# Barriers to power sector decarbonisation in India

Doctoral Presentation

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- Chapter 4: Early just transition of coal-bearing states in India*
- Chapter 5: Synthesis and Outlook

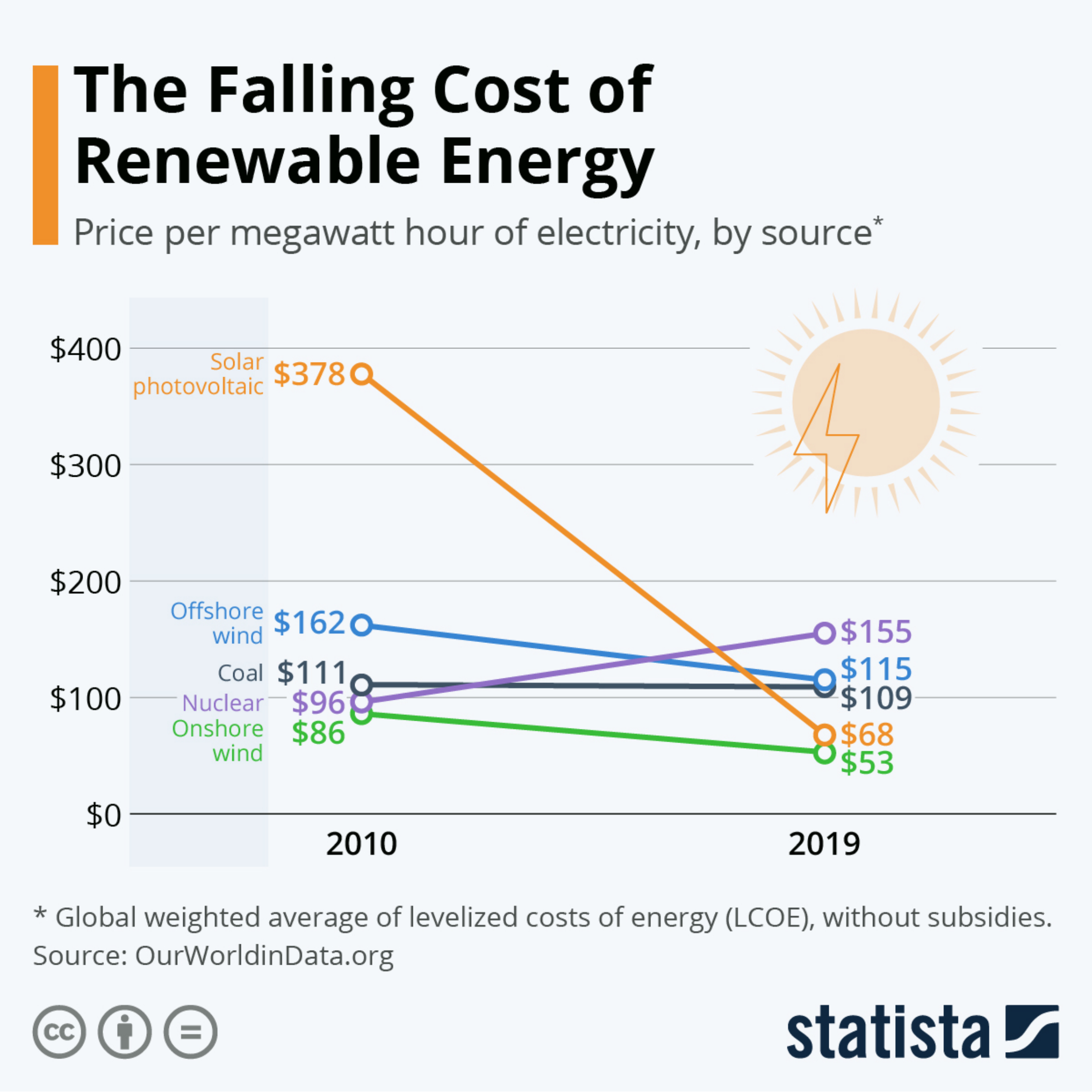
* Published research papers with novel contribution

# Chapter 1: Introduction

# Background

**Why should developing countries mitigate their emissions?**

- Pledging and achieving: Paris Agreement
- Co-benefits with development objectives: Energy access, energy security, human health
- Climate impacts could push back development gains
- Lower cost of energy provision: Falling cost of renewable energy

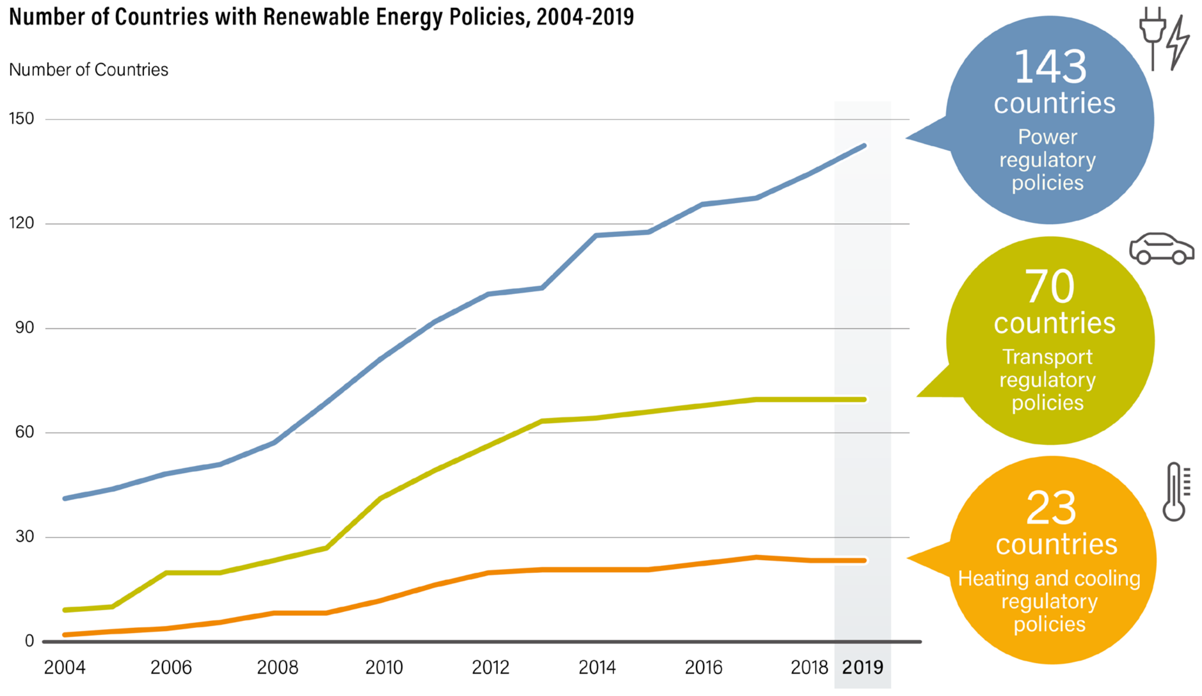



Source: OurWorldinData.org/Statista

# Background

## Where should mitigation begin?

- **Power sector**
  - “Low hanging fruit” of decarbonisation
  - Increasing RE support policies
  - Strong path dependency and lock-ins



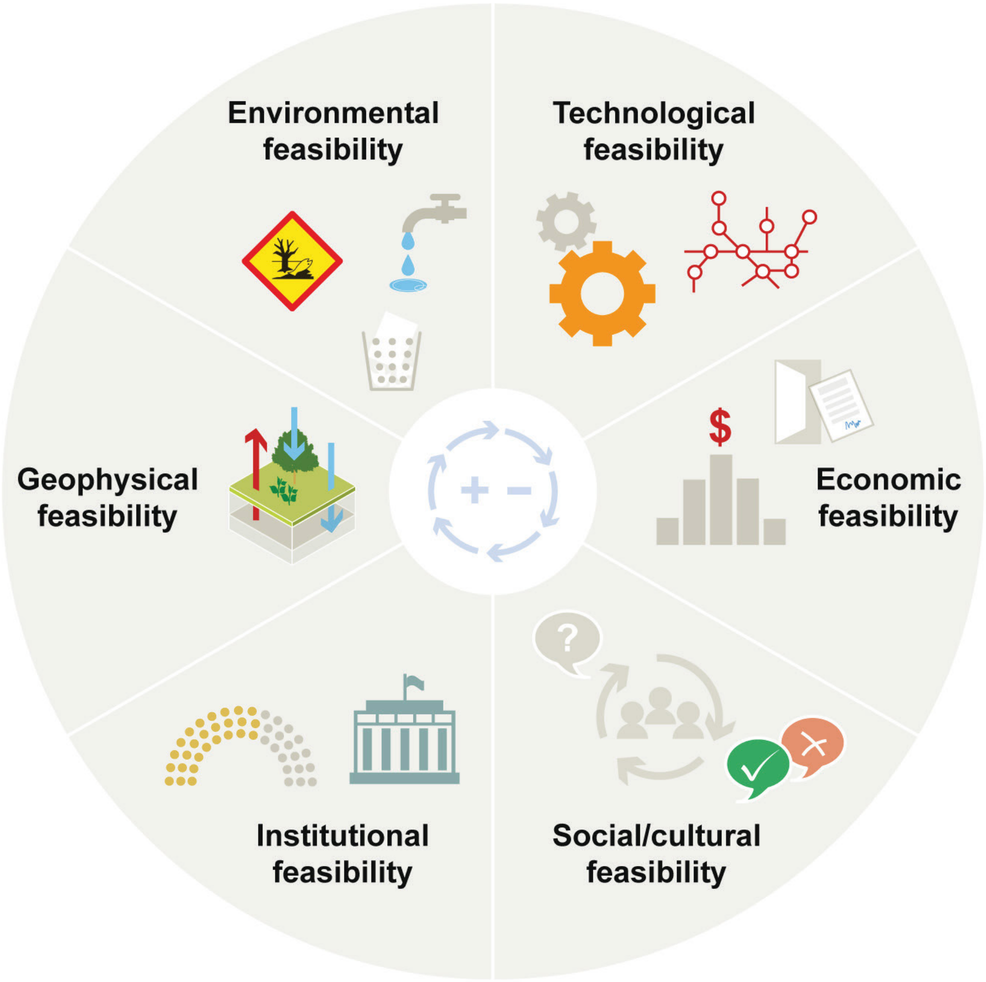



Source: REN21, Global Status Report

# Background

## Challenges to mitigation in developing countries

- Large population with low-income: highly sensitive to cost of energy
- Energy system deeply politically embedded
- Highly regulated power system
- Weak institutions
- High cost of capital




Source: IPCC SR1.5, Chapter 4 FAQ

# Conceptual Framework

Based on Seto et al. (2016); Unruh et al. (2000)

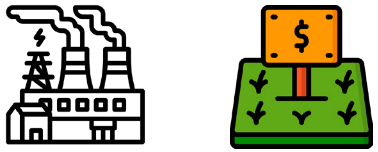
## Macro objectives

- Economic growth
- Energy security
- Energy access
- Job creation

## Barriers to power sector decarbonisation

### Techno-economics

- Relative cost of power generation
- Lifetime of infrastructure
- Land-use, resource, and technology diffusion constraints

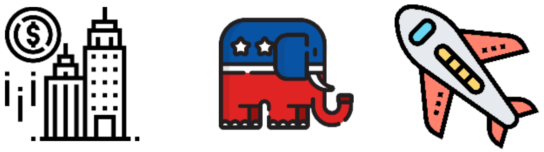


### Governance and institutions

- Institutional capacity
- Existence of power markets
- Electricity pricing
- Regulation compliance

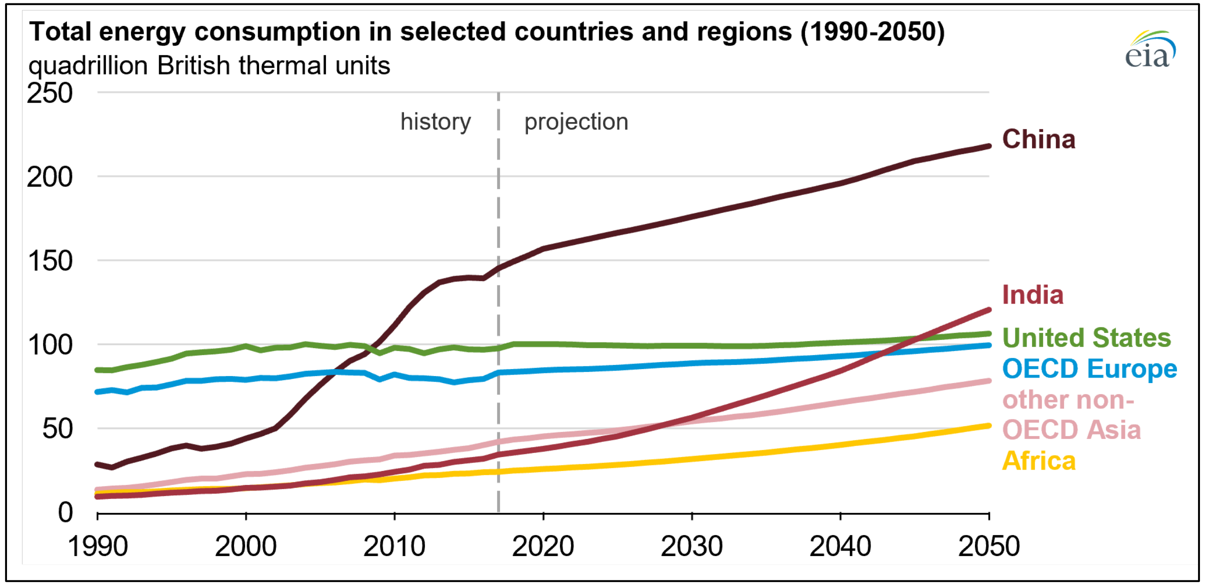
### Socio-economics and politics

- Political economy constraints
  - Vested interests
  - High energy consumers
  - Just transition
- Behavioural change



# Focus on India

- Significant increase in energy demand
- One of the largest coal reserves and second largest coal consumer
- India’s energy choices affect global energy markets, emissions, and flows of technology and capital.






Source: US Energy Information Administration, *International Energy Outlook*, 2019

# Meta-overview of Chapters (2-4)

| Chapter | Spatial Focus | Temporal focus | Methodological tools used<br>*Innovations in bold-italics* |
|---|---|---|---|
| # 2 | India | 2030 and 2050 | • Model intercomparison of national and global energy-economy models<br>• ***Bottom-up data on policies and planned capacities*** |
| # 3 | Global | 2030 and 2050 | • ***Energy employment model***<br>• REMIND* scenarios |
| # 4 | Sub-regions in India | 2030 | • REMIND scenarios<br>• ***Energy employment model***<br>• ***Bottom-up data of energy infrastructure at sub-national level*** |

* energy-economy-climate model from PIK

# Papers and code: Openly accessible

All published papers, including their data and code are open-access

**Ch2:** Malik, A., Bertram, C., Despres, J., Emmerling, J., Fujimori, S., Garg, A., Kriegler, E., Luderer, G., Mathur, R., Roelfsema, M., Shekhar, S., Vishwanathan, S., & Vrontisi, Z. (2020). **Reducing stranded assets through early action in the Indian power sector.** *Environmental Research Letters*, *15*(9), 094091. https://doi.org/10.1088/1748-9326/ab8033

- Code: https://gitlab.pik-potsdam.de/amalik/reducingstrandedassets

**Ch.3**: Malik, A., Bertram, C., Kriegler, E., & Luderer, G. (2021). **Climate policy accelerates structural changes in energy employment.** *Energy Policy*, *159*, 112642. https://doi.org/10.1016/j.enpol.2021.112642

- Code: https://zenodo.org/record/5901604 (CC BY 4.0)

**Ch.4:** Malik, A., & Bertram, C. (2022). **Solar energy as an early just transition opportunity for coal-bearing states in India.** *Environmental Research Letters.* https://doi.org/10.1088/1748-9326/ac5194

- Code: https://zenodo.org/record/6035783 (CC BY 4.0)

# Chapter 2

# Chapter 2

**Barriers to power sector decarbonisation**

**Techno-economics**

- Relative cost of power generation
- Lifetime of infrastructure
- Land-use, resource, and technology diffusion constraints

**Governance and institutions**

- Institutional capacity
- Existence of power markets
- Electricity pricing
- Regulation compliance

**Socio-economics and politics**

- Political economy constraints
  - Vested interests
  - High energy consumers
  - Just transition
- Behavioural change

2 Reducing stranded assets through early action in the Indian power sector.

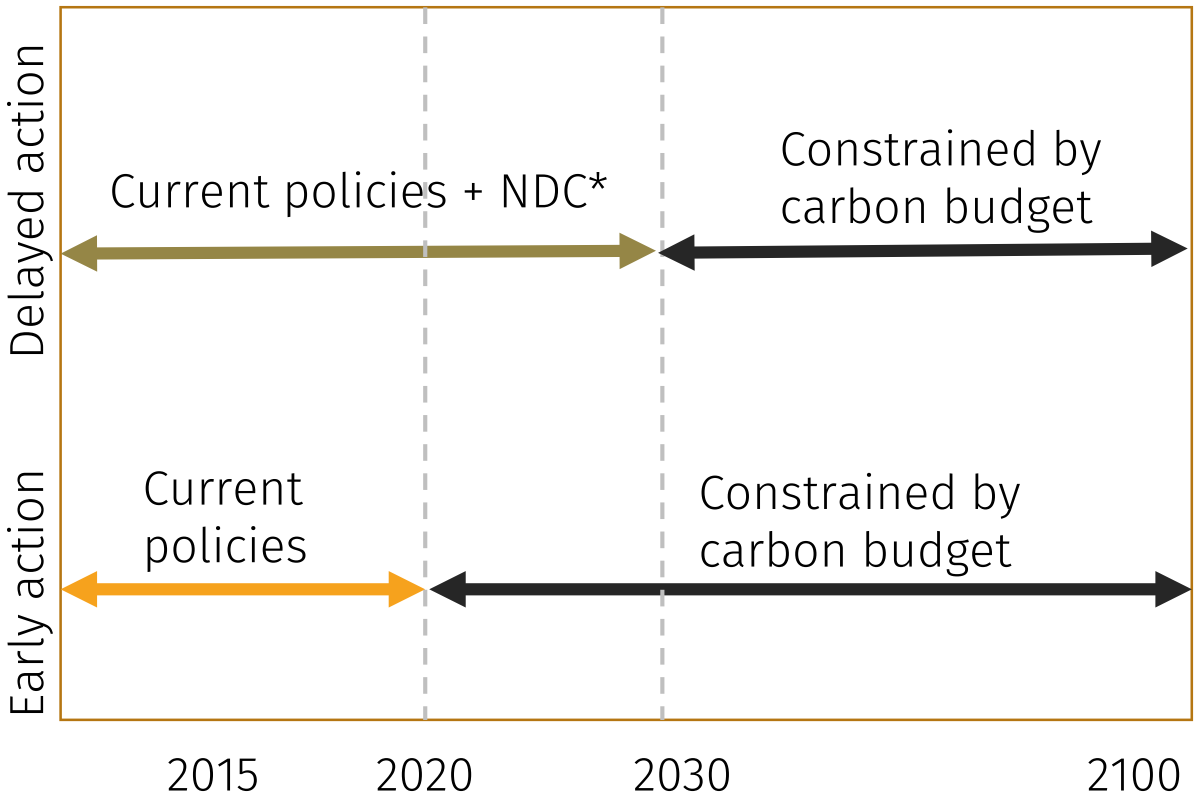
- How could near-term policies in India impact longer term decarbonisation efforts to achieve Paris Agreement targets?
- What set of decarbonisation options does India have in the near- and long-term?

# Methodology

1. Model intercomparison of 8 different energy-economic models : 6 global and 2 models

2. Two scenarios: Early action and Delayed action

3. Compare near-term results with bottom-up developments in policymaking

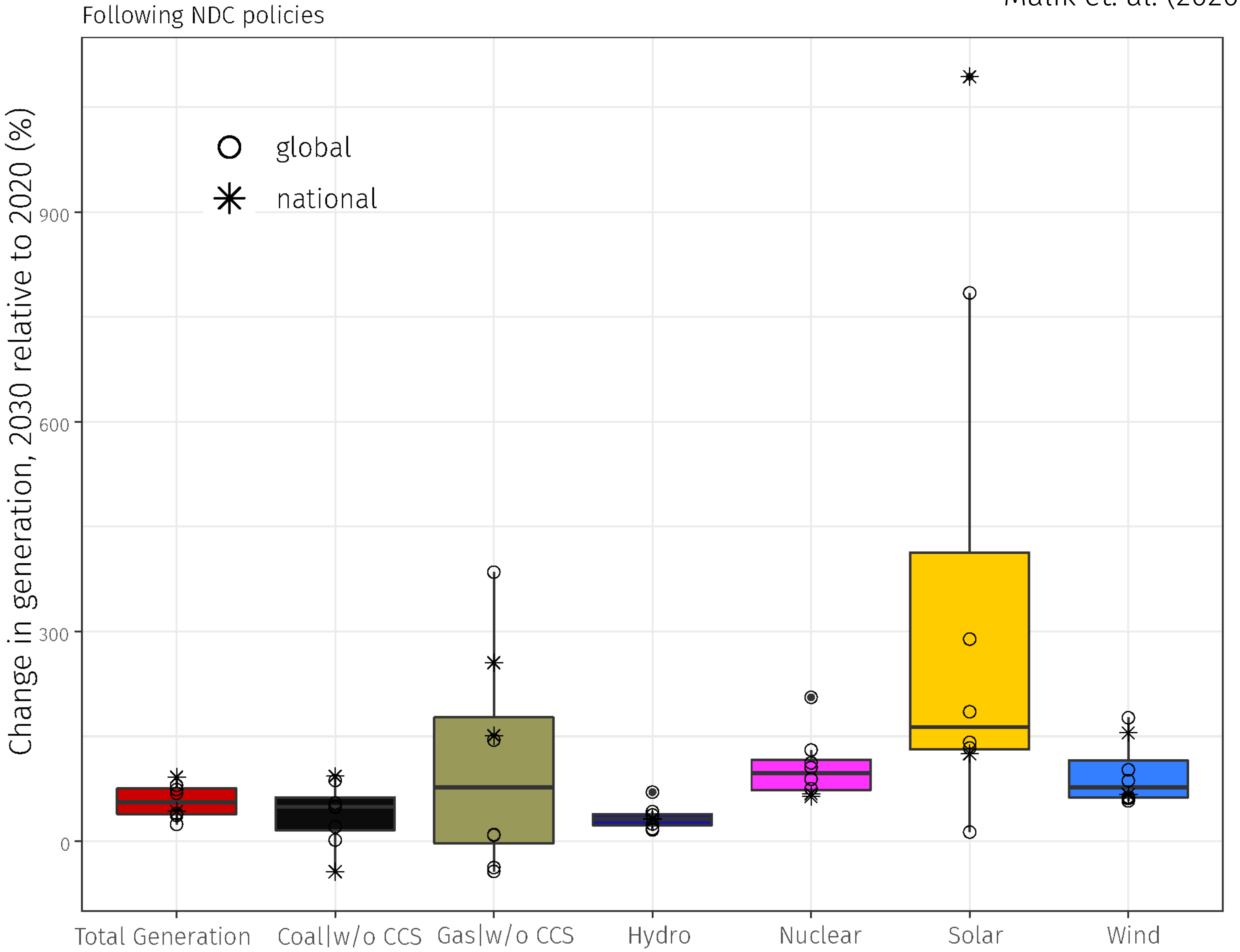



*Nationally Determined Contributions

# Results (1/3): Delayed action (NDC) until 2030

- Coal-based generation continues to increase (~50 %)
- Most rapid in Solar energy (~165%), followed by nuclear energy (97%)
- Decarbonisation of power: share of fossil in power generation decreases by ~10%, coal by ~15%

Malik et. al. (2020)



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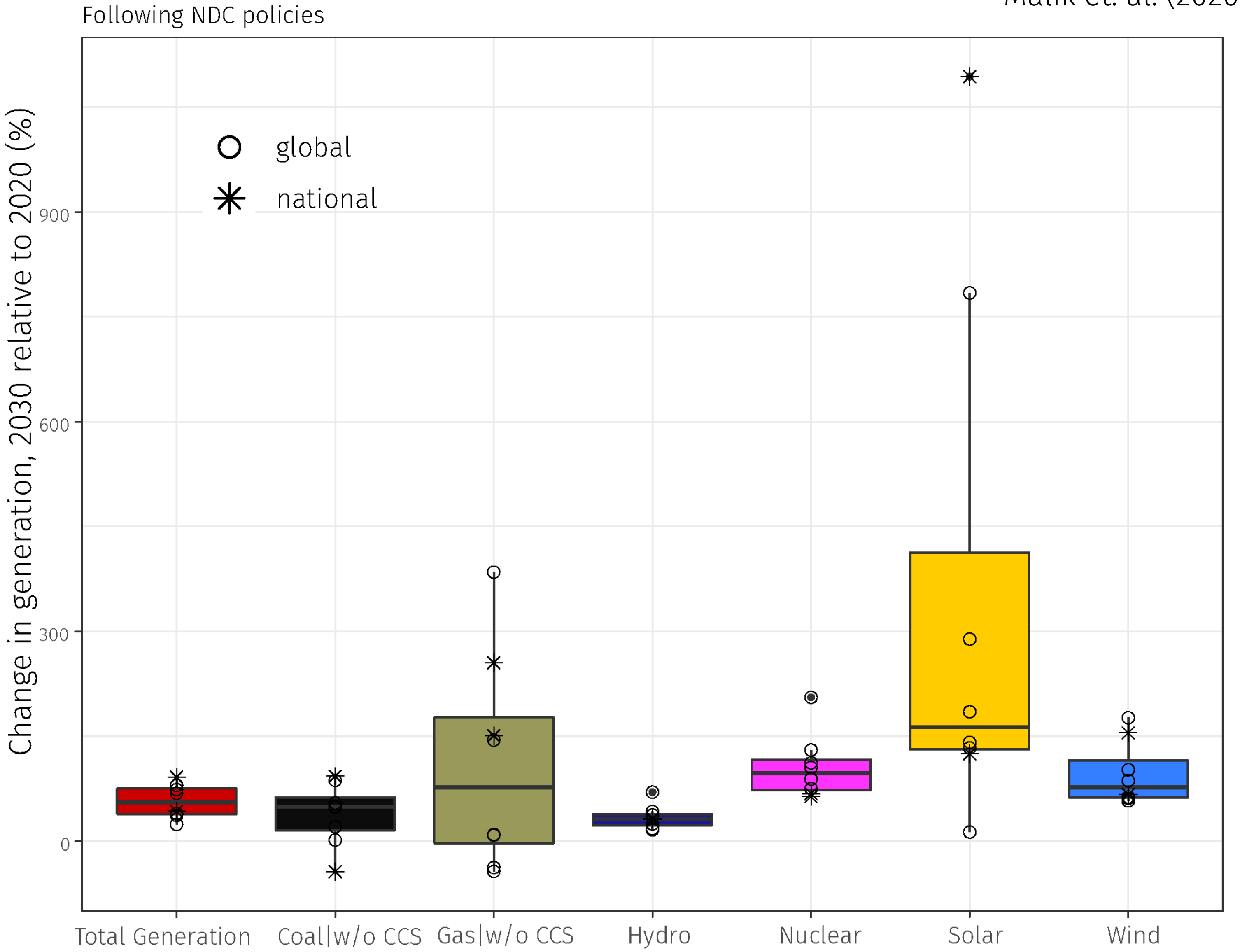

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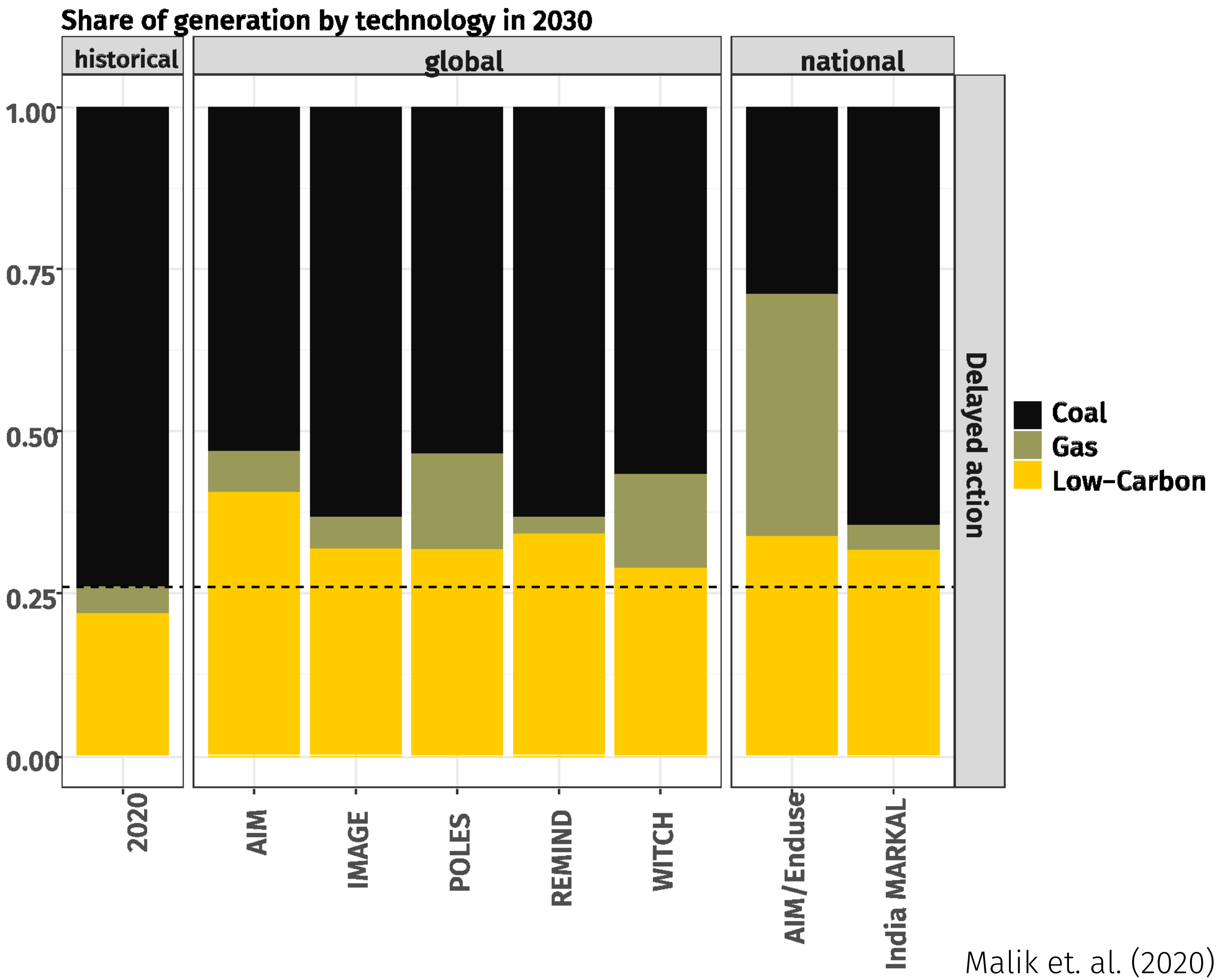
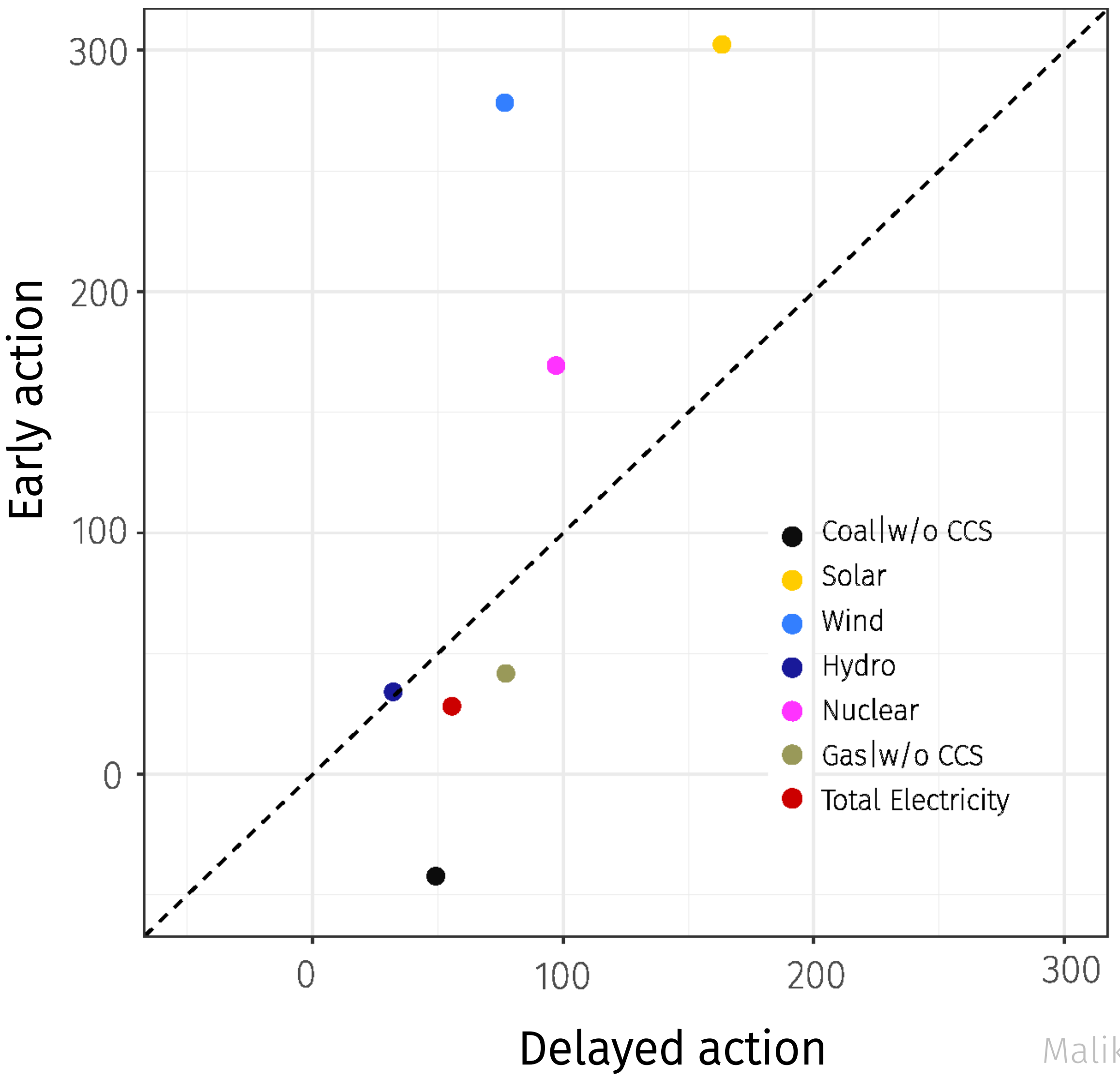



Malik et. al. (2020)

# Results (2/3): Early vs. Delayed

- Early action – Immediate action in 2020
- Delayed action – "Action" delayed until 2030
- In Early vs. Delayed action,  no new coal generation comes online and electricity demand is fulfilled mainly through addition of solar and wind energy.

2030 change relative to 2020 (%)




Malik et. al. (2020)

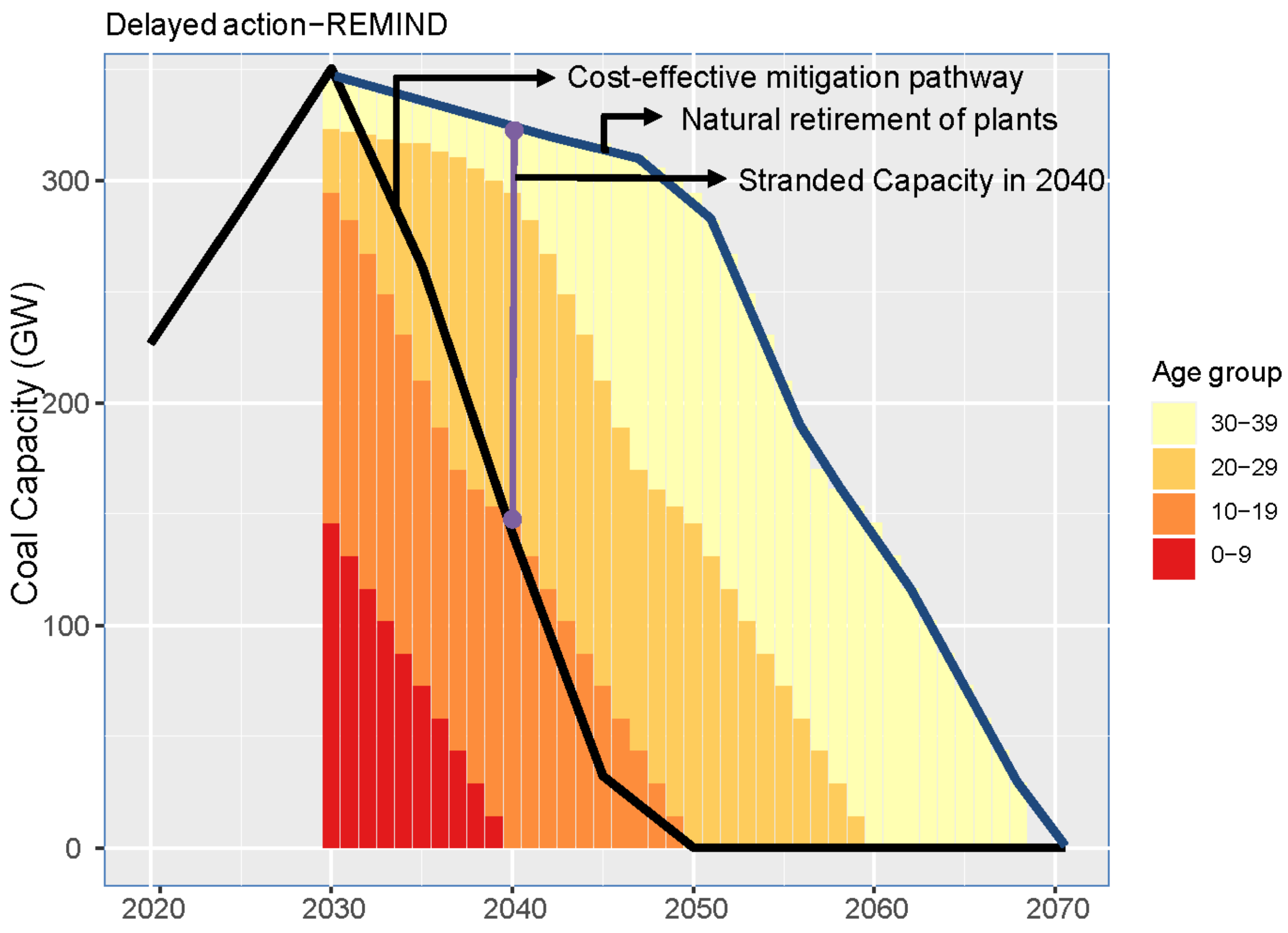
# Results (3/3): Comparing Stranded coal capacity

- Stranding results from the difference in a cost-effective mitigation pathway and a natural retirement pathway

- Significant stranding from plants yet to be built

- Stranded capacity in both early and delayed action scenarios

- Significant stranding avoided by mitigating early: Early action (14-139 GW), Delayed action (133-237 GW)






Malik et. al. (2020)

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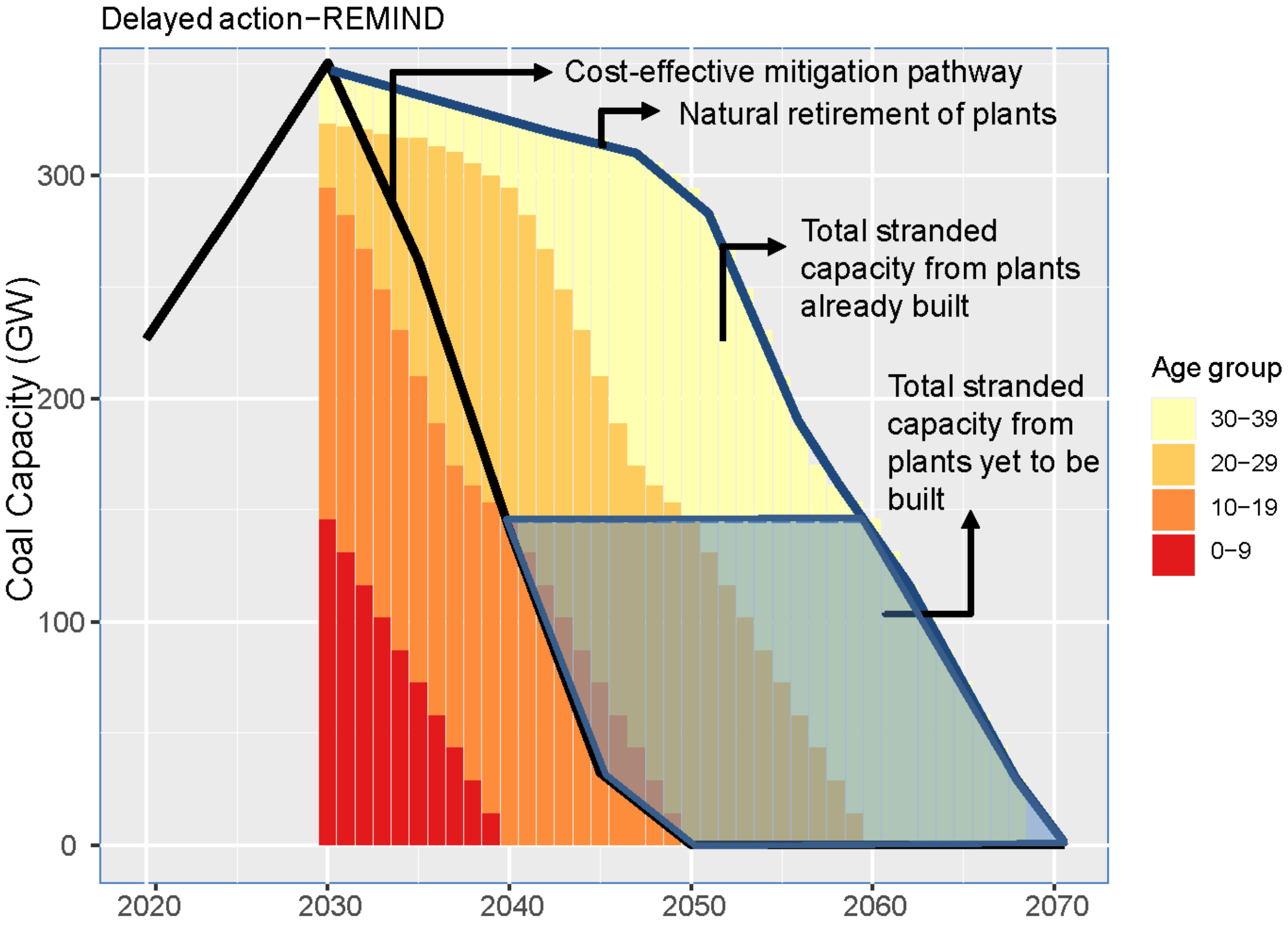




Malik et. al. (2020)

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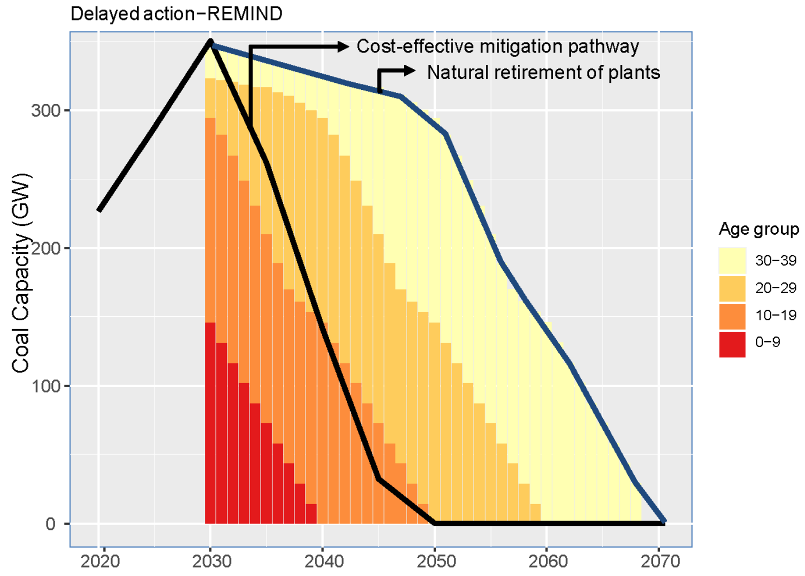
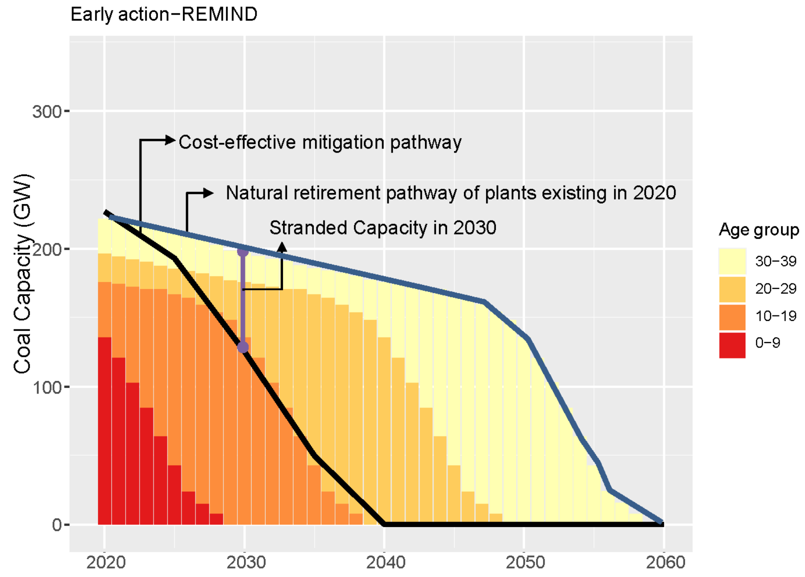
- Significant stranding from plants yet to be built
- Stranded capacity in both early and delayed action scenarios
- Significant stranding avoided by mitigating early:
  - REMIND (109 vs. 179 GW)*
  - All models median (114 vs. 173 GW)

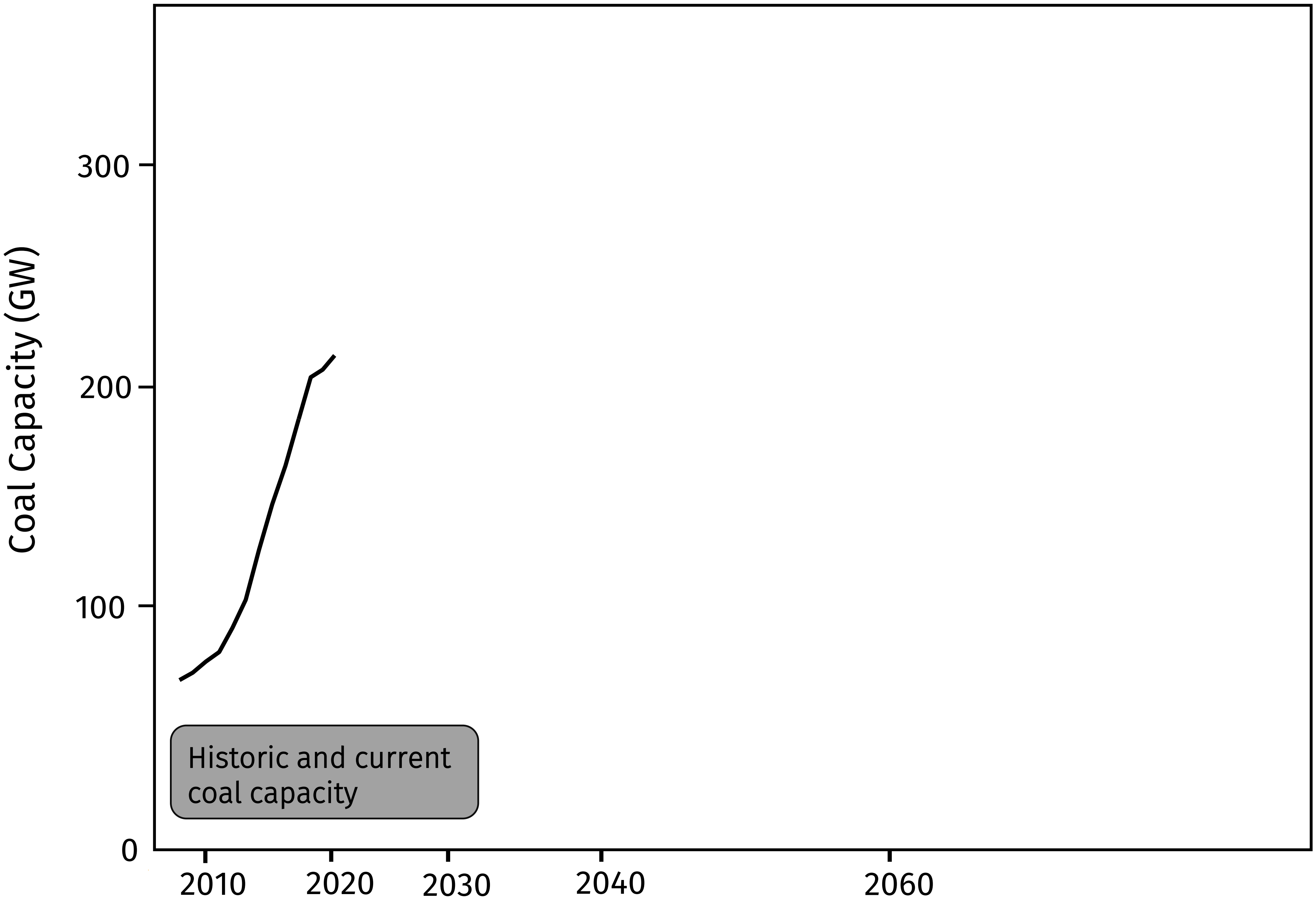


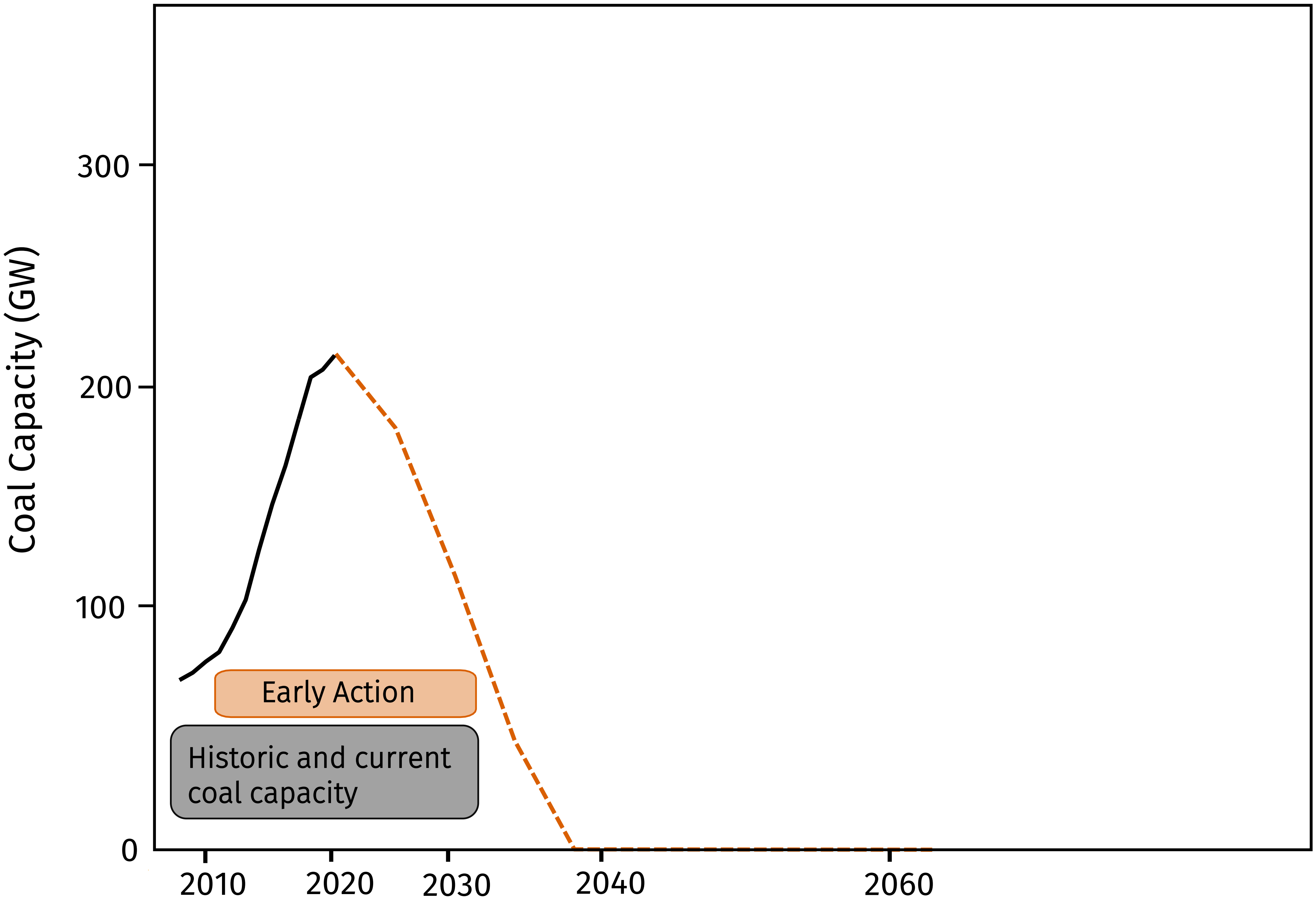




Malik et. al. (2020)



* Average stranding capacity over a time-period


Coal Capacity (GW)
300
200
100
0
2010
2020
2030
2040
2060
Historic and current
coal capacity


Coal Capacity (GW)
300
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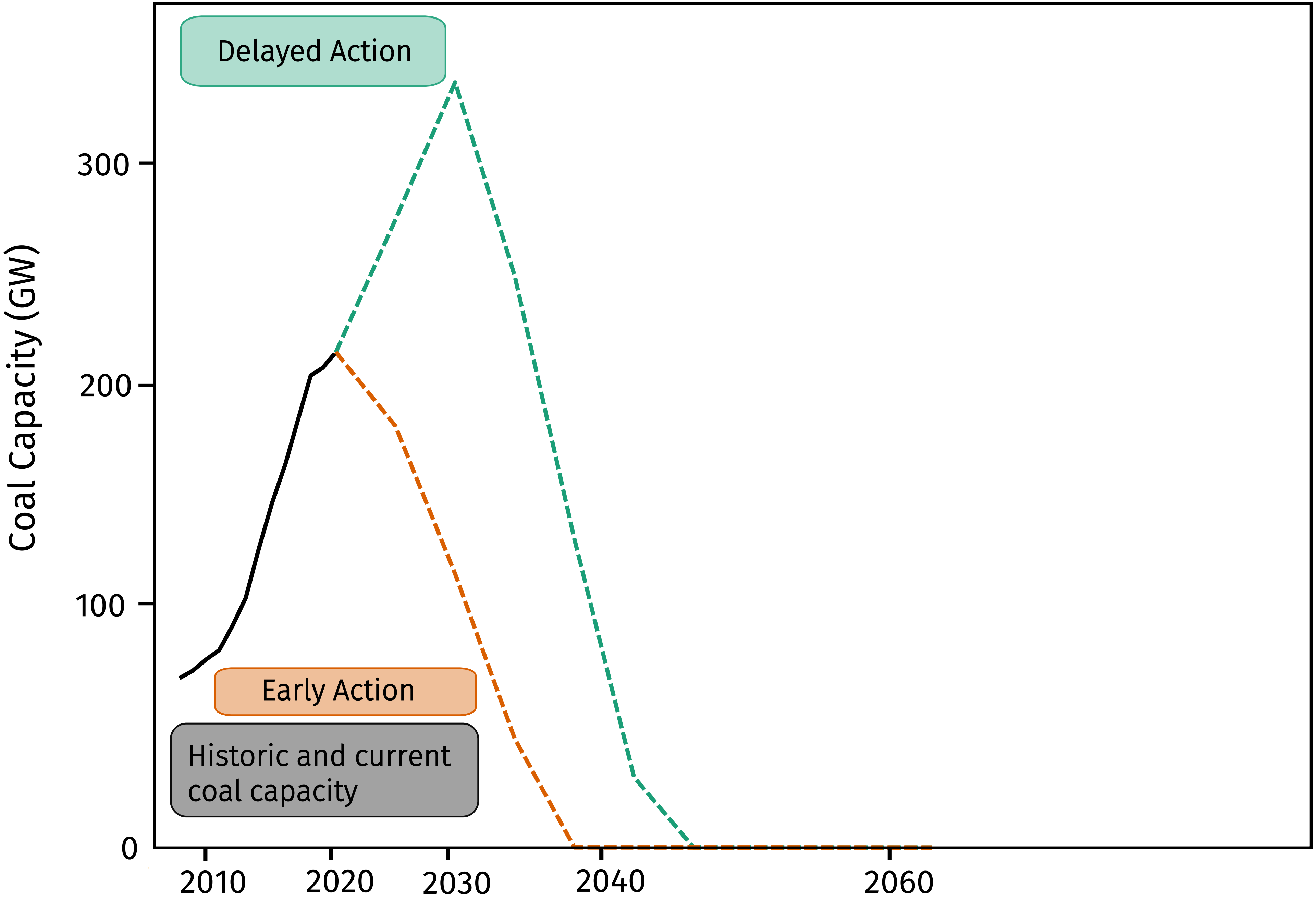
Early Action
Historic and current coal capacity


Delayed Action
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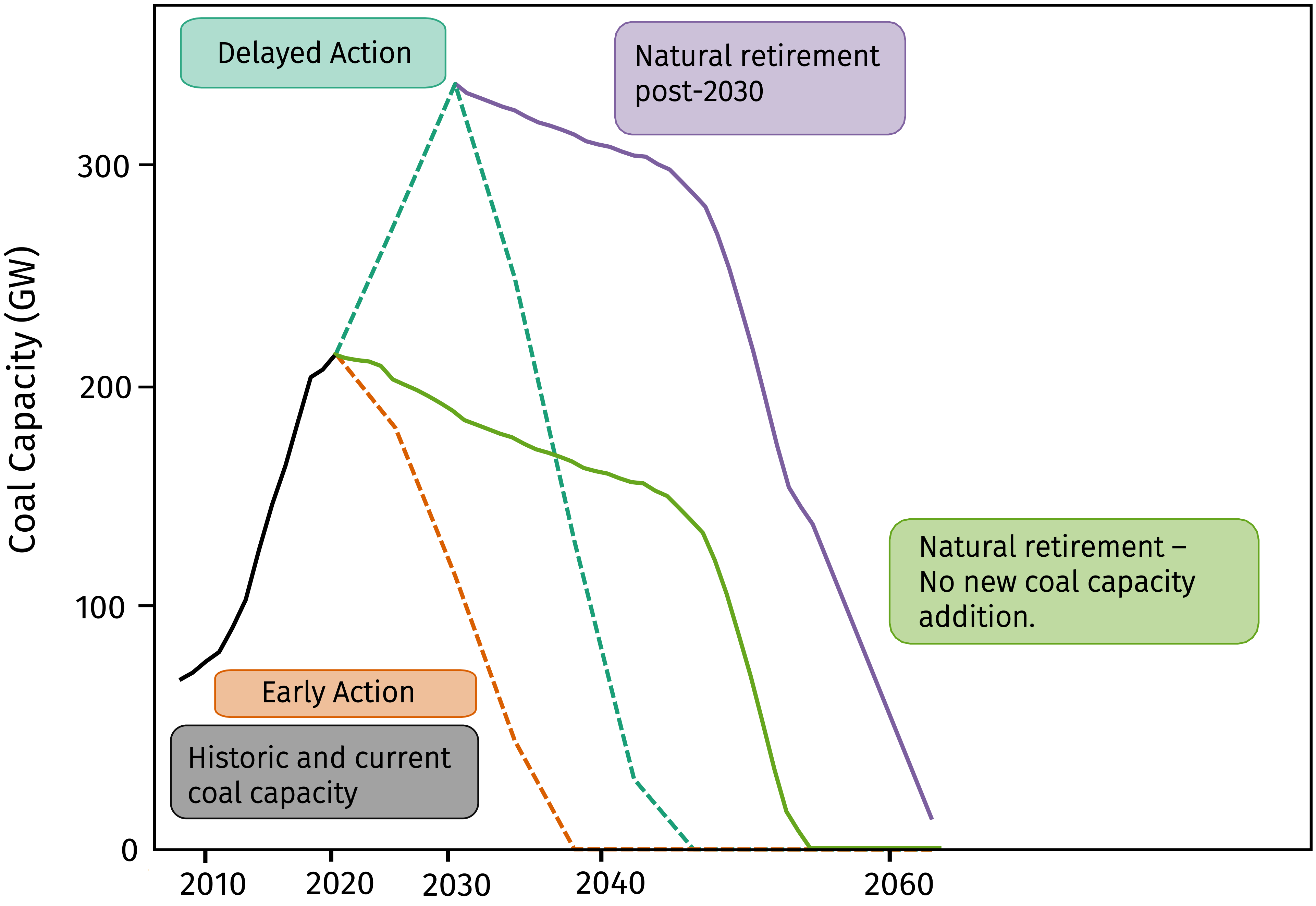
Delayed Action
Natural retirement post-2030
Natural retirement – No new coal capacity addition.
Early Action
Historic and current coal capacity
Coal Capacity (GW)
300
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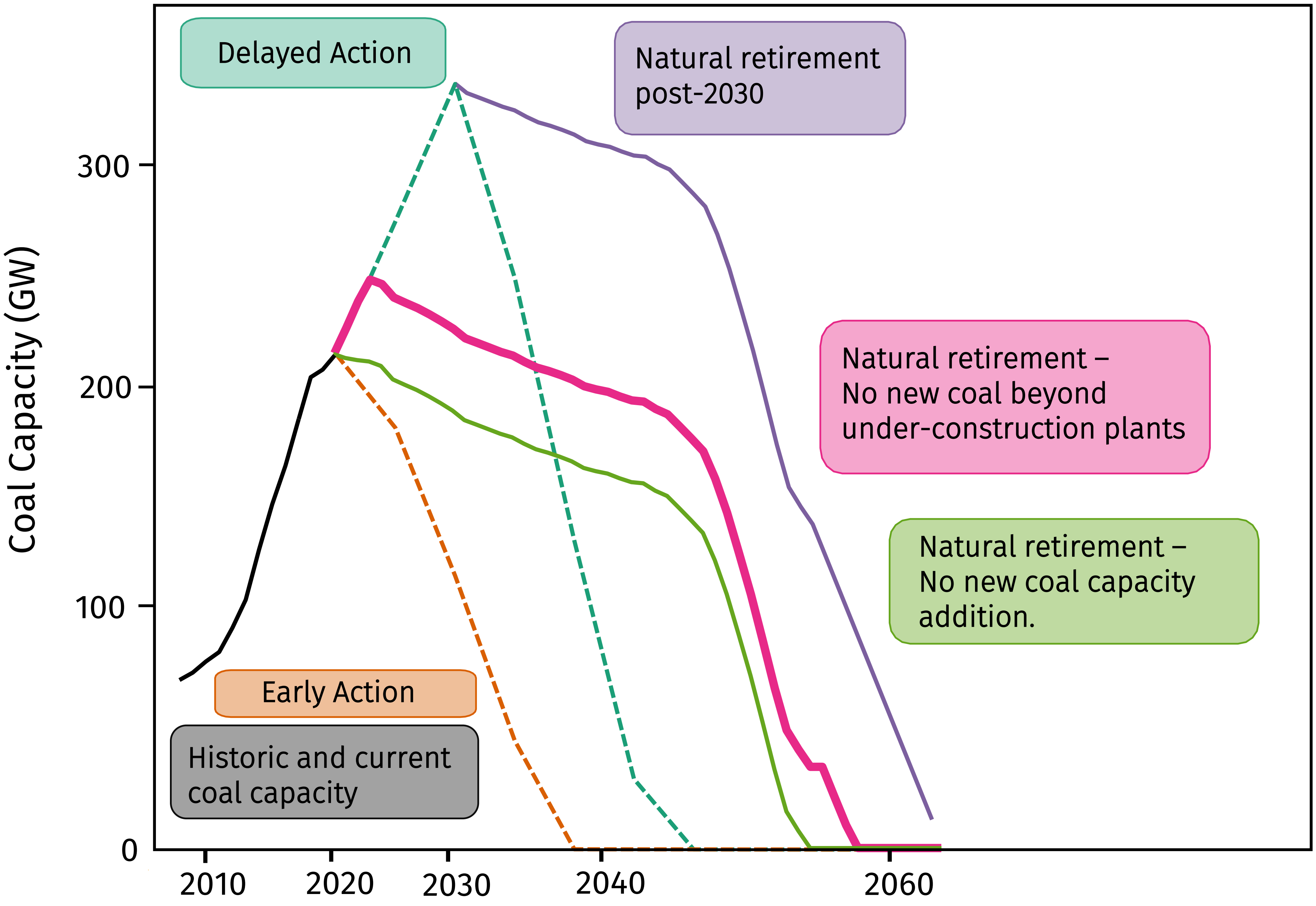
0
2010
2020
2030
2040
2060



Delayed Action
Natural retirement post-2030
Natural retirement – No new coal beyond under-construction plants
Natural retirement – No new coal capacity addition.
Early Action
Historic and current coal capacity
Coal Capacity (GW)
300
200
100
0
2010
2020
2030
2040
2060

# Conclusions

- Current policies lead to increase in both coal and low-carbon energy.
- The coal capacity, especially, from plants yet to be (fully) built is at risk of stranding from stringent mitigation.
- A coal moratorium could reduce the risk and be politically feasible.
- Power demand met through higher solar and wind targets.

# Chapter 3

# Chapter 3

## Barriers to power sector decarbonisation

### Techno-economics

- Relative cost of power generation
- Lifetime of infrastructure
- Land-use, resource, and technology diffusion constraints

### Governance and institutions

- Institutional capacity
- Existence of power markets
- Electricity pricing
- Regulation compliance

### Socio-economics and politics

- Political economy constraints
  - Vested interests
  - High energy consumers
  - Just transition
- Behavioural change

- Despite the “political attractiveness” of a coal moratorium, limited examples in the world.
- How could other “socio-economic and political” factors be integrated into modelling work?
- Literature includes list of “political feasibility” indicators.
- Employment dimension not included and not available from conventional energy-economy models.

## Barriers to power sector decarbonisation

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3

### Socio-economics and politics

- Political economy constraints
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  - High energy consumers
  - Just transition
- Behavioural change

**3 Climate policy accelerates structural changes in energy employment**

- How do different decarbonisation scenarios change the number and structure of energy jobs globally ?
- What impact could they have on the success of decarbonisation policies?

# Energy employment and energy transitions

- Energy sector employment ~1.2% of total global employment (3.3 billion vs. 40 million )
- Core energy sector jobs
  - directly linked to energy policy,
  - source of indirect job creation, and
  - important revenue for states.
- Just transition of energy – how to and in what form to compensate the losers of the transition

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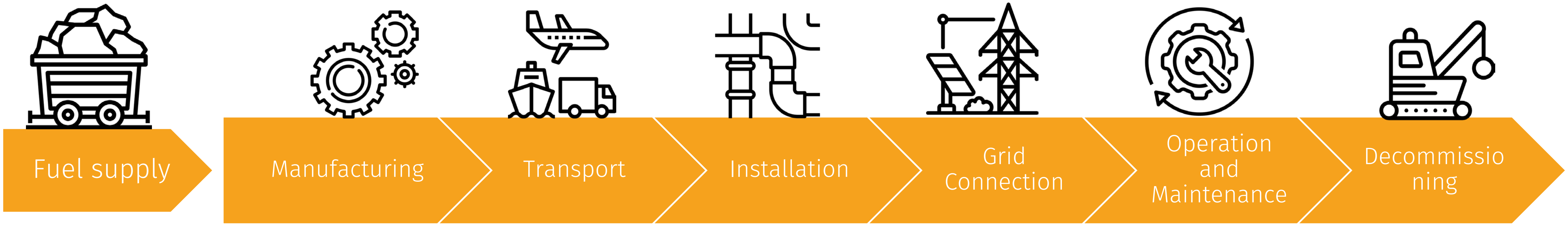
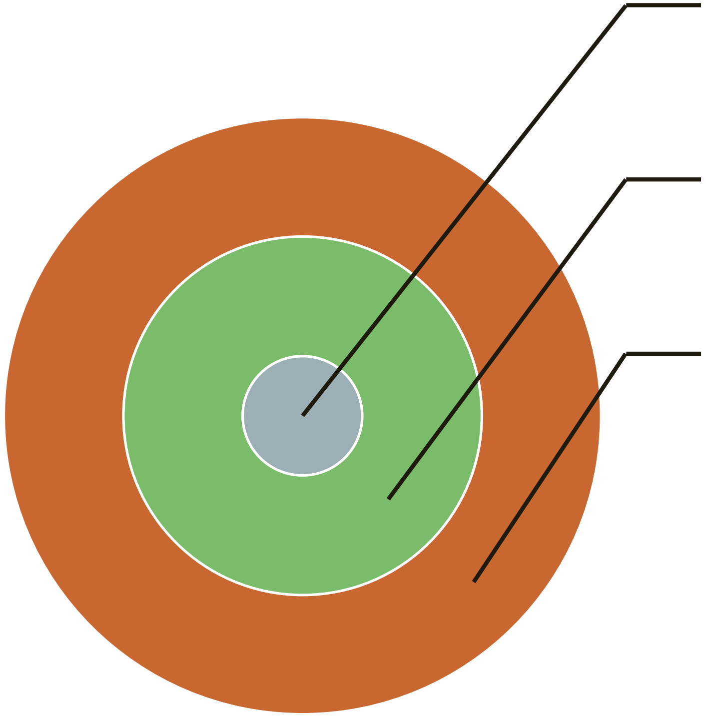
# Energy employment



**Direct Jobs:** Jobs related to core activities.

**Indirect Jobs:** Upstream jobs, e.g., Extraction and processing of raw materials.

**Induced Jobs:** Jobs arising from the economic activities of direct and indirect employees.

# Methodology (1/3) : Employment factor approach

JOBS $_{\text{energy supply}}$ = Manufacturing Jobs + Construction and Installation Jobs + O & M jobs + Fuel Supply Jobs



* FTE = Full-time equivalent

Based on Rutovitz et al. (2009, 2015)

# Methodology (1/3) : Employment factor approach

Construction and Installation Jobs = Added capacity (MW) X Employment factor (FTE/MW)

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# Methodology (1/3) : Employment factor approach

Manufacturing Jobs = Jobs with export component + Jobs without export component

Jobs with export component = World installed capacity (MW) X Employment factor (FTE/MW) X Share of world manufacture

Jobs without export component = Added capacity (MW) X Employment factor (FTE/MW)

Construction and Installation Jobs = Added capacity (MW) X Employment factor (FTE/MW)

O & M jobs = Existing capacity (MW) X Employment factor (FTE/MW)

Fuel Supply Jobs = Production (PJ) X Employment factor (FTE/PJ)

JOBS energy supply = Manufacturing Jobs + Construction and Installation Jobs + O & M jobs + Fuel Supply Jobs

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Based on Rutovitz et al. (2009, 2015)

# Methodology (2/3) : Employment factor model

**Input**

- Energy-related variables – capacity, fuel consumption etc.
- Employment factors

**Assumptions**

- Regional multiplier
- Evolution of employment factor
- Share of world export
- Share parameter for unrepresented technologies

**Employment factor model**

**Output**

Total full time employment for each region, technology, activity, and time-step.

**Only direct energy supply jobs!**

Malik et. al. (2021)

# Methodology (3/3)

- REMIND as energy-economy model
- Energy employment model (direct energy jobs only)
- Two scenarios: **NDC and 1.5°C**

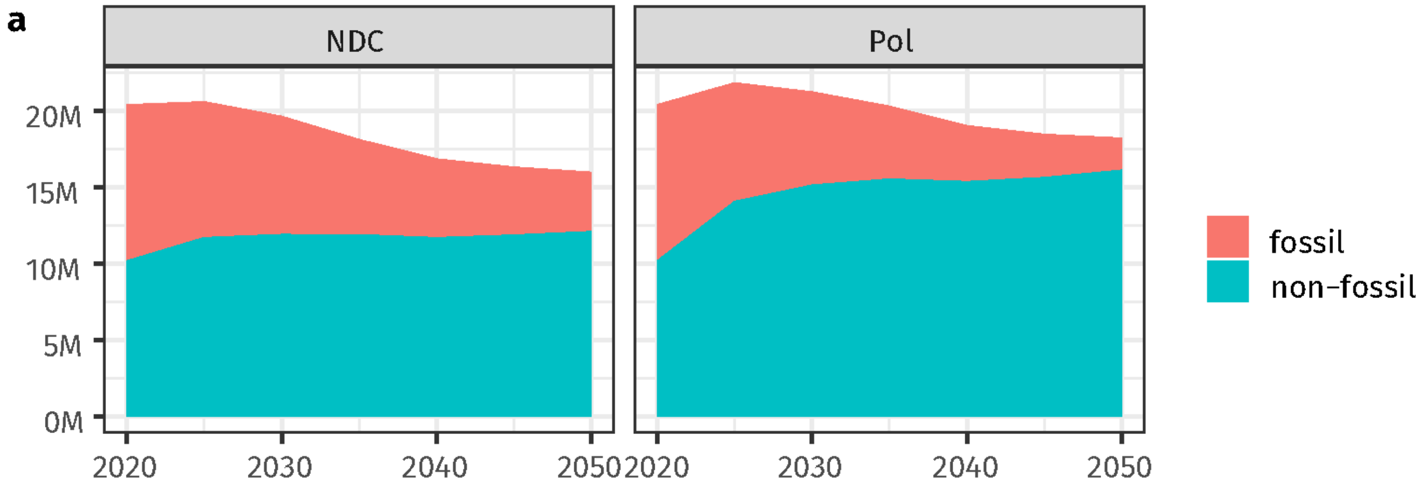
| Scenario name | Scenario description |
|---|---|
| NDC | Reaching NDC targets in 2030 via iteratively adjusted carbon prices, assuming gradual convergence at average prices thereafter. |
| 1.5°C/"Pol" | Constraint in carbon budget (900 $GtCO_2$) from 2011-peak of $CO_2$ emissions; ~ 66% chance below 1.5°C end of century |



Malik et. al. (2021)

# Results (1/2)

- Peak in 2025; global energy jobs decrease compared to today (20 mi), however, jobs still higher in a 1.5°C vs. NDC scenario (18 mi vs. 16 mi). **(a)**
- Job additions mainly from solar and wind **(b)**
- Operation and maintenance jobs dominate future energy supply jobs (~30%), replacing fuel supply jobs now (~50%)






Malik et. al. (2021)

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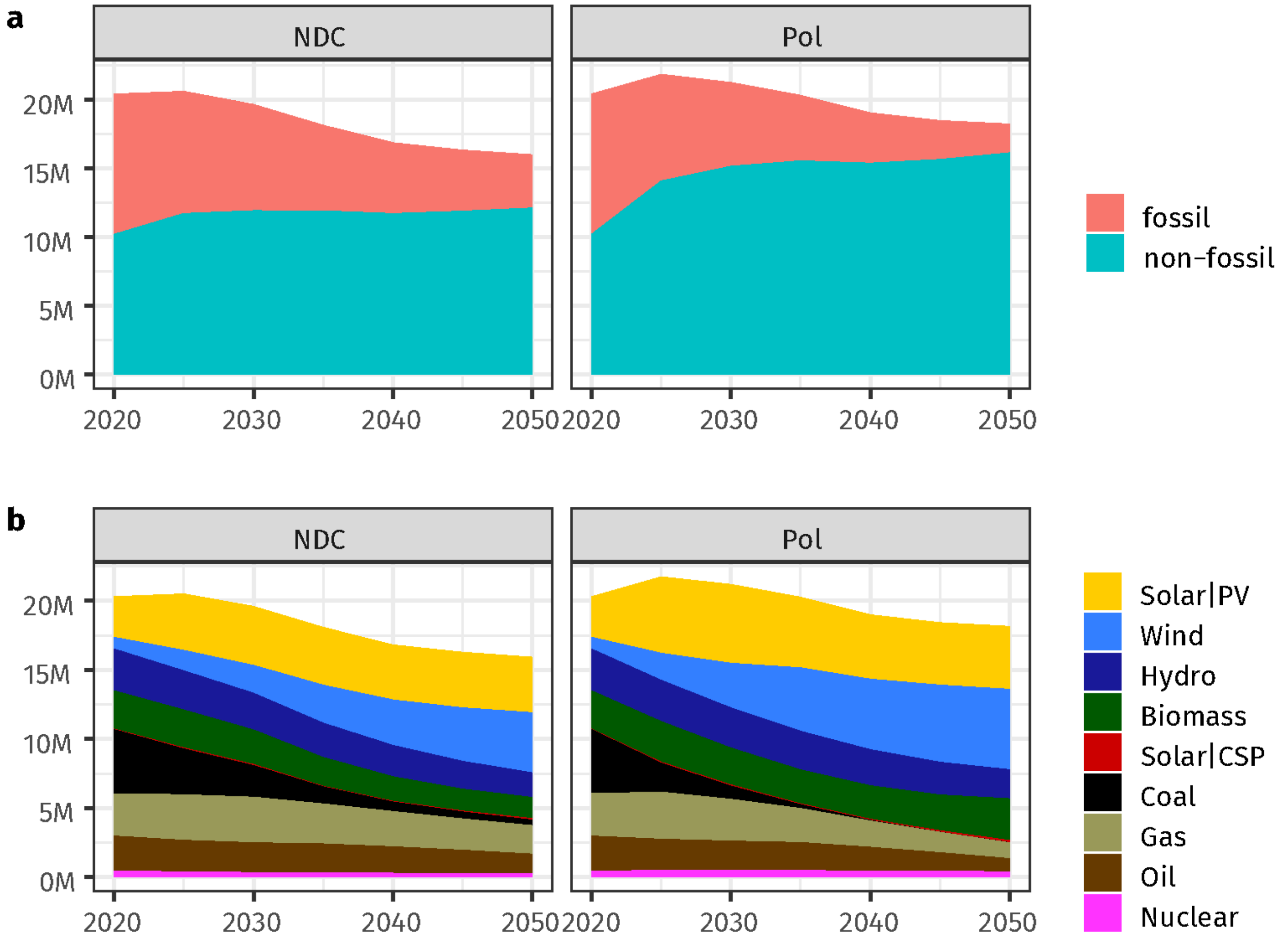


Malik et. al. (2021)

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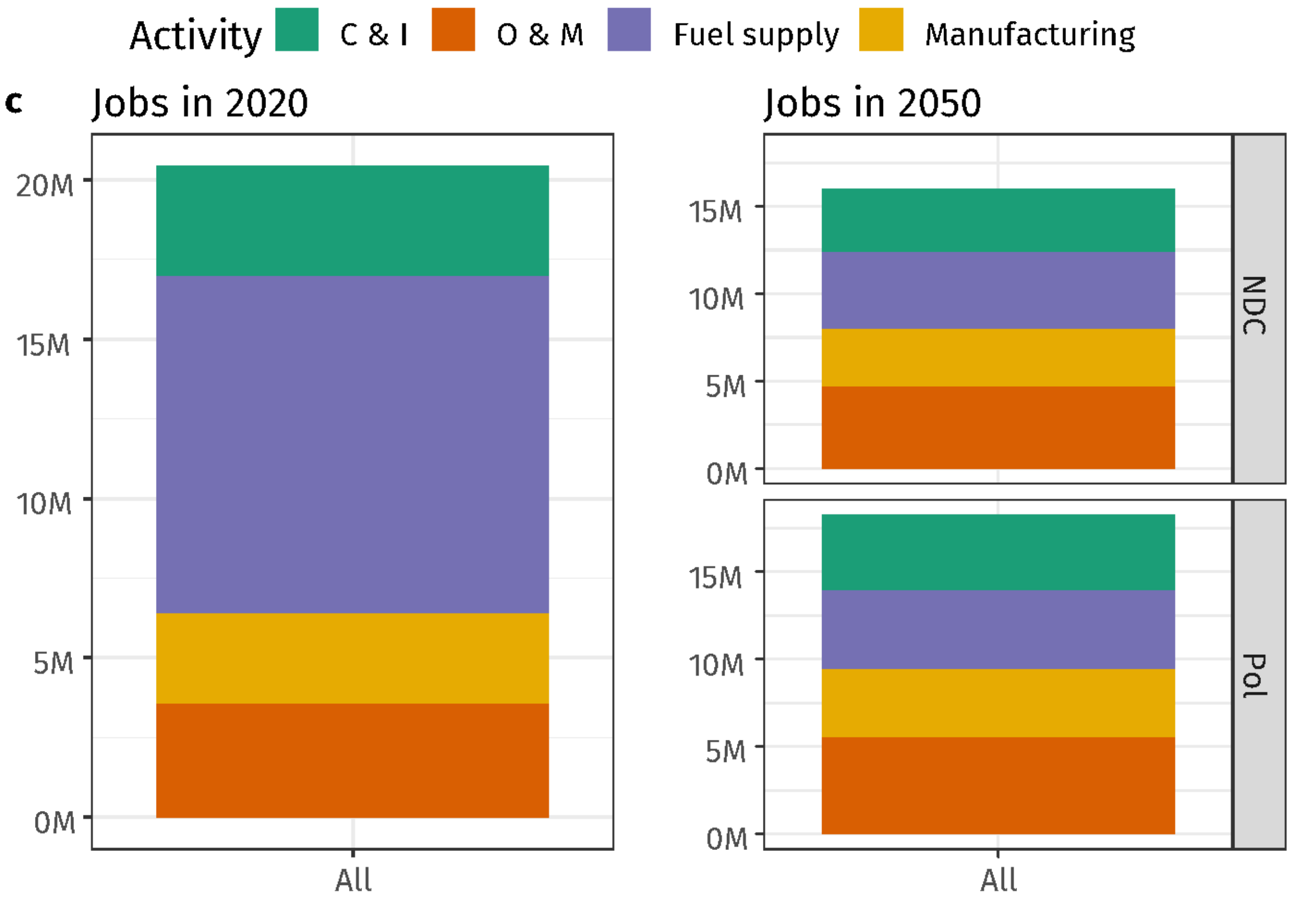
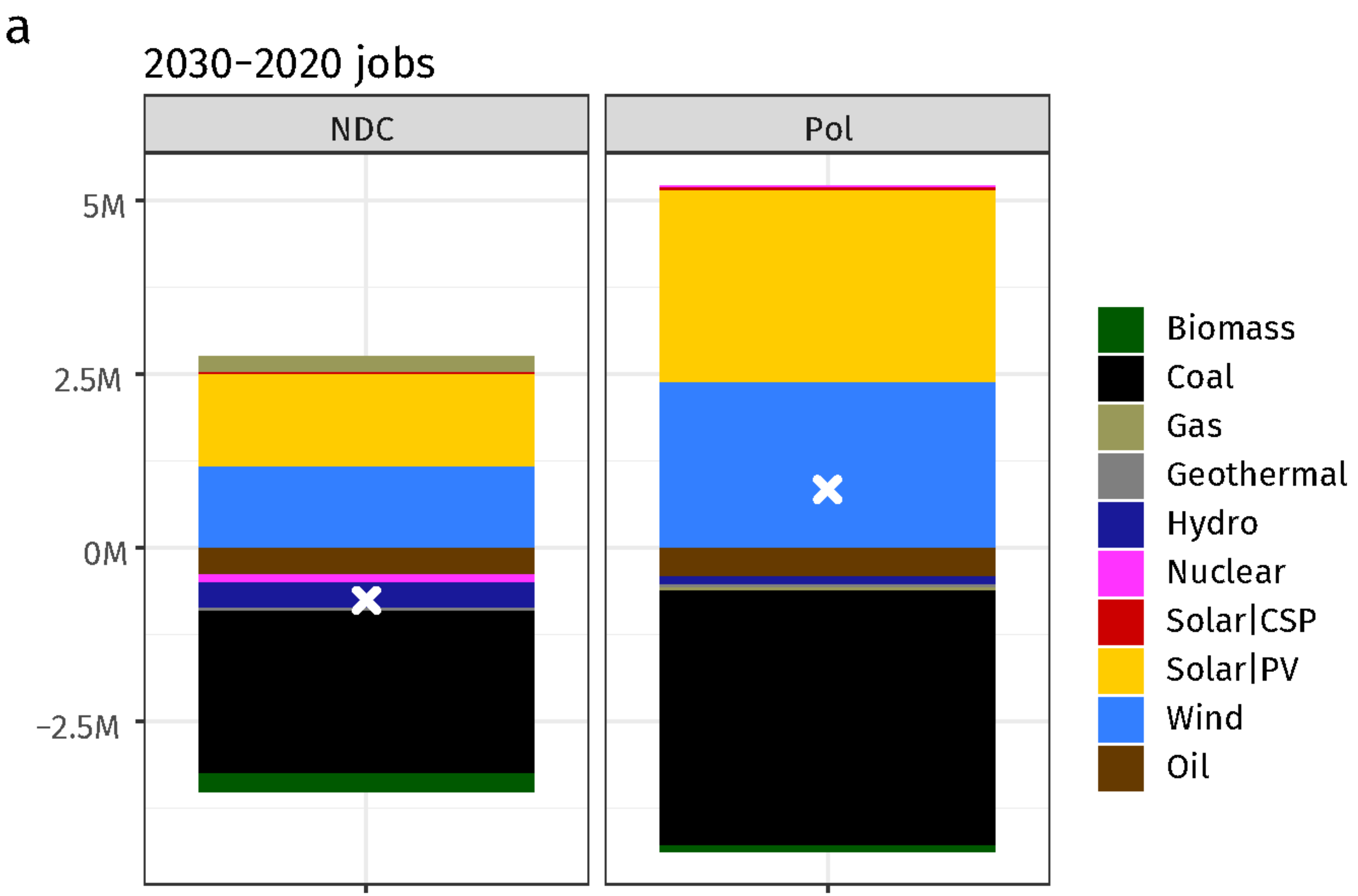



Malik et. al. (2021)

# Results (2/2)

- Stringent mitigation leads to a net increase (850K) in jobs.
- Gained through solar and wind jobs in construction, installation, and manufacturing.
- Stringent mitigation leads to additional ~600K job loss in coal mining.

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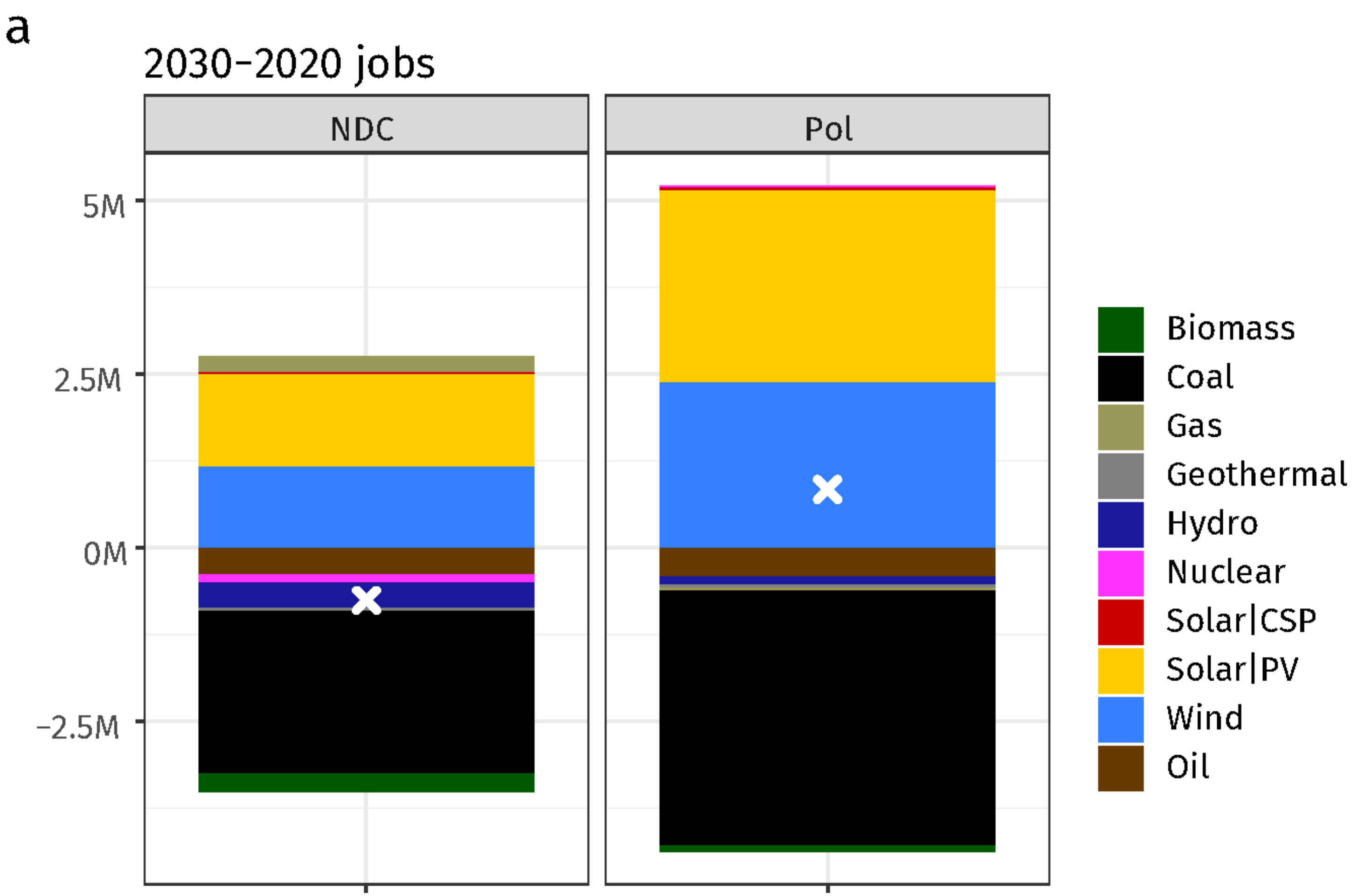


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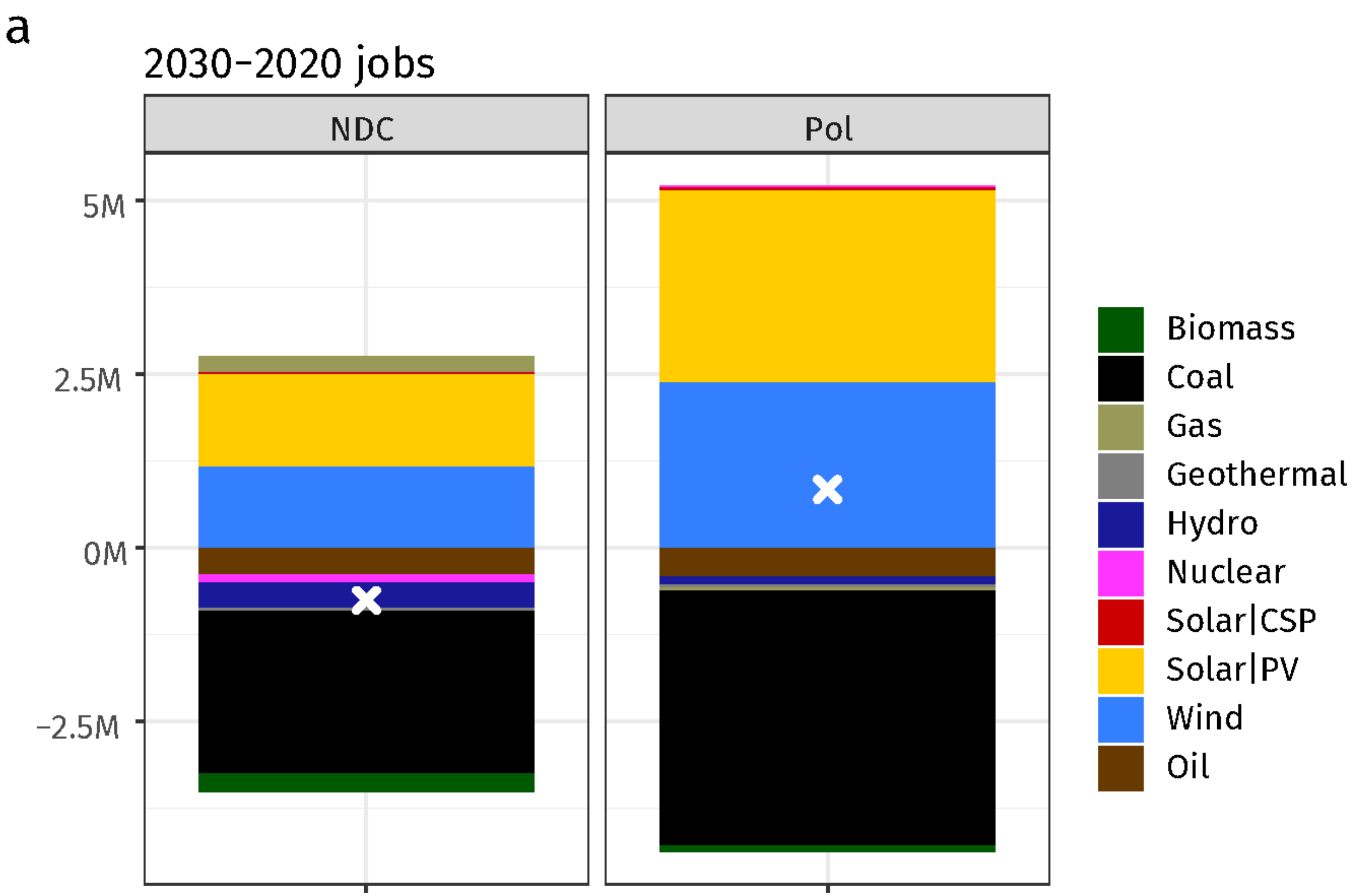


Malik et. al. (2021)

# Conclusions

- Energy jobs move from resource-extraction (in specific areas) to local jobs in O & M and C & I, although manufacturing jobs “up for grabs”.
- Significant additional losses in coal mining; -----> political constraints in decarbonisation
- Policies aimed at retraining of coal workers under “just transition”

# Chapter 4

## Barriers to power sector decarbonisation

### Techno-economics

- Relative cost of power generation
- Lifetime of infrastructure
- Land-use, resource, and technology diffusion constraints

### Governance and institutions

- Institutional capacity
- Existence of power markets
- Electricity pricing
- Regulation compliance

### Socio-economics and politics

- Political economy constraints
    - Vested interests
    - High energy consumers
    - Just transition
- Behavioural change

What are political energy transition challenges at sub-regional level in India?

# Chapter 4

**Barriers to power sector decarbonisation**

### Techno-economics

- Relative cost of power generation
- Lifetime of infrastructure
- Land-use, resource, and technology diffusion constraints

### Governance and institutions

- Institutional capacity
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### Socio-economics and politics

- Political economy constraints
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- Behavioural change

4

4 Early just transition opportunities for coal-bearing states in India.

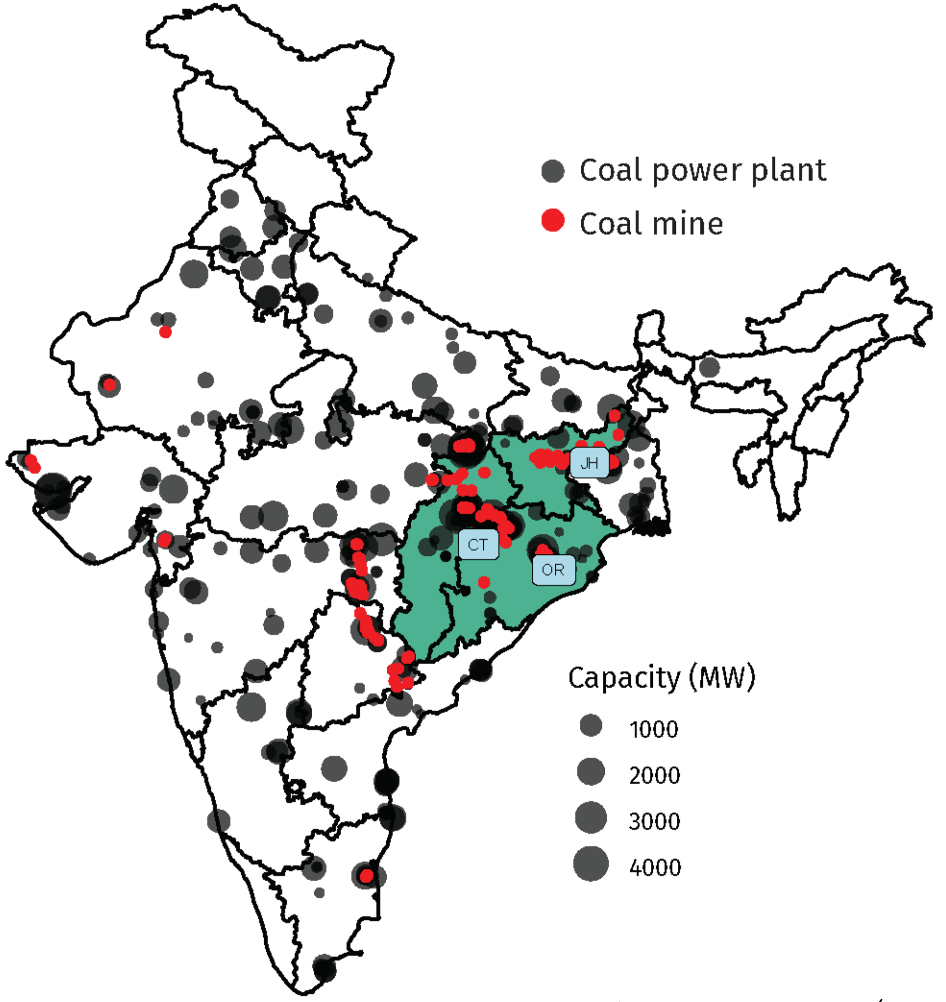
1. How do current energy policies and planned decarbonisation policies impact the distribution of energy assets and energy jobs across the country?

2. How could this distribution affect the pace of decarbonisation viz. the concept of just transition?

# Coal Mining in India

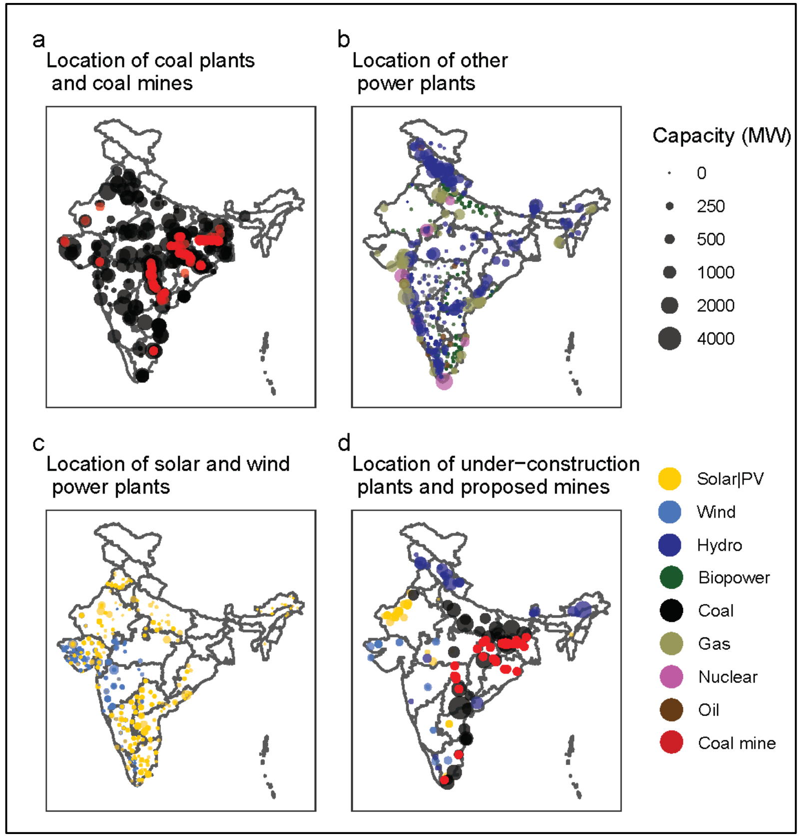
Operating coal mines ~ 730 MT
Coal power plants ~ ~ 228 GW

- Important source of energy sufficiency
- Coal mines concentrated in a few states
- Mining largely government owned; recently “liberalised”
- Mining - source of regional development and employment
  - Directly employs ~ 400K people.
  - Contribute ~9% of state GDP for some states
  - Cross-subsidisation of rail freight and passenger transport

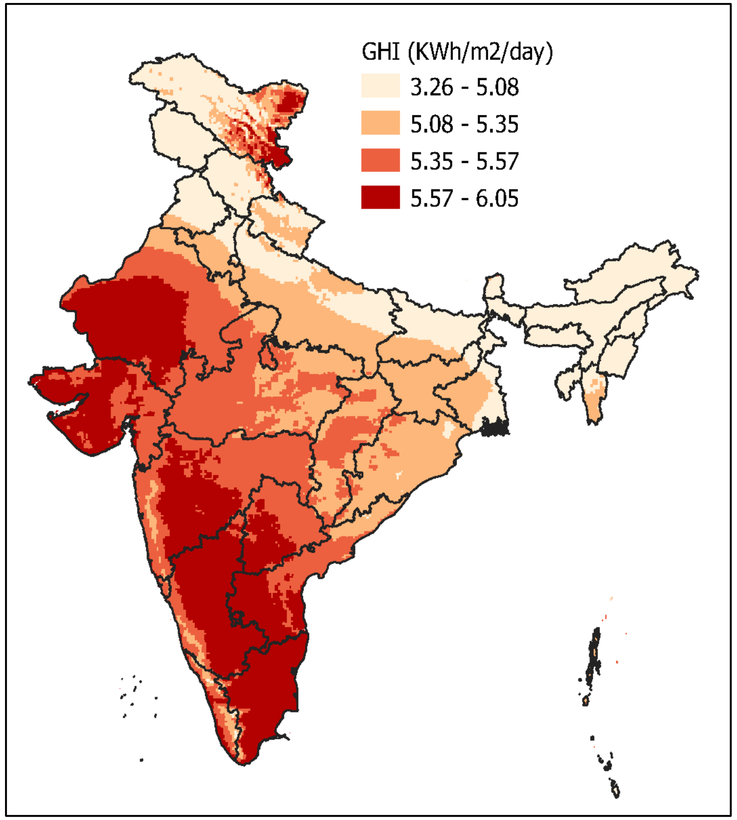



Malik and Bertram (2022)

# Methodology




Operating, under-construction, power plants and coal mines




Resource potentials of solar and wind

REMIND (NDC and 1.5°C scenarios)

↓

Employment model



Malik and Bertram (2022)

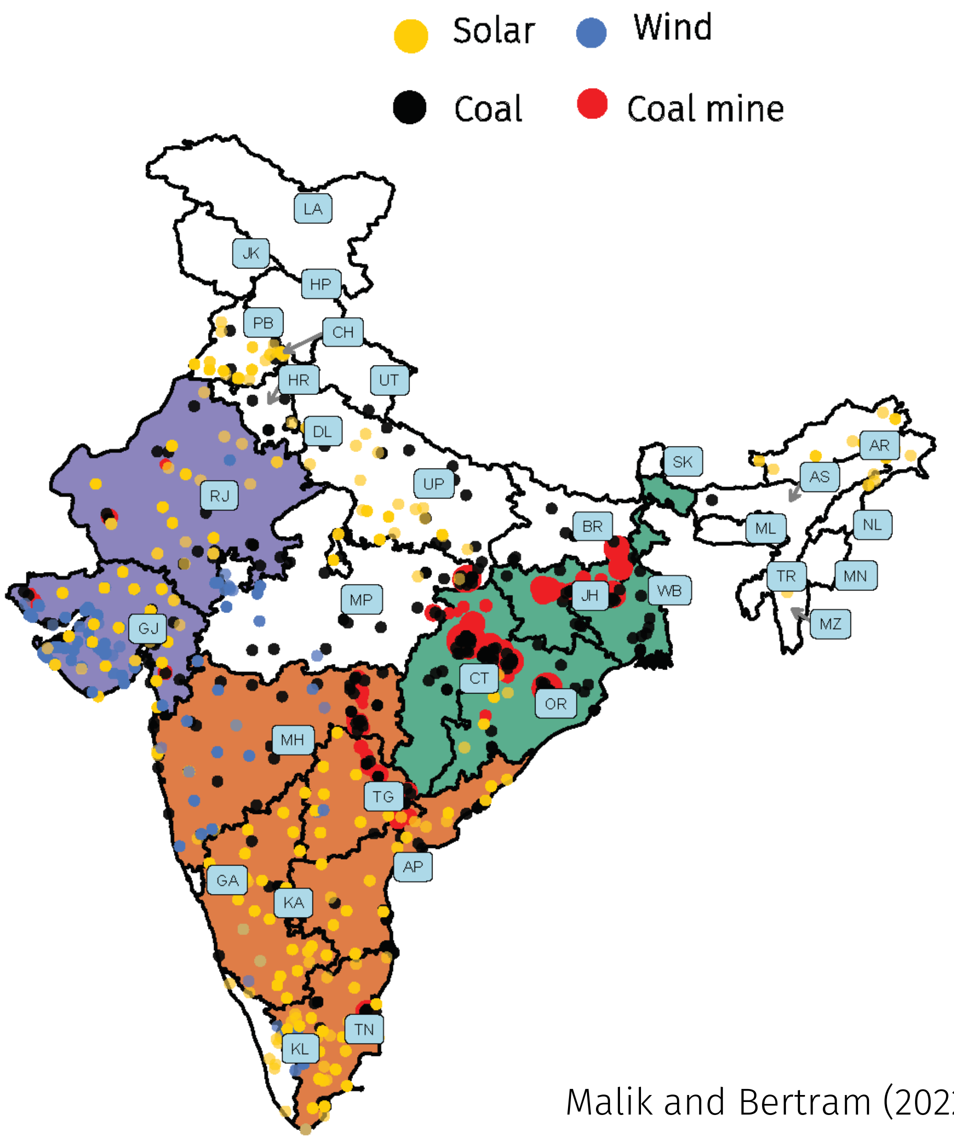
# Results

- Solar and wind potential concentrated in western and southern states
- Installed and under-construction projects largely follow potentials
  - Higher resource quality
  - Suitable areas
  - Failure of rooftop policy
- Without additional distribution policies, RE installations follow current patterns. Why?
  - Potentials >> Projected all-India installation under deep decarbonisation.
  - Demand centres in west and south

Western states

Southern states

Eastern states




Malik and Bertram (2022)

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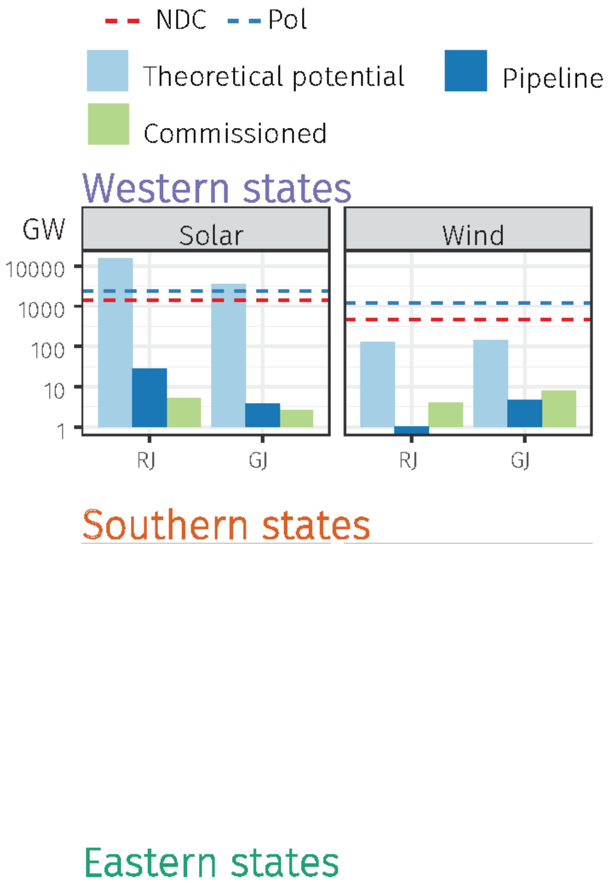


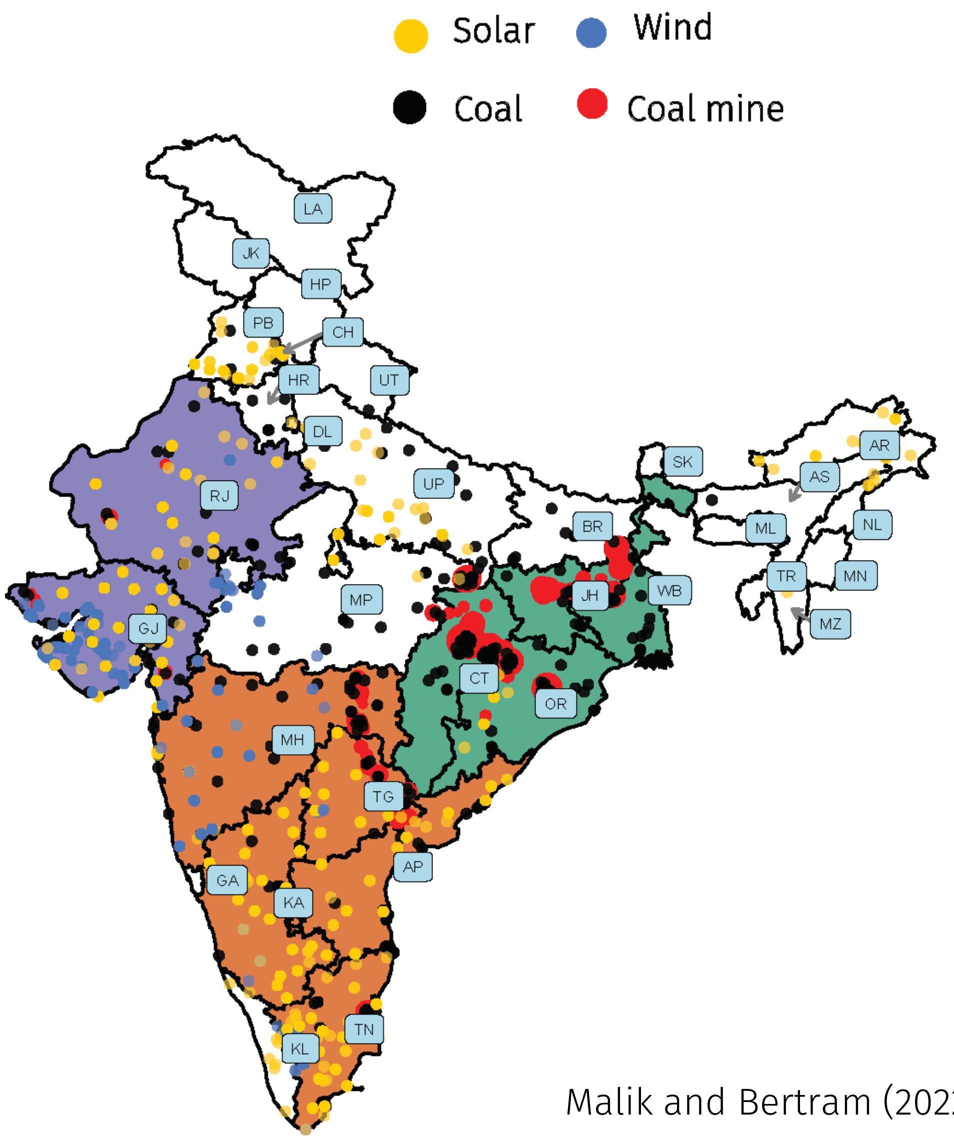


Malik and Bertram (2022)

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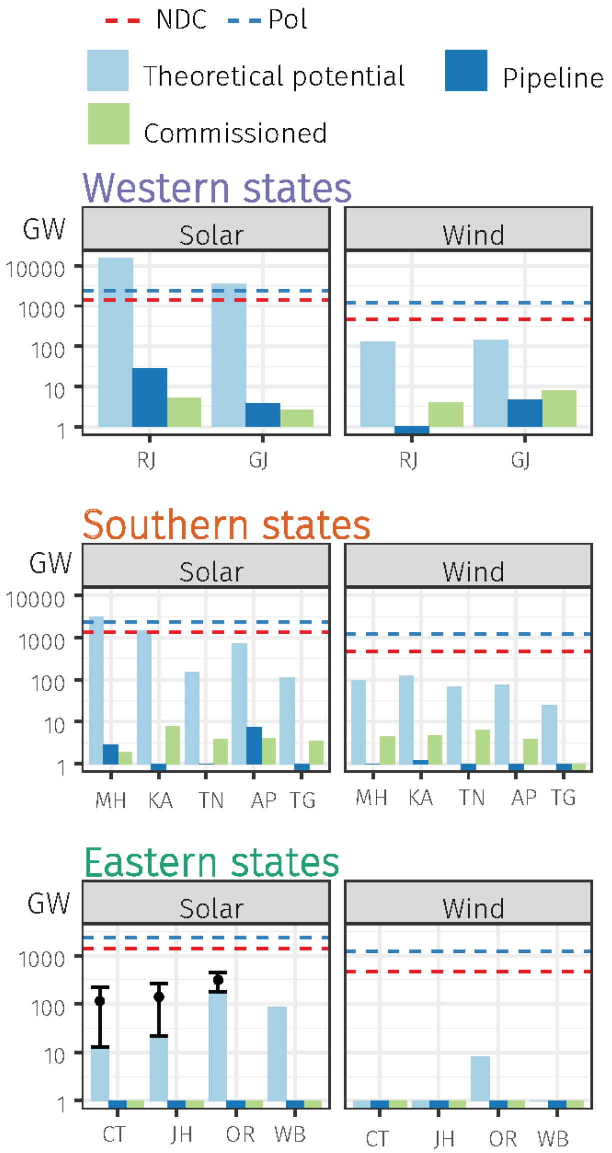


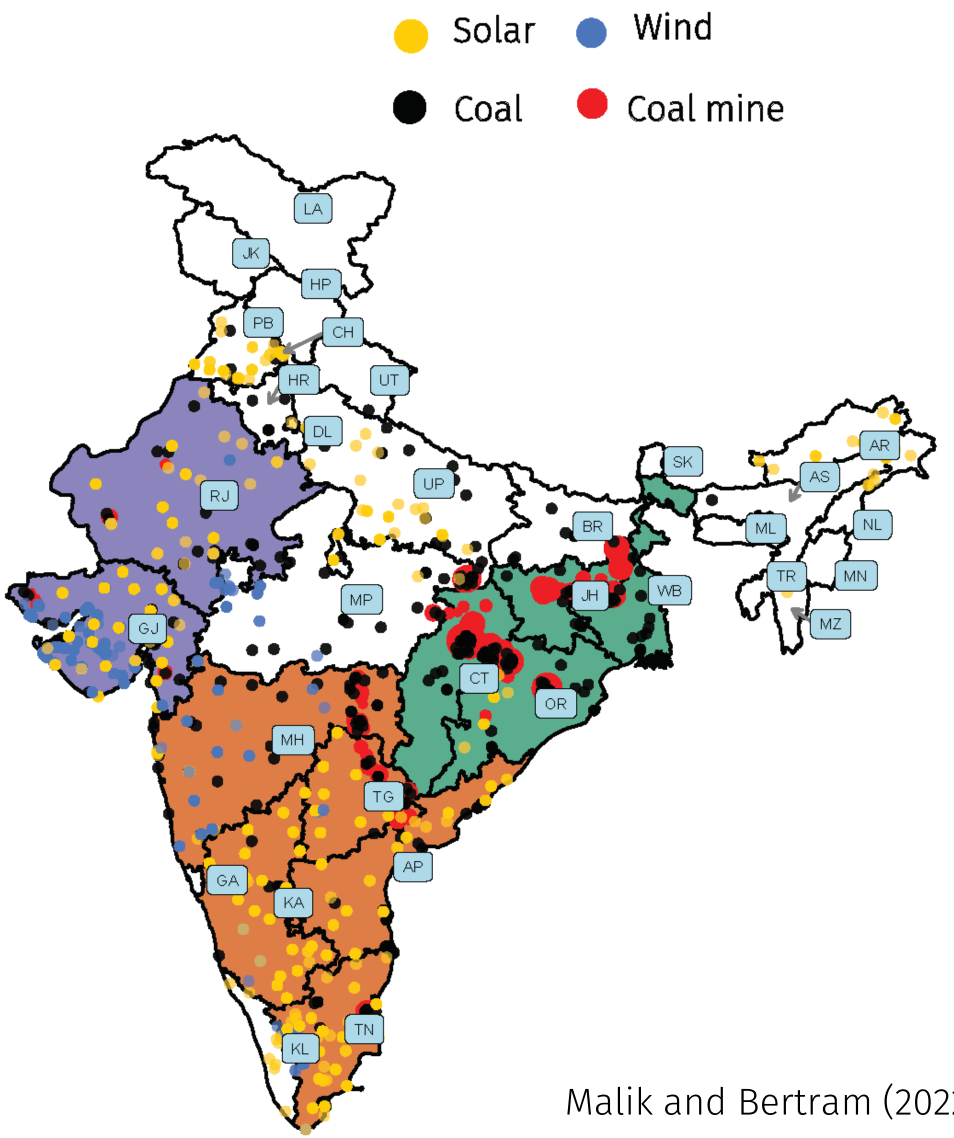


Malik and Bertram (2022)

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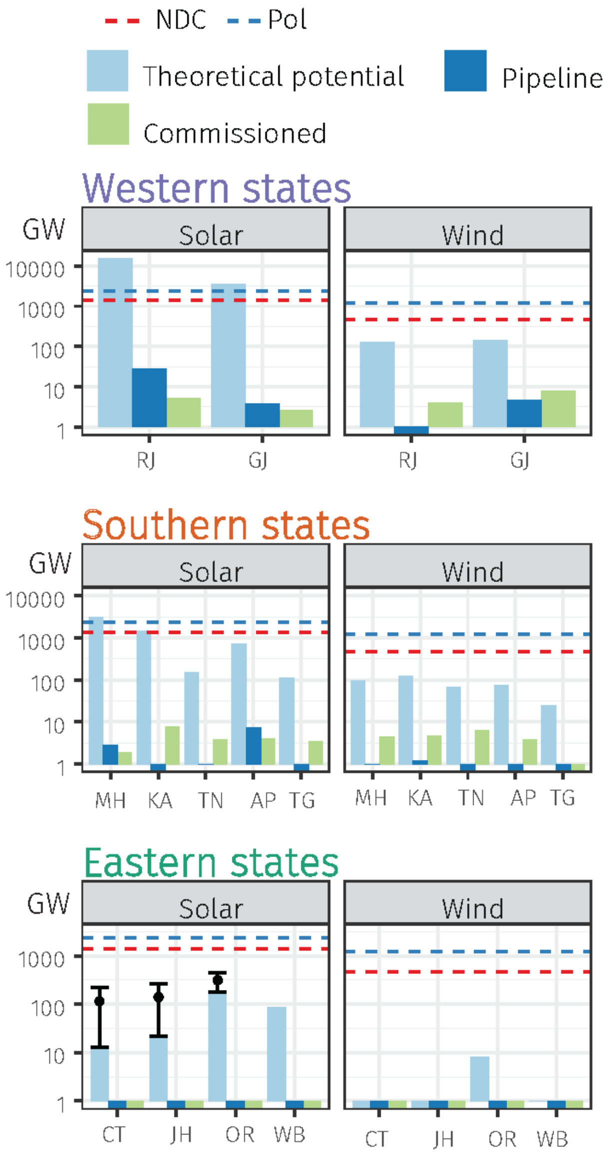


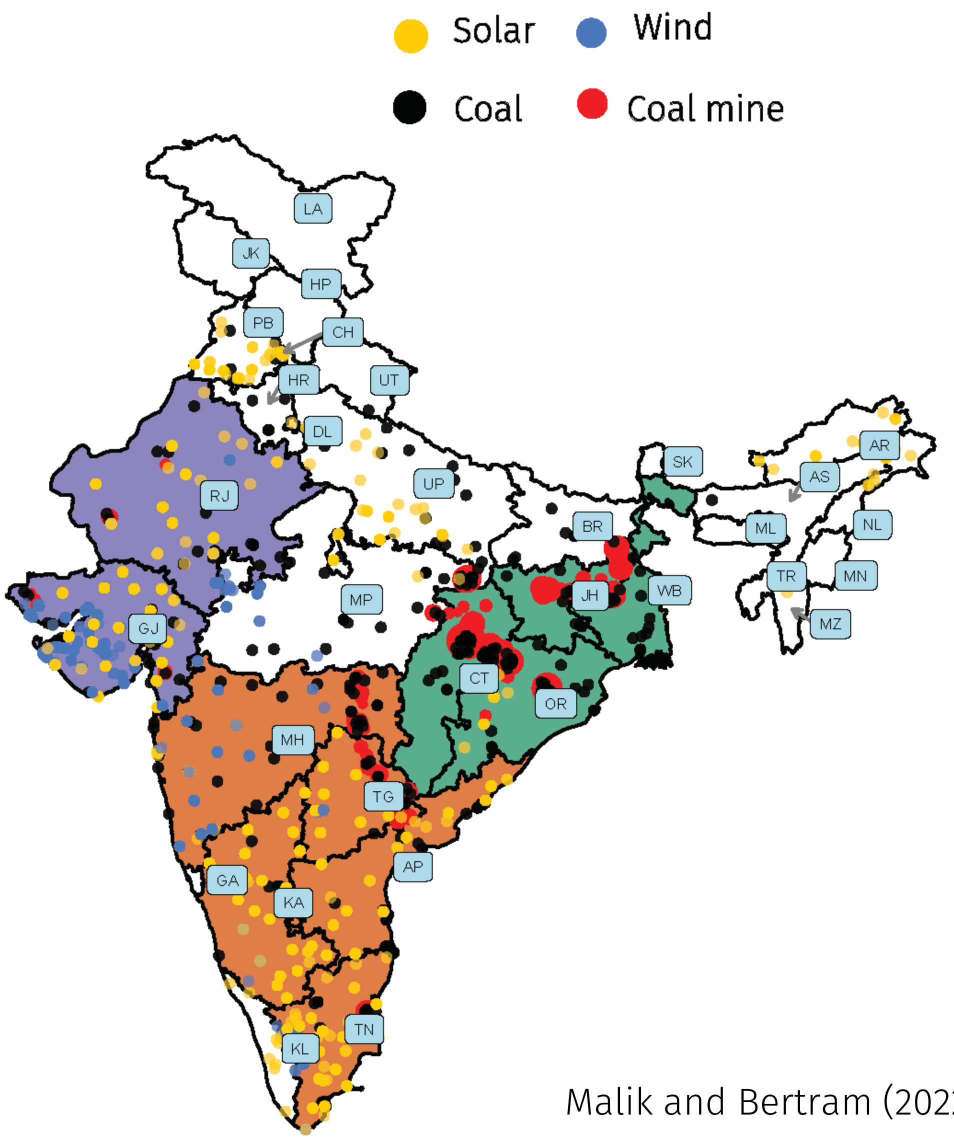


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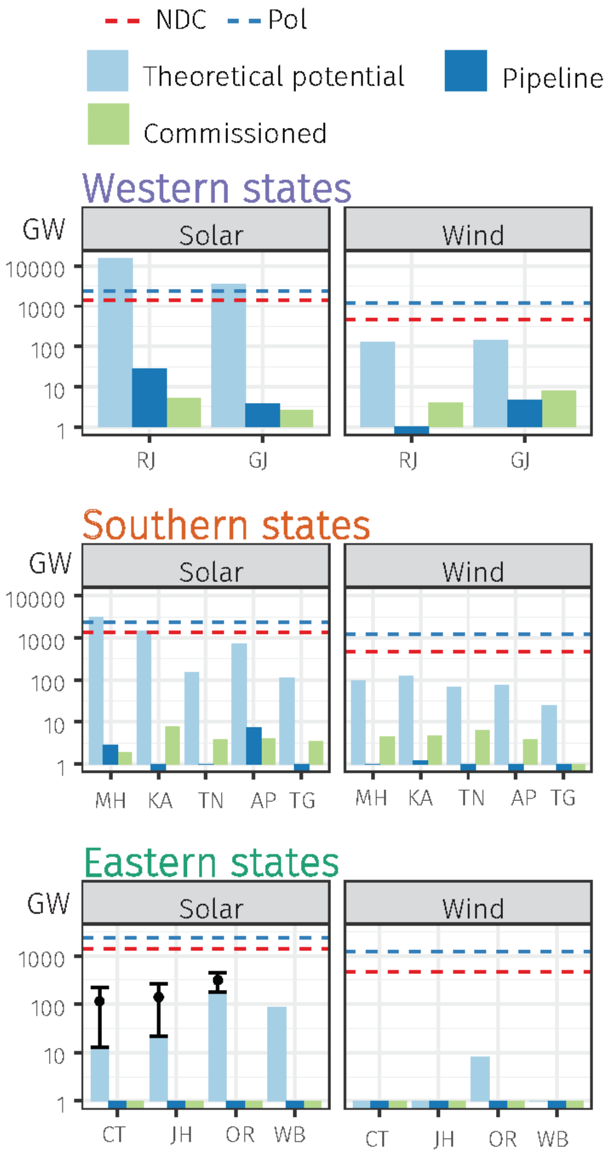
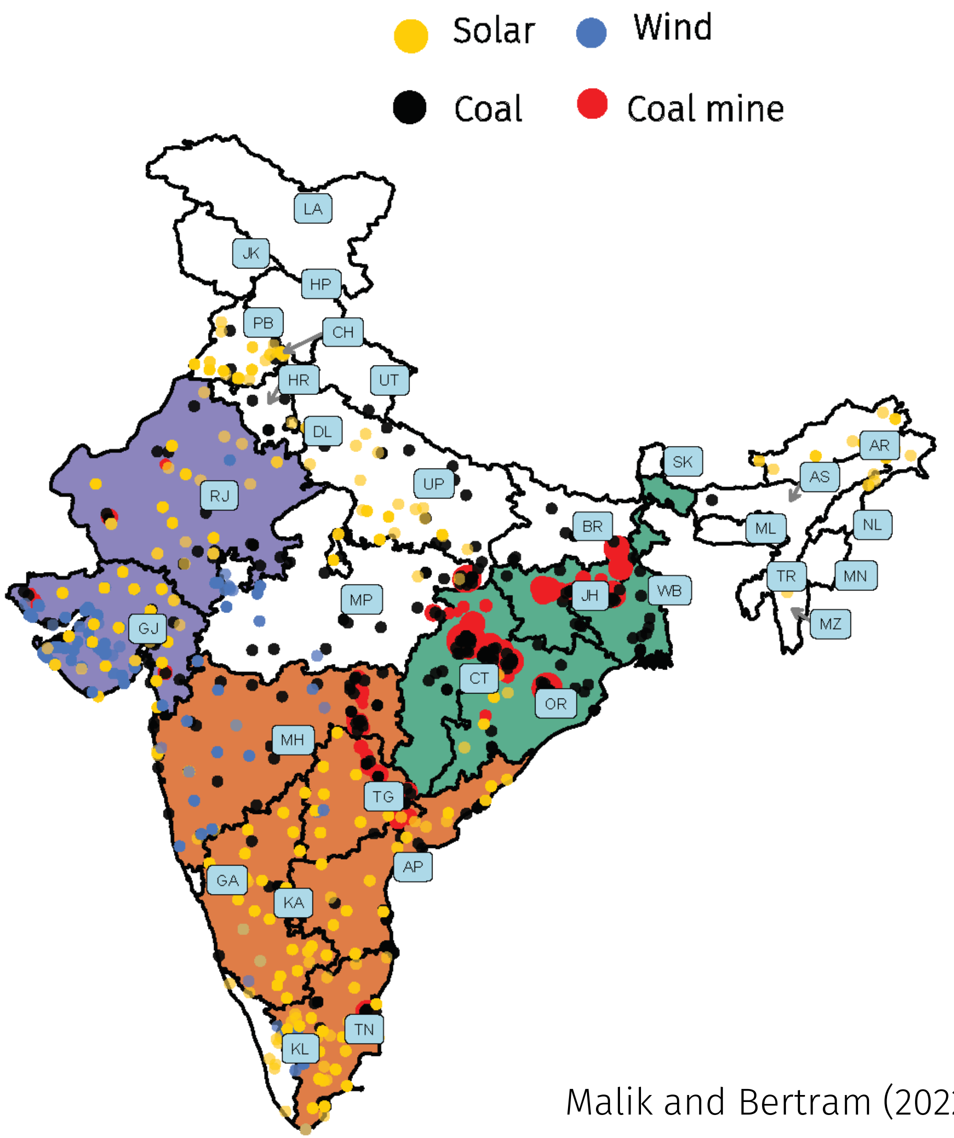
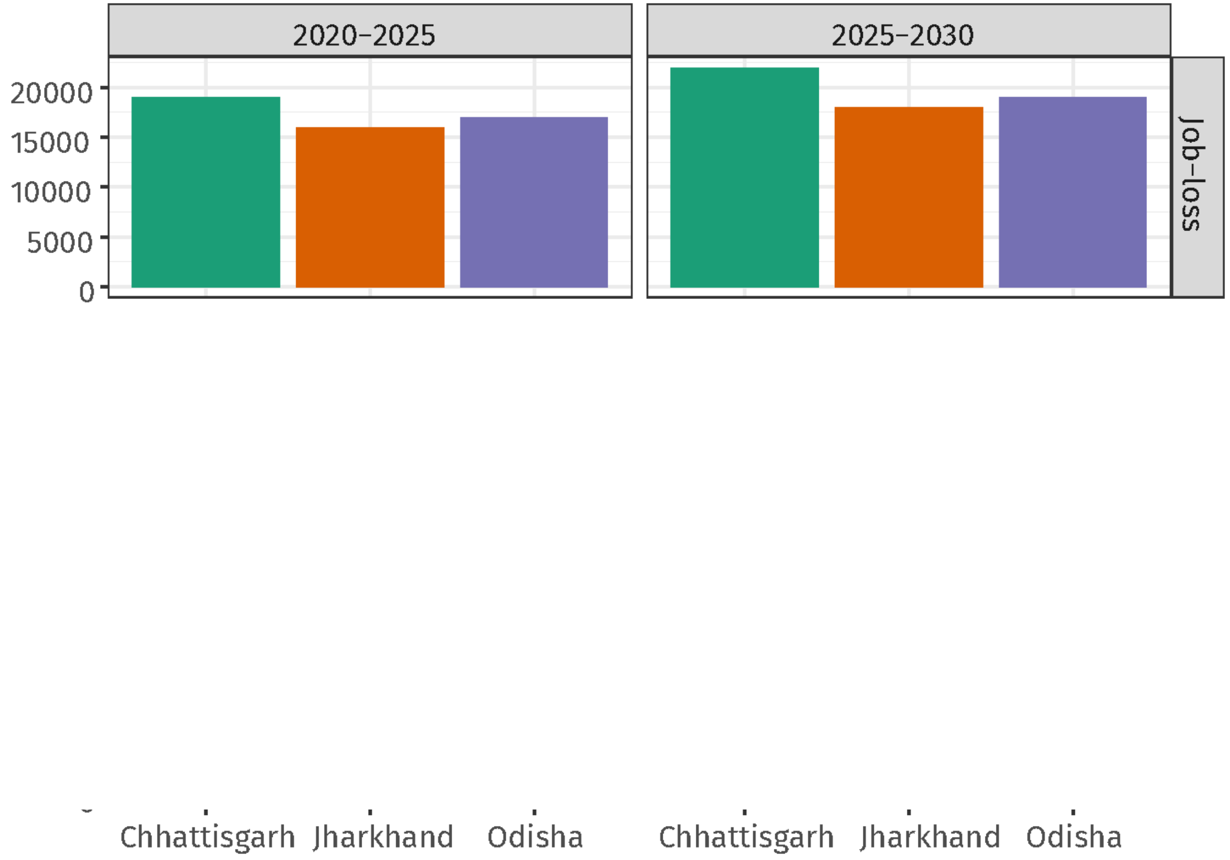



Malik and Bertram (2022)

# Results: role of solar (1/2)

How much solar capacity is needed to substitute coal jobs?




Job-losses in 1.5°C scenario

# Results: role of solar (1/2)

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*Conservative:* Only Solar-utility O & M jobs replace coal mining jobs

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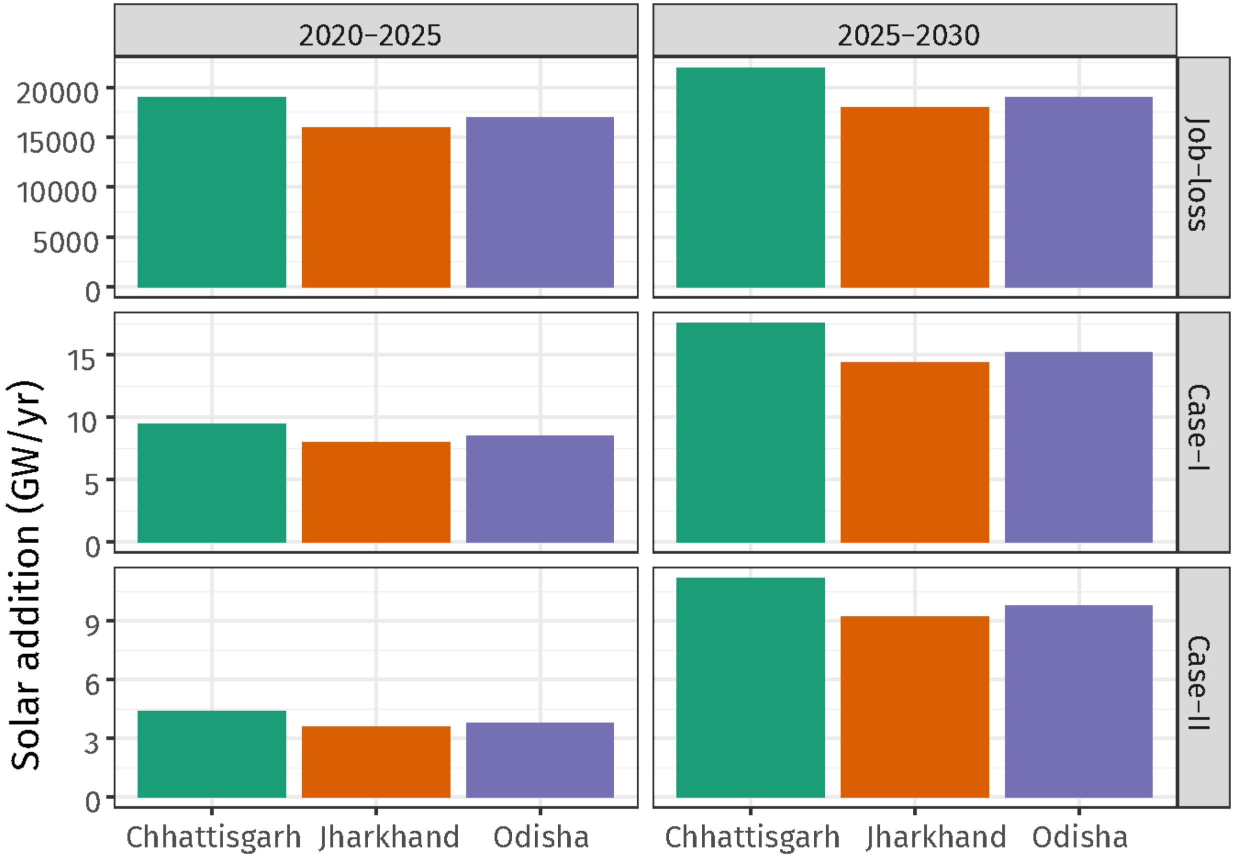



Job-losses in 1.5°C scenario

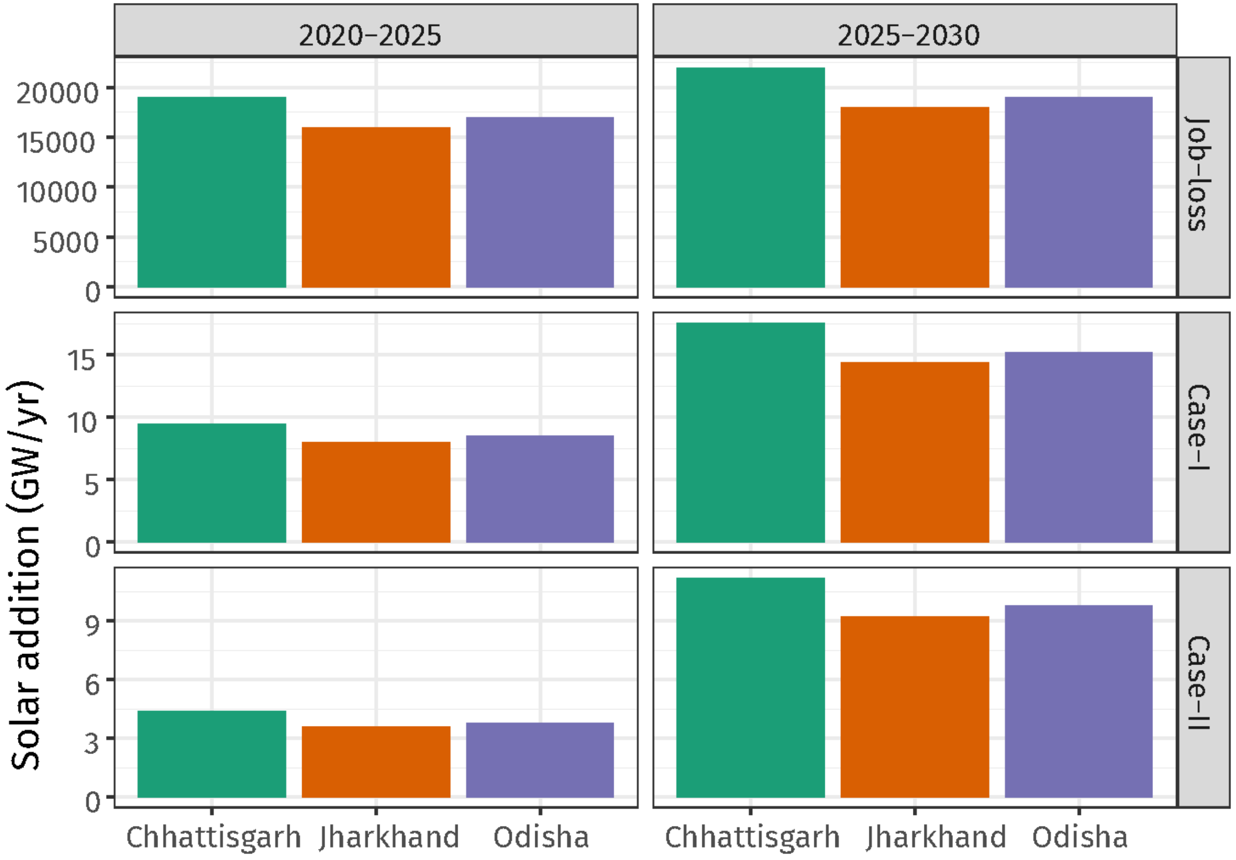
*Conservative:* Only Solar-utility O & M jobs replace coal mining jobs

*Optimistic:* Solar-rooftop (20%) + C & I + O & M jobs replace coal mining jobs

# Results: role of solar (1/2)

## How much solar capacity is needed to substitute coal jobs?

- Solar additions are much lower  for the optimistic case.
- However, advantage erodes with time.

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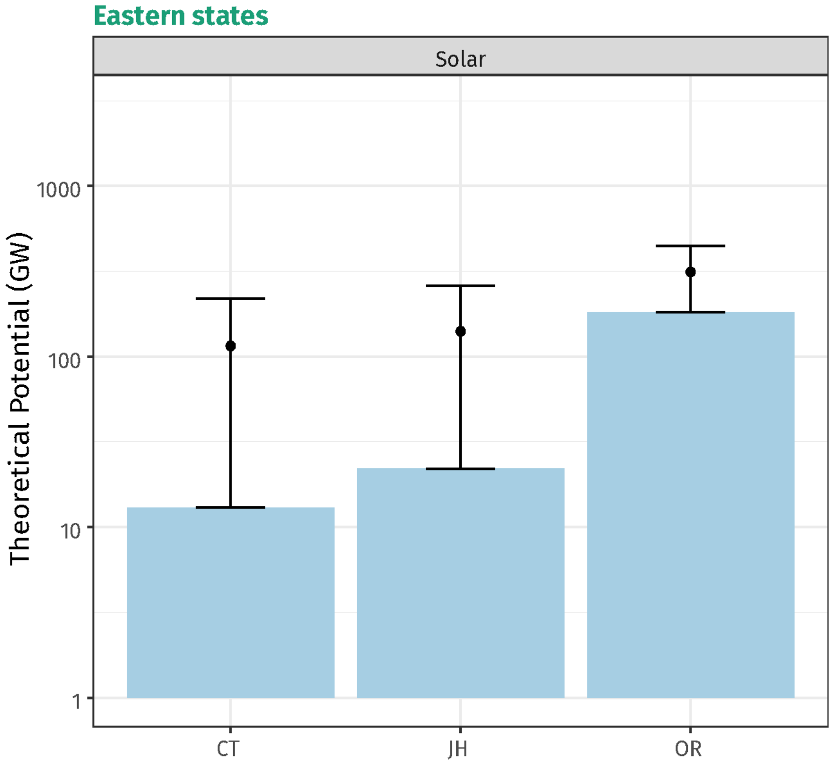
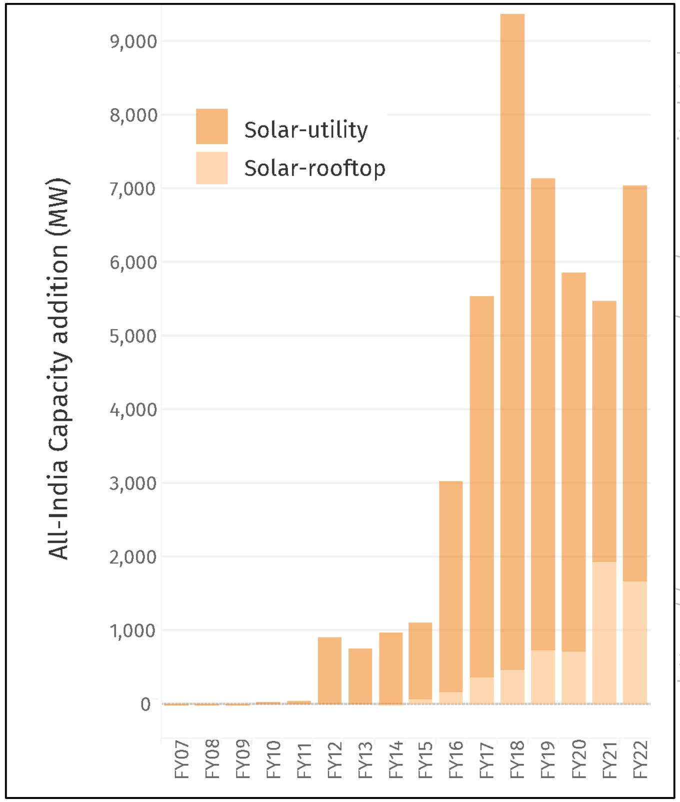
# Results: role of solar (1/2)

## Limitations from annual additions and resource potential

- Theoretical potential ~ 10 – 100 GW
- Annual All- India capacity addition ~ 10 GW (max.)



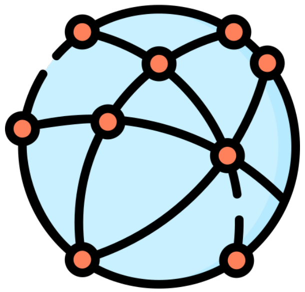




https://www.prayaspune.org/peg/re-capacity.html

- Early addition of solar energy could compensate some job losses in coal mining

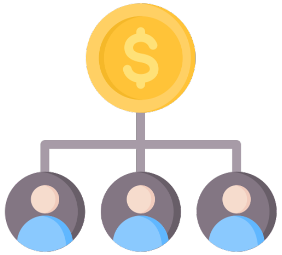
# Role of Solar (2/2)

Additional costs of power generation (10-15 %).



However,

- Large spatial distribution could benefit balancing of fluctuations from RE and reduce transmission requirement



- Use existing road and transmission infrastructure
- Boost near-term economic diversification

- Ease political support

# Chapter 5: Synthesis and Outlook

# Synthesis

1. Risky nature of coal investments, through carbon lock-ins. A coal moratorium in India offers several advantages.

2. Decarbonisation causes significant loss of coal global jobs. Retraining of coal workers in solar and wind energy might ease transition.

3. Without additional policies, decarbonisation will negatively affect coal-states, increase inequality. Dedicated Solar energy installations and retraining might ease energy transition.

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# Key Limitations and uncertainties

1. Barriers in “governance and institutions” indirectly addressed.
2. Energy employment as a proxy for political and socio-economic challenges
3. Only energy employment considered.
4. Narrowly look at just transition; need to expand to other energy consumers and explore other alternatives.

# Outlook

- Preventing fossil lock-ins in all countries, but especially coal in developing countries

- Need to understand political, institutional, and governance challenges and constraints

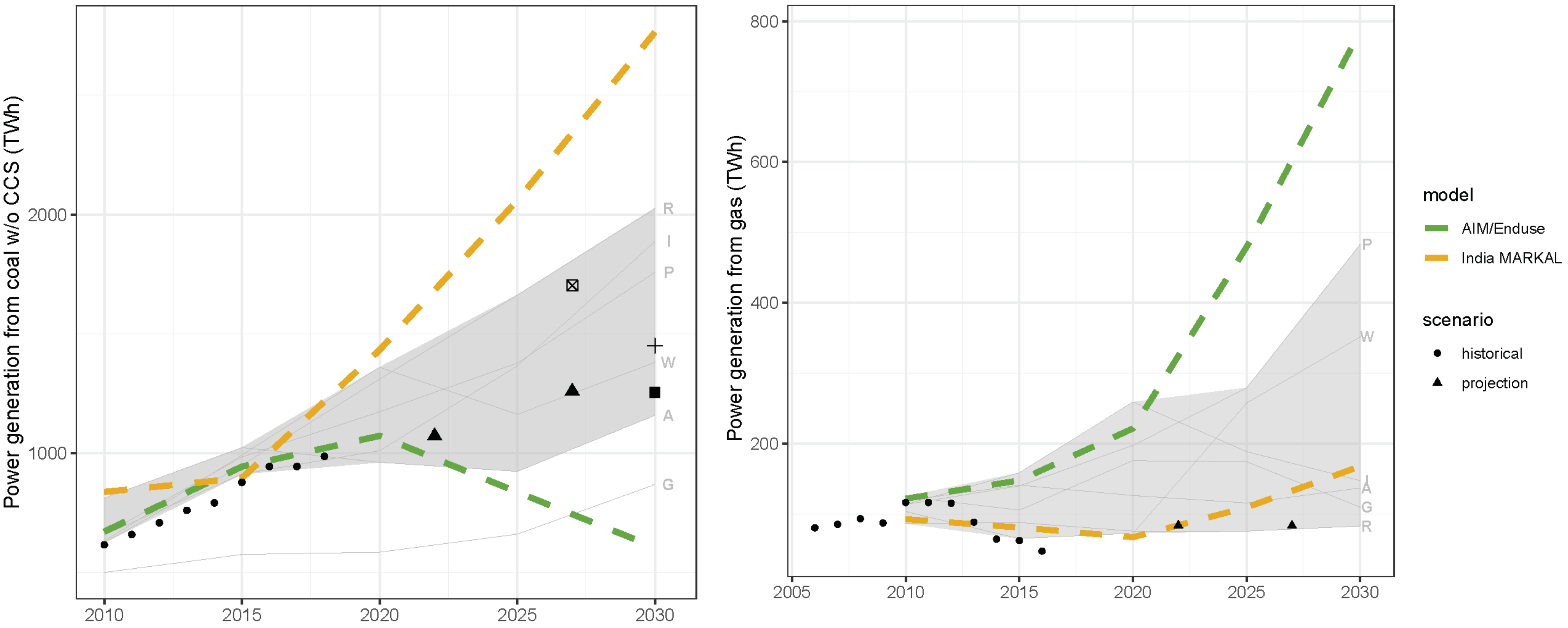
- International cooperation to reduce these challenges:
  - <u>Increase RE addition</u>:
    - Current RE growth in India relying on domestic capital
  - <u>Phase – out coal</u>
    - Just transition partnership: Netherlands and Colombia
    - Just Energy Transition Partnership with South Africa to phase out coal

# End.

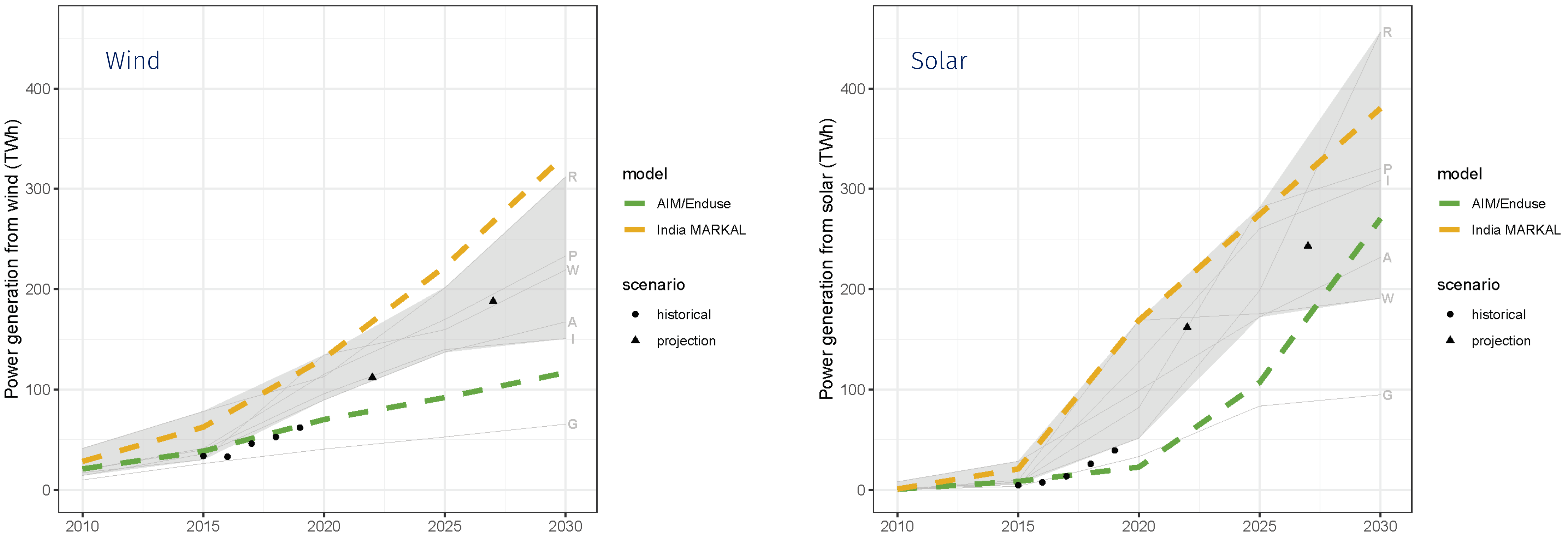
Credits

- Icons from https://www.flaticon.com/
- Font: Fire sans from https://github.com/mozilla/Fira
- Presentation design inspired from the *metropolis* theme: https://github.com/matze/mtheme

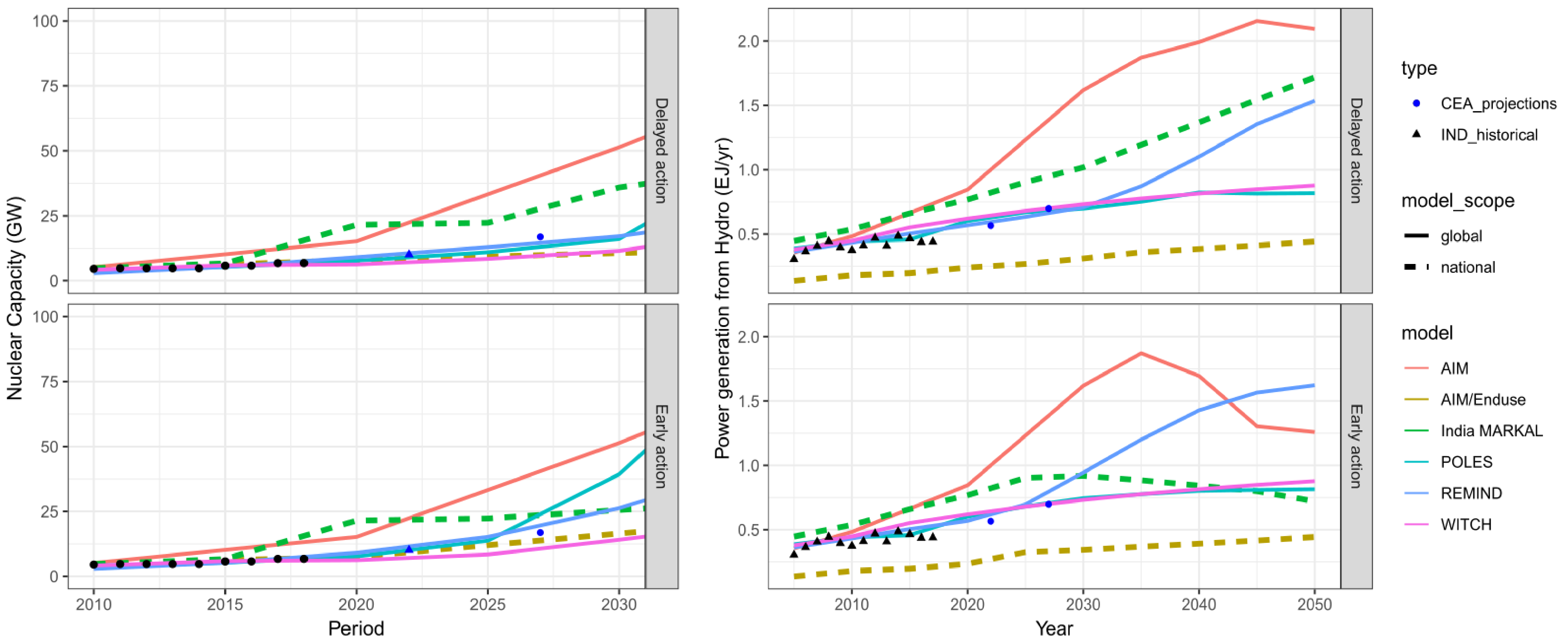
# Power generation from coal w/o CCS and gas until 2030



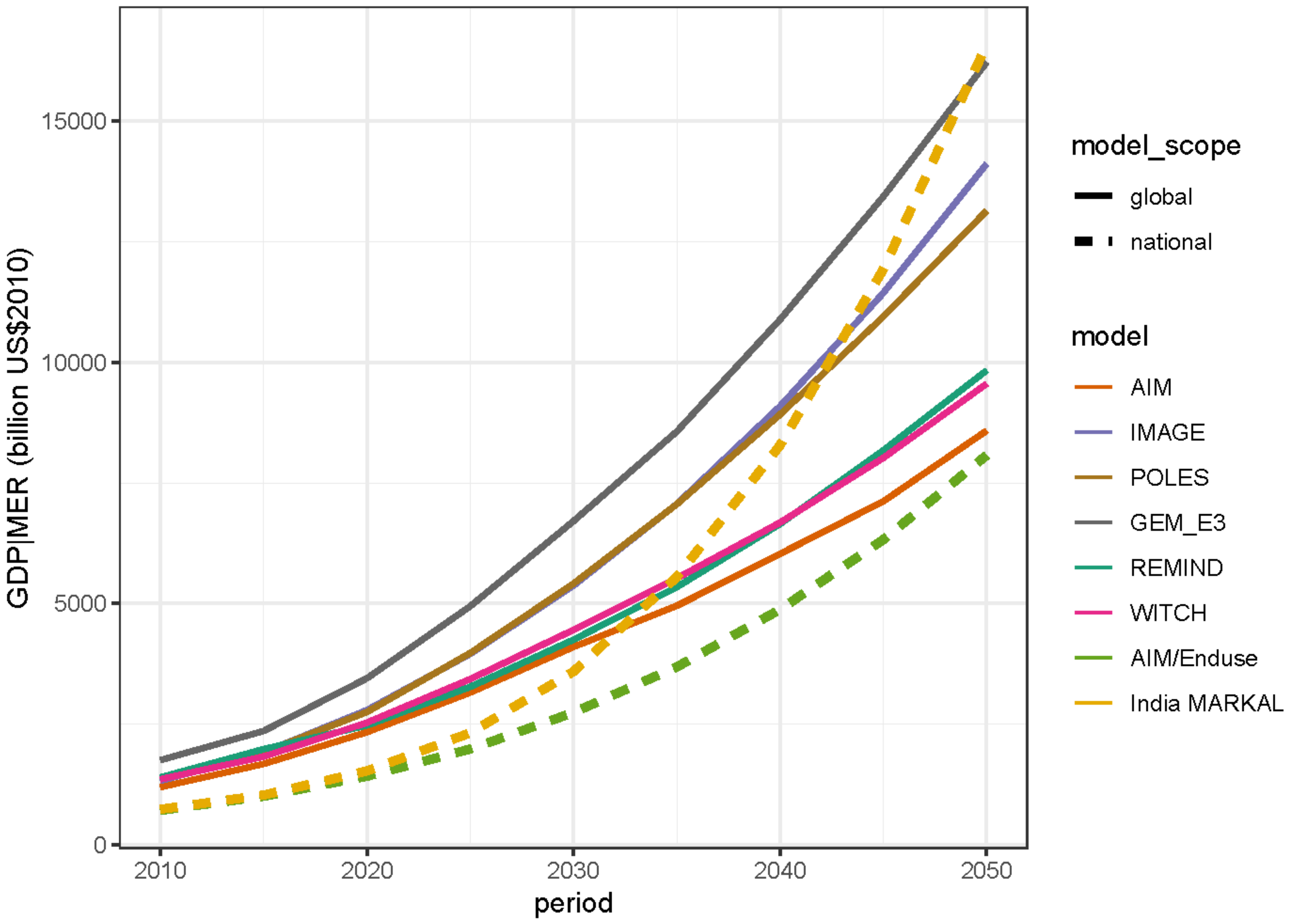
# Power generation from wind and solar until 2030



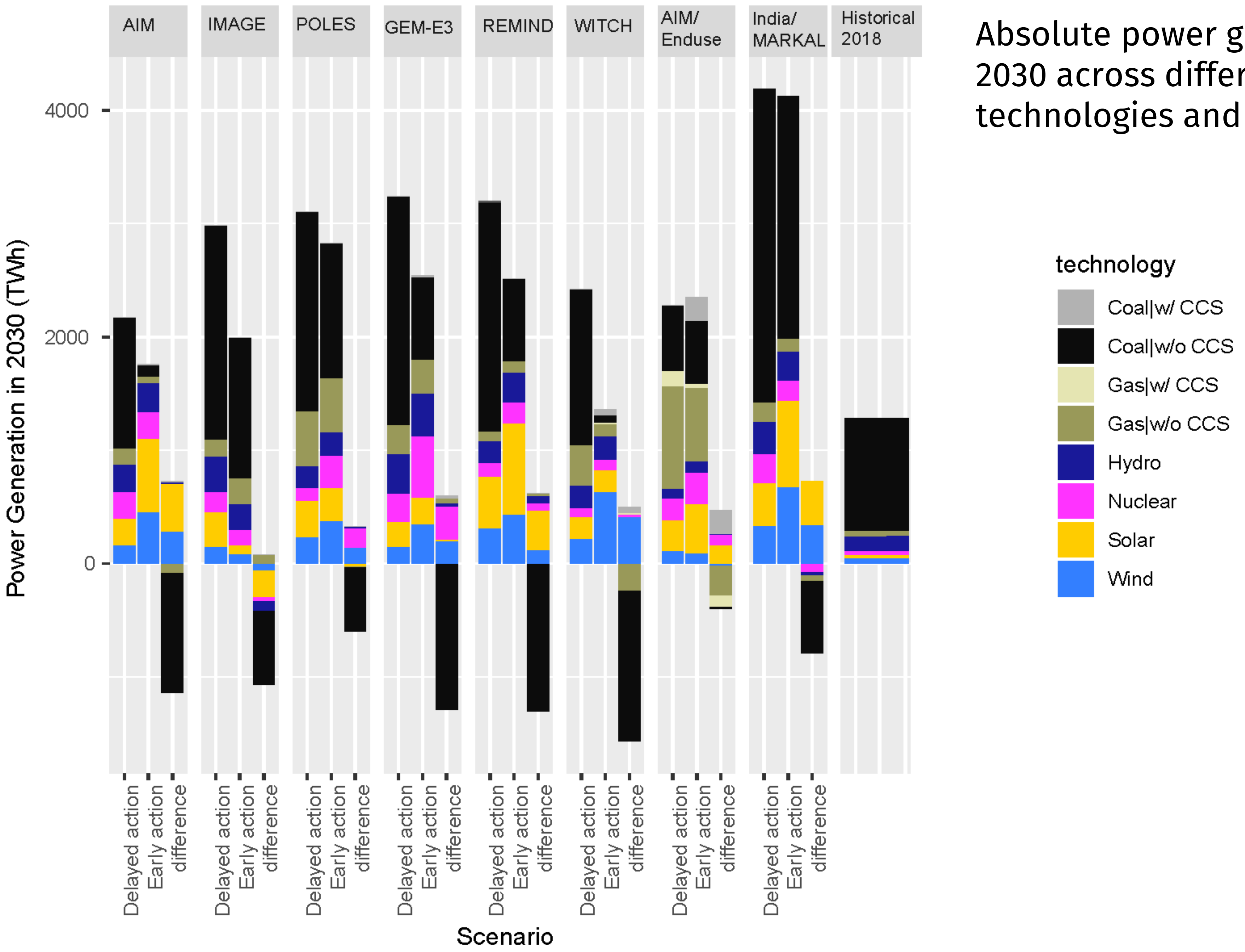
# Nuclear capacity and power generation from hydro until 2030



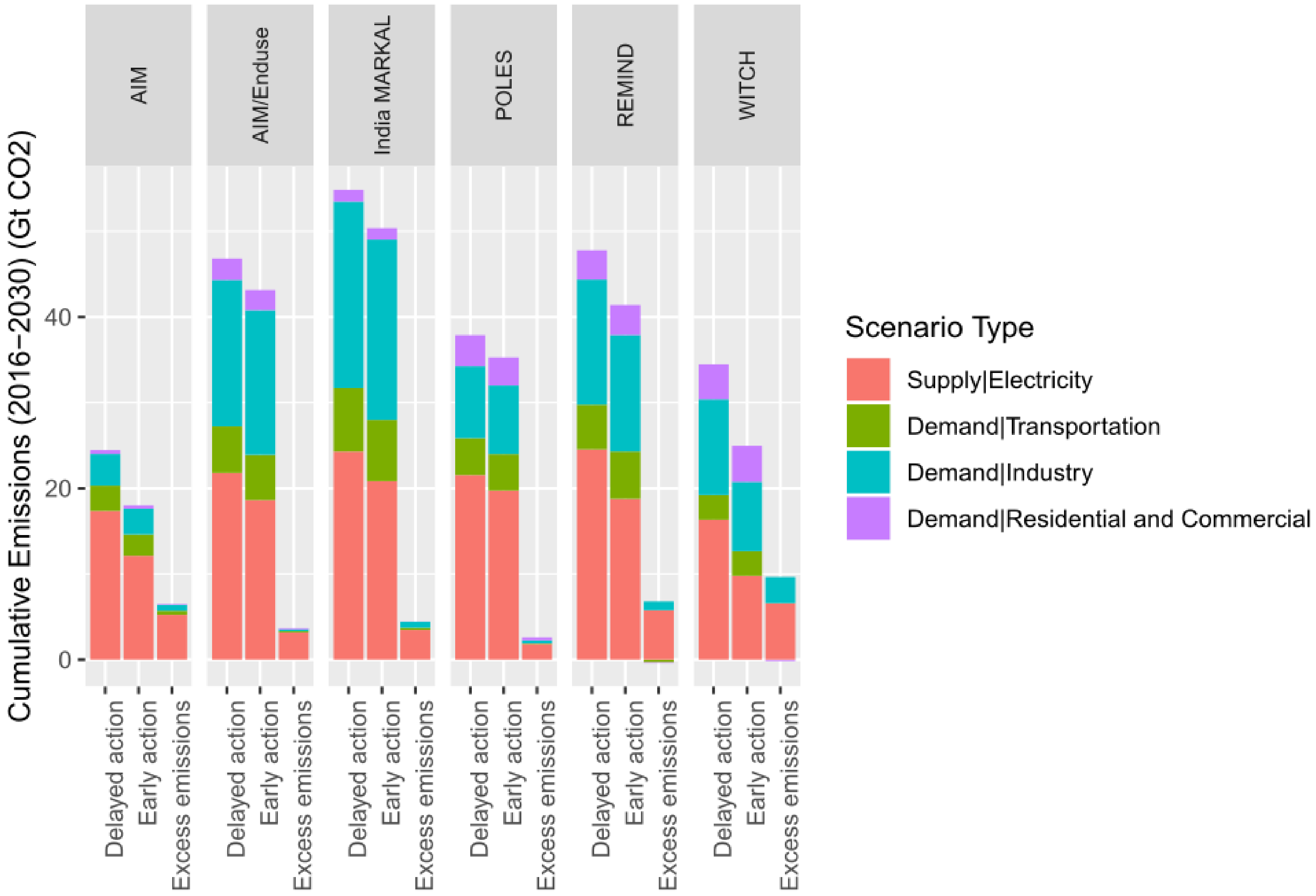
## GDP assumptions across models

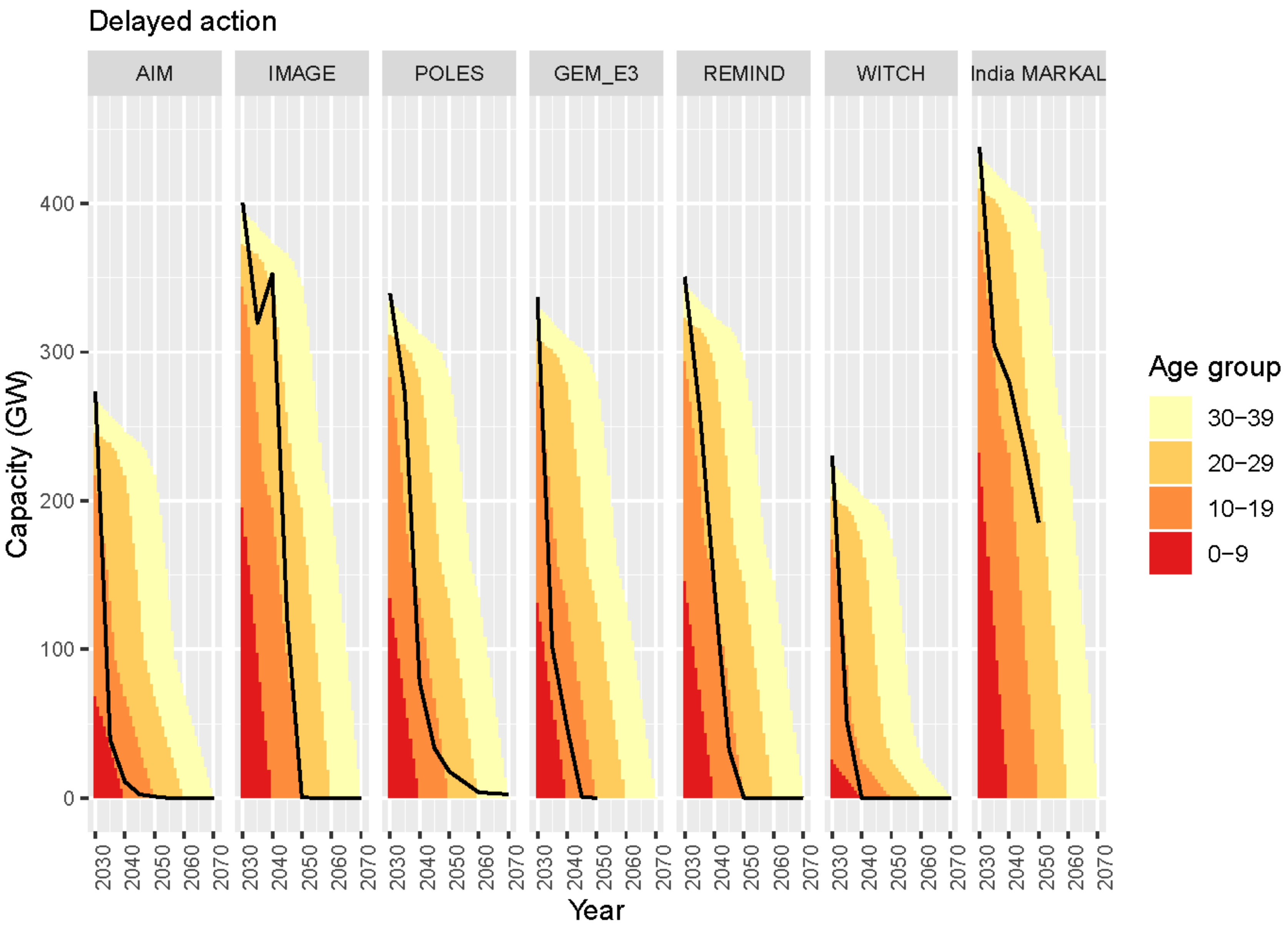


## Absolute power generation in 2030 across different technologies and models

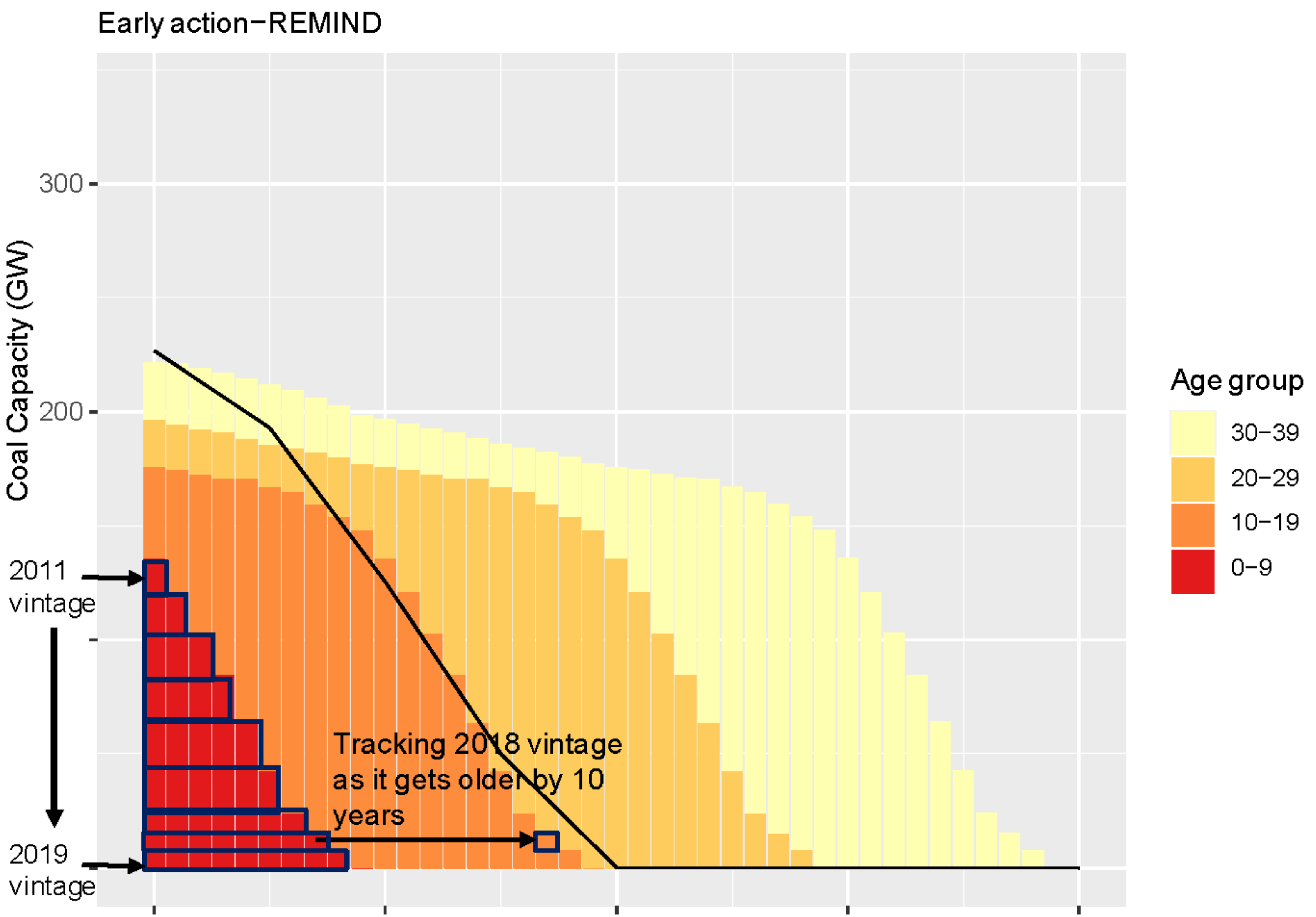


Cumulative emissions (2016-2030) (GtCO2)

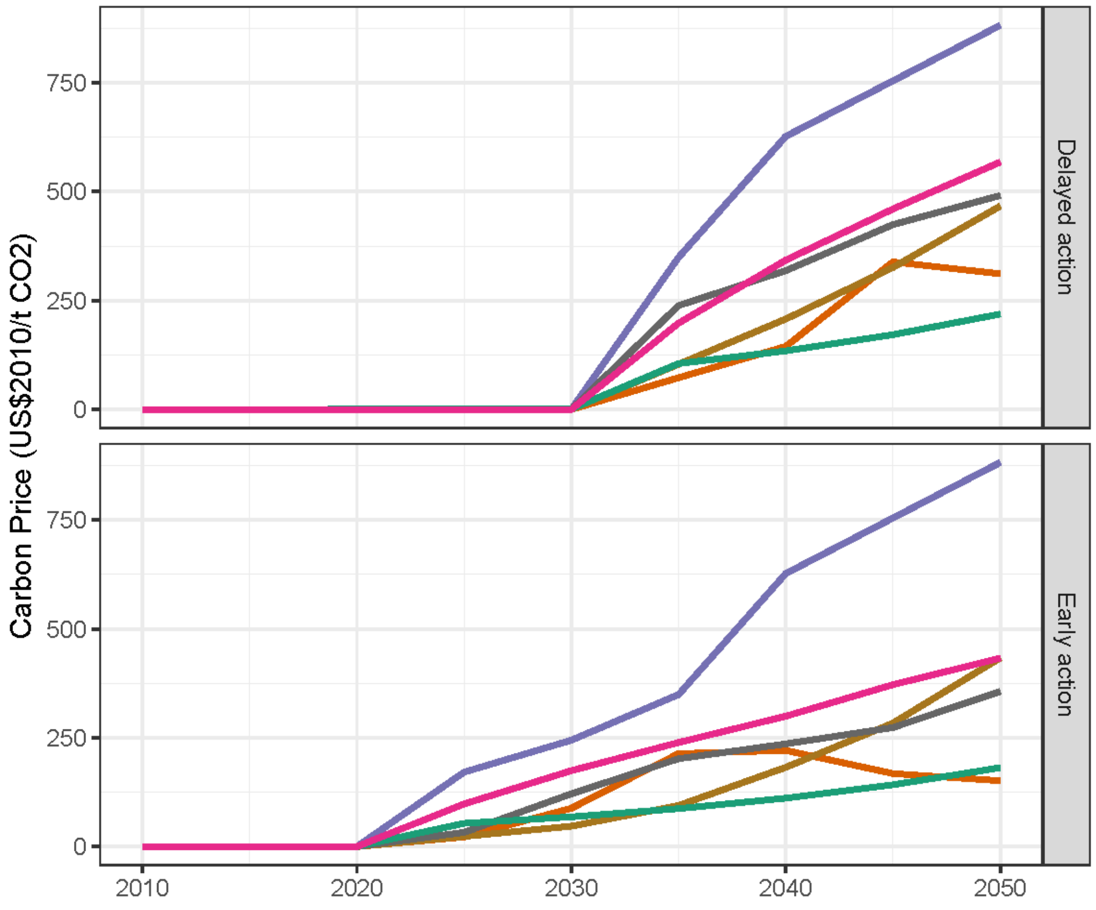


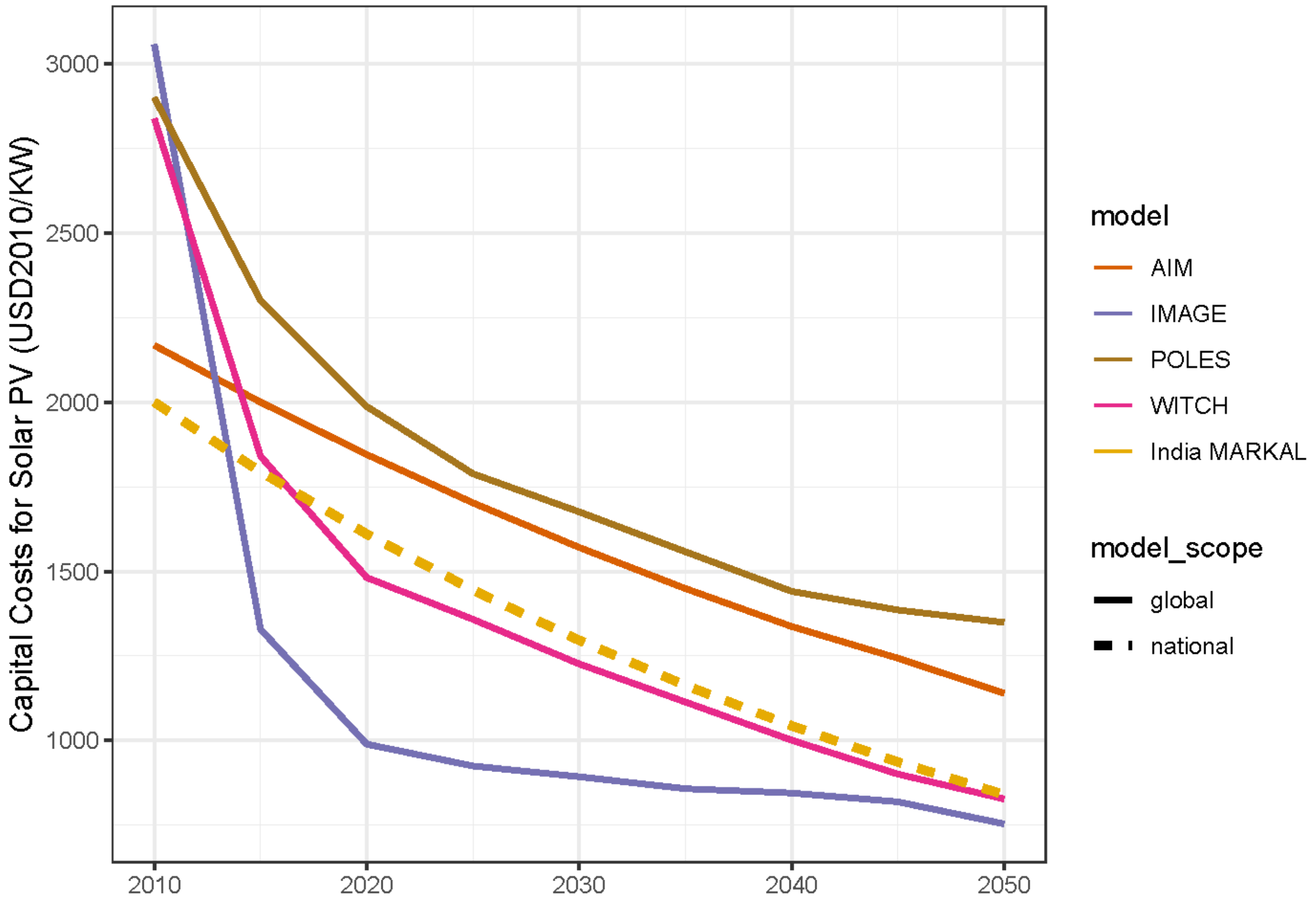


Delayed action
AIM
IMAGE
POLES
GEM_E3
REMIND
WITCH
India MARKAL
Capacity (GW)
400
300
200
100
0
2030
2040
2050
2060
2070
Year
Age group
30−39
20−29
10−19
0−9


Early action−REMIND
Coal Capacity (GW)
300
200
2011
vintage
2019
vintage
Tracking 2018 vintage
as it gets older by 10
years
2020
2030
2040
2050
2060
Age group
30−39
20−29
10−19
0−9

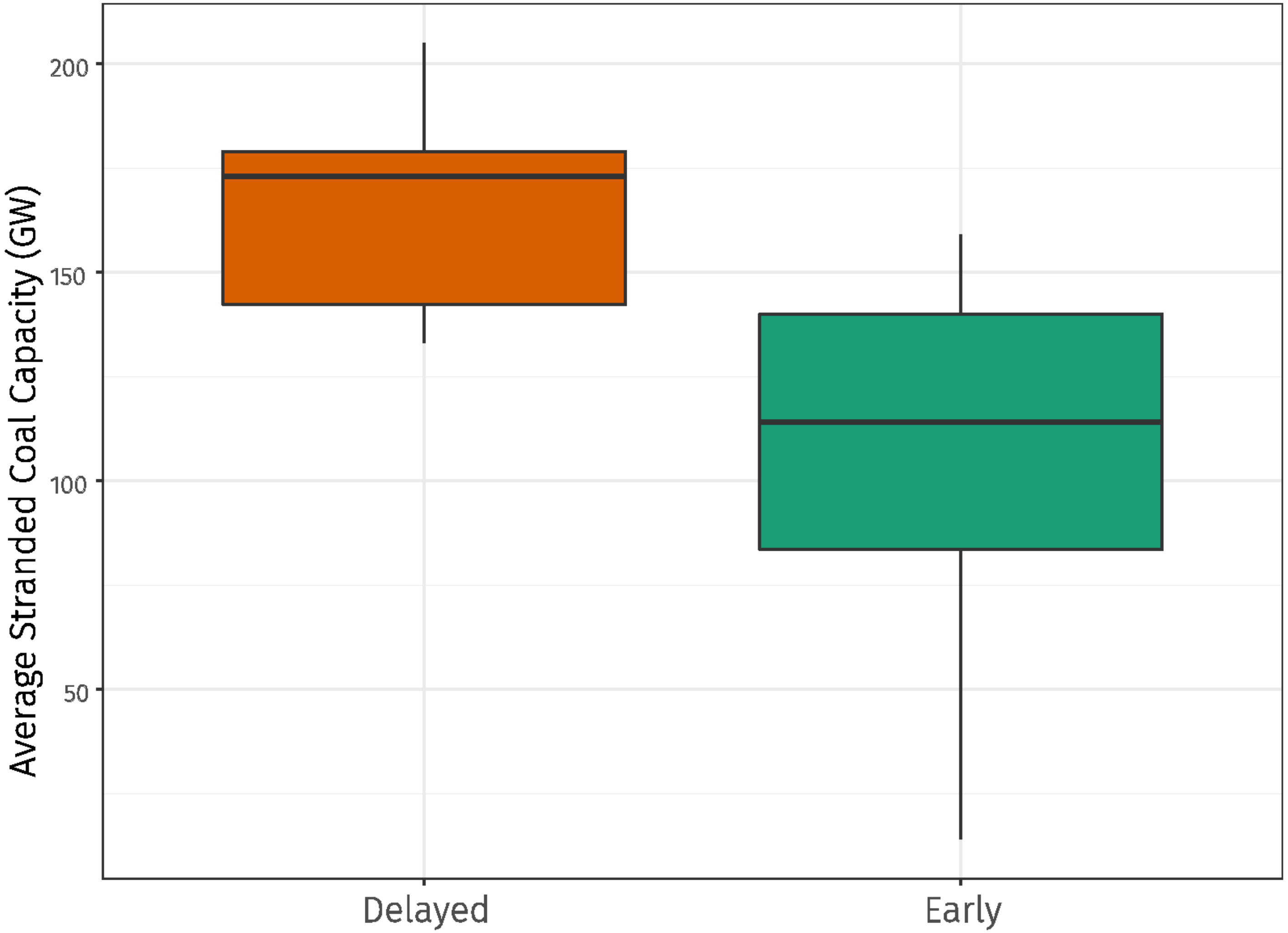
# Carbon price and capital costs of solar PV



# Results (3/3)

- Stranded capacity results from the difference in a cost-effective mitigation pathway and a natural retirement pathway
- Significant stranding from plants yet to be built
- Stranded capacity in both early and delayed action scenarios
- Significant stranding avoided by mitigating early: Early action (14-139 GW), Delayed action (133-237 GW)




Malik et. al. (2020)

# Scope

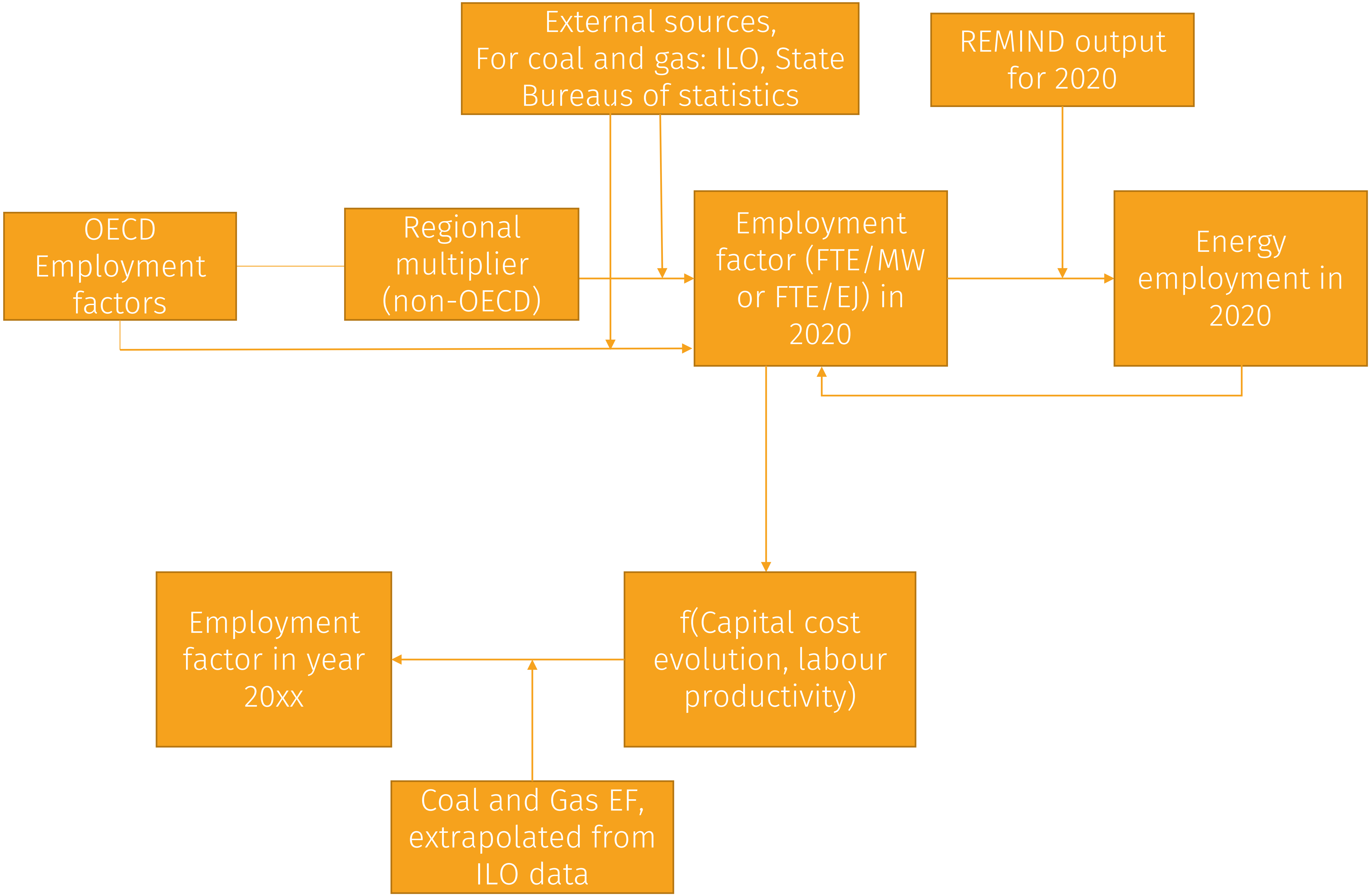
## What is covered?

Coal
Gas
Oil
Biomass
Nuclear
Solar PV
Wind
Hydro
Solar CSP

Divided into *solar PV rooftop and utility*, *wind onshore and offshore* and *small and large hydro* through an external share parameter.

## What is not covered?

- Transmission and distribution
- Battery-storage
- Decommissioning
- Oil and gas jobs do not cover distribution e.g., at petrol pumps


External sources,
For coal and gas: ILO, State Bureaus of statistics
REMIND output for 2020
OECD Employment factors
Regional multiplier (non-OECD)
Employment factor (FTE/MW or FTE/EJ) in 2020
Energy employment in 2020
Employment factor in year 20xx
f(Capital cost evolution, labour productivity)
Coal and Gas EF, extrapolated from ILO data

# Methodology (2/3) : Employment factor model

**Input**

- Energy-related variables – capacity, fuel consumption etc.
- Employment factors

**Assumptions**

- Regional multiplier
- Evolution of employment factor
- Share of world export
- Share parameter for unrepresented technologies

**Employment factor model**

**Output**

Total full time employment for each region, technology, activity, and time-step.

**Only direct energy supply jobs!**

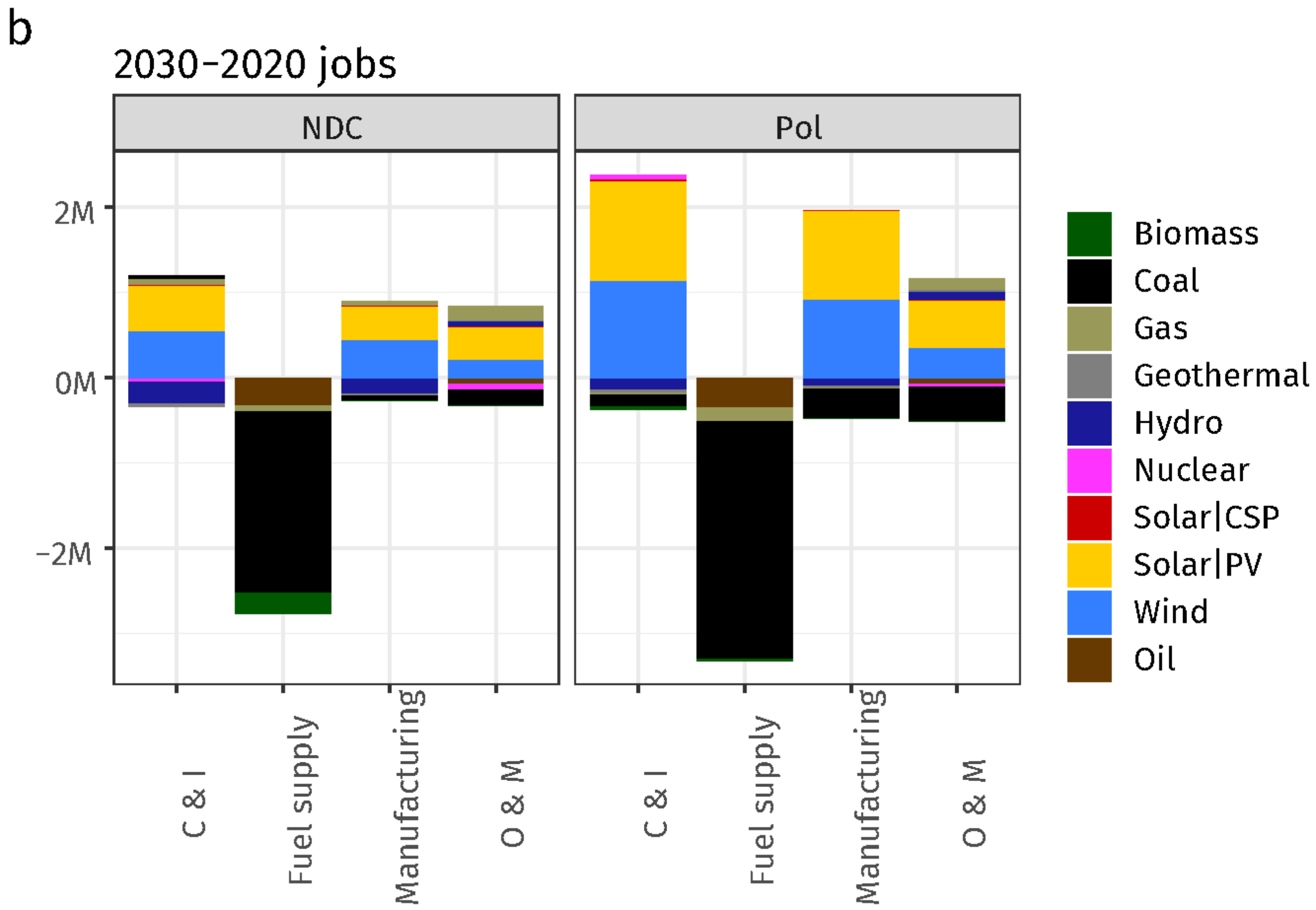
Innovations:

- Updating existing employment factors
- Adding non-OECD capacity factors Comparison of model employment numbers with bottom-up
- Drivers of energy employment

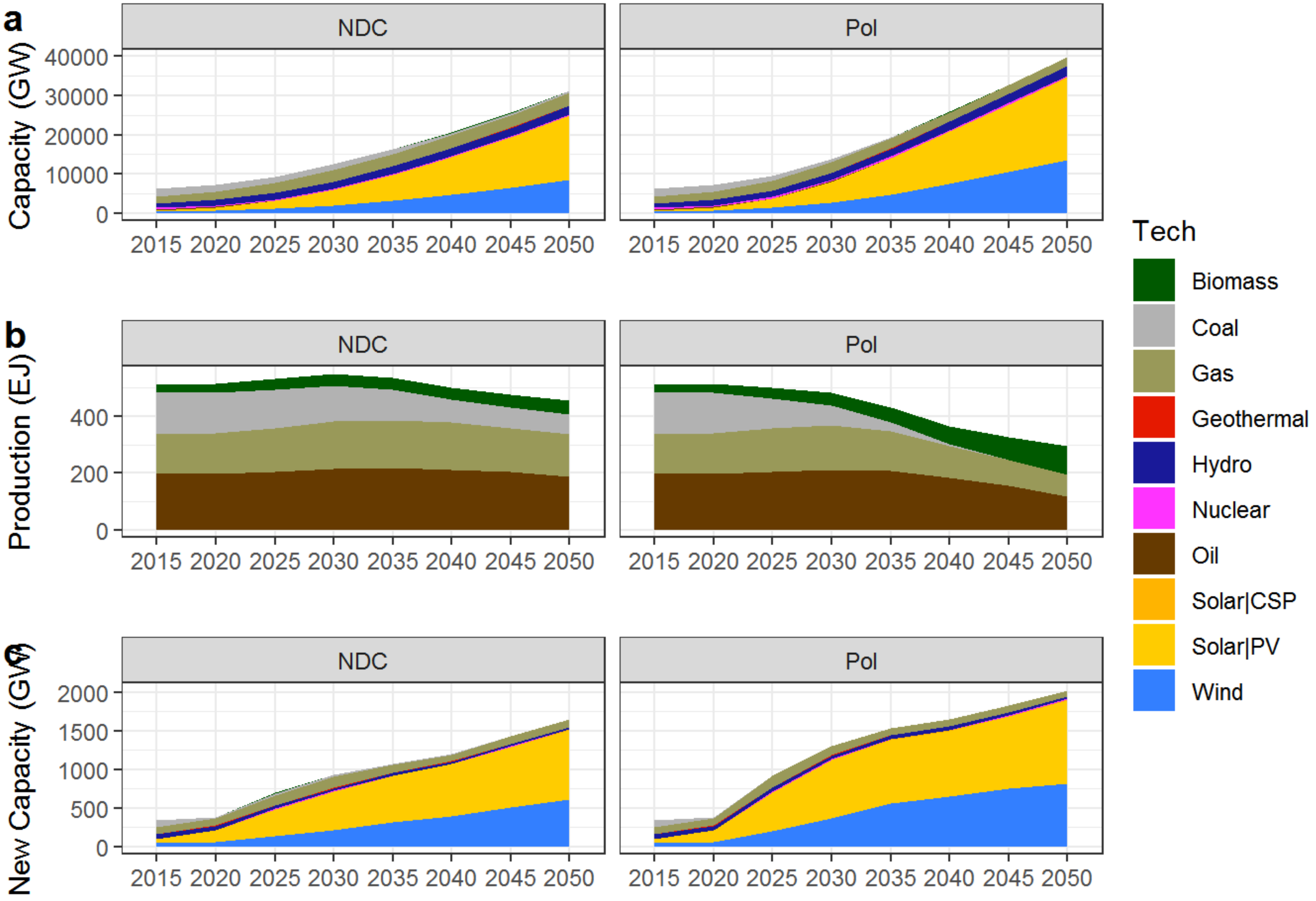
Malik et. al. (2021)

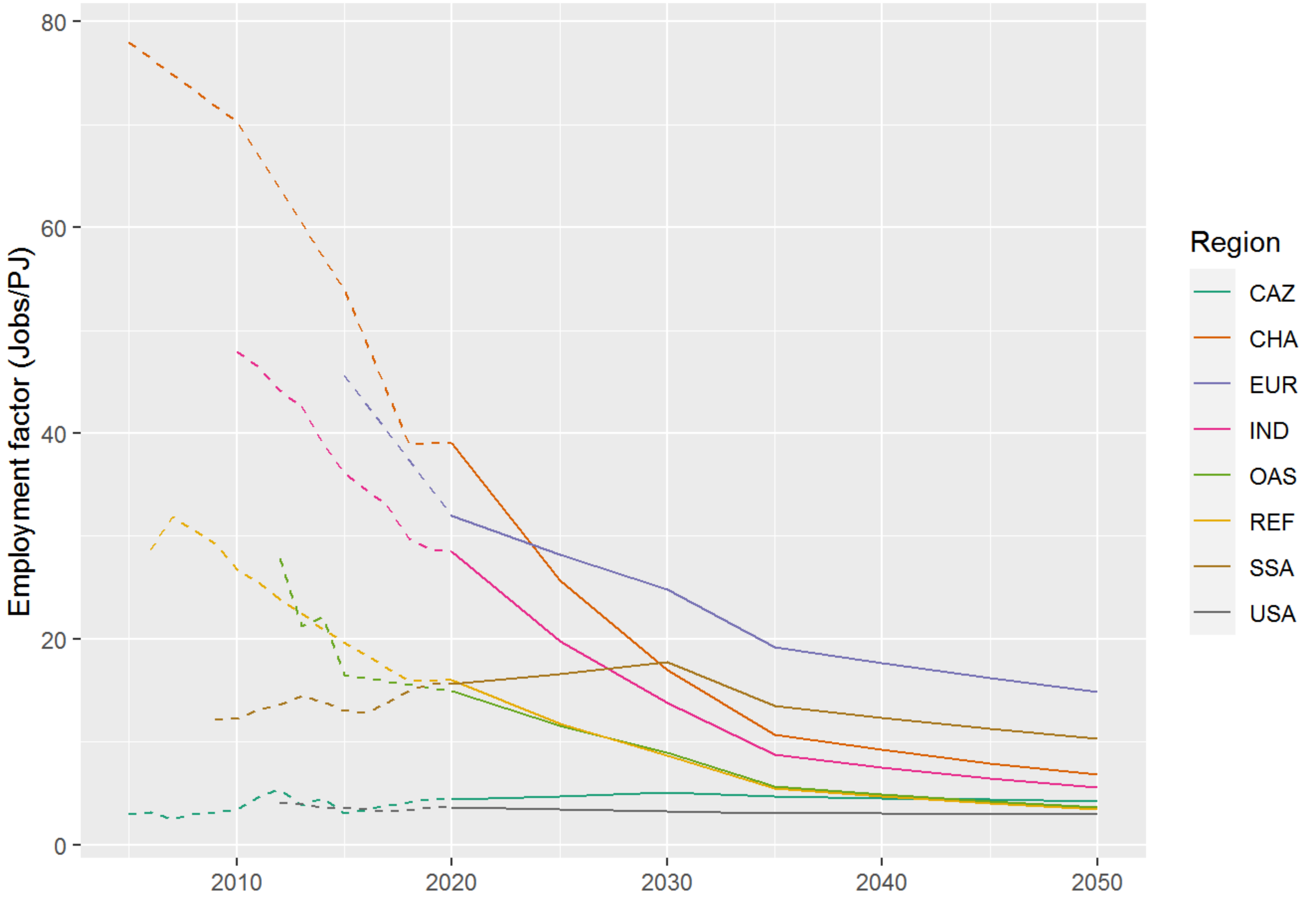
# Results (2/2)

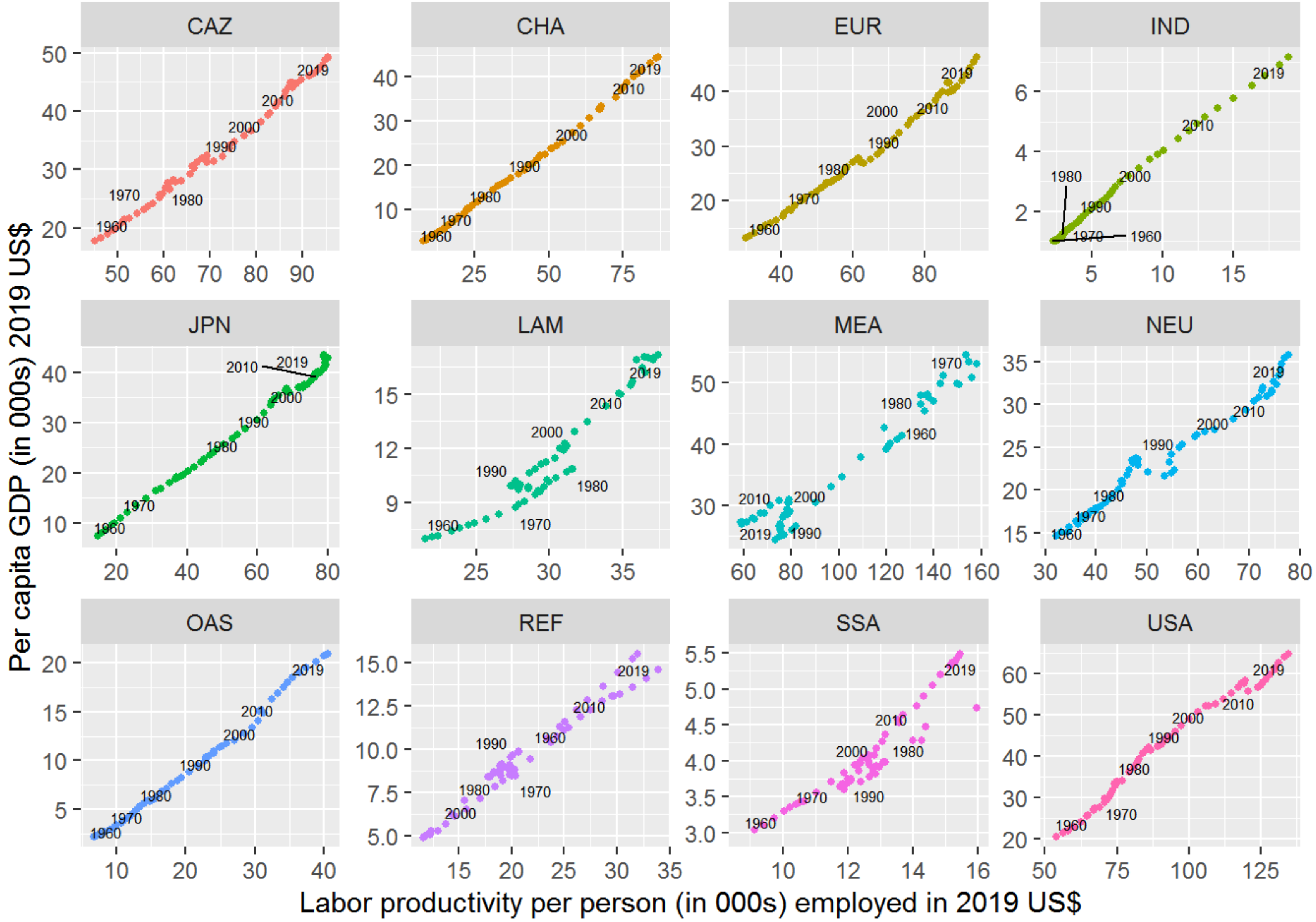
- Stringent mitigation leads to a net increase (850K) in jobs. **(a)**
- Gained through solar and wind jobs in construction, installation, and manufacturing. **(b)**
- Stringent mitigation leads to additional ~600K job loss in coal mining. (**b**)




Malik et. al. (2021)

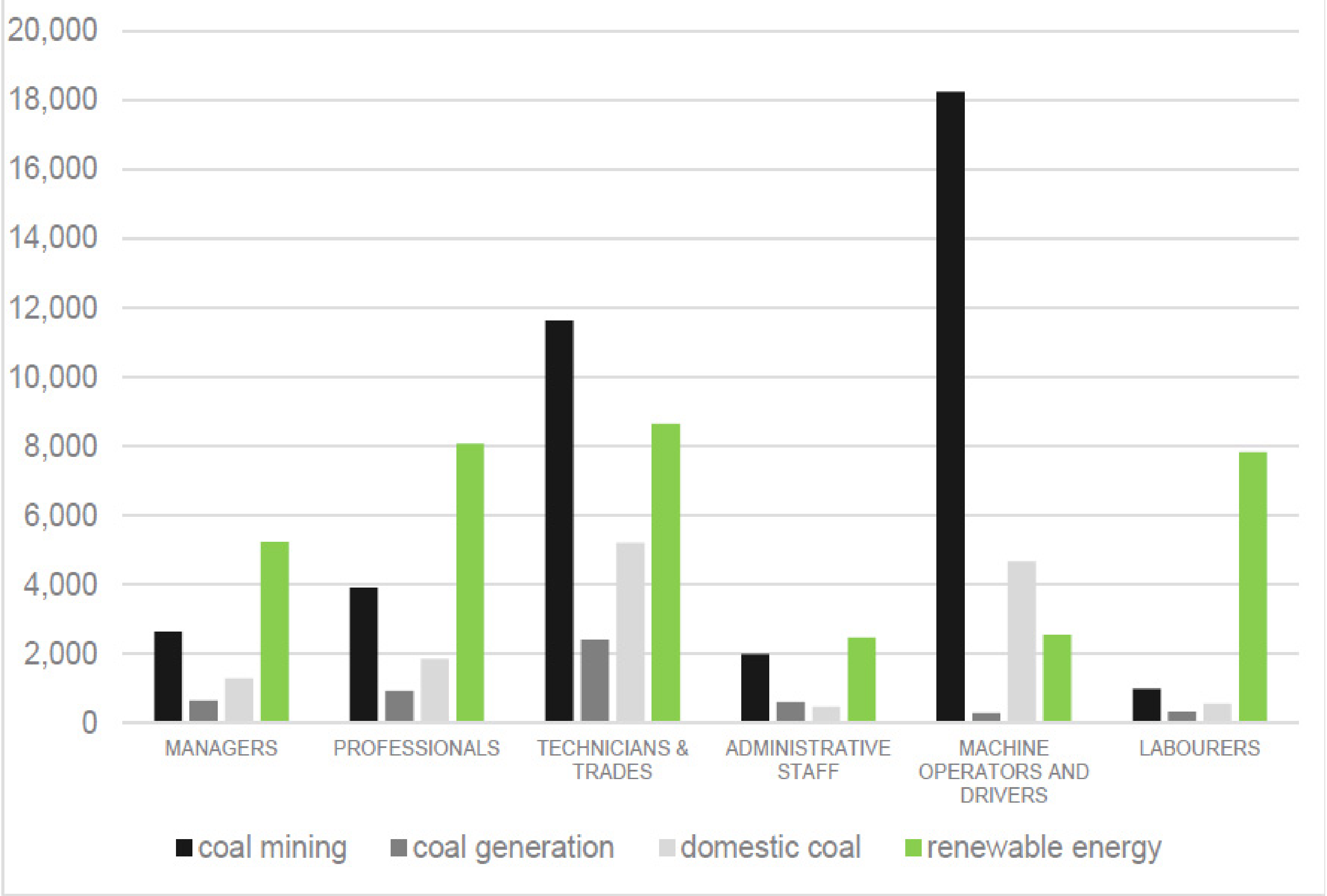

a
b
c
NDC
Pol
Capacity (GW)
Production (EJ)
New Capacity (GW)
40000
30000
20000
10000
0
400
200
0
2000
1500
1000
500
0
2015 2020 2025 2030 2035 2040 2045 2050
Tech
Biomass
Coal
Gas
Geothermal
Hydro
Nuclear
Oil
Solar|CSP
Solar|PV
Wind


Employment factor (Jobs/PJ)
80
60
40
20
0
2010
2020
2030
2040
2050
Region
CAZ
CHA
EUR
IND
OAS
REF
SSA
USA

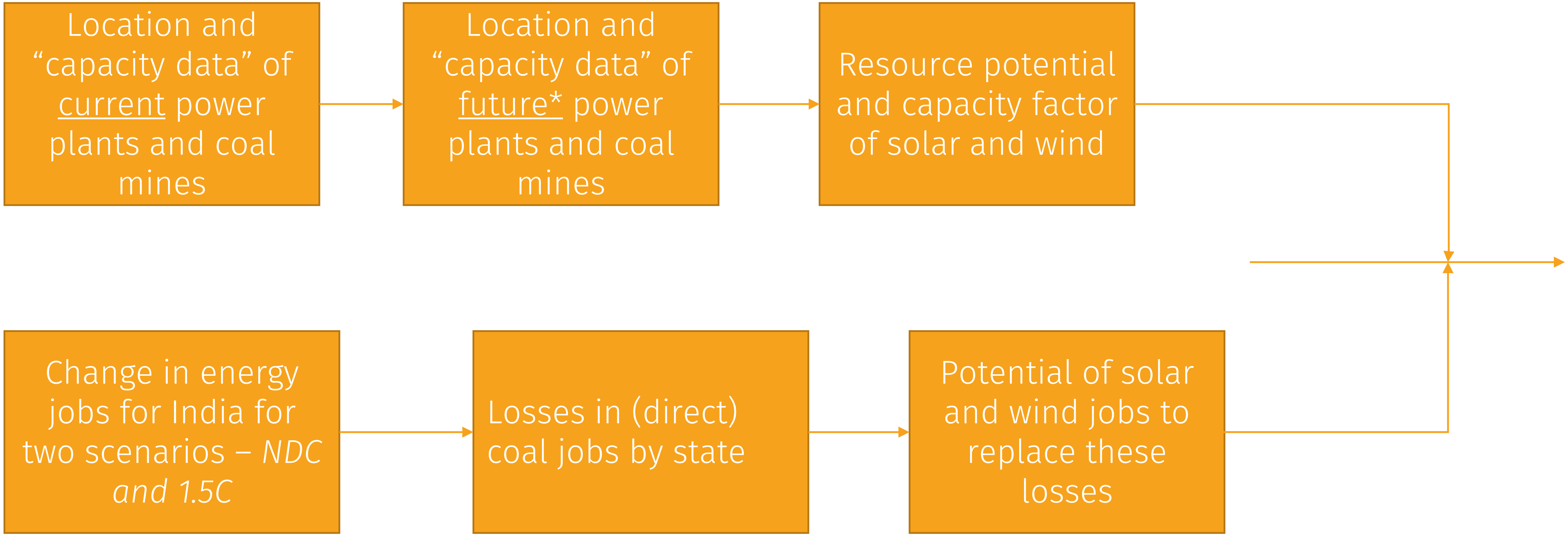

CAZ
CHA
EUR
IND
JPN
LAM
MEA
NEU
OAS
REF
SSA
USA
Per capita GDP (in 000s) 2019 US$
Labor productivity per person (in 000s) employed in 2019 US$

## For Australia: Occupational Overlap

Briggs et al. (2021)



# METHODOLOGY

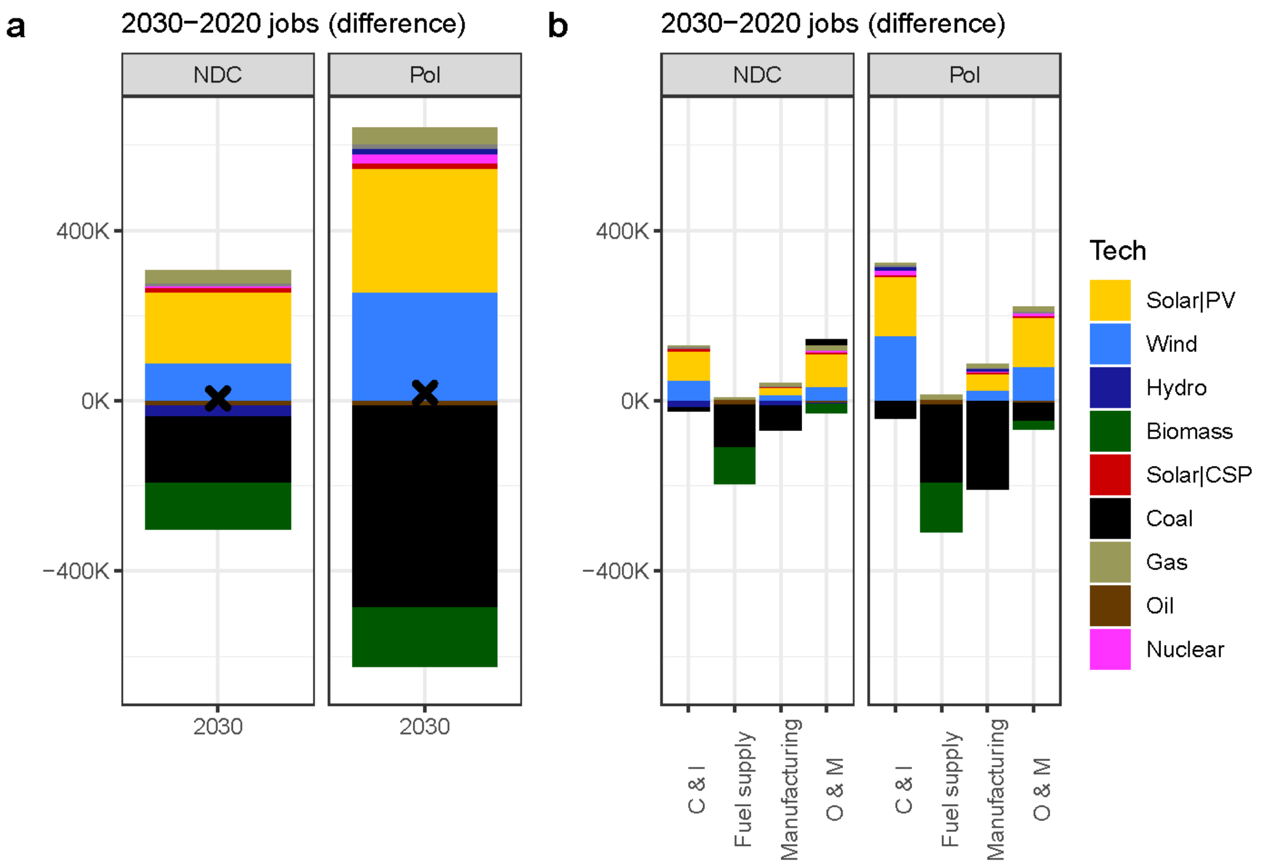


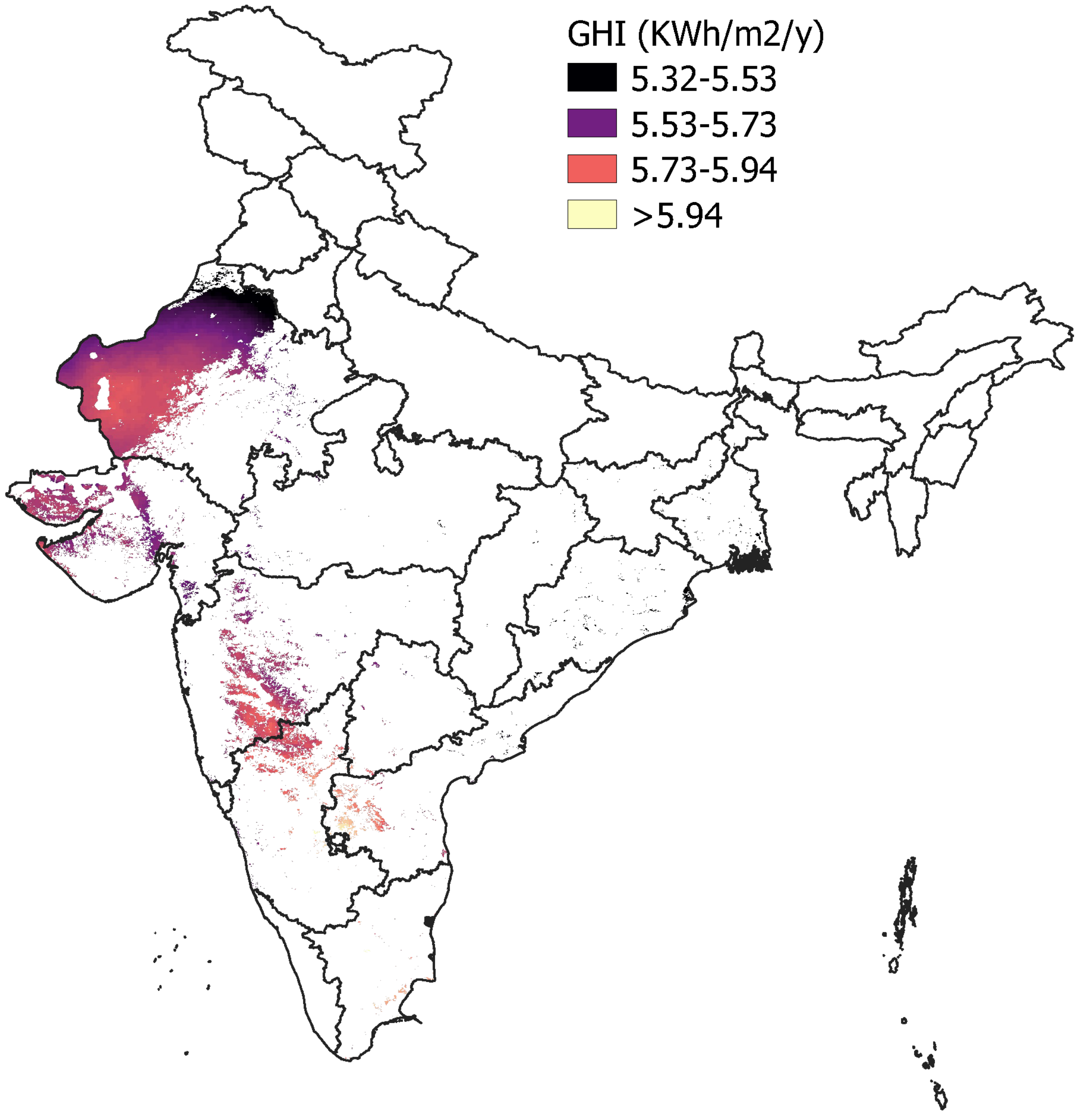


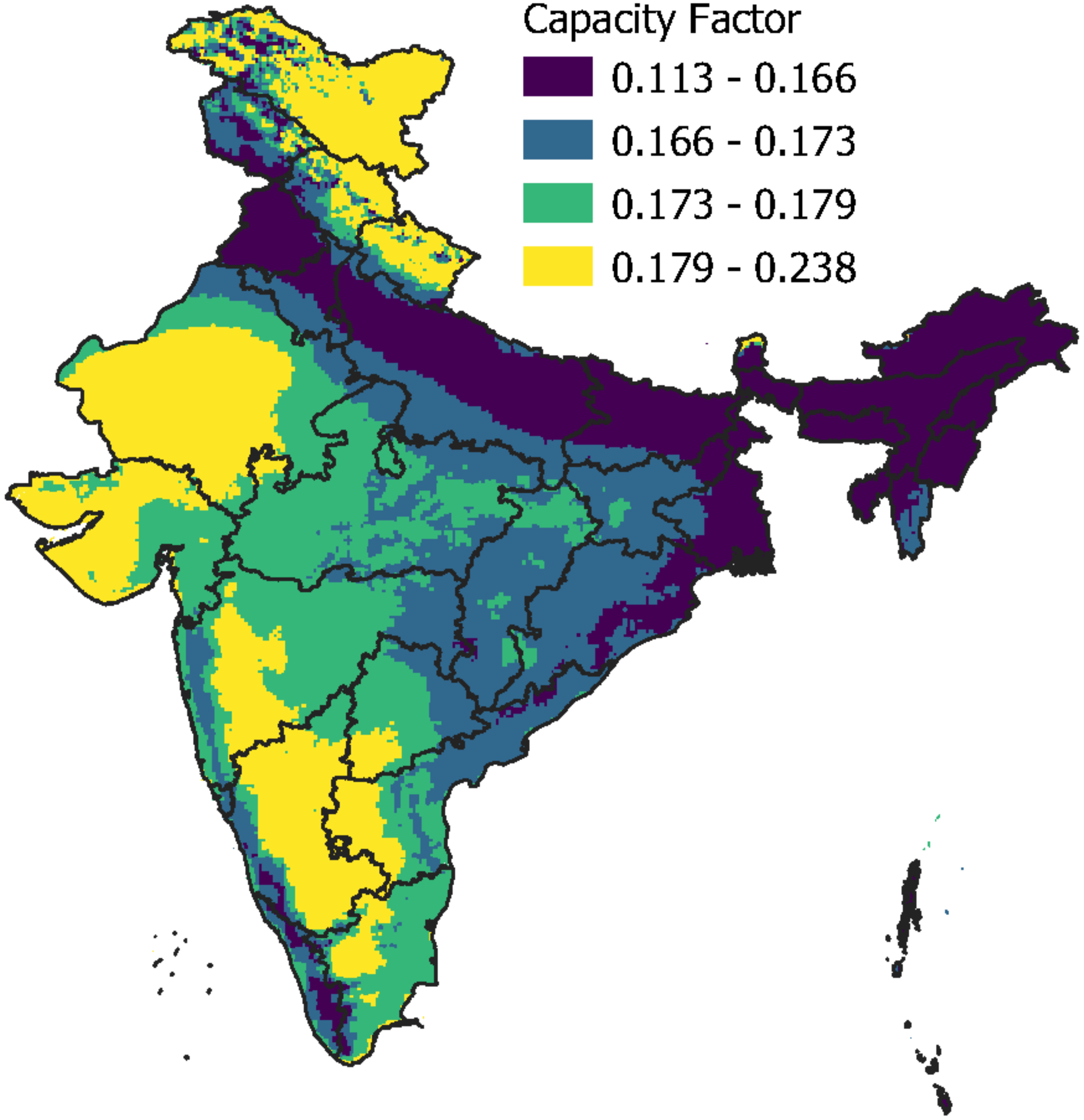

*under-construction or planned

# Results

- Net change in jobs same, NDC~1.5° C
- Job gains in solar and wind energy: southern and western states
- Job losses in coal mining  i.e., coal bearing-states




GHI (KWh/m2/y)
5.32-5.53
5.53-5.73
5.73-5.94
>5.94


Capacity Factor
0.113 - 0.166
0.166 - 0.173
0.173 - 0.179
0.179 - 0.238