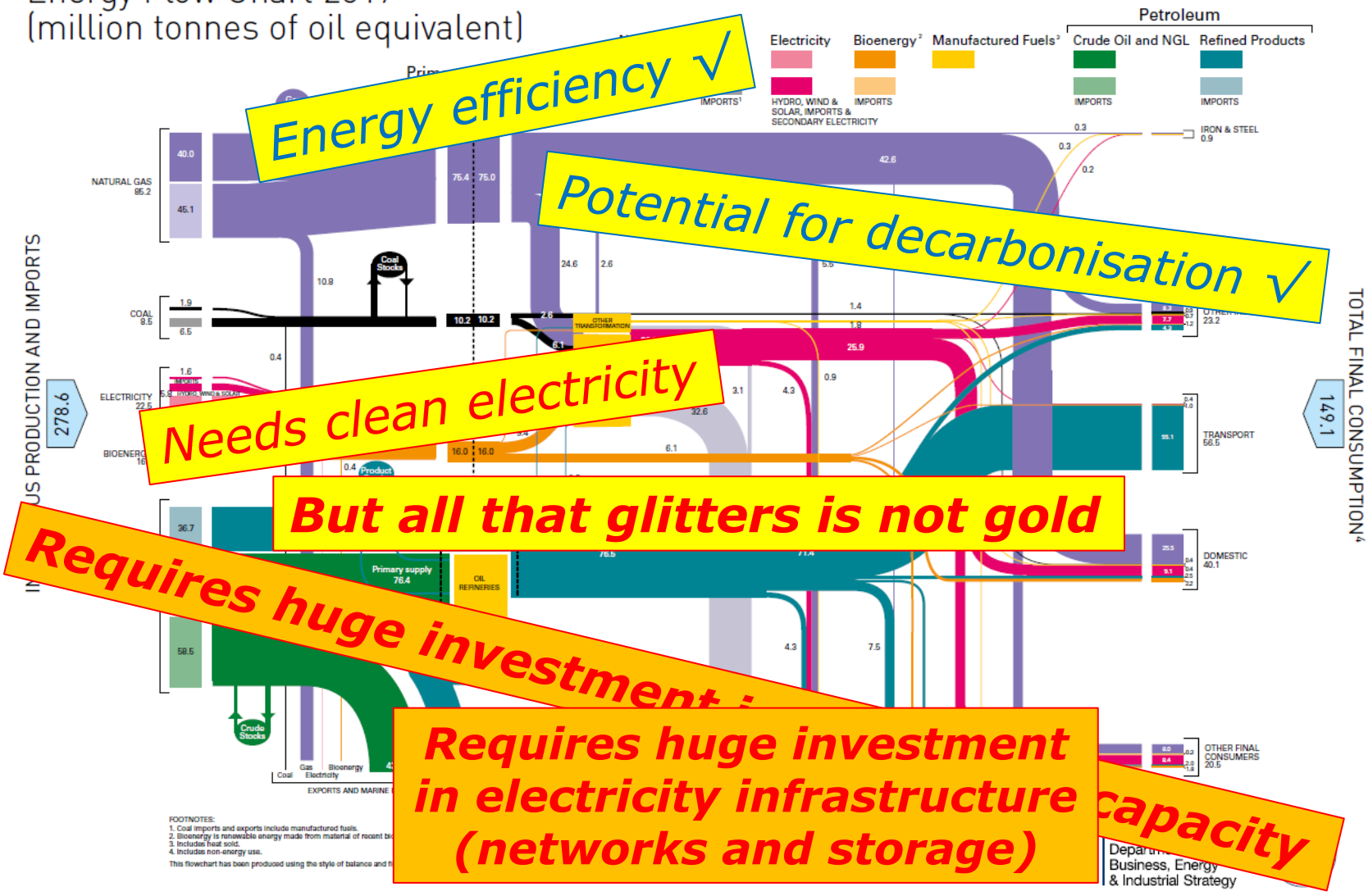
This led AEMO to trigger a pricing "safety net" and capping prices at $300/MWh (much less than the normal cap of $15,100/MWh).

Unfortunately, $300/MWh is currently less than the cost of generating power from gas power stations and possibly even some coal power stations. Some generators subsequently withdrew their availability from the market, leading to further shortfalls.

The low price cap also meant there were weaker price signals as to when power stations with limited "fuel" should use it. This includes some diesel generators as well as batteries and hydro.

Source: https://theconversation.com/australias-national-electricity-market-was-just-suspended-heres-why-and-what-happens-next-185136

Electrify! Electrify! Electrify!



Energy efficiency √

Potential for decarbonisation √

Needs clean electricity

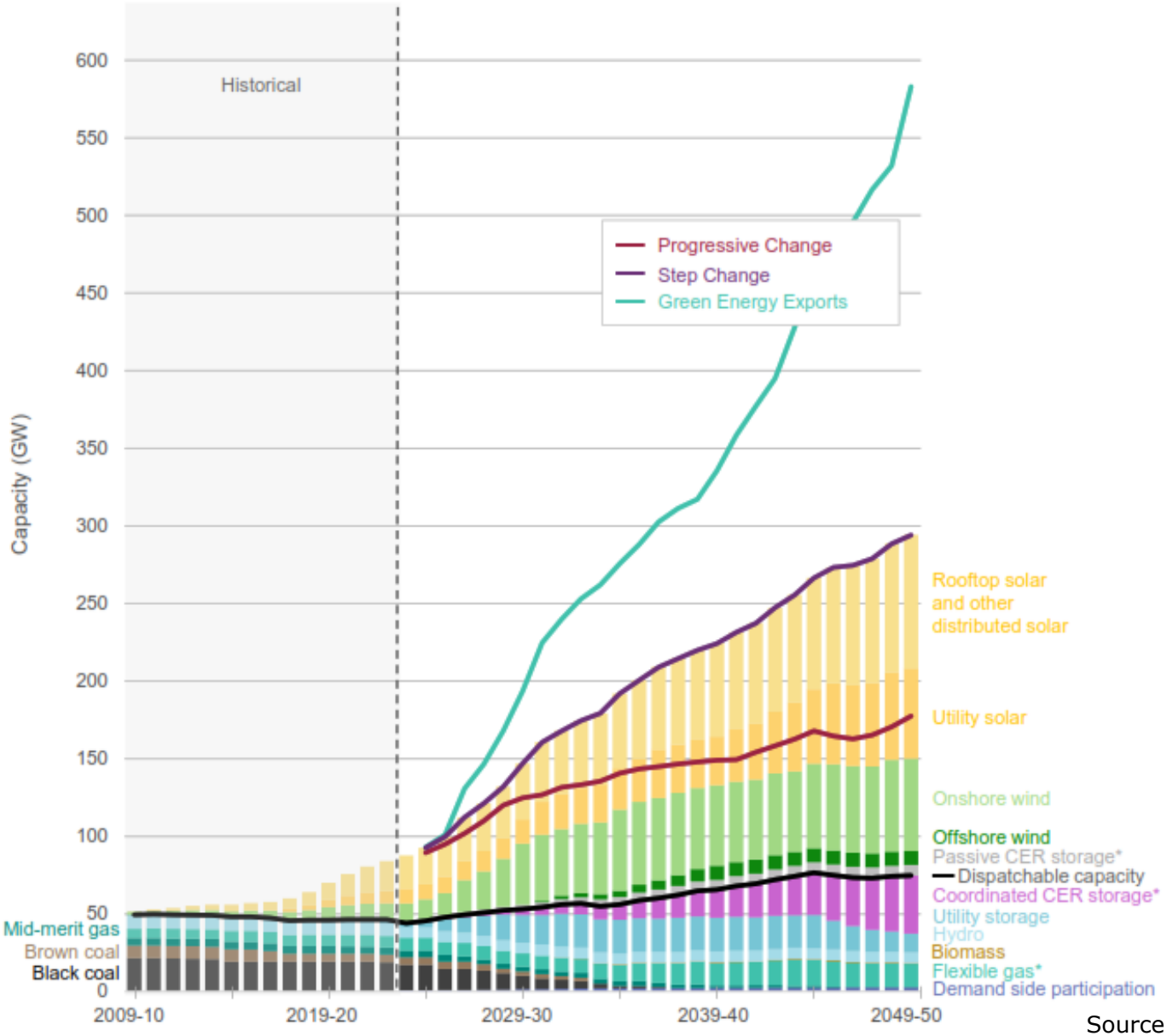
But all that glitters is not gold

Requires huge investment ;

Requires huge investment in electricity infrastructure (networks and storage)

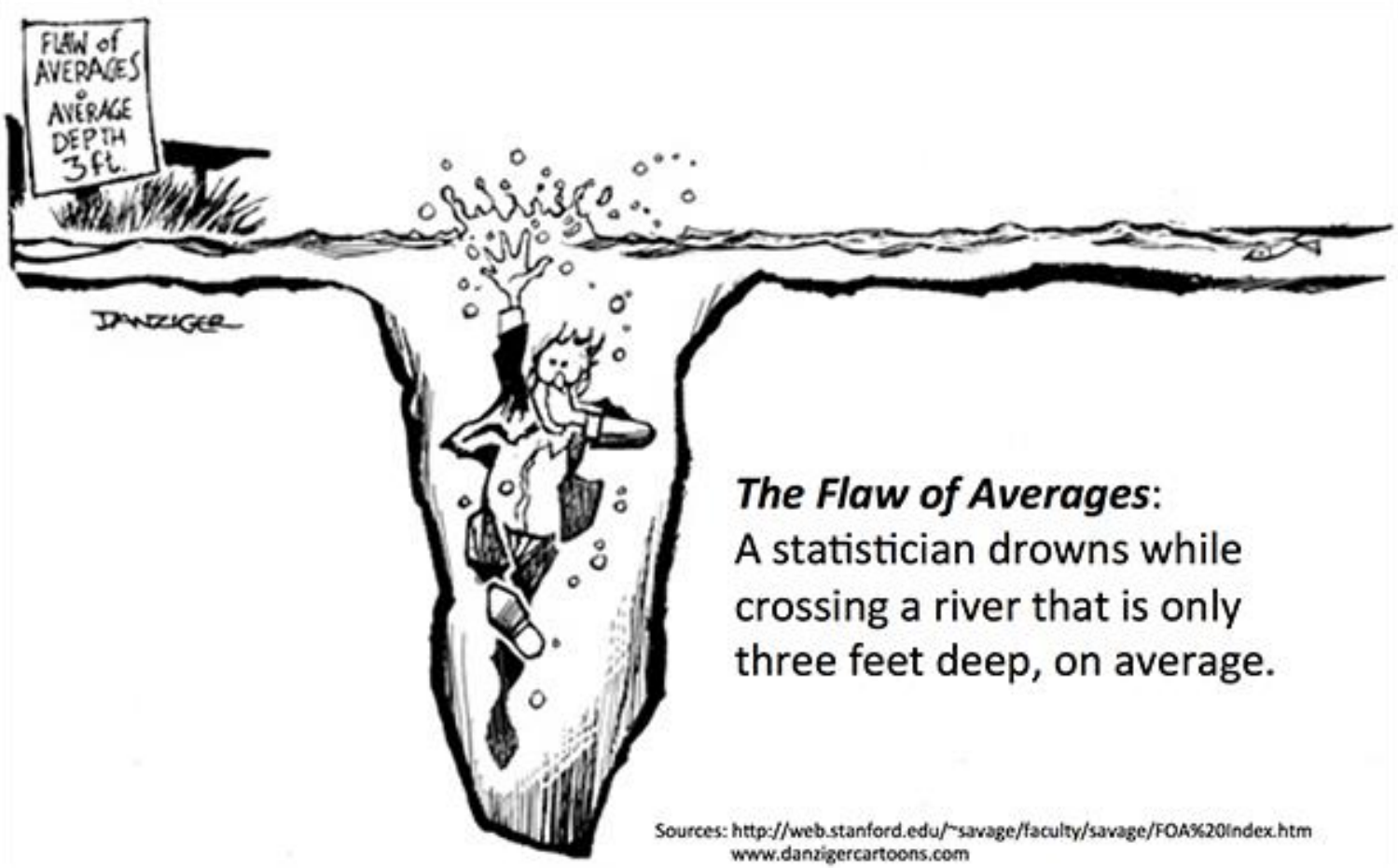
capacity

What future do we plan for?

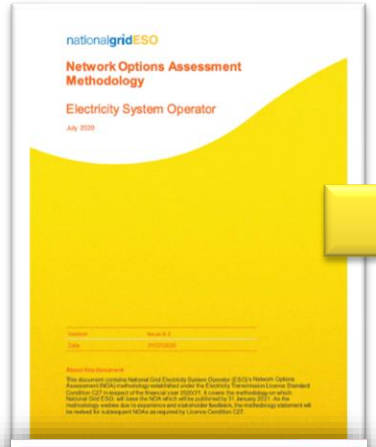


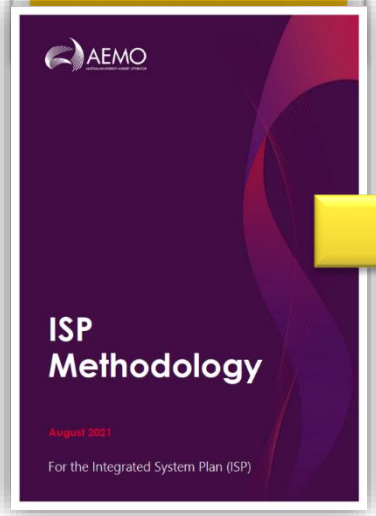
Source: AEMO, ISP 2024

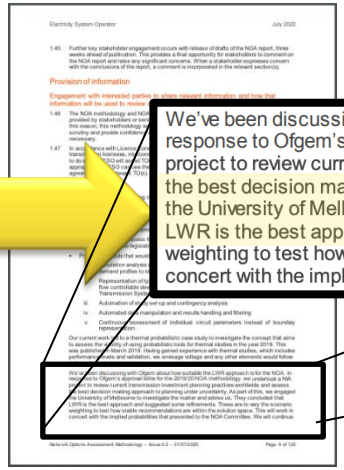
Shall we plan for the *expected* future?



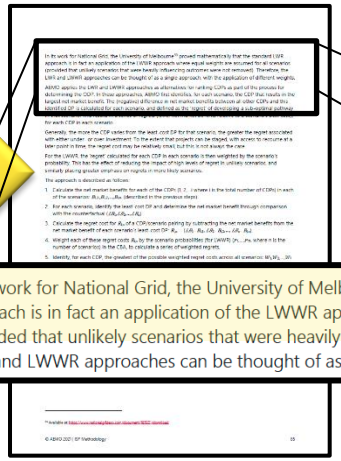
Risk-aware panning under uncertainty







We've been discussing with Ofgem about how suitable the LWR approach is for the NOA. In response to Ofgem's approval letter for the 2019/20 NOA methodology, we undertook a NIA project to review current transmission investment planning practices worldwide and assess the best decision making approach to planning under uncertainty. As part of this, we engaged the University of Melbourne to investigate the matter and advise us. They concluded that LWR is the best approach and suggested some refinements. These are to vary the scenario weighting to test how stable recommendations are within the solution space. This will work in concert with the implied probabilities that presented to the NOA Committee. We will continue



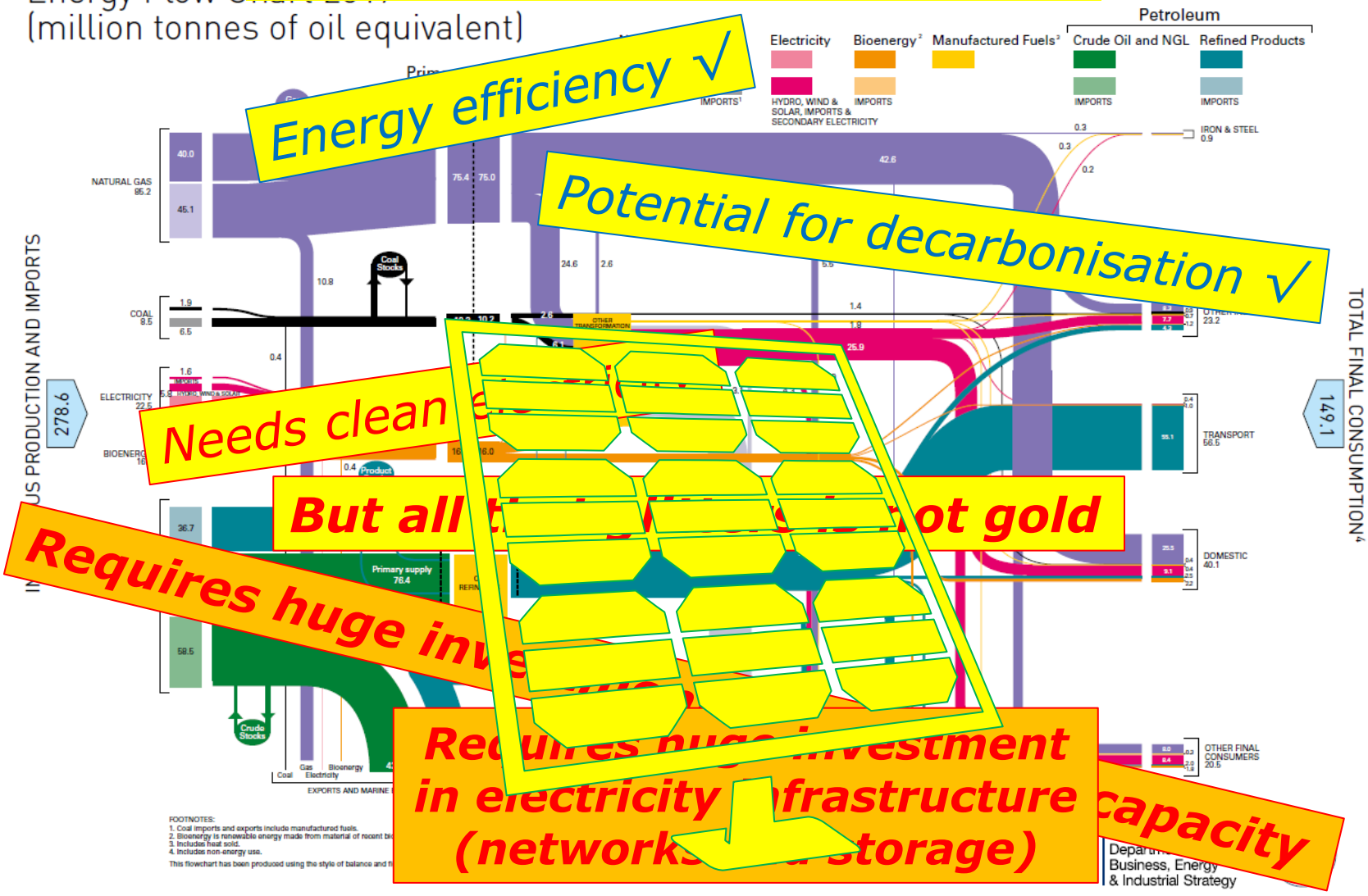
Least-Worst Weighted Regret (LWWR) analysis

In its work for National Grid, the University of Melbourne[59] proved mathematically that the standard LWR approach is in fact an application of the LWWR approach where equal weights are assumed for all scenarios (provided that unlikely scenarios that were heavily influencing outcomes were not removed). Therefore, the LWR and LWWR approaches can be thought of as a single approach, with the application of different weights.

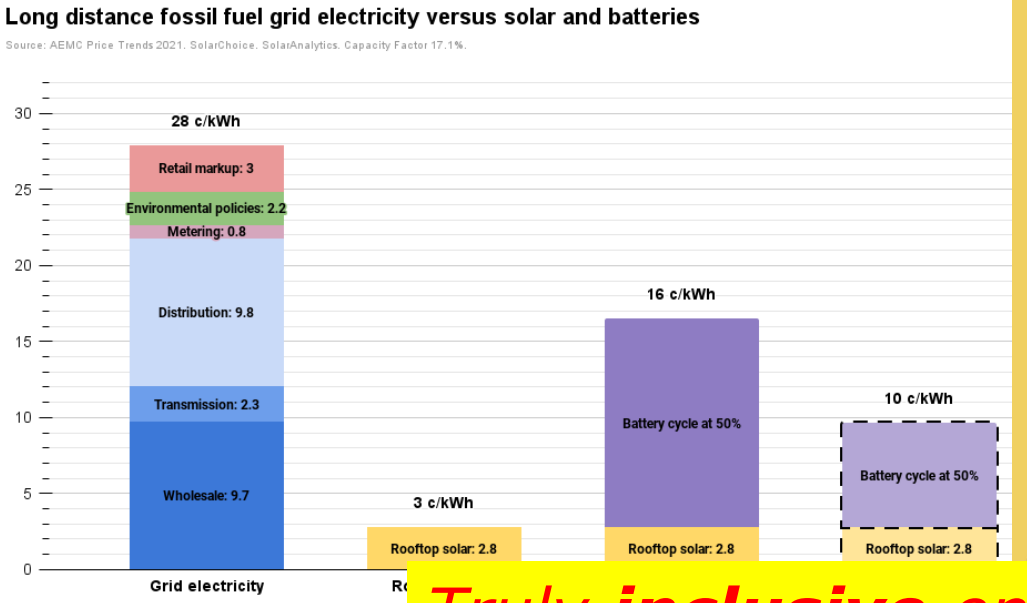
See : P. Mancarella, *et al.*, "Study of advanced modelling for network planning under uncertainty - Part 1", Report for National Grid ESO, 2020: https://www.nationalgrideso.com/document/185821/download

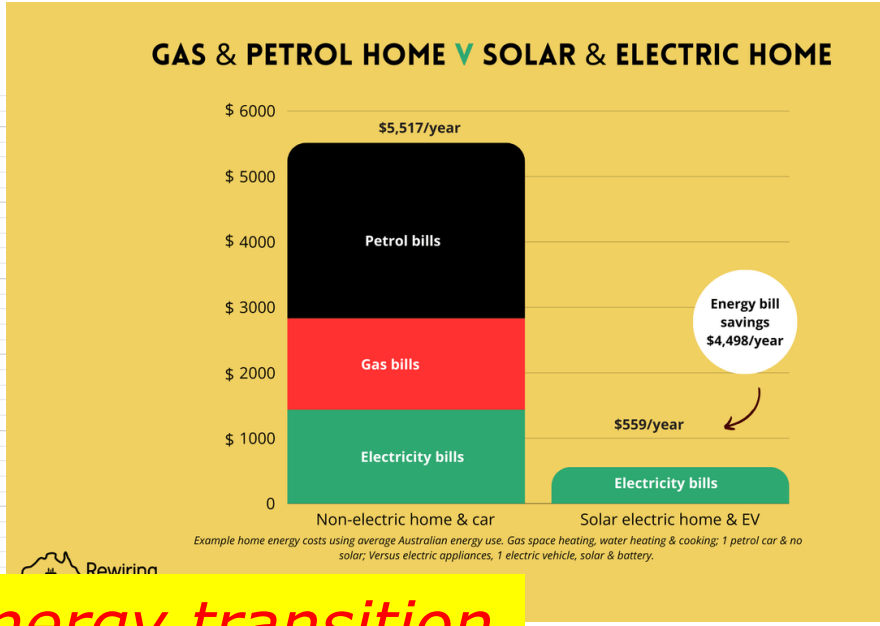
Electrify! Electrify! Electrify!

The super-hero of our story



A back of the envelop analysis of what could be…





*Truly **inclusive** energy transition*

*Huge, historical **wealth transfer to consumers and local communities!***

*Distributed energy may be **more resilient and anti-inflationary***

Our zero-emission and intelligent homes** should be treated and financed like (public) **energy infrastructure!

*Calls for **socio-techno-economic integrated planning** of transmission and distribution systems*

Source: https://www.rewiringaustralia.org/; S. Griffith, "The Big Switch"

New view on sustainability:
Decouple growth from emissions

Electrify EVERYTHING you can!

Build renewables, especially distributed ones!

- **Energy co ion**
  - Reduc tts")
- **Energy efficiency** *bric first"*
  - Reduce losse integrate systems
- **Zero-carb**
  - Wind, ydro, nuclear, etc.

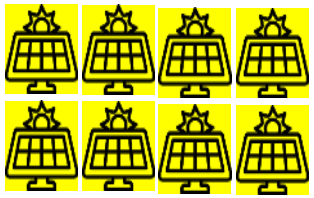
Integrated energy systems in an electrified world

Supply side

Demand side

MARKET SERVICES

INFLEXIBLE CONSUMPTION



IMPORTED FLEXIBILITY

- INTECONNECTIONS
- AC LINES
- HVDC

(Image sourced from the internet)

SOUTH ASIA SUBREGIONAL WORKSHOP

Frontier Technologies: Techno-Economic and Socio-Technical Challenges

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Chair of Electrical Power Systems

The University of Melbourne

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23 May 2025 • Paro, Bhutan