TransitionZero

Cables to change the world

The benefits of transmission to decarbonise global electricity supply

November 2023

Report at a glance

Here's what we discovered:

Expanding transmission lines will save the global economy almost **$USD 3 trillion** in the net-zero transition.

Many countries could become net exporters of clean electricity by reinforcing transboundary interconnectors, providing them with new export revenue.

Grids have the potential to form **several new trade relationships**. This highlights the importance of multilateralism at a time when countries are looking inwards.

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Report collaborators

SFU | Climate Compatible Growth | DARTMOUTH | Green Grids Initiative | One Sun One World One Grid

Background

The importance of transmission across the global economy

Power grids are the lifeline of net-zero

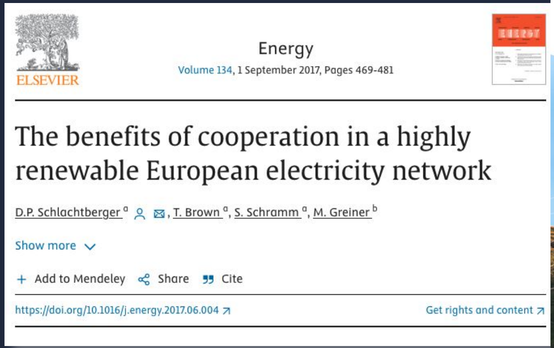
The energy transition will not happen if we do not bolster our grid infrastructure

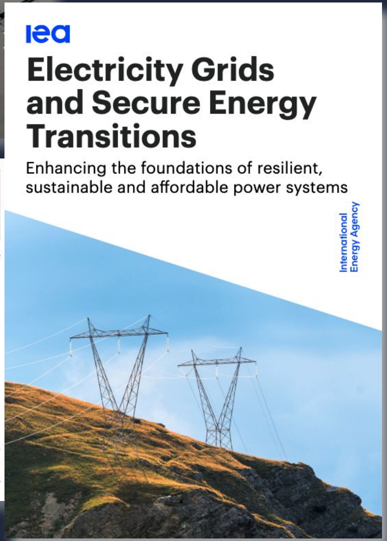
- Almost all of the world's critical infrastructure **depend on grids** for its electricity supply.
- **Power demands are increasing**, particularly in developing and emerging economies.
- **Electrification** is at the heart of global decarbonisation plans, which is also increasing electricity demand.
- Increasing demand + increasing electrification = More electrons **= More grids needed**
- If we think of electrons as cars, then grids are the highways along which electricity flows. **We are running out of road.**

The need to expand grids is now well-established

In the energy community, there is widespread and growing consensus on the vital role of transmission and distribution

Research and analysis by the scientific community, multilateral organisations and the private sector all points in the same direction: **power grids need urgent attention for countries to deliver on net-zero goals.**





...but there are many unresolved questions

Decision-making investors need clarity on targeting investments for greatest impact

How much new grid infrastructure is needed for net-zero? By when?

What will this cost?

Can we get away with taking no action on grids?

Which countries need the most investment?

Which existing transmission lines need to be upgraded?

Which regions/countries stand to benefit the most from new transmission lines?

We need open data and models

Despite their multinational nature, there is a distinct lack of openly available data and analyses covering the global transmission network.

This hinders our ability to make good decisions.

TransitionZero's ambition is to break down the data and modelling barriers.

Our Analysis

We use our cutting-edge energy systems models to test two scenarios to reach net-zero

We assume two grid expansion scenarios

Scenarios in *Cables to change the world* is underpinned by TransitionZero's Future Energy Outlook (FEO) platform, an open-source energy systems planning tool that will be Beta-launched at COP

In one scenario, today's grid remains fixed and only capacity expansion is utilized to reach net zero. The second scenario that allows for grid upgrades yields higher savings. The difference between the two scenarios represents the opportunity cost of no action on grids. Full details and methodology are available in the Technical Annex.

Scenarios

No Grid Scenario (NGS)

Meet net-zero by 2040 **without** expanding existing grid systems

Grid Upgrade Scenario (GUS)

Meet net-zero by 2040 **allowing** expansion of existing grid systems

FEO: A global energy systems planning model

- 2020–2040
- Covers 163 countries and 99% of the world's population
- Subnational scale (at least one node per country)
- Hourly, seasonal and annual representation
- Captures generation, storage and transmission systems

Results database

- Total System cost (USD)
- Generation Capacity (GW)
- Storage Capacity (GWh)
- Grid Capacity (GW)
- Emissions (MtCO2eq.)

Findings

Quantifying the global consequences of inaction on transmission systems

Grid expansion could save nearly $3 trillion

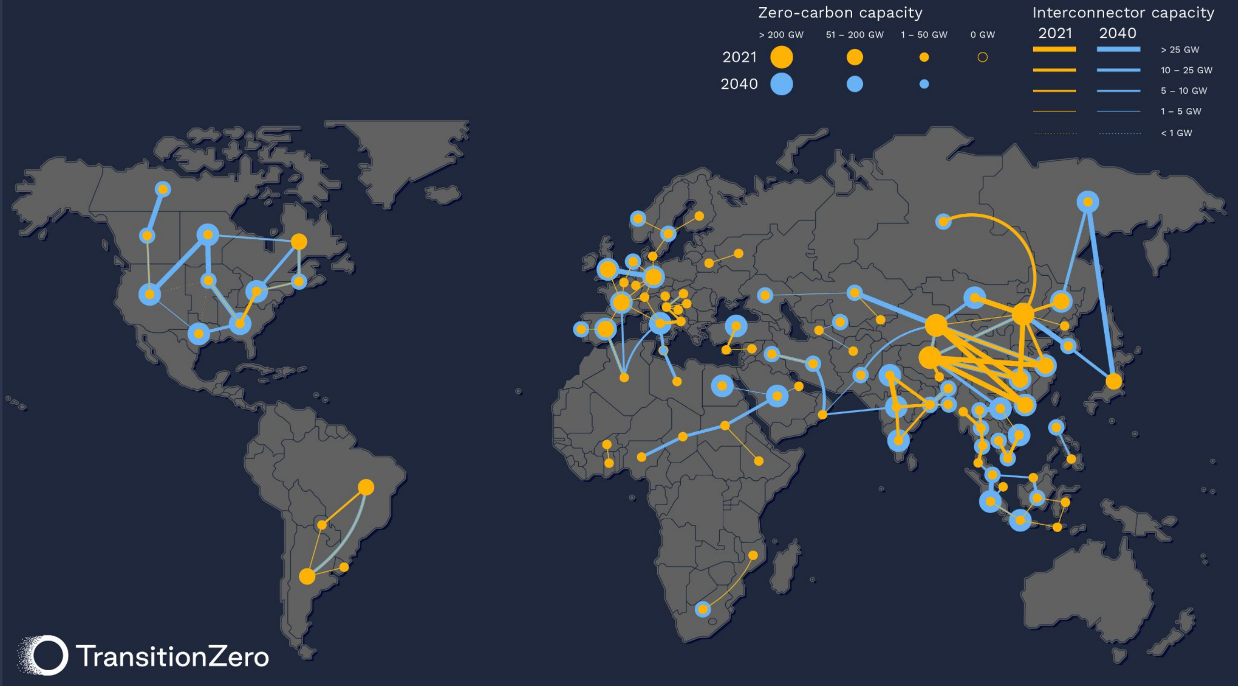
- Cost savings calculated as the difference in total system costs between the two scenarios (NGS–GUS).
- Savings vary by region and country (see Table)
    - Africa and Asia become net-exporters of clean electricity. While this sees their system costs increase, this would be offset by export revenue.
    - North America stands to benefit the most from interconnectors, saving over $1.5 trillion in transition costs.
    - Europe, Middle East and Southeast Asia also see substantial savings.
- Economic **savings could be greater** still when resilience benefits are considered.

Region	Additional transmission (Gigawatts)	Cost saving (USD billion)
Africa	37	-106
Southeast Asia	231	99
Rest of Asia	946	-164
Middle East	53	898
Europe	74	350
North America	372	1,572
Latin America	15	97
World	1,528	2,980

Source: TransitionZero, 2023

Grids act as global clusters and corridors of trade

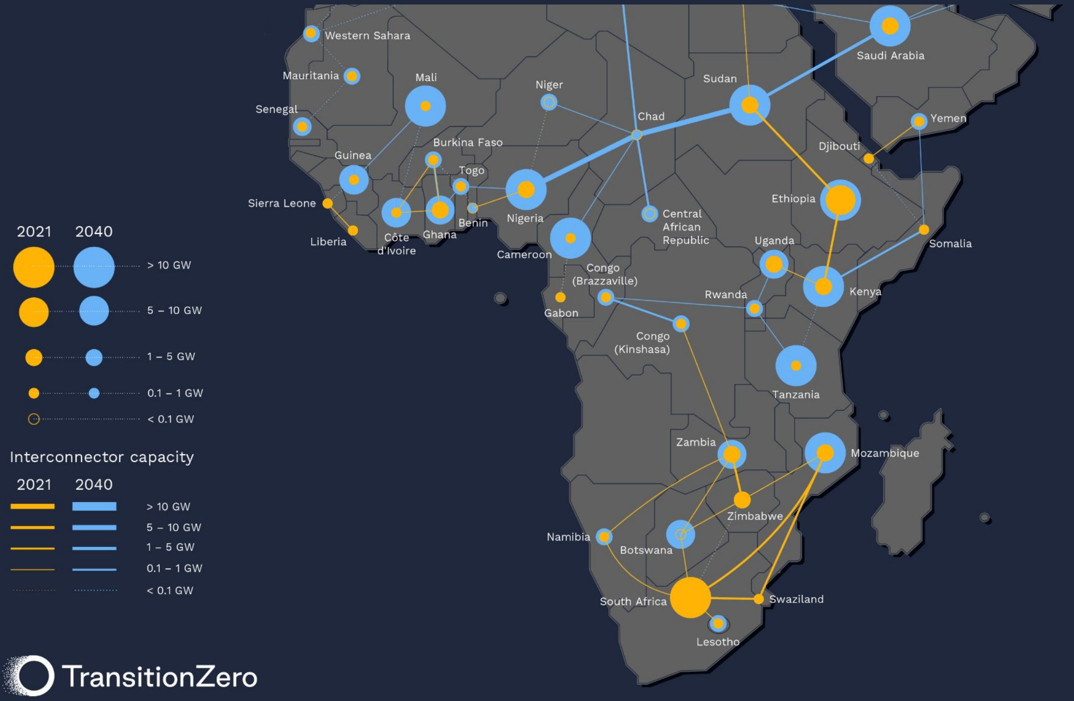
- Massive expansions of zero-carbon generation and transmission across the world.
- East-to-West corridors from Asia.
- Notably, no major transmission build outs in Africa.



In-Focus: Africa

Sub-Saharan Africa needs a balance of interconnectors and mini grids

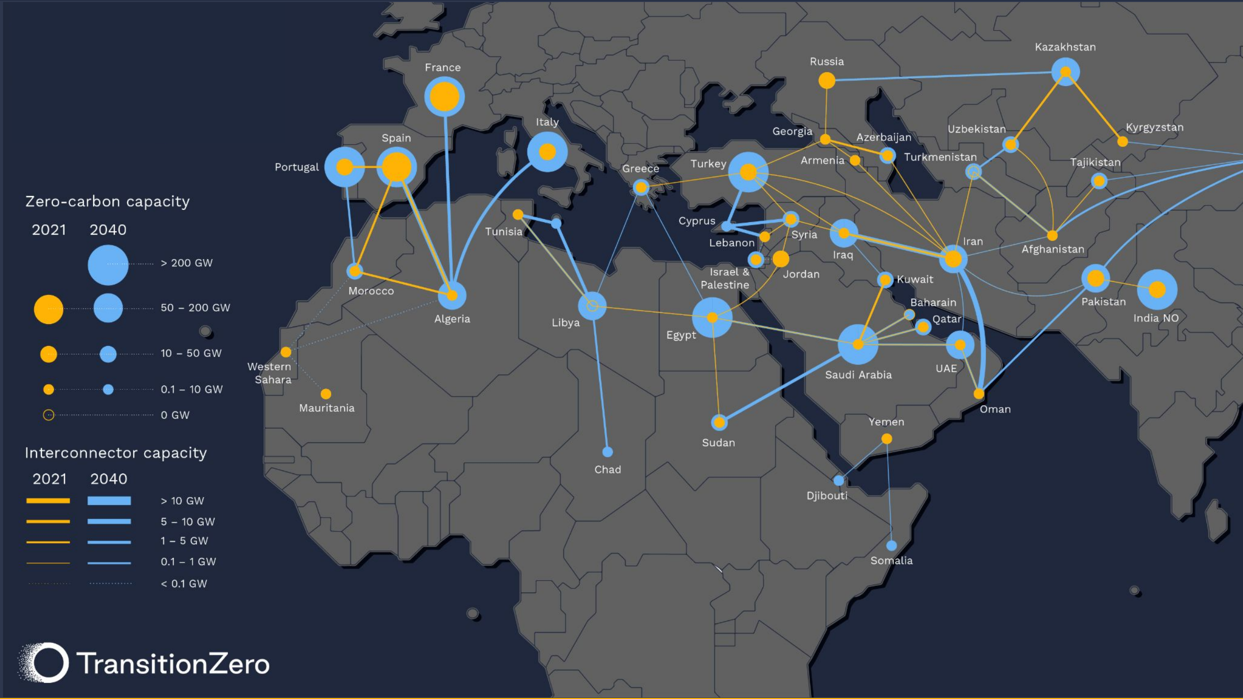
- Our analysis does not support a case for an African super grid as has been proposed by some. Mega projects may not be the solution here.
- New interconnectors link Middle East and Asia with large demands across Central Africa.
- Total zero-carbon capacity reaches 460 GW, comprising solar PV (18.3%), onshore wind (20%), offshore wind (11%) hydro (31%), and nuclear (2.5%).



In-Focus: Middle East and North Africa

MENA becomes the world's electricity hub

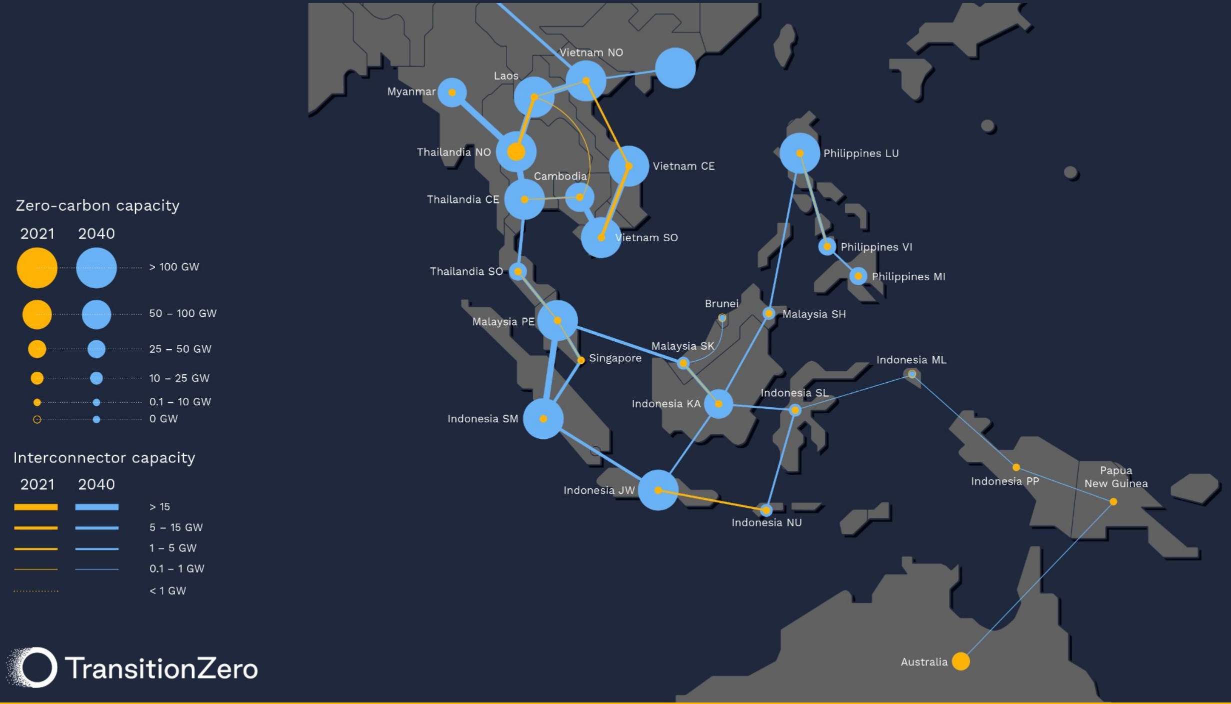
- MENA countries become exporters or hubs to Asia, Europe and Africa.
- New Euro-African ties see clean power exports from North Africa into Europe.
- Total system capacity reaches 2000 GW, made up of solar PV (27%), onshore wind (33%), offshore wind (10%) hydro (2.5%), and nuclear (1%).



In-Focus: South East Asia

A regional power cluster could unlock clean power in SEA

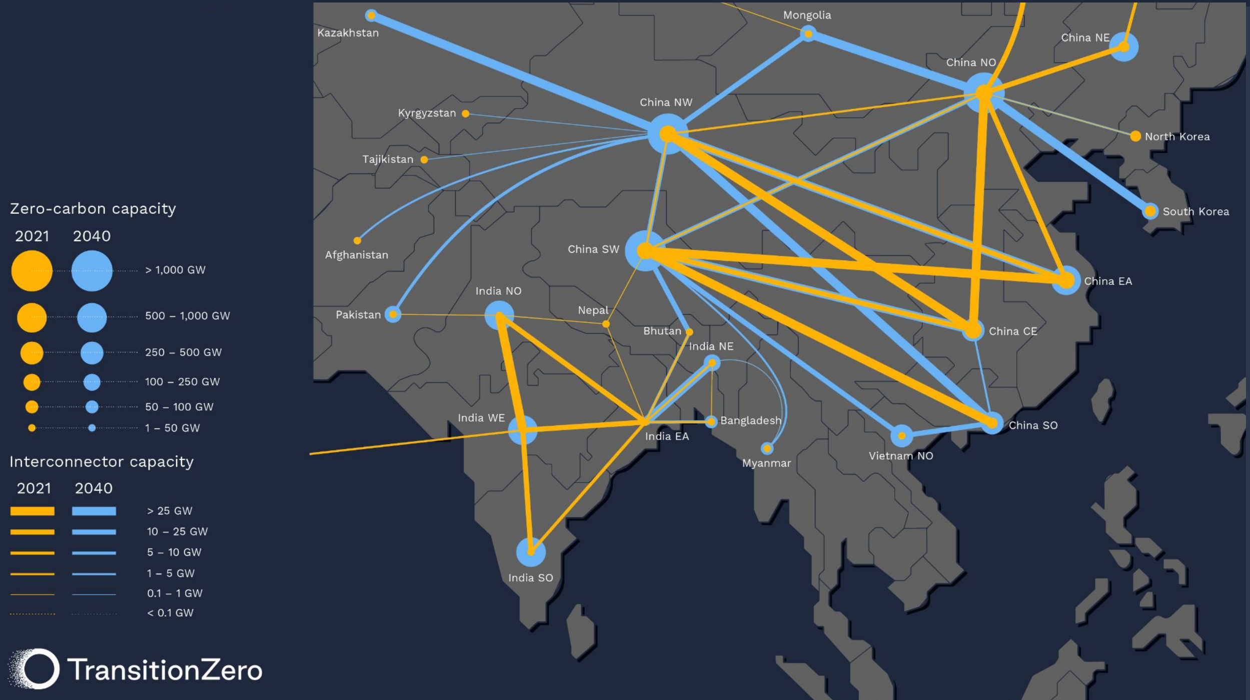
- There is strong potential for zero-carbon power across SEA. Nonetheless, a regional grid system is built-out.
- SEA countries have a complementary power system, which suits connectivity.
- Total power capacity mix amounts to 2800 GW, comprising solar PV (29%), onshore wind (33%), offshore wind (10%), hydro (9%), and nuclear (1%).



In-Focus: China and India

China and India can become renewable energy powerhouses

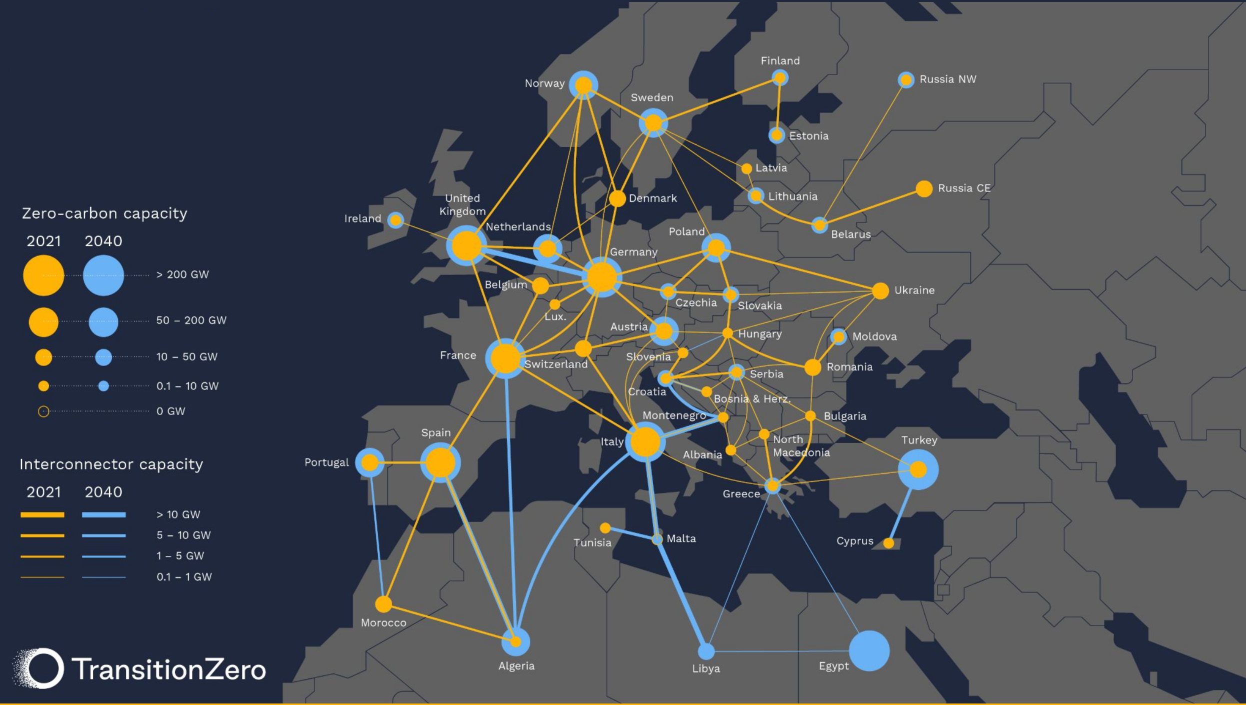
- China becomes the largest exporter of clean power globally by 2040 (5000 TWh per annum).
- Despite their significant exports, both countries still import some electricity. This highlights that interconnectors lead to **reciprocal** power exchanges.
- Total zero-carbon capacity reaches a staggering 10,600 GW made up of solar (40%), wind (25%), hydro (4%) and nuclear (13%).



In-Focus: Europe

Strengthening Euro-African links can help decouple Europe from Russia

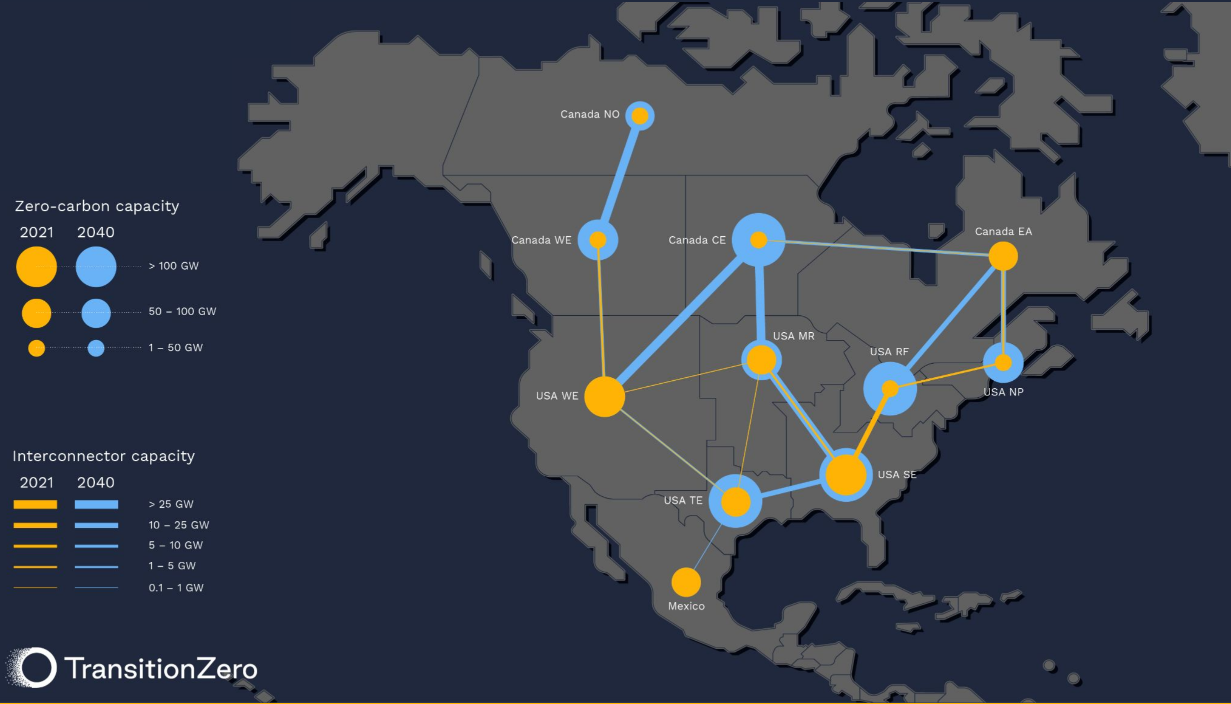
- Europe's power network is already highly connected. This sees modest expansions by 2040, which create new trade relationships with Africa.
- Interconnectors enable Europe to import power from Algeria, Tunisia, Libya, Egypt and Turkey.
- Total zero-carbon capacity reaches 3000 GW made up of solar PV (32%), onshore wind (19%), offshore wind (15%) hydro (17%), and nuclear (6%).



In-Focus: North America

The trillion dollar relationship between the USA and Canada

- There is limited integration in the Canadian American power system today.
- Total grid capacity between the two reaches 419 GW by 2040, representing a 13-fold increase relative to today.
- Transition costs in North America reduce by $USD 1.5 trillion if transmission cables are reinforced.
- Zero-carbon portfolio reaches 3100 GW made up of solar PV (28%), onshore wind (26%), offshore wind (16%) hydro (9%), geothermal (1.6%) and nuclear (2%)



In-Focus: Latin America

The new Pan-American highway

- Transmission cables spanning a distance of nearly 10,000 km see power flowing across Latin America and beyond.
- Total grid capacity amounts to 48 GW in 2040.
- Reinforcing transmission avoids around 70 GW of zero-carbon generation.
- Total zero-carbon capacity reaches 330 GW by 2040, comprised of solar PV (16%), onshore wind (16%), offshore wind (10%) hydropower (50%), and nuclear (1%)

Ten cables to change the world

Cables that, if built, could accelerate the zero-carbon power transition

TransitionZero

Cables to change the world

Implemented correctly, these ten cables could accelerate the global transition to zero-carbon power.

These ten links represent bulk capacity of interconnectors between two regions. In reality, some of these bulked links will be many individual interconnectors.

Link	Region	Capacity (GW)	Rationale
Canada Central — USA Midwest	North America	100	• Regions with large demand. • Strong existing trade relationships. • Large untapped offshore wind and hydropower potential.
USA Midwest — USA Southeast	North America	100	• Addresses critical existing transmission bottleneck. • Complementary renewable potential: solar in the Southeast and wind in the Midwest
South China — Southwest China	Asia	92	• Regions with large and growing demand. • Facilitates massive uptake of zero-carbon energy in the country. • Unlocks export potential and encourages grid flexibility.
East India — Northeast India	Asia	42	• Facilitates massive uptake of zero-carbon energy in the country. • Unlocks export potential.
Germany — United Kingdom	Europe	36	• Connects two large European demand centres. • Complementary generation mixes. • EU power trading is long-established.
Argentina — Brazil	Latin America	22	• Facilitates significant zero-carbon deployment in Argentina, allowing it to become a net-exporter by 2040. • Builds on existing bilateral relationships in power sector.
Saudi Arabia — Sudan	Middle East and North Africa	18	• Exploits Saudi Arabia's vast zero-carbon potential. • Opens up greater power trading relationships between Middle East and North Africa.
Algeria — Spain	North Africa and Europe	14	• Diversifies imported supplies to Europe, building on the Morocco-Spain link. • Provides Algeria valuable export revenue. • Builds greater technical and diplomatic ties on energy between Europe and North Africa.
Tunisia — Malta — Italy	North Africa and Europe	15	• Vital connection for Malta, which is essentially an energy-island. • Links Europe with the Pan-Arab power grid, enhancing supply security for many countries in the region
Indonesia — Singapore	Asia	7	• Singapore's decarbonisation target amidst scarce domestic resources. • Existing Memorandum of Understanding (MOU) between countries.

Policy Insights

Urgent and practical steps to enable transmission build out

Enablers that promote greater transmission rollout

Policies and planning processes must address the many barriers to the scale of transmission buildout that is necessary to support net zero energy systems

01

Reform transmission planning and permitting urgently

New transmission projects can take decades to build, blocking construction-ready zero-carbon energy projects from feeding into the grid.

Protracted and inefficient transmission planning and permitting processes need to be reformed to enable faster and more cost-effective transmission rollout. Such regulatory and policy reform must ensure that environmental and community checks in these processes are preserved.

02

Set long-term national targets for transmission

Grid development is a large-scale and multi-year undertaking. As with any complex sector, master planning exercises with clear pathways, milestones and review processes can ensure timely delivery and policy adjustments.

At a country level, this means that transmission should be integrated into the wider capacity planning. Such processes can also improve coordination between decision-makers and responsible entities.

03

Attract investment by identifying the no-regret options

Building the grids of the future will require trillions of dollars of capital, meaning blended finance mechanisms will likely be essential. Uncertainty and risk perception still hinder capital flows into projects that will enable the energy transition. It is therefore essential for energy managers to identify no-regrets transmission projects that can offer reliable returns. Energy systems models can help derive a merit-order list of options that could bring the greatest impact.

Enablers that promote greater transmission rollout

Addressing barriers to transmission should align with countries' social and economic development priorities

04

Prepare labour force and supply chains

Transmission projects will be rolled out simultaneously across the world, creating stiff competition for labour, materials and supply chains. Without proactive planning, these factors could become constraints.

Worker upskilling and training programmes will need to be put in place, alongside a robust national industrial strategy to ensure timely construction of transmission lines.

05

Ensure public stakeholder engagement and inclusion

Public support and community buy-in is vital for building new power cables. Project developers will need to account for and mitigate against *NIMBYism*.

Community engagement and communication strategies need to be devised to ensure stakeholders are properly consulted and that real value is secured for hosting communities.

06

Assess potential for international cooperation

Put simply, a decarbonised power sector without international cooperation on interconnectors is unlikely to happen, as illustrated by our analysis.

In a time of increasing protectionism, countries need to explore opportunities for cooperation with their neighbours to coordinate transmission rollouts, while balancing the associated risks.

Contributors

This study was led by the Energy Systems Modelling (ESMOD) team at TransitionZero.

We would like to thank our partners at Dartmouth College, Simon Fraser University, University College London and Climate Compatible Growth who contributed to this work.

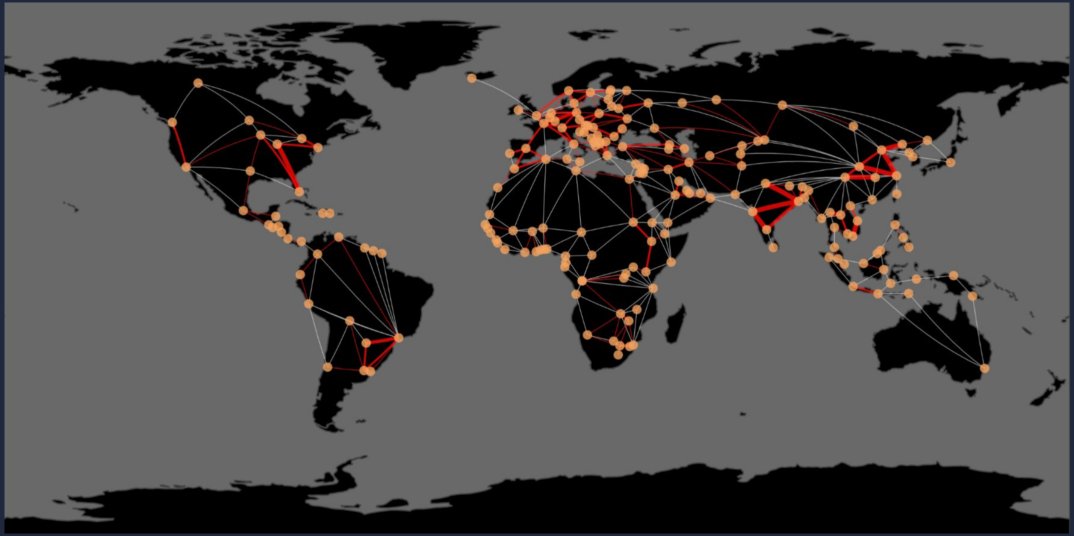
Maarten Brinkerink (Dartmouth College) and Trevor Barnes (Simon Fraser University) helped author the blog and technical annex.

Maarten Brinkerink (Dartmouth College), Gordon Sherman (Dartmouth College), Simone Osei-Owusu (University College London), Reema Mohanty (Climate Compatible Growth), Trevor Barnes (Simon Fraser University), Taco Niet (Simon Fraser University) and Erin Mayfield (Dartmouth College) all contributed to the underlying data in this work.

Appendix

Geographical scope

FEO covers 163 countries and 99% of the world's population



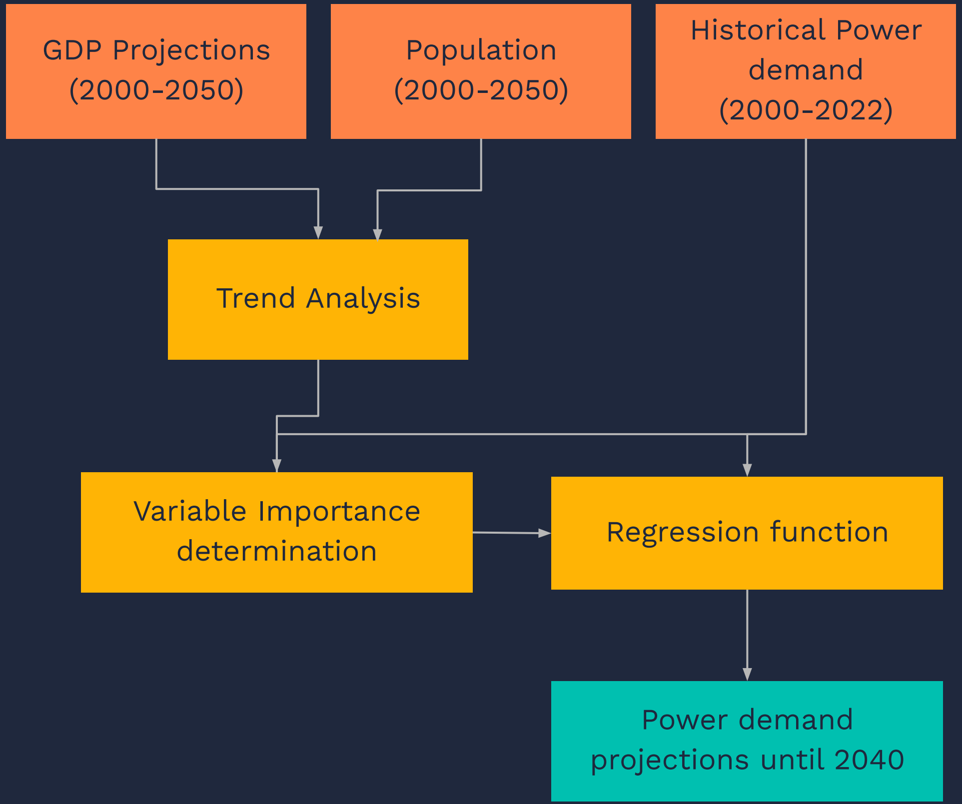
153 countries are represented at the national level and the remaining 10 at the sub-national level.

Country/Region	Number of nodes
Canada	4
USA	6
Russia	7
India	5
China	7
Indonesia	7
Vietnam	3
Malaysia	3
Philippines	3
Thailand	3
Rest of the world	153

Source of graph goes here (DATE)

Demand projections

- A unique demand curve is assigned to each of the **201 unique nodes**.
- Demand curves are annualised and computed between 2020 and 2050.
- We use a four-step method to compute annualised demand projections:
  - Collate historical GDP, population trends and power demands
  - Forecast future trends of GDP and population growth using an appropriate statistical model (linear, polynomial or exponential)
  - Combine the trends with historical power demand to determine appropriate weighting
  - Use a regression model to forecast power demands



Renewable energy potentials and profiles

How do we calculate renewable potential? And how do we represent variability in renewables?

- Renewable potentials for solar photovoltaic (PV), onshore wind, and offshore wind were computed across each of the 201 model nodes. This process involves calculating the available area for new projects, ensuring for instance that agricultural or cultural heritage sites are excluded.

- Hydropower potentials were obtained from Hoes et al. (2017), an online database providing a collection of potential hydropower locations. This information was aggregated at the node level after excluding any potential locations within protected areas.

- Profiles for onshore wind, offshore wind, and solar PV were extracted from Renewables.ninja. This platform utilises the VWF model to convert wind speed data from NASA MERRA reanalysis data into power output and computes solar profiles using the GSEE model (Global Solar Energy Estimator).

- Hydropower profiles were obtained from the PLEXOS World Model data. This in turn consolidated location-specific monthly capacity factors for every hydro power plant (7155 in total) from the Global Reservoir and Dam Database (GRAND) and a study by Gernaat and colleagues.

Scenario design

- Main goal of this study is to assess the techno-economic benefits of increased interconnection across the global power system in the net-zero transition.
- We assume two scenarios (Table)
- Both scenarios achieve net-zero in the power sector by 2040, emphasising an orderly transition. They focus on maintaining security of supply with well-planned and synchronised policies.
- Choices regarding technology use are influenced by factors such as cost, how advanced the technology is, market conditions, existing infrastructure, and policy priorities.

Scenario	Description
No Grids (NGS)	Meet net-zero by 2040 **without** expanding existing grid systems
Grid Upgrades (GUS)	Meet net-zero by 2040 **allowing** expansion of existing grid systems

Interconnectors candidates

How do we choose which interconnectors are allowed or not?

- We assume interconnector capacities can be expanded between any country or region that are geographically adjacent or those that already have an existing connection, including by means of subsea interconnectors (e.g., France and United Kingdom).

- We also conducted a country-by-country analysis to map feasible expansions or new connections. In this case, qualitatively assessed announcements, pledges and planned projects, while also conducting a literature review on theoretically positive connection points (e.g. Australia - Indonesia).

- Similarly, we also assessed whether certain connections are unlikely to be expanded or created based on costs or geopolitics (e.g., Ukraine and Russia). In these cases, we prohibit the model from building between these regions or countries.

The global interconnectors database is open-source

Download Study Database (Zenodo)

The database includes existing- and planned interconnector capacities between all countries globally as well as inter-regional capacities for a sample of larger countries (Australia, Brazil, Canada, China, India, Indonesia, Japan, Philippines, Russian Federation, Thailand, United States, Vietnam). For this study, we only integrate existing interconnector capacities given that the database is still in development when it comes to planned interconnector capacities. Capacities from interconnectors with higher spatial detail as provided in the database are aggregated to match the spatial representation as used for this study.

Interconnectors costs

Parameter	Unit	HVAC	HVDC	HVDC Subsea
CAPEX Line	$2020/MW/km	779.4	237.8	295.1
CAPEX Converter Pair	$2020/MW	47,699.8	148,754.5	148,754.5
Fixed O&M Costs	% of CAPEX/yr	3.5	3.5	3.5
Line Losses	%/1000 km	6.75	3.5	3.5
AC/DC Converter Pair Losses	%	0	1.3	1.3
Technical Life	yr	40	40	40

Power plant data collection and standardisation

How do we calculate renewable potential? And how do we represent variability in renewables?

- Powerplant data was obtained from the Global Energy Monitor's (GEM) power plant trackers. These trackers provide detailed information about power plants, including their capacity, location, and start date. This information was consolidated and standardised to ensure consistency.

- Subsequently, we harmonised this data with the specific nodes employed in the model. This matching process was facilitated by employing latitude and longitude coordinates, enabling us to compute the total power capacity associated with each node.

Inclusion Criteria:

Our dataset encompasses power plants that meet the following statuses as labelled by GEM.

- ***Operating:*** These are plants that have been successfully commissioned and are now operating commercially.
- ***Under Construction:*** These are plants in which equipment installation is actively underway.
- ***Permitted:*** This category comprises power plants that have obtained all the necessary environmental approvals, even if physical construction has not yet commenced.

Technology costs

Technology capital and fixed operating costs were sourced from the IEA's 2022 World Energy Outlook Report, and extracted from the IEA's 2050 Stated Policies scenarios for Europe, United States, Japan, Russia, China, India, Middle East, Africa and Brazil.

Key assumptions include capital costs sourced were considered on a weighted average basis, with costs associated with renewable energy technologies and CCS-equipped power plants based on below assumed learning rates sourced from IEA (IEA, 2022).

Renewables Category	Plant Specification	Technological rate of learning
Bioenergy	Large-scale unit	5%
	Medium-scale CHP	5%
	Small-scale CHP	5%
	Biogas	5%
	Waste incineration	5%
	Cofiring	5%
Geothermal	Geothermal electricity only	5%
	Geothermal CHP	5%
Hydropower	Large-scale unit	1%
	Small-scale unit	1%
Solar Photovoltaic	Large-scale	20%
	Buildings	20%
Concentrated Solar Power		10%
Marine		14%
Wind Energy	Onshore	5%
	Offshore	14%

Fuel costs

Fuel Price Data

The fuel price data utilised in this study is sourced from the Climate Compatible Growth (CCG) data repository available on the CCG Energy and Transport Starter Data Kit website. The dataset encompasses various fuel types, including Crude Oil, Heavy Oil, Light Oil, Biomass and Coal. This data is projected up to the year 2050, captured at 5-year intervals. The base year for calculating fuel prices is referenced as USD 2020.

References for Base Year and Fuel Price Projection Calculation

- IRENA, Planning and prospects for renewable power: West Africa, International Renewable Energy Agency, Abu Dhabi, 2018
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- World Energy outlook 2016
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