Applied Energy 265 (2020) 114778

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Complexities and contradictions in the global energy transition: A re-evaluation of country-level factors and dependencies

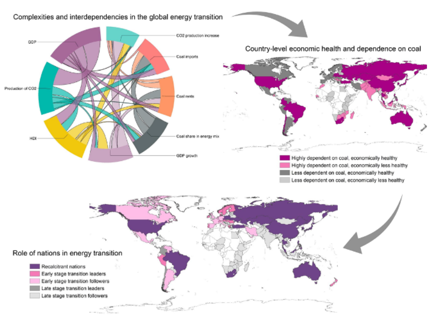
K. Svobodova*, J.R. Owen, J. Harris, S. Worden

Centre for Social Responsibility in Mining, Sustainable Minerals Institute, Sir James Foots Building (47a), The University of Queensland, St Lucia Campus, QLD 4072, Australia

HIGHLIGHTS

- Research maps global potential for nations to achieve coal phase-out goals.
- Assessment framework measures country level factors affecting phase-out.
- A final sample of 118 countries was analyzed based on the framework.
- Dependences between CO_2 emissions, size of economy and coal imports are shown.
- Enhanced country-level understanding of global transition landscape.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Climate change
Economic growth
Renewable energy
Just transition
Coal phase-out

ABSTRACT

The aim of this paper is to map the potential for nation states to adapt to global coal phase-out targets. An assessment framework using three core indicators: 'economic health', 'dependency on coal' and 'carbon contribution to climate change' is used to identify key constraints and contradictions. The indicators include 8 secondary measures. From a complete global list of 264 countries provided by World Bank, a final sample of 118 countries was selected, based on availability of data for the indicators. The sample was further refined using a two-step process. First, 118 countries were characterized according to their capacity to transition from coal (combining 'economic health' and 'dependency on coal') then divided into 4 groups of countries (A-D). Second, the groups were categorized by their level of carbon dioxide (CO_2) contribution. This step resulted in a further refinement of the categories showing the different constraints to nations achieving set transition goals. In designing and analyzing our framework, we considered the importance of interrelationships between the measures. 'Carbon contribution to climate change' and 'economic health', in particular, show strong links across the evaluated indicators. Our research demonstrates a direct correlation between CO_2 emissions and the size of national economies, as well as the important role of coal imports in transitioning market systems. Green growth is widely promoted as a lever for continued economic expansion. The new energy-efficient technologies and capital investment required for this environmentally sustainable economic growth, however, present significant challenges, particularly for nations that have historically contributed little to global CO_2 levels. This article provides a comprehensive multi-step analysis of country-level dependencies that will shape the decision-making pathways available to individual nation states. Recalcitrant nations frame this pathway as a trade-off between short-term economic viability and long-term, even deferrable, climate security issues. While policy platforms that defer climate action are becoming deeply unpopular in most democratic societies, there remains the fundamental question of how coal-dependent nations will stabilize their economies in the absence of coal. In a choice between imperfect alternatives, conservative politics appears to gravitate towards maintaining a cautious

* Corresponding author.
E-mail addresses: k.svobodova@uq.edu.au (K. Svobodova), j.owen@uq.edu.au (J.R. Owen), jill.harris@uq.edu.au (J. Harris), s.worden@uq.edu.au (S. Worden).

https://doi.org/10.1016/j.apenergy.2020.114778
Received 12 December 2019; Received in revised form 25 February 2020; Accepted 27 February 2020

balance of market protectionism with the façade of supporting incremental investments in cleaner energy alternatives.

1. Introduction

Demand for climate action is at peak levels. Following the Paris Agreement in 2015, fundamental changes have emerged in the structuring of finance and public policy. For instance, more than 100 major financial institutions created or strengthened policies to divest from thermal coal [1]. To date, 477 institutions have signed the Global Investor Statement to Governments on Climate Change, calling for a complete thermal coal phase-out by 2050; in China by 2040, and in the OECD and EU by 2030 [2]. In fiscal terms, these institutions represent more than US$34 trillion in assets. The movements suggest that coal mining and coal-fired power will become unsustainable in the near future. However, in this same period, global CO_2 emissions increased by more than 2% [3]. In 2018, coal consumption increased after three years of decreases [4]. Moreover, the share of fossil fuels as a function of total primary energy supply has remained at 81% for the past three decades [5]. This landscape of ambitious financial and policy reforms set against deeply entrenched patterns of energy usage highlights the complexity of a global transition to a lower-carbon energy system.

The call for a low-carbon energy future is driven by a range of factors, including health impacts from air pollution [6,7], market forces [8,9], energy security [10,11], and a popular movement calling for climate change mitigation [12,13]. Many urban centers have air quality levels that fall below the World Health Organization's (WHO's) guideline of 10 μg/m^3 for fine particulates. National governments are instigating air pollution reduction targets. China, for example, has set a target of 35 μg/m^3 for all cities [6], which is in line with the WHO Interim 1 target [14]. Electric cars, buses and trains are being introduced to reduce pollution, and renewable energy generation is being installed. Market forces, such as record level deployment of renewable technologies and infrastructure, a 50% drop in oil prices, growth in oil shale production in North America, and the rising cost of thermal coal production, are contributing to the diversification of the global energy mix [9,15].

Key challenges remain for energy transition, particularly imbalances in the development pathways between individual countries, and the need for rapid and unprecedented global-scale solutions. The energy transition agenda faces major uncertainties, including scale, complexity and interdependencies across different systems [11]; the pressure of economic growth on emission reductions [7,16]; energy justice [17–19], equitable transition [20,21]; global versus national interests [22,23]; the pace of change required to meet the Paris Agreement [6,15]; the ability to attract investment for transition [24,25]; structural issues [26,27]; and the regulatory environment [9,28]. All this is accompanied by the continuous increase of energy consumption in emerging countries [9]. As the energy world is largely intertwined, developments in the energy sector of one large economy will have direct or indirect effects on another.

One global-scale solution proffered under the Paris Agreement is Nationally Determined Commitments (NDCs). The 195 parties to the agreement are required to outline and submit their post-2020 climate actions, or NDCs, to the UNFCCC secretariat every five years [29]. According to Jernnäs et al. [22], NDCs represent a 'pledge and review' approach rather than legally binding targets and timetables. They note that most NDCs include a mix of substantive and procedural policies aimed at influencing the production and consumption of societal goods and services. However, the documents lack detail, such as how the market and governance mechanisms will be implemented and assessed. Delina [30] argues that NDCs are insufficient in their ambition, and analysis from the Climate Action Tracker [31] supports this view. Twenty-four of the 31 NDCs being tracked are rated as critically insufficient (≥ 4 °C; e.g. the USA and the Russian Federation), highly insufficient (< 4°C; e.g. China and South Africa) or insufficient (< 3 °C; e.g. Australia, Canada and Norway).

Jewell et al. [32] argue that coal phase-out is feasible when it does not incur large-scale economic losses, such as the closure of newly constructed power plants or coal mines or significant market restructures. Germany, for instance, has earmarked €40 billion to compensate affected coal regions as part of its ambitious coal phase-out plan by 2038 [33]. China's five year plans have set ambitious targets for energy consumption per unit of GDP, CO_2 emissions per unit of GDP and increases in renewable energy production. According to Campbell [34], China has been the top investor in clean energy for nine of the past 10 years. In 2019 the country pursued plans to build more new coal power plants than the rest of the world combined. China is also actively financing a quarter of all new coal projects, primarily in developing countries [35]. Advanced economies such as the United States and Australia exhibit less extreme but similar contradictions in the management of their coal sectors due to powerful mining interests and vague plans to exit. The United States, for instance, has signaled its intention to withdraw from the Paris Agreement, citing national interest concerns [31]. India recently opened its coal sector for foreign investment as national coal power plants become unprofitable compared with renewable wind and solar energy alternatives [36]. Russia, the world's sixth largest coal producer and fourth largest emitter of carbon dioxide from fossil fuels, ratified the Paris Agreement in 2019 without clear coal phase-out plans.

National transition pathways are diverse and complex. To understand the dependencies and contradictions associated with plans to phase-out coal globally, we examined country-specific circumstances and points of connectedness between the energy systems of different societies and economies. Although an extensive literature exists on energy transition policies, there is an acute lack of research demonstrating the country-level constraints to realizing global transition goals. This paper maps the potential for individual nation states to phase out coal-based power. For the purposes of this paper, we review the transition potential based on national capacity, ability and urgency to transit using key indicators developed in our assessment framework.

2. An assessment framework for analysing country-level factors

The World Energy Council [37] frames energy transition as occurring through established economic, social and political systems that have their own scope, key players, priorities and challenges. Progress has been impeded due to the scale and complexity of the available transition pathways. Scale refers to the extensive energy supply chain; the size of installed power generation capacity around the world; the level of capital investment; and the global, national, sub-national and individual decision-making landscape. Complexity arises from divergent system components and their interdependency with external mechanisms recognizing that an action in one system can affect an initiative in another.

To examine country-level potential to phase out coal and the roles of particular state nations in the global transition, we designed an assessment framework comprising three key indicators: 'economic health', 'dependency on coal' and 'carbon contribution to climate change'. The indicators are composed from country-level measures as shown in Fig. 1.

'Economic health' and 'dependency on coal' consider the ability of nations to adapt to coal phase out; and 'carbon contribution to climate change' indicates the urgency of transition. For example, a country with high economic health, low dependency on coal and high carbon

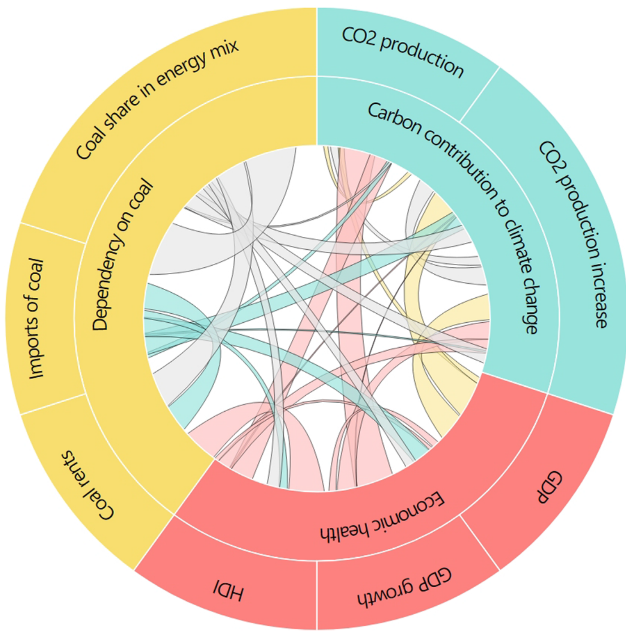


Fig. 1. Scheme of the assessment framework.

contribution to climate change is considered highly capable of sustaining a transition and changing its energy policy and systems. Due to high carbon contribution, it should start transitioning urgently. On the other hand, a country with poor economic health, high dependency on coal and high CO_2 emissions, is regarded as having a low likelihood of phasing out coal by 2050.

The assessment framework aims to map the global composition of countries based on their profile, which is characterized by relationships between the indicators. Identifying groups of countries with similar conditions provides a picture of global transition capacity, which can reveal potential roles, path direction and speed of change in the uptake of energy initiatives.

2.1. Economic health

Gross national income and human well-being are used to measure the economic health of countries in terms of their capacity to transition to non-coal sources of energy. To measure economic health, Human Development Index (HDI) [38], gross domestic product (GDP) [39] and GDP growth were combined [40]. These measures provide a means of establishing a country's level of human development, the size of its overall economy and long-term economic performance. Including these three measures is important to avoid forming misleading conclusions about the underlying economic prospects of a given country. For instance, a large national GDP does not necessarily mean that the residents of that country are doing well. Similarly, high GDP growth does not necessary equate to healthy economic performance. Economic well-being, as measured by GDP, can be used as a positive indicator for developing countries like China and India, where greater fiscal capacity can be utilized to improve the well-being of many. Once a country reaches a threshold point in its economic prosperity, economic growth and human well-being can then be separated.

The Human Development Index is a summary measure of a country's overall achievement in core dimensions of human development, such as people's health, level of education attained and standard of living. HDI represents the geometric mean of normalized indices for each of the three dimensions. The health dimension is assessed by life expectancy at birth. The education dimension is measured by: mean of schooling years for adults aged 25 years+, and expected years of schooling for children of school age. The standard of living dimension is measured by gross national income per capita. HDI uses the logarithm of income to reflect the diminishing marginal utility of transforming income into human capabilities. In this study we use the 2017 set from the UNDP database [38]. Thresholds were set using the UNDP's Human Development Indices and Indicators Statistical Update [41]. All countries with a HDI of 0.7 or higher are considered to have high levels of human development.

Gross domestic product (GDP) provides an economic snapshot of a country and estimates the size of its economy. It is the monetary value of all the finished goods and services produced within a country's borders during a year. GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes, minus any subsidies not included in the value of the products. GDP rather than GDP per capita was used in this research to avoid misleading interconnections with HDI data where the GNI coefficient is included. Data were drawn from the 2018 World Bank database [39] and are in current U.S. dollars, converted by the World Bank from domestic currencies using single year official exchange rates. In this study, countries with GDP above US$100 billion are considered to have large economies with high GDP.

GDP growth is commonly used as a yardstick to measure economic performance between countries. A country with high GDP growth is classified as economically healthier than one with a relatively low growth rate. However, arbitrarily categorizing an economy based solely on GDP growth rate may lead to deficiencies in the analysis and classification of an economy. A country with a low economic base would naturally have a high GDP growth rate compared with a developed country. The world's fastest growing economies are almost always developing countries that have started from low development baselines. As these countries build roads and schools, and introduce existing technologies, their economies grow quickly. Some countries in Africa and Asia, for example, grow at 8–9% per year. In contrast, for advanced economies with sizable GDPs like the United States, Canada and the UK, GDP growth rates of 2–4% per year are considered noteworthy [42]. To analyze long-term performance in GDP, data on GDP growth were calculated. A mean of 10 years (2008 to 2018) of national data published by World Bank database [40] was used. GDP growth of 2% or higher are considered to represent high, long-term economic growth.

2.2. Coal dependency

To map the importance of coal in a country's economy and energy needs, a combination of three measures were analyzed: coal rents (% of GDP), coal share in the energy mix (% of total energy consumption), and import of coal (% from total energy imports). While coal rents show size of the profit from coal in GDP, coal share in the mix and coal imports indicate reliance on coal for national energy supply.

Earnings from coal account for a sizable share of GDP in some countries. Much of these earnings come in the form of economic rents, i.e. revenues above the cost of extracting the resources. **Coal rents** refer to the difference between the value of both hard and soft coal production at world prices and their total costs of production. This study uses 2017 coal rents data from the World Bank database [43]. We consider coal rents above 0.1% GDP to be high.

Coal share in the energy mix shows coal's contribution to final energy consumption of the national energy mix. While some countries are heavily coal dependent upon a narrow range of another energy sources, others have a diversified energy mix. Data were drawn from 2016 *Energy Balances* datasets [44]. We used data on final consumption of coal as the bottom block of an energy balance in the mix that refers to all fuel and energy that is delivered to users for both their energy and non-energy uses. Countries with 5% or more coal in the energy mix consumption are considered to have a high share.

A country's reliance on coal imports has implications for its energy security. We assess **imports of coal** as % of total energy imports using datasets published in 2016 *Energy Balances* [44]. Countries are considered to be significant coal importers when their total energy imports comprise more than 20% coal.

2.3. Carbon contribution to climate change

The Intergovernmental Panel on Climate Change [45] is more than 95% confident that over the past 60 years human activities have increased the global average temperature. The statistics are staggering. Since 1751, the world has emitted more than 1.5 trillion tons of CO_2 [38]. Over the past 150 years, industrial activities have raised atmospheric CO_2 levels from 280 parts per million to 400 parts per million. Stepping down from the global to national level, we mapped countries' contributions to global CO_2 emissions using 2017 data from the CO_2 Global Carbon Atlas dataset [46]. The data represent CO_2 emissions from the combustion of fossil fuels, cement production and land-use change over multiple decades, including their drivers. Annual CO_2 production above 100Mt CO_2 is considered to be high and countries at this level are considered to be major emitters.

To track long-term performance in production of CO_2 emissions, we used a measure **CO_2 production increase**. The measure maps changes in national CO_2 production over the past decade. The data were calculated as a mean of countries' CO_2 emissions from 2007 to 2017 using the CO_2 Global Carbon Atlas dataset [46]. We consider production increases greater than 1Mt CO_2 to be significant and more than 10Mt CO_2 to be a major long-term increase.

All data used in this study reflect the latest country level information available for each analyzed measure. The data were downloaded from reliable public sources. Although particular measures are from different years, the purpose of this research is to map the latest publicized performance rather than the performance of a given country in one particular year.

3. Sample, analytical groupings and data analyses

To understand the global picture of countries in the coal phase out, a multi-step sampling methodology was used. From a complete list of 264 countries published by the World Bank [47], a final study sample of 118 countries was selected based on data availability of measures in the proposed assessment framework. All countries with missing HDI, GDP or CO_2 emissions data were removed in favor of those with full data records.

The assessment framework utilized a two-step sampling procedure as shown in Fig. 2. First, a sample of 118 countries was divided based on their capacity and ability to transit from coal (combining two indicators: 'economic health' and 'dependency on coal'; see I. in Fig. 2), resulting in 4 groups of countries with different capabilities. Second, the groups were categorized in terms of their CO_2 contribution indicating urgency and pressure to transit, which led to 8 final groups of countries (see II. in Fig. 2). These countries have different national potential to exit coal.

Scatterplots were produced to examine the visual relationship of pairs of indicators and for the presence of outliers. Outliers were confirmed using an interquartile range rule: Q3 + 3(IQR) or Q1-3(IQR) and found to be present in the right tail of the distributions of the following variables: (i) GDP - the United States, China, Japan, Germany, United Kingdom; (ii) coal rents – Mongolia, Mozambique, South Africa; (iii) coal share in energy mix - Mongolia, Afghanistan, China, Lesotho, India, Kazakhstan, South Africa; (iv) import of coal – Madagascar, Russia, Lesotho; (v) production of CO_2 – China, the United States, India, Russia, Japan; and (vi) CO_2 production increase – Luxembourg, Finland. The logarithm transformation (log10) was used to normalize indicators with a positive skew and reduce the influence of outliers, except for CO_2 production increase where the cube root transform was used due to it having negative values. The scatterplots showed that curvilinear relationships existed between two sets of bivariates, being (i) GDP × CO_2 production increase and (ii) production of CO_2 × CO_2 production increase.

Pearson's *r* correlation tests were conducted to test the strength and direction of the relationships between indicators in the framework, and determine whether they were statistically significant. The relationship between indicators was considered to be strong if the *r* coefficient was equal to or greater than 0.50. The alpha value was set at 0.05 with *p*-values lower than this, indicating a statistically significant result (two-tailed). Bootstrapped 95% confidence intervals (BCa 95% CI) were conducted to further confirm correlation outcomes. IBM SPSS Statistics for Windows, version 25, was used to conduct the analyses.

4. Findings

4.1. Complexity and interconnectedness

The results of the Pearson's *r* correlation tests are shown in Table 1 and Fig. 3. There were 13 statistically significant associations whose correlation coefficients indicated a moderate to very strong relationship (i.e. ≥0.30).

In designing and analyzing the assessment framework, we note the importance of understanding the coexistence of measures and relationships between them. The linkages between measures inside an indicator (e.g. HDI and GDP in 'economic health'; coal imports and coal share in the energy mix in 'dependency on coal') and also between measures from different indicators (e.g. HDI and CO_2 production change or coal imports and production of fossil CO_2) suggest multiple impacts through the framework. In particular, 'carbon contribution to climate change' and 'economic health' indicators demonstrate significant links across the framework.

In terms of particular measures and their interconnections, a very strong, almost linear, positive correlation was identified between GDP and production of CO_2 emissions. This strongest relationship in the

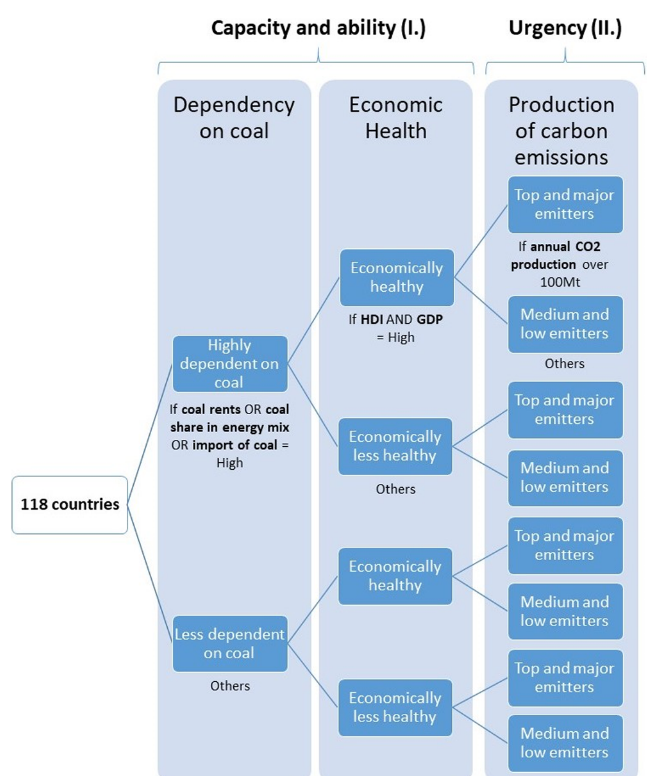


Fig. 2. A scheme of multi-step sampling. The sample of 118 countries was divided into 4 groups based on their capacity and ability to transition from coal (indicated by 'economic health' and 'dependency on coal'). These 4 groups were further divided into 8 groups based on urgency to phase out coal ('production of carbon emissions').

Table 1
Correlation coefficients between measures. Statistically significant relationships between the measures were calculated at two significance levels $p < 0.01$ and $p < 0.05$ (** significant at $p < 0.01$, v * significant at $p < 0.05$). Different strengths of correlation were identified in the data. If the Pearson correlation coefficient (r) was between 0.70 and 0.99, the correlation was very strong. Values between 0.50 and 0.69 indicate strong correlations, 0.30–0.49 moderate correlation, 0.10–0.29 weak correlation, less than 0.10 shows very weak or no correlation.

Variables		Economic health			Dependency on coal			Carbon contribution to climate change	
		HDI	GDP	GDP growth	Coal share in energy mix	Coal rents	Coal imports	CO_2 production	CO_2 production increase
Economic health	HDI	1.00	0.54**	-0.55**	0.07	-0.23	-0.02	0.43**	0.37**
	GDP	0.54**	1.00	-0.19*	0.17	-0.22	0.31**	0.93**	0.04
	GDP growth	-0.55**	-0.19*	1.00	0.11	0.30*	-0.01	-0.13	-0.58**
Dependency on coal	Coal share in energy mix	0.07	0.17	0.11	1.00	0.44**	0.56**	0.30**	-0.10
	Coal rents	-0.23	-0.22	0.30*	0.44**	1.00	-0.32*	-0.03	-0.15
	Coal imports	-0.02	0.31**	-0.01	0.56**	-0.32*	1.00	0.32**	-0.08
Carbon contribution to climate change	CO_2 production	0.43**	0.93**	-0.13	0.30**	-0.03	0.32**	1.00	-0.08
	CO_2 production increase	0.37**	0.04	-0.58**	-0.10	-0.15	-0.08	-0.08	1.00

Note. * $p < 0.05$, ** $p < 0.01$.

framework shows that GDP is deeply interconnected with CO_2 emissions, $r(1\ 1\ 8) = 0.93$, $p < 0.001$, BCa 95% CI [0.90, 0.95], Fig. 3a. A strong negative correlation was found between GDP growth and CO_2 production increase, $r(1\ 1\ 8) = -0.58$, $p < 0.001$, BCa 95% CI [−0.68, −0.45] (both measured as an average of records across the previous decade). The negative relationship shows that as CO_2 emission growth increases in value, the rate of long-term GDP growth decreases in value. Countries with long-term low GDP growth report continuously higher CO_2 emission increases than countries where GDP growth has been continuously high (see Fig. 3b). One explanation is that countries with high GDP but low GDP growth usually represent advanced economies. The carbon emissions of these countries are increasing as a consequence of keeping their developed economies high and continuing to grow. The significant moderate correlations between HDI and CO_2 emissions ($r(1\ 1\ 8) = 0.43$, $p < 0.001$, BCa 95% CI [0.29, 0.57]) and HDI and CO_2 emission increase ($r(1\ 1\ 8) = 0.37$, $p < 0.001$, BCa 95% CI [0.24, 0.50]) support these findings. Higher human development tends to be followed by high production of carbon emissions and their long-term increase to maintain standards of living in these countries. Moderate correlations were also found between CO_2 emissions and coal share in the energy mix ($r(1\ 1\ 6) = 0.30$, $p = 0.001$, BCa 95% CI [0.12, 0.44]), CO_2 emissions and import of coal ($r(1\ 0\ 3) = 0.32$, $p = 0.001$, BCa 95% CI [0.14, 0.50]), import of coal and GDP ($r(1\ 0\ 3) = 0.31$, $p = 0.002$, BCa 95% CI [0.94, 0.48]), and GDP growth and coal rents ($r(61) = 0.30$, $p = 0.02$, BCa 95% CI [0.60, 0.52]).

Some of the correlations between measures supported our rationale behind the design of the indicator framework. A strong positive correlation ($r(1\ 0\ 1) = 0.56$, $p = 0.001$, BCa 95% CI [0.25, 0.76]) was identified between coal share in the energy mix and coal imports – both variables of the ‘coal dependency’ construct (Fig. 3c). This strong relationship indicates the importance of coal imports for its share in national energy mix and the continuing value of this commodity in many countries. Our findings show that an increase in the share of coal in the overall national energy mix is followed by an increase of coal imports. This is evident in countries such as India, China and Hong Kong, that report high levels of coal consumption and high coal imports. However, there are exceptions, such as Mongolia and Cuba, with high coal share in their energy mix but with low imports. Another ‘inside indicator’ correlation was found between HDI and GDP ($r(1\ 1\ 8) = 0.54$, $p < 0.001$, BCa 95% CI [0.41, 0.66]). This strong positive correlation shows that level of human development tends to go hand-in-hand with size of the national economy (Fig. 3d), although there are exemptions, such as India and Indonesia, which have very high GDP but medium levels of HDI. If two countries have similar GDPs but their HDIs are out of sync, it can help policy makers identify the fundamental issues in their countries that need to be addressed, such as education or health. Countries with high GDP growth are fast growing economies and almost always developing countries with emerging economies and low levels of human development. Moderate correlations were identified between coal share in the energy mix and coal rents ($r(61) = 0.44$, $p < 0.001$, BCa 95% CI [0.14, 0.68]) and coal rents and Import of coal ($r(52) = -0.32$, $p = 0.02$, BCa 95% CI [−0.58, 0.01]). Although, for the latter correlation, it is important to note that the confidence interval boundary crosses zero, which means that the population coefficient could be zero [48]. Scatterplots characterizing all strong-to-moderate relationships in the framework are presented in Supplementary material 1.

4.2. Mapping the dependency landscape: Analytical groupings by country

We analyzed countries’ capacity to transit, indicated by their economic health and dependency on coal, which resulted in 4 groups of state nations with different capacities (A-D). These groups were further analyzed through the lens of national CO_2 emissions and countries were evaluated as ‘top and major emitters’ and ‘medium and low emitters’. This sampling enabled the characterization of 8 different groups of countries playing 6 different roles in the global transition landscape as shown in Fig. 4. The list of countries per group, with their particular roles in the transition, is provided in Supplementary Material 2.

The group A represents 21 economically healthy countries with high levels of coal dependency. Sixteen of these countries are major contributors of CO_2 emissions, led by China, United States and Russia as top world’s emitters, producing more than 1Bt CO_2 annually. The remaining 5 countries (Chile, Colombia, Israel, Hong Kong and Slovakia) are described as ‘late stage transition leaders’ and show medium CO_2 emission production, between 84 and 35Mt CO_2. Since human and economic development indicators in these countries are high, they are all capable of transitioning from coal to renewables. In terms of urgency of the change, the group of 16 top and major emitters (‘recalcitrant nations’) faces a high level of urgency to phase out coal. These nations have the capacity and, more importantly, the responsibility to lead climate change mitigation.

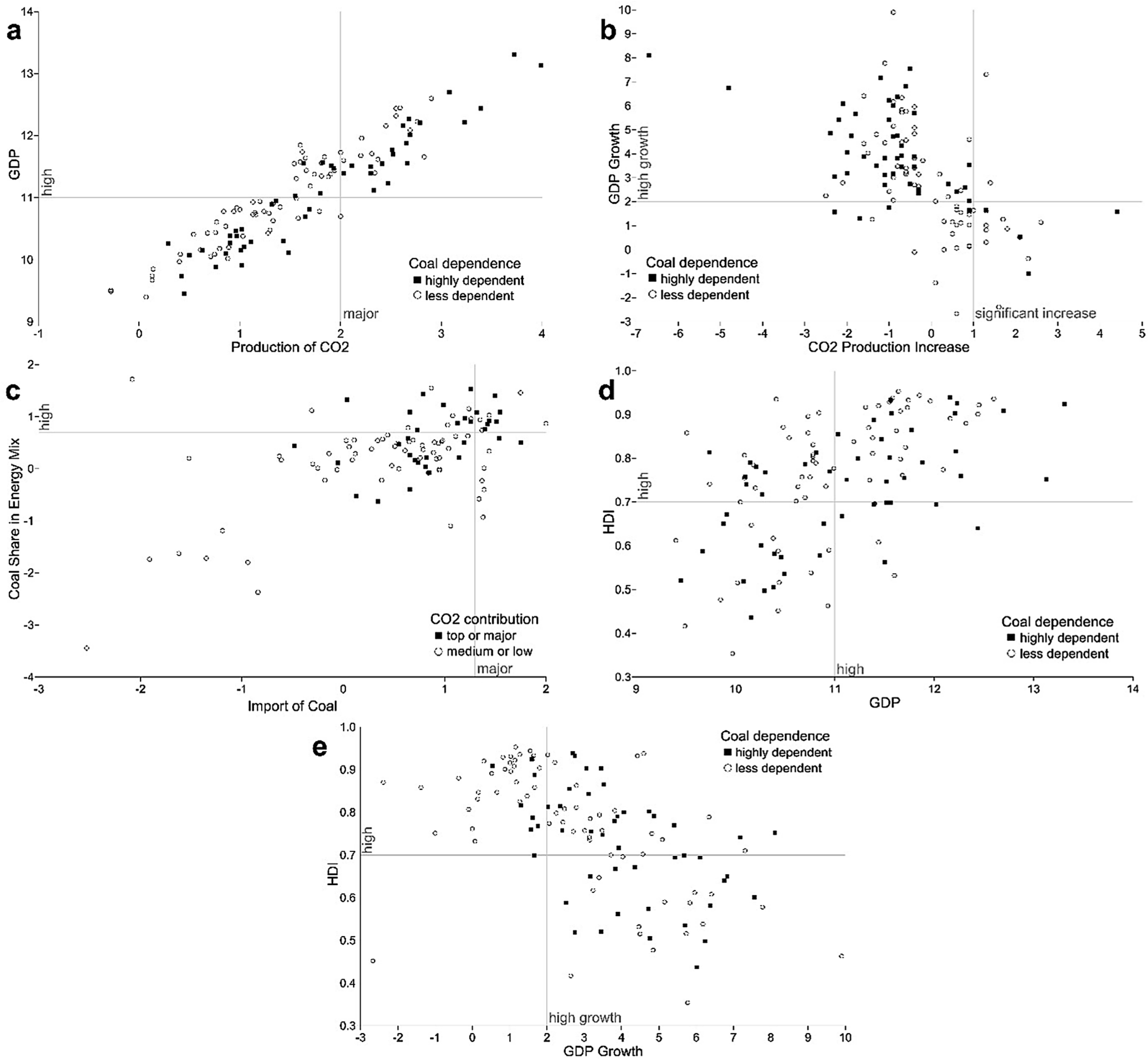


Fig. 3. Strong or very strong correlations presented in scatterplots show significant trends and relationships in the framework (a. GDP × Production of CO_2; b. GDP growth × CO_2 production increase; c. Coal share in energy mix × Coal imports; d. HDI × GDP; e. HDI × GDP growth). The countries presented in the points were coloured according to the non-represented construct using a dichotomous scale. Except where relationships were tested within a construct, in which case the effects of the other two constructs were explored separately.

The group B includes 28 state nations that are highly dependent on coal but, at the same time, they are not economically healthy enough to make the change without extensive external support. Their role in the transition was described as 'late stage transition followers'. In this group of countries, four major emitters (India, Indonesia, Pakistan, Vietnam) have a crucial role to play in urgently replacing their coal-based energy with renewables to decrease CO_2 emissions. Although the remaining countries in this group show medium-to-low CO_2 production, their dependency on coal is alarming and their capacity to transition is low, potentially facing a long and difficult transition path. To successfully transit from coal, these nations must diversify their energy mix, develop human capital for the future energy system and reduce fossil fuels subsidies.

The group C represents 27 nation states that are economically healthy with a low dependency on coal. Looking through the lens of CO_2 emissions, 2 different sub-groups with different transition roles are evident. The first sub-group ('early stage transition followers') includes 13 countries rated as major emitters, led by Germany (799Mt CO_2/y) and followed by Iran (672Mt CO_2/y) and Canada (572Mt CO_2/y). Although these countries have a diverse energy mix in terms of renewable sources, lower imports of coal or lower coal rents, their contribution to global CO_2 emissions is significant. Due to their very high stage of human and economy development, they are capable of decreasing their emissions. The second sub-group 'early stage transition leaders' represents 14 developed nations that already follow a greener path of development. These countries report medium-to-low production of carbon emissions, are wealthy, and have high levels of human development. They include, for instance, Austria, Denmark, Finland, Portugal and New Zealand. These countries have the capacity to be energy transition role models.

There are 42 countries in **group D** that are less dependent on coal, with less healthy or unhealthy human and economic development.

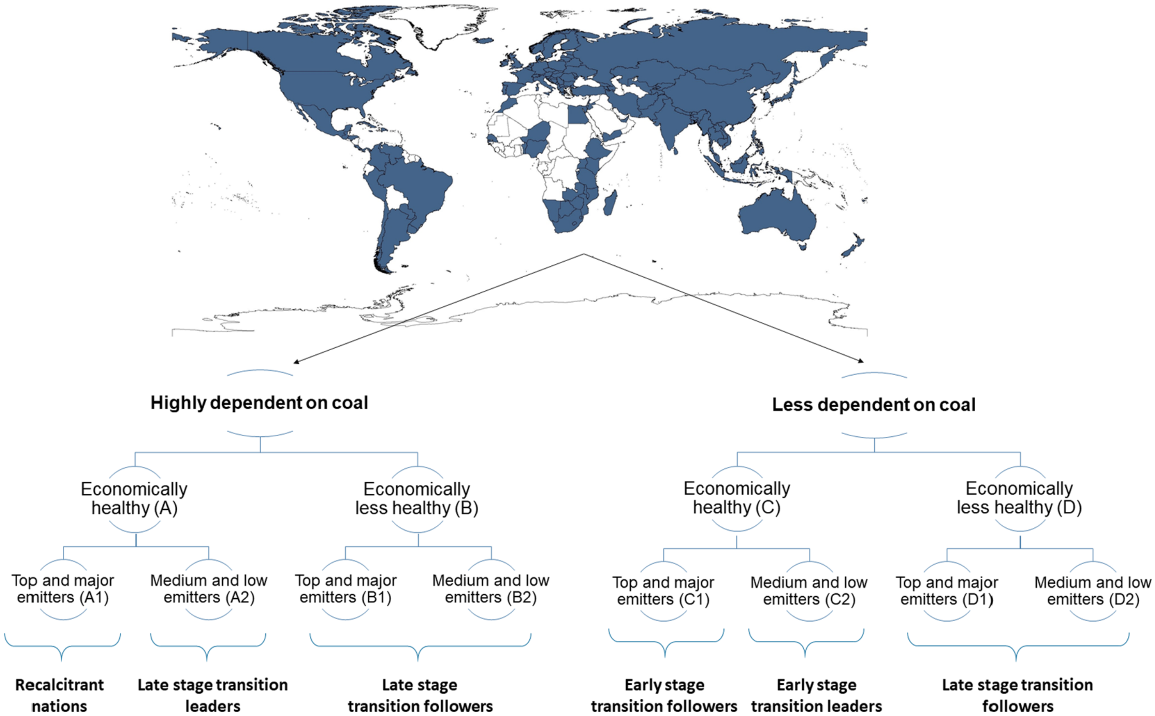


Fig. 4. Analytical groupings by country was applied in the framework. The sample of 118 countries was analyzed mapping national capacity and urgency to transit. Using a multi-step procedure combining indicators 'dependency on coal', 'economic health' and 'production of CO_2', eight groups of countries with different potential to transit from coal were identified. Within these groups, we suggest six different potential roles in the energy transition.

While two African states, Egypt and Nigeria, are major emitters, the remaining 40 countries report medium-to-low emission production. These groups primarily include post-Soviet, African and emerging Asian countries that face challenges delivering affordable, reliable power supply. These countries have a low capacity to deal with the substantial political and economic changes needed to increase their competitiveness in renewable energy markets. Their role in the transition is to achieve affordable and reliable power supply, and to stabilize their economic and human development status. We describe these countries as 'late stage transition followers'.

Identifying these groups and their roles in the global transition enable to characterize and explain contradictions associated with coal phase-out that occur worldwide and to suggest a variety of pathways to energy transitions in a current global energy landscape. These are discussed in the next chapter.

5. Discussion

The following sections outline key contradictions in the energy transition landscape that were highlighted by our findings. We discuss pathways and notable constraints for two groups of countries with the highest contribution to global CO_2 emissions where the prospects for change are regarded as highest. The groups are recalcitrant nations (A1) and early stage transition followers (C1).

5.1. Contradictions in energy transition landscape

The prospect of a global energy transition requires complex interaction between different systems. This leads to the range of diverse difficulties as shown by Creti and Nguyen [49] and Sung and Park [50]. A clear divergence is evident between an expressed urgent need for global action to phase out coal and the real-world increase in coal-generated power. Recent studies completed by Jewell et al. [32] and van Vuuren et al. [51] confirm it is unlikely that an absolute decoupling from carbon emissions will occur at a rate rapid enough to prevent a global temperature increase of 1.5 °C. Similarly, Spencer et al. [52] have pointed to practical challenges related to the geopolitics of supply and demand, national level dependencies on import and export revenues, in addition to sub-national factors, such as regional level employment in areas where few viable alternatives seem possible.

A major constraint concerns the reigning in of less developed, but rapidly emerging nations, such as India and China. Smaller nations where access to low-cost energy is considered essential to reaching internal human development targets are also constrained. Our research findings demonstrate a direct correlation between CO_2 emissions increases and national economic growth. Green growth is widely promoted as a lever for continued economic expansion [16]. The new energy-efficient technologies and the capital investment required for this strategy, however, present significant challenges, particularly for target nations that have historically contributed little in terms of global CO_2 levels, such as countries in Groups B2 and D2. This is akin to the problem noted by the German economist Friedrich List [53] "it is a very common clever device that when anyone has attained the summit of greatness, he kicks away the ladder by which he has climbed up, in order to deprive others of the means of climbing up after him". A radical emissions reduction strategy could focus on countries identified in Groups A1 (recalcitrant nations), C1 (early stage transition followers) and D1 (late stage transition followers). We argue, however, that progress towards meeting global targets are ostensibly more viable for Group C countries, given the low net cost of investing in energy infrastructure and reducing their domestic production of thermal coal. Moreover, this avoids the double-standard suggested in *Bad Samaritans* [53], in which wealthier countries undermine the development prospects of others through formalized trade conditions.

Economic growth is closely associated with increasing energy consumption [54]; and a country's stage of development is a dominating factor in this relationship [55]. For example, access to a reliable, affordable supply of coal-generated power has driven the major economic uplift witnessed among emerging Asian economies over the past decade. According to World Economic Forum [9], total primary energy supply for emerging countries in Asia grew by 28% over the past 8 years. Transformation in the Chinese economy is largely attributed to the country's investment in developing the energy infrastructure needed to connect people with modern opportunities and bulk services. An estimated 850 million people have been lifted out of poverty. The Chinese economic miracle is almost universally hailed as one of the greater success stories of the 21st Century [56]. The country has, however, the highest global production of CO_2 emissions and an infamous pollution crisis plaguing many of its key cities. The Chinese case raises the question of whether green growth is possible and, if so, on what scale and at what cost?

The difficult process of coal phase-out is more likely to be pursued by independent and transparent governments in wealthy countries in Groups A and C. These countries have the capacity to bear substantial political, social and economic risks. Lower costs of coal phase-out alone are not sufficient to trigger transition pledges by nation states [32]. A small coal sector, for example, with aging power plants provides a space for governments to choose between investing in energy alternatives or to underwrite the continued use of coal power with extra government support. The declining competitiveness of coal will not automatically lead to its demise, particularly in markets that have governments with close political ties to the coal industry or in circumstances where coal is both an affordable source of power and a major contributor to national GDP. Governments may choose to boost the use of uncompetitive coal through favorable regulation and subsidies, as in some post-Soviet countries in Group B2 [57–58].

Significant correlations between coal imports and GDP and coal imports and CO_2 production indicate the importance of coal imports and exports for transition pathways and their interconnections with national economic development. In this way, Climate Transparency [59] argues that declining global coal demand will have the most significant effect on the largest coal exporters, such as Australia (37% of global coal exports), Indonesia (16%), Russia (12%), the United States (9%) and South Africa (5%) [60]. The International Energy Agency (IEA) estimates when declines in demand from the largest coal importers will occur [61]. Coal demand in China, for instance, is projected to decline from the early 2020 s, as a result of heavily saturated industrial growth, the country's clean air measures and its broad-scale commitment to investment in renewables. India's thermal coal imports are expected to decrease due to the government policies to reduce the country's long-term dependence on foreign sources of fuel [62].

Differences between the capacity and likely speed of transition are apparent across the groups identified in our research. For instance, in the past six months Finland (C1) and the Netherlands (C2) have accelerated their coal phase-out from 2030 to 2029. The Austrian (C2) Minister of Environment has announced a coal phase-out by 2020, five years ahead of previous commitments. While Spain (C1) and the Czech Republic (A) are currently formulating their coal phase-out targets, Poland (A), Romania (C2) and Turkey (A) have yet to commence their policy journey in this area [63].

5.2. High capacity, high impact countries and their transition status

'Early stage transition leaders' tend to be wealthier countries. Their transparent and independent governments notionally enable them to formulate and implement coal phase-out policies. Most C2 countries have already made advanced phase-out pledges, including the early retirement of a number of coal power plants [63]. In the following section, we focus on two groups: recalcitrant nations (A1) and early stage transition followers (C1). These groups are wealthy countries that have the largest impact on emissions. Within those groups, we highlight 6 countries with significant influence over the global transition landscape. Since Group A1 represents countries with the highest dependency on coal, we focus on this group. We further discuss the global transition status for: China (A1), Australia (A1), Germany (C2), Japan (A1), the United States (A1) and Russia (A1). China is the world's top CO_2 emitter, the largest producer and consumer of coal, the largest user of coal-derived electricity and, most importantly, the largest international funder of coal projects [64]. Australia is the largest global exporter of coal (37% of global coal exports). Germany has been the world's largest lignite producer since the beginning of industrial mining, and has emerged as an energy transition leader among major industrial economies. Japan is the biggest global coal importer (18% of global imports). The United States and Russia are the top CO_2 emitters and they have weak national renewables commitments.

China, given its population and global economic ambitions, is clearly a pivotal country in the post-Paris era. According to Simon Nicholas, an analyst at the Institute for Energy Economics and Financial Analysis, Beijing's championing of renewables is 'partly an attempt to position itself globally regarding climate issues, but also to distract from the fact that it's also heavily pushing coal-fired technology to developing countries' (cited in [34]). Though the country is assumed to be making significant progress in phasing out its dependency on coal, the key measures on economic health and energy mix indicate that any major changes will happen at an incremental pace. China's coal production is presently reported at about 1.5 times larger than Canada on a per capita basis, and supplies approximately 69% of the country's energy needs. Human development targets, relative to other Group A countries, suggest lower levels of economic health, a key deterrent. A further disincentive is the median age of the country's coal power fleet, estimated to be just over a decade old [32], suggesting that it could be several years before the cost-benefit of transition can be substantiated in economic terms. Efforts to stabilize coal use in order to minimize its negative social and environmental effects over the medium term are largely linked to these constraints. The Chinese government has no public phase-out plans for coal but has stated its intent to reduce the share of the country's overall energy mix from 64% in 2019 to 58% by 2020 [65]. The government introduced strict requirements for the construction of new coal power plants in 2016 to prevent an oversupply in specific regions. China's air pollution policies, recently strengthened through the 2018–2020 Air Pollution Plan, have already resulted in reduced coal use. In 2019, the government announced trial periods for a new emissions trading scheme for the power sector. According to Climate Transparency [59], China has no long range renewables target but is aiming to reach 680GW of installed renewable capacity by 2020. The country is expected to surpass its 2020 solar energy target, the result of a successful feed-in tariff system. There are almost 3.5 million workers in the country's coal mining sector. The Chinese government has allocated 30 billion yuan (US$4.56 billion) over the 2018–2021 period to support the closure of small, inefficient coal mines [59]. In addition to decommissioning a large number of coal projects, this move will have pronounced regional economic effects on urban centers whose viability until now has depended greatly on the coal economy. Moreover, the closure of these mine is expected to displace one million jobs [66], which are to be redeployed through programs supported by a government-established fund.

Australia is the biggest net exporter of coal, accounting for 32% of global exports in 2016 (389Mt out of 1213Mt total), and was the fourth-highest producer with 6.9% of global production (503Mt out of 7269Mt total). Three quarters of production (77%) was exported (389Mt out of 503Mt total) [67]. There is no existing policy to accelerate the phase-out of coal in Australia, apart from the nationally stated renewable energy target, which will expire in 2020. According to current government plans, it is not anticipated that the plan will be replaced. Like China, sub-national constraints play a considerable role in determining the direction of national policy efforts. While a number of older coal-fired power plants have been decommissioned, the government is reluctant to move against coal due to its economic importance in predominantly agricultural regions where drought conditions have drastically altered the viability of transition alternatives. New coal power generation capacity is widely seen as high risk by the private sector. The permitting of coal projects continues to challenge the government and there is growing public awareness of the tensions between climate and economic viability.

Germany is frequently identified as the frontrunner in the transition to renewable energy. Plans are in place to decommission nuclear power plants by 2022, replacing them with hydrogen technologies. Germany's ambition is to become a global leader in this sector [68]. The country already produces 38% of its electricity from renewable sources, mostly wind and solar. Although Germany may not have a carbon footprint as small or as quickly decreasing as some Scandinavian countries from 'early stage transition leaders' (C2), it remains the only major industrial economy that has steadily decreased its reliance on fossil fuels over almost a quarter century. The first phase of Germany's energy transition focused on creating a market for renewables where gradual saturation and investment among market leaders resulted in lower technology costs. The country pushed ahead with its so-called feed-in tariffs enabling citizens, communities, municipalities and cooperatives to participate in the energy transition. As a result of this policy, more than 40% of the country's facilities producing clean power are owned by citizens, farmers and cooperatives. This helped Germany reach its renewable energy goals and created a democratic energy system. The second transition phase deals with managing the increasing renewables inventory while controlling cost and access across the system. The strategy favors large developers who can operate at scale, and this has invoked criticism over the competitiveness and inclusiveness of the system [69]. Observers have argued that despite progress, policymakers have largely disregarded the vast societal benefits that come with the switch to renewables, and have failed to develop a long-range vision to meet the kinds of transition objectives advocated by its citizens. Turner [70] suggests that more than 90% of German citizens support an expedited approach to energy transition, a level of popular consensus atypical in modern democracies. With around 46.5GW of open coal capacity, the country is unlikely to meet its 2020 climate target [63].

Under the current 2030 Strategic Energy Plan, **Japan** aims to reduce its share of coal power in the national electricity mix to 26% (from 32% in 2016) [59]. This goal would see coal power and renewables reach similar levels within the national energy mix by 2030. Like China, Japan has not adopted a 2050 renewables target. In April 2019, the Japanese government published a draft long-term strategy for transitioning to low-carbon alternatives, that references the global 'just transition' agenda. However, the draft contains few details on the range of resourcing, timeframes or policy commitments needed to realize this ambition. At the beginning of 2019, Japanese banks and trading houses began withdrawing from coal power projects, with several financiers divesting their interest in Australian-based coal mines (Japan is Australia's largest export customer). Meanwhile, major Japanese investors are seeking to back large-scale renewables projects across Asia [71].

The United States has no federal plans to phase-out coal in power generation. The current Trump administration vowed to revive the coal industry and, in 2017, started processes to repeal the Clean Power Plan established under the Obama administration. In line with other nations in the A1 and C1 groupings, the United States has not declared a 2050 target for renewable energy. In 2018 the federal government introduced tariffs on the import of solar panels that led renewable energy companies to freeze or cancel investments of around US$2.5 billion [59]. Despite the policy inertia at the national level, there is notable variation the policy discourse and actions by states. California has long advocated for energy diversification. The state has more than 30% of its energy mix derived from renewable sources and less than 3.5% from coal [72]. States in the Appalachian coal region (e.g. Kentucky, West Virginia) established the Power Plus initiative in 2015 to offset the negative effects of demobilizing from coal, including worker retraining and underwriting benefits accrued by the sector's long-term workforce.

The **Russian** government aims to increase the share of coal in electricity generation by 16% to 17% until 2035, which implies a 24% increase of coal consumption by 2035. This runs counter to the trend promoted by other Group A1 nations. Unsurprisingly, the country does not have a public agenda for phasing coal out of its energy mix. According to its 2009 Strategy for Development of Renewable Energy, Russia aims to marginally increase the share of renewables in the electricity mix from around 1% to 2.5% by 2020. The previous target of 4.5% by 2024 has since been abandoned and there are no longer-term targets for renewable energy [59]. Like the United States, Russia has focused on deepening its own energy security, given rising concerns over future world conflicts and disruptions to global supply as pressure mounts around major energy corridors to which Russia's economic prosperity is inextricably linked. The government has proffered policies that encourage the development of renewables using long-term capacity agreements that are expected to continue for at least the next decade. Following the collapse of the Soviet Union and heavy industries, Russia has already experienced the realities of managing the economic costs of transition. These include supporting the mass migration of workers from industrial sectors, particularly coal mining that could no longer be sustained through a highly centralized, almost insolvent state.

6. Conclusions

What is clear from this research is that the global energy system is complex and any wholesale endeavor at deep structural changes will require countries to take both economic and political risks. Coal dependent nations face myriad challenges in their energy transition journey for precisely these reasons. We provide a comprehensive review of the global transition landscape. We identify the high country-level dependences that will shape the decision-making pathways available to individual nation states. Recalcitrant nations frame this pathway as a trade-off between short-term economic viability and long-term, even deferrable, climate security issues. While policy platforms that defer climate action are becoming deeply unpopular in most democratic societies, there remains a fundamental question of how coal-dependent nations will stabilize their economies in the absence of coal. In a choice between imperfect alternatives, conservative politics in Group A1 nations, in particular, appears to gravitate toward maintaining a cautious balance of market protectionism with the façade of supporting incremental investments in cleaner energy alternatives.

Coal mining, as any other mineral extraction activity, relies on the location of deposits. The implications of the energy transition will therefore be substantial at the sub-national level for regions whose local economic health is primarily coal dependent. If coal is to be successfully phased-out of the global electricity mix, even at a devastatingly slow rate by non-coal producing nations as first leaders, a more robust discussion is needed about socially and economically just alternatives for coal dependent regions. Policy coordination is required at the global level if we are to avoid a situation where wealthier and willing nations, say in Group C2, determine the pace of change for emerging countries, where access to affordable coal is a clear pathway to realizing human development goals; while economically powerful nations in Group A1 resist from the sidelines.

Our research contributes to a broader understanding of the global transition landscape. It illustrates the implications for individual nations, based on their own characteristics, of striving to meet the objectives of the Paris Agreement. Shallow coordination between countries, guided by deep structural constraints at the national level, is evident. The conditions for global coordination are weak given the regional differences, varying dependencies between nations, and the enormous costs that only some advanced developed nations can carry. Research confirms a uniformity of approach among nations based on short-term economic opportunism. In other words, there is a direct correlation between country-level pledges to phase out coal and the low financial and political costs associated with demobilizing stranded assets and managing the economic fallout within regions. There are, however, exceptions, such as Germany and the Netherlands. Despite their inherent positions of advantage, these countries are developing future transition pathways that less advantaged nations can consider when restructuring their energy policies.

CRediT authorship contribution statement

K. Svobodova: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **J.R. Owen:** Supervision, Conceptualization, Methodology, Resources, Writing - original draft, Writing - review & editing. **J. Harris:** Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization. **S. Worden:** Conceptualization, Methodology, Investigation, Resources, Writing - original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Part of this research was jointly funded by the Transforming the Mine Lifecycle and Complex Orebodies programs at the Sustainable Minerals Institute, The University of Queensland in Australia.

Data Availability

The authors are willing to share the datasets used for this research in Excel format with those who wish to replicate the results of this study. Please contact the corresponding author Dr Kamila Svobodova (k.svoboodva@uq.edu.au; +61 733461366).

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apenergy.2020.114778.

References

[1] Buckley T. Over 100 global financial institutions are exiting coal, with more to come Retrieved from Cleveland: Institute for Energy Economics and Financial Analysis; 2019.
[2] 27four, Aalto University Foundation, APK, Aberdeen Standard Investments, ABP, Achmea Investment Management … Zurich Insurance Group. Global investor statement to governments on climate change; 2019. Retrieved from https://globalinvestorcoalition.org/wp-content/uploads/2019/09/190916-GISGCC-for-UNCAS.pdf.
[3] Mead L. IEA, Global Carbon Project forecast global CO_2 emissions growth Retrieved from SDG Knowledge Hub: International Institute for Sustainable Development; 2019.
[4] Dawid I. Global coal consumption grows after three years of decline Retrieved from https://www.planetizen.com/news/2018/11/101411-global-coal-consumption-grows-after-three-years-decline; 2018.
[5] International Energy Agency (IEA). Global energy demand grew by 2.1% in 2017, and carbon emissions rose for the first time since 2014; 2018a. Retrieved from https://www.iea.org/newsroom/news/2018/march/global-energy-demand-grew-by-21-in-2017-and-carbon-emissions-rose-for-the-firs.html.
[6] Ma J. The economics of air pollution in China: Achieving better and cleaner growth; 2016. Retrieved from http://ebookcentral.proquest.com.
[7] Proedrou F. Energy policy and security under climate change. Cham: Palgrave Macmillan; 2018.
[8] Basso L, Viola E. Chinese energy policy progress and challenges in the transition to low carbon development, 2006–2013. Revista Brasileira de Política Internacional 2014;57:174–92. https://doi.org/10.1590/0034-7329201400211.
[9] World Economic Forum. Fostering effective energy transition. Geneva: Author; 2019. Retrieved from http://www3.weforum.org/docs/WEF_Fostering_Effective_Energy_Transition_2019.pdf.
[10] Herran DS, Fujimori S, Kainuma M. Implications of Japan's long term climate mitigation target and the relevance of uncertain nuclear policy. Climate Policy 2019;19(9):1117–31. https://doi.org/10.1080/14693062.2019.1634507.
[11] Rocco R. Policy frameworks for energy transition in England: challenges in a former industrial city. J Settlements Spat Plan 2016;5:41–52.
[12] McCauley D, Heffron R. Just transition: Integrating climate, energy and environmental justice. Energy Policy 2018;119:1–7.
[13] Delina Laurence L. Conclusion Retrieved from Accelerating sustainable energy transition(s) in developing countries: The challenges of climate change and sustainable development2017. p. 170–2.
[14] World Health Organization (WHO). WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide: Summary of risk assessment Retrieved from Geneva: Author; 2005.
[15] Yanguas Parra PA, Ganti G, Brecha R, Hare W, Schaeffer M, Fuentes U. Global and regional coal phase-out requirements of the Paris Agreement: Insights form the IPCC Special Report on 1.5 °C. Climate Analytics; 2019. Retrieved from https://climateanalytics.org/publications/2019/coal-phase-out-insights-from-the-ipcc-special-report-on-15c-and-global-trends-since-2015/.
[16] Hickel J, Kallis G. Is green growth possible? New Polit Econ 2019. https://doi.org/10.1080/13563467.2019.1598964.
[17] Castán Broto V, Baptista I, Kirshner J, Smith S, Neves Alves S. Energy justice and sustainability transitions in Mozambique. Appl Energy 2018;228:645–55. https://doi.org/10.1016/j.apenergy.2018.06.057.
[18] Sareen S, Haarstad H. Bridging socio-technical and justice aspects of sustainable energy transitions. Appl Energy 2018;228:624–32. https://doi.org/10.1016/j.apenergy.2018.06.104.
[19] Sovacool BK, Dworkin MH. Energy justice: conceptual insights and practical applications. Appl Energy 2015;142:435–44. https://doi.org/10.1016/j.apenergy.2015.01.002.
[20] International Bank for Reconstruction and Development & World Bank. Turkey's energy transition: Milestones and challenges. Report No: AC14951; 2015. Retrieved from http://documents.worldbank.org/curated/en/249831468189270397/Turkey-s-energy-transition-milestones-and-challenges.
[21] Wolfe R. Why wealthy countries must not drop nuclear energy: coal power, climate change and the fate of the global poor. Int Affairs 2015;91(2):287–301.
[22] Jernnäs M, Nilsson J, Linnér B-O, Duitc A. Cross-national patterns of governance mechanisms in nationally determined contributions (NDCs) under the Paris Agreement. Climate Policy 2019. https://doi.org/10.1080/14693062.2019.1662760.
[23] Cherp A, Vinichenko V, Jewell J, Brutschin E, Sovacool B. Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. Energy Res Social Sci 2018;37:175–90. https://doi.org/10.1016/j.erss.2017.09.015.
[24] Kalehsar OS. Iran's transition to renewable energy: Challenges and opportunities. Middle East Policy 2019;26(2):62–71.
[25] Syngellakis S, Brebbia C, Gitelman LD, Magaril ER, editors. Challenges and solutions in the Russian energy sector Cham: Springer International Publishing AG; 2018. https://doi.org/10.1007/978-3-319-75702-5.
[26] García-Gusano D, Iribarren D, Dufour J. Is coal extension a sensible option for energy planning? A combined energy systems modelling and life cycle assessment approach. 413–321 Energy Policy 2018;114. https://doi.org/10.1016/j.enpol.2017.12.038.
[27] Nielsen H, Warde P, Kander A. East versus West: Energy intensity in coal-rich Europe, 1800–2000. Energy Policy 2018;122:75–83. https://doi.org/10.1016/j.enpol.2018.07.006.
[28] Wassermann S, Reeg M, Nienhaus K. Current challenges of Germany's energy transition project and competing strategies of challengers and incumbents: The case of direct marketing of electricity from renewable energy sources. Energy Policy 2014;76:66–75. https://doi.org/10.1016/j.enpol.2014.10.013.
[29] United Nations. Nationally Determined NDCs: The Paris Agreement and NDCs; 2019. Retrieved from https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs#eq-2.
[30] Delina L. Study countries Retrieved from Accelerating sustainable energy transition(s) in developing countries: The challenges of climate change and sustainable development2017. p. 21–40.
[31] Climate Action Tracker; 2019. Retrieved from https://climateactiontracker.org.
[32] Jewell J, Vinichenko V, Nacke L, Cherp A. Prospects for powering past coal. Nat Clim Change 2019;9(8):592–7.
[33] Groll S. Coal Commission final report – Assessment Retrieved from https://www.boell.de/en/2019/02/18/coal-commission-final-report-assessment; 2019.
[34] Campbell C. China Is bankrolling green energy projects around the world. Time; 2019, Retrieved from https://time.com/5714267/china-green-energy/.
[35] Ambrose J. China's appetite for coal power returns despite climate pledge. The Guardian; 2019, November 21. Retrieved from https://www.theguardian.com/world/2019/nov/20/china-appetite-for-coal-power-stations-returns-despite-climate-pledge-capacity.
[36] Russell C. Coal going from winner to loser in India's energy future: Russell. Reuters; 2019, February 20. Retrieved from https://www.reuters.com/article/us-column-russell-coal-india/coal-going-from-winner-to-loser-in-indias-energy-future-russell-idUSKCN1Q90OP.
[37] World Energy Council. World energy resources Retrieved from https://www.worldenergy.org/publications/entry/world-energy-resources-2016; 2016.
[38] United Nations Development Programme (UNDP); 2019. Retrieved from http://hdr.undp.org/en/data.
[39] WorldBank GDP (Current US$); 2019. Retrieved from https://data.worldbank.org/indicator/NY.GDP.MKTP.CD).
[40] WorldBank GDP growth (annual %); 2019. Retrieved from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG).
[41] UNDP. Human development indices and indicators: 2018 statistical update. New York: Author; 2018. Retrieved from http://hdr.undp.org/sites/default/files/2018_

human_development_statistical_update.pdf.
[42] Chen J. Economic growth rate. Investopedia; 2019, July 8. Retrieved from https://www.investopedia.com/terms/e/economicgrowthrate.asp.
[43] World Bank. Coal rents (% of GDP); 2019. Retrieved from https://data.worldbank.org/indicator/NY.GDP.COAL.RT.ZS.
[44] United Nations. 2016 Energy Balances. Department of Economic and Social Affairs Statistics Division; 2018. Retrieved from https://unstats.un.org/unsd/energystats/pubs/balance/.
[45] IPCC. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, von Stechow C, Zwickel T, Minx JC, editors. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014.
[46] Global Carbon Project. CO2 Global Carbon Atlas dataset; 2019. Retrieved from (http://www.globalcarbonatlas.org/en/CO2-emissions).
[47] World Bank. Countries and economies; 2019. Retrieved from https://data.worldbank.org/country.
[48] Field A. Discovering statistics using IBM SPSS statistics: And sex and drugs and rock 'n' roll. 4th ed. Los Angeles: Sage; 2013.
[49] Creti A, Nguyen DK. Energy and environment: Transition models and new policy challenges in the post Paris Agreement. Energy Policy 2018;122:677–9.
[50] Sung B, Park SD. Who drives the transition to a renewable-energy economy? Multi-actor perspective on socialinnovation. Sustainability 2018;10(2):448.
[51] van Vuuren DP, Stehfest E, Gernaat DE, van den Berg M, Bijl DL, de Boer HS, et al. Alternative pathways to the 1.5 C target reduce the need for negative emission technologies. Nat Clim Change 2018;8(5):391–7.
[52] Spencer T, Colombier M, Sartor O, Garg A, Tiwari V, Burton J, et al. The 1.5°C target and coal sector transition: at the limits of societal feasibility. Climate Policy 2018;18(3):335–51. https://doi.org/10.1080/14693062.2017.1386540.
[53] Chang H-J. Bad Samaritans: the myth of free trade and the secret history of capitalism. New York: Bloomsbury Press; 2008.
[54] Wang S, Li G, Fang C. Urbanization, economic growth, energy consumption, and CO_2 emissions: Empirical evidence from countries with different income levels. Renew Sustain Energy Rev 2018;81:2144–59.
[55] Belke A, Dobnik F, Dreger C. Energy consumption and economic growth: New insights into the cointegration relationship. Energy Econ 2011;33(5):782–9.
[56] Harrison V. Palumbo D. China anniversary: How the country became the world's 'economic miracle'. BBC News; 2019, October 1. Retrieved from https://www.bbc.com/news/business-49806247.
[57] Ocelík P, Svobodová K, Hendrychová M, Lehotský L, Everingham JA, Ali S, et al. A contested transition toward a coal-free future: Advocacy coalitions and coal policy in the Czech Republic. Energy Res Soc Sci 2019;58(101283):1–13.
[58] Osička J, Kemmerzell J, Zoll M, Lehotský L, Černoch F, Knodt M. What's next for the European coal heartland? Exploring the future of coal as presented in German, Polish and Czech press. Energy Res Soc Sci 2020;61:101316.
[59] Climate Transparency. Managing the coal phase-out – a comparison of actions in G20 countries. Humboldt-Viadrina Governance Platform, Berlin, Germany; 2019. Retrieved from https://www.climate-transparency.org/wp-content/uploads/2019/06/CT-Managing-the-phase-out-of-coal-DIGITAL.pdf.
[60] Workman D. Coal Imports by country [Web log post]; 2019, September 20. Retrieved from http://www.worldstopexports.com/coal-imports-by-country/.
[61] IEA. World Energy Outlook 2018; 2018b, Retrieved from https://www.iea.org/reports/world-energy-outlook-2018.
[62] IEA. Coal 2017; 2017. Retrieved from https://www.iea.org/coal2017/.
[63] Europe Beyond Coal. Which countries are moving beyond coal? 2019. Retrieved from https://beyond-coal.eu/coal-exit-tracker/?type=maps&layer=4.
[64] Lechner AM, Tan CM, Tritto A, Horstmann A, Teo HC, Owen JR, et al. The Belt and Road Initiative: Environmental Impacts in Southeast Asia. vol. 18. ISEAS Yusof Ishak Institute; 2019. p. 1–13 In this issue.
[65] Xu M, Singh S. China expects to hit 2020 coal cap targets; demand overshadows: study. Reuters; 2019, May 29. Retrieved from https://www.reuters.com/article/us-china-energy-coal/china-expects-to-hit-2020-coal-cap-targets-demand-overshadows-study-idUSKCN1SZ17M.
[66] Han S, Chen H, Stemn E, Owen J. Interactions between organisational roles and environmental hazards: The case of safety in the Chinese coal industry. Resour Policy 2019;60:36–46.
[67] IEA. Key world energy statistics. Archived (PDF) from the original on 7 July 2018; 2019. p. 17.
[68] Energiewende Team. Germany eager to become global leader in developing hydrogen technologies [Web log post]; 2019, August 7. Retrieved from https://energytransition.org/2019/08/germany-eager-to-become-global-leader-in-developing-hydrogen-technologies/.
[69] The Beam. Understanding the German energy transition: from leader to laggard [Web log post]; 2018. Retrieved from https://medium.com/thebeammagazine/understanding-the-german-energy-transition-from-leader-to-laggard-751d122341f.
[70] Turner C. The greenprint: Checking up on Germany's transition to renewable energy (Opinion). The Globe and Mail; 2019, June 1. Retrieved from https://www.theglobeandmail.com/opinion/article-the-greenprint-checking-up-on-germanys-transition-to-renewable/.
[71] Smee B, Hurst D. Energy analysts forecast 'the end of coal' in Asia as Japanese investors back renewables. The Guardian; 2019. Retrieved from https://www.theguardian.com/environment/2019/mar/18/energyanalysts-forecast-the-end-of-coal-in-asia-as-japaneseinvestors-back-renewables.
[72] California Electricity Commission (CEC). 2018 Total system electric generation in gigawatt hours; 2019. Retrieved from https://ww2.energy.ca.gov/almanac/electricity_data/total_system_power.html.