LONG-TERM DECARBONIZATION PATHWAYS IN EMERGING ECONOMIES: INSIGHTS FROM 12 MODELING CASE STUDIES

Adam Suski, Power System Planning Group, ESMAP, World Bank, asuski@worldbank.org
Claire Nicolas, Power System Planning Group, ESMAP, World Bank

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Unequal costs of climate change
Poorer countries face greater risks from climate change and are less able to adapt to them.

(adaptive capacity and exposure indexes, points out of 1)

Developing countries face a unique challenge of having to achieve their economic development goals in the context of climate change

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• High climate change vulnerability because of high economic dependance to climate sensitive sectors
• Climate change and need for decarbonization is reinforcing existing vulnerabilities
• Limited human, institutional, and financial capacity to anticipate and respond

Source: IMF staff calculations based on 2015-18 data from the European Commission, the United Nations University Institute for Environment and Human Security, the University of Notre Dame, and the April 2020 World Economic Outlook.
Note: Dotted lines show estimated linear relationships for advanced economies, and for emerging market and low-income countries combined, respectively.

Source: Poor and Vulnerable Countries Need Support to Adapt to Climate Change By Kristalina Georgieva, Vitor Gaspar and Ceyla Pazarbasioğlu
To support the alignment of development and climate objectives at the country level, the World Bank Group has launched a new core diagnostic tool: the Country Climate and Development Report (CCDR).

The CCDRs integrate climate change and development considerations and aim to help governments, private sector investors, citizens, and development partners prioritize the most impactful actions.

The modeling group in ESMAP supports country dialogue, CCDRs and innovation with the ambition to inform decision-makers on the trade-offs created by the energy transition and to identify policies and strategies that will minimize transition costs and maximize its development impacts.
IDENTIFYING THE ENERGY TRANSITION TRADE-OFFS

Published or in press
Argentina  Mali
Bangladesh  Mauritania
Burkina Faso  Morocco
Cameroon  Nepal
Chad  Niger
China  Pakistan
Egypt  Peru
Ghana  The Philippines
Iraq  Rwanda
Jordan  South Africa
Kazakhstan  Türkiye
Malawi  Vietnam

Forthcoming
Angola  Indonesia
Brazil  Mozambique
Honduras

Initiated
Azerbaijan  Dominican Republic
Bhutan  Eastern Caribbean
Cambodia  (Antigua and Barbuda,
Central African Republic  Dominica, Grenada, St. Kitts
Colombia  and Nevis, St. Lucia, and St.
Democratic Republic of Congo  Vincent and the Grenadines)
Côte d’Ivoire

Ecuador  Paraguay
Guinea-Bissau  Romania
India  Tunisia
Kenya  Uzbekistan
Lebanon  West Bank and Gaza
Liberia  Zimbabwe
Madagascar

On hold
Ukraine  Sudan

• Power system decarbonization pathways are rarely compared across a wide range of different countries or regions

• Comparison allows to derive insightful differences or similarities in speed, type, or scope of transformation and derive high-level multinational relationships.

• This study compares a series of long-term decarbonization studies conducted for developing countries or regions.

• The comparison is made on the technical, economic, and environmental levels, capturing the key indicators and parameters relevant for effective decarbonization.

• This presentation will show the preliminary results from data analysis, focusing on high-level trends and relationships, that will later be also analyzed from the case context.
Electricity Planning Model (EPM) is a least-cost planning framework.

- It minimizes the costs of expanding and running a power system, whilst meeting requirements defined by the model.
- It is formulated as linear programming problem, coded in GAMS and solved with off-shelf solver (CPLEX)
The project includes ten independent country analyses and two regional analyses. Countries include Vietnam, Ghana, Morocco, Ukraine, Turkiye, Egypt, Jordan, Iraq, Bangladesh, and Mauritania, while regional analyses include West Africa Power Pool (WAPP) and South Africa Power Pool (SAPP).
Individual modelling analyses
- Vietnam
- Ghana
- Morocco
- Ukraine
- Türkiye
- Egypt
- Jordan
- Iraq
- Bangladesh
- Mauretania
- SAPP
- WAPP

Data analysis

Discussion of the results with broader team

Publication

State of the current analysis
Results are preliminary
The end goal of each analysis could differ, but fundamentally it is aimed at informing decision-makers of the magnitude and urgency of action that is required to deeply decarbonize the power system over the next 20 to 30 years.

Each analysis included a specific assessment of underlying technological, economic, regulatory and environmental factors.

Analyses included uniformly defined **scenarios**

- **Business-as-usual (BAU)**: most cost-effective route for the power sector to meet anticipated electricity demand, considering existing and actionable policies.

- **Decarbonization**: least-cost optimization for expanding electricity generation while adhering to a specific emissions limit by a set target year.
Emission trajectories in the BAU/Least cost scenarios present very heterogenous behaviors that are system dependent.

Some countries/regions display a decreasing or relatively limited increase (WAPP or Egypt) in the BAU while others show significant increase (Vietnam, Morocco, or Bangladesh). In the Decarb scenarios, emission trajectories are constrained.
Solar is a powerhouse of the capacity expansion even under BAU scenario, becoming the technology with largest installed capacity.
Results – Investment Challenge

Most of the countries will need between 1% and 3% of the current GDP for annual investments to reach ambitious decarbonization targets.

For most of the countries (with exception of Morocco and Vietnam) the level of investments under BAU would be below 1.5% of GDP only to keep up with the growing consumption and meet the binding targets. This trend will be amplified significantly when ambitious decarbonization objectives are added to the story, up to even over 3% on average for countries like Ghana or Vietnam. Smaller and poorer countries can expect higher annual capacity additions (CAGR) compared to their greater and developed counterparts.
The required level of annual investments under BAU is relatively stable, but gradually increases over the analyzed horizon under decarbonization.
The level of required investments is not only determined by the estimated increase in power demand, but also other techno-economic factors. The magnitude of the increase is not directly commensurate to the demand growth because it depends on the technologies deployed (which in turn are highly constrained by the country resources).

The relationship between demand increase and capital expenditures is consequently not linear, but estimating the correlation allows to establish a benchmark and potential impact of carbon limits.
Decarbonization scenarios display a rapid shift towards systems with a heavy share of renewable, both in individual cases and cumulatively.

Solar continues to be the powerhouse of growth, with the largest share in the 2040 capacity mix, with 32%. In the case of onshore wind, it similarly experiences rapid expansion under the Decarbonization scenario, increasing installed capacity in 2040 by 89% (+121GW).
RESULTS – OPERATIONAL CHALLENGE

OPERATION OF CONVENTIONAL TECHNOLOGIES

Reshape of average daily production profiles for conventional units.

Distribution of conventional production follows the pattern of residual demand after significant expansion of VREs. Production is reduced midday with abundance of solar energy and ramped up in the evening and night.
Results – Operational Challenge

Operation of Conventional Technologies

Substantially increased flexibility requirements of conventional units

- Left plot shows the box plot distributions of the hourly ramp rates as a percentage of the installed capacity of the unit. Although the mean of the ramp rate do not increase substantially, the distribution on the high end becomes much wider.
- Right plot shows the maximum observed ramp rate each year in each case. There is a visible upward trend, with average maximum ramp rate three folding over the horizon.
While the decarbonization process will change the daily dispatch patterns of conventional units and need for their flexibility, the overall annual utilization will decrease. The above plots show the annual utilization factor of coal and gas units, plotted against the renewable energy share, where the clear downward trend is visible.
Rate of storage installations increases over the analyzed horizon. Cumulatively, the rate of storage installations to VRE installations is similar between BAU and Decarbonization scenarios.
ANNEX - RESULTS – OPERATIONAL CHALLENGE

FLEXIBILITY

Reservoir hydro to even greater extent used for flexibility

Storage follows similar pattern but with much more profound effect. While in the early years of the horizon discharge is far more harmoniously distributed throughout the years, by the end of the horizon the discharge is allocated almost exclusively to meet the evening peak.
RESUS — COSTS CHALLENGE

On average the annual systems costs increase in both scenarios, with Decarbonization being around 30% more expensive at the end of the horizon. Costs of individual countries are however diverse.
The marginal costs of emissions indicate the price of carbon in the potentially functioning market, the average cost of emission reduction states the annual cost per unit of CO2 from a more systemic view.

For most of the analyzed cases, marginal costs of emissions experience an upward trend over the planned horizon and end up in the range of 20-120$/t in 2040. While the marginal costs of emissions indicate the potential price of carbon in the potentially functioning market, the average cost of emission reduction states the annual cost per unit of CO2 from a more systemic view. Our analysis shows that while the mean value reaches 75$/t in 2040, it oscillates throughout the horizon between 20$/t and 100$/t.
While in the NPV terms costs per emission reduction are kept relatively low, the investment needs are substantial.
CONCLUSIONS

• Using the uniform modelling methodology with a similar scenario design allows to derive a series of high-level statistics and relationships.

• Investments outcomes:
  • Average annual investment increases from 1% of 2021 GDP to 1.9% under Decarbonization scenario
  • The required level of investments will increase throughout the horizon
  • Investments in terms of demand increase will double on average with ambitious decarbonization objectives.

• Operational outcomes:
  • Under decarbonization scenarios countries will reach substantial percentages of VRE already in 2040
  • Conventional units dispatch patterns will reshape under decarbonization scenario: average difference between low and high dispatch will increase from 8% to 28% in terms of installed capacity
  • Utilization rate will decrease significantly, by 0.4% for coal and 0.3% for gas for every 1% decrease in VRE share.
  • Storage to VRE capacity installation ratio on average amounts to 20% and does not change much under different scenarios, but increases throughout the horizon

• Cost outcomes:
  • While in the NPV terms costs per emission reduction are kept relatively low, the investment needs are substantial.
THANK YOU

Adam Suski
Power System Planning Group, ESMAP, World Bank
asuski@worldbank.org
ANNEX - RESULTS – INVESTMENT CHALLENGE

All countries have an enormous opportunity to expand renewable energy to meet growing demand for electricity.
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Even in the absence of decarbonization objectives, investment needs will substantially increase in developing countries to meet the growing demand.

Countries, and regions will experience a massive increase in installed capacity up to 2040. The cumulative demand growth across cases amounts to 88% over the 18-year horizon and translates to the cumulative average growth rate of 3.6% over the entire horizon.
Storage plays an important role in providing flexibility and integrating VREs.
Reservoir hydro to even greater extent used for flexibility

Distribution of (reservoir) hydro generation changes relatively insignificantly throughout a years, with more and more discharge pushed outside of midday time. This is due to the fact that in the analyzed countries, especially operating with aged and inefficient coal units, hydro plants are often main providers of flexibility.