Where is the Second Deep Transition most likely to emerge?

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Abstract

Sustainability transitions research has recently started to stress the importance of switching attention from individual socio-technical systems to the mechanisms, patterns, and broader impacts of multi-system interactions. In particular, the Deep Transitions framework (Schot and Kanger, 2018; Kanger and Schot, 2019) has conceptualized multi-system co-evolution over the last 250 years as the First Deep Transition, resulting in the build-up of industrial modernity – a set of traits underpinning contemporary industrial societies and hindering major transformative change. In this paper, we use the DT framework to develop a comprehensive multi-dimensional and multi-domain Industrial Modernity Index, containing information on some of the most durable and expansive ideas, institutions, and practices of industrial societies related to the natural environment, science, and technology. The index is used to assess the likelihood of the Second Deep Transition in 30 countries. We find that the top-performing group includes countries from three continents, cross-cutting the conventional North-South divide. This supports the argument that the Second Deep Transition should be seen as a global response to the grand challenge of environmental degradation involving transformative experiments in a number of locations all over the world.

Keywords

Deep Transitions, industrial modernity, composite index, country comparison

1. Introduction

Starting from the late 18th century, industrial modernization has enabled an unprecedented rise in global well-being and population (van Zanden et al., 2014) while accelerating climate change, resource depletion, and loss of biodiversity (Krausmann et al., 2018; IPBES, 2019; IPCC, 2021).

Terms like the Anthropocene (Crutzen, 2002) and the Great Acceleration (Steffen et al., 2015) point to the increasingly global scale of human activities and their environmental impacts. Work in the sustainability transitions field (Grin et al., 2010; Köhler et al., 2019) has amply demonstrated that these problems have been generated by the lock-in of various socio-technical systems (e.g. energy, mobility, food, waste management, housing) on energy- and material-intensive developmental trajectories. Recently, the 250-year genesis, co-evolution, and crisis of multiple systems have been theorized as the First Deep Transition (Schot and Kanger, 2018). Arguably, redirecting these systems onto a sustainable and just path of evolution requires Second Deep Transition, meaning an overhaul of many taken-for-granted features of industrial societies built up during the modernization process (Kanger and Schot, 2019).

This paper focuses on the following question: where is the Second Deep Transition most likely to emerge? For this purpose, we draw on the Deep Transitions framework (Kanger and Schot, 2019; Kanger et al., 2020) to construct a composite indicator containing information on some of the most durable and expansive traits of industrial societies. The resulting index effectively expresses structural constraints on major transformative change in different countries. We employ a novel comprehensive multi-dimension and multi-domain approach, simultaneously measuring the fundamental ideas, institutions, and practices of industrial societies related to the natural environment, science, and technology. This enables us to assess the potential of locations where ideas, institutions, and practices are in tension. For example, in developed countries, green rhetoric and institutional reforms might be offset by high dependence on resource-intensive systems (Hickel and Kallis, 2020), whereas in developing countries, relatively low materials and energy usage (Haberl et al., 2019) can be coupled with beliefs in the primacy of economic growth and lax environmental regulations (Xing and Kolstad, 2002), driving industrialization at all costs.

Drawing on various databases such as the World Values Survey, ECOLEX, U.S. Energy Information Administration, and OECD patent statistics, we assess the likelihood of the Second Deep Transition in 30 countries. We show that the likely loci of major transformative change include a mixture of developed and developing countries. Our results thus offer broad support to the argument that the Second Deep Transition involves a transnational response to the grand challenge of environmental degradation, cross-cutting the conventional North-South divide and stimulating transformative experiments in several locales all over the world (Kanger and Schot, 2019).

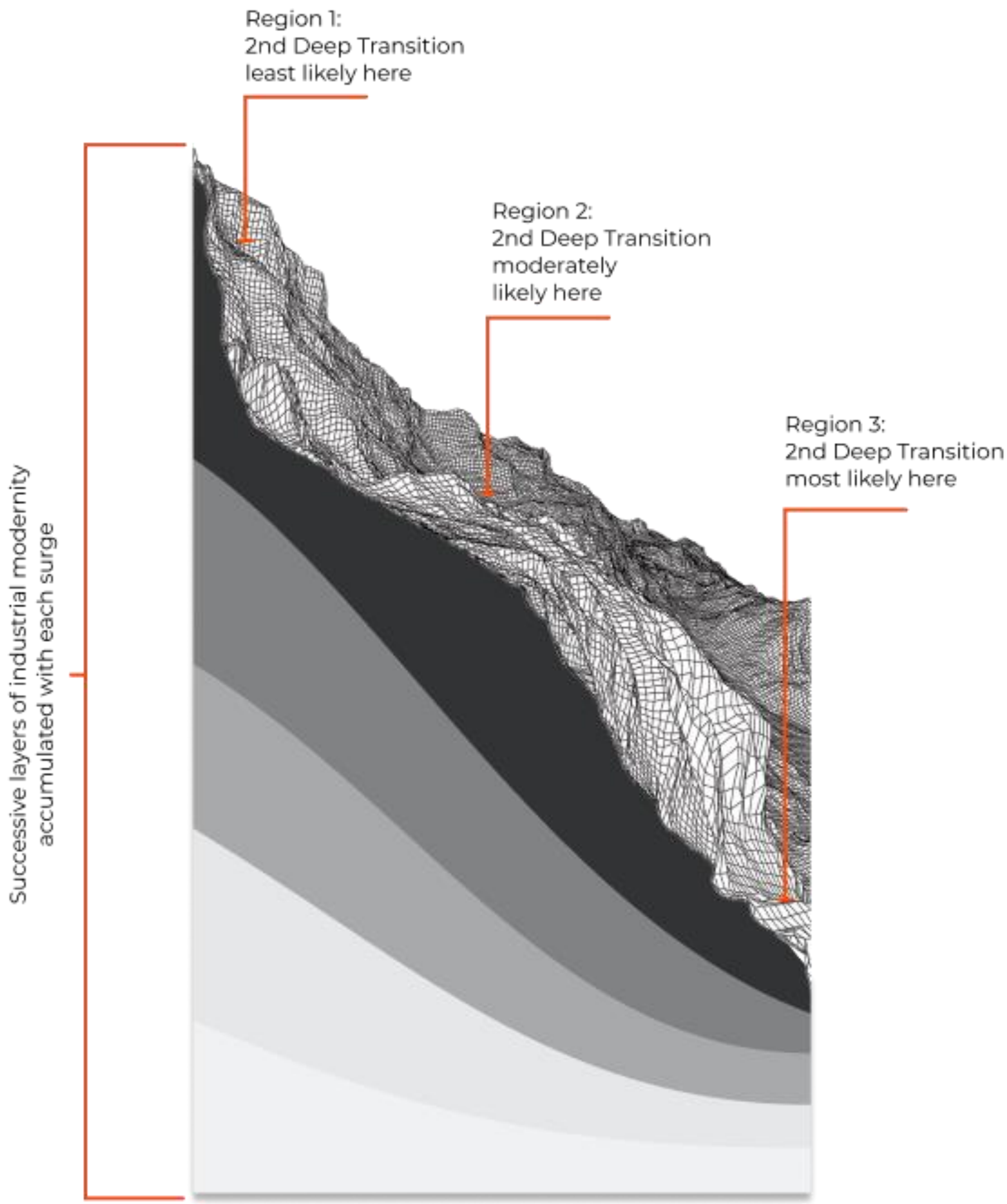
2. Theoretical framework

Our approach is based on the Deep Transitions (DT) framework (Schot and Kanger, 2018; Kanger and Schot, 2019) that synthesizes insights from sustainability transitions (Grin et al., 2010; Geels et al., 2017; Köhler et al., 2019), long wave (Freeman and Louçã, 2001; Perez, 2002), and industrialization literature (Stearns, 2013; Mokyr, 2017). The framework proposes that starting from the end of the 18th century, the co-evolution of multiple socio-technical systems has unfolded in five 40-60 year and increasingly global 'great surges of development': 1) The Industrial Revolution (1771); 2) Age of Steam and Railways (1829); 3) Age of Steel, Electricity and Heavy Engineering (1875); 4) Age of Oil, the Automobile and Mass Production (1908); 5) Age of Information and Telecommunications (1971) (Perez, 2002). The surges, in turn, have generated a set of traits characterizing every contemporary industrial society – an industrial modernity – manifested in various long-term trends and persistent problems. Examples include assumptions that waste is not a problem, that resources are endlessly substitutable through continued technological innovation, or that technology-created problems could be solved by the introduction of new and more complex technologies. Actions based on these assumptions contribute to increasing energy and materials usage per capita (Haberl et al., 2019), pervasive rebound effects where increasing technological efficiency is offset by a corresponding rise in demand (Magee and Devezas, 2017), and attempts to address climate change through major and highly risky techno-fixes such as solar geoengineering (Irvine et al., 2019). According to the DT theory, the traits of industrial modernity are therefore seen as significant constraints that need to be dropped, altered, or reinvented for a major transformative change of industrial societies, a Second Deep Transition, to occur.

Based on a comprehensive review of literature on industrialization and modernization more than 30 basic traits of industrial modernity have been previously identified (Kanger and Schot, 2019). These, in turn, have been shown to cluster into two major themes: 1) treating the natural environment as a blind spot, resulting in its relative neglect in rhetoric, institution-building, and resource use; 2) overconfidence in science and technology, resulting in a regular overestimation of their promises, underestimation of their perils (or vice versa in dystopian accounts) and misspecification of their impacts (Kanger et al., 2020). Results from a recent quantitative study involving 5 countries (Australia, Germany, India, the Soviet Union/Russia, USA) between 1900-2020 show that the characteristic ideas, institutions, and practices of industrial modernity exhibit notable and durable variation between countries (Kanger et al., 2020; Kanger et al., forthcoming).

Invoking a widespread geological metaphor from the Multi-level Perspective on socio-technical transitions (Rip and Kemp, 1998), we propose that the aggregate of particular industrial modernity related ideas, institutions, and practices in a particular location can be imagined as its socio-material 'landscape'. The thicker the landscape, the harder it would be for a particular location to enact major transformative change (Figure 1).

Figure 1. The socio-material landscape of industrial modernity.



Here, we develop a measure of the 'thickness' of industrial modernity, using it to determine locations most favourable to the emergence of the Second Deep Transition. For this purpose, we define industrial modernity as:

1. a set of mutually supporting foundational beliefs and assumptions (ideas), formal and informal rules (institutions), and characteristic behaviour (practices),
2. encompassing the domains of the natural environment (as a source of inputs), science, technology and innovation, that
3. characterize two or more successive great surges of development, and
4. have become so widespread that they can be found in almost any socio-technical system in almost any contemporary industrial society.

3. Methods and data

Guided by the OECD's principles of developing a composite indicator (Freudenberg, 2003; Nardo et al., 2005), we have created the Industrial Modernity Index (IMI) to measure the thickness of the landscape of industrial modernity in particular countries. Composite indicators (synonymous with index in this paper) are synthetic indices of individual indicators (Freudenberg, 2003). Composite indicators have numerous strengths: 1) they are a suitable tool for summarizing complex multi-dimensional issues; 2) they are easy to interpret compared to a collection of multiple separate indicators; 3) they allow ranking countries and assessing progress over time while giving input to policymakers and facilitating communication with citizens (Nardo et al., 2005). The surface-level simplicity of the composite indicator also entails dangers as misleading, simplistic, or downright wrong interpretations can lead to erroneous conclusions, messages, and policies (*ibid*.). Nevertheless, given the complexity and multi-dimensionality of the concept of industrial modernity as well as the aim to compare country-level performance, we find a composite indicator a fitting analytical tool to use.

3.1 Indicator selection and data

Following the framework developed by Kanger et al. (2020), IMI is divided into three dimensions (ideas, institutions, and practices) and two domains (natural environment, science, technology, and innovation), resulting in a 6-cell table. We selected the theoretical traits to cover the two major themes of industrial modernity (environment as a blind spot, overconfidence in science and technology), operationalizing each through selected indicators. All indicators included in the index aim to describe the pervasiveness of different facets of industrial modernity against a transformative trend that could indicate a rupture in these traits. Thus, *an aggregate high score of IMI means the presence of higher structural constraints and hence fewer possibilities for enacting major transformative change in the country*. Table 1 provides an overview of the traits of industrial modernity, the indicators, and the data sources included in the study.

Table 1. Traits of industrial modernity, indicators, and data sources.

<table>
<tr><th>Dimension ↓</th><th>Domain →</th><th>Natural environment</th><th>Science, technology, and innovation</th></tr>
<tr><td rowspan="3">Ideas</td><td>Trait</td><td>Instrumental view of nature</td><td>Highly exaggerated beliefs about the societal impacts of science and technology (usually unlimited progress)</td></tr>
<tr><td>Indicators</td><td>Attitudes towards economic growth: share of respondents prioritizing economic growth and more jobs over protecting the environment</td><td>Attitudes towards science and technology: share of respondents selecting “Strongly disagree”, “Disagree”, “Strongly agree” and “Agree” to “Science and technology are making our lives healthier, easier, and more comfortable”</td></tr>
<tr><td>Data</td><td colspan="2">World Values Survey, 6th and 7th wave (see Appendix A for input from 6th wave)</td></tr>
<tr><td rowspan="3">Institutions</td><td>Trait</td><td>Prioritization of societal over environmental concerns in institutional design</td><td>Largely reactive approach: institutions are mainly directed to regulating the consequences of technological innovation</td></tr>
<tr><td>Indicators</td><td>Innovation-supporting vs. environmental institutions: the relative performance of country's innovation-supporting vs. environmental institutions, the quality of environmental institutions</td><td>Environmental regulations: the combined share of the country’s reactive and conservation-oriented environmental regulations from overall environmental regulations (including proactive ones)</td></tr>
<tr><td>Data</td><td>Global Innovation Index, Environmental Performance Index</td><td>ECOLEX</td></tr>
<tr><td>Practices</td><td>Trait</td><td>Specific socio-metabolic profile: ‘mineral’, fossil fuel based and linear economy</td><td>The overall directionality of innovative activities and the actual use of technology is largely indifferent to environmental concerns</td></tr>
</table>

	Indicators	**Per capita DMI:** direct material input (domestic extraction and import) per capita	**Passenger vehicles:** share of non-electric new passenger vehicles from the country's total new vehicles (including electric vehicles)
		Energy consumption: share of energy consumption characteristic to industrial modernity in country's total energy mix (including renewables)	**Non-environment related technologies:** share of non-environment related domestic patents from total patents (including green ones)
	Data	DMI: Global Material Flows Database Energy: U.S. Energy Information Administration	Patents: OECD Passenger vehicles: MarkLines, Knoema, various country-specific sources (see Appendix A)

The construction of the index has been shaped by two general constraints. First, the availability of databases dictates the choice of traits towards ones that can be readily quantified. Second, since this is the first time presenting IMI, the objective was to cover as many countries as possible without compensating for or imputing missing data. However, as country coverage differs significantly between databases, we have only included countries where complete (or near-complete) data for the most recent period could be obtained. As such, our study includes 30 countries but with a good spectrum of diversity in terms of geography and national income.

3.1.1 Ideas

In the Ideas dimension, we measure the extent to which the natural environment is viewed instrumentally and the extent of highly exaggerated beliefs about the societal impacts of science and technology. The Ideas index is an aggregated value based on two items from the World Values Survey (WVS), a global research project for measuring the attitudes and values of people in different countries. To reach maximum country coverage, we use data from two WVS waves: the 6th wave taking place between 2010-2014 and the 7th wave, taking place between 2017-2020 (see Appendix A for items used and a list of countries that use data from the 6th wave).

For the ideas*environment cell, we use the share of respondents selecting the option stating *"Economic growth and creating jobs should be the top priority, even if the environment suffers to some extent*". A high share of respondents agreeing with this statement contributed to a higher score on the Ideas index. For the ideas*STI cell, we use the share of extreme agreement or disagreement (1, 2, 9, and 10 on a 10-point scale) with the claim that *"science and technology* *are making our lives healthier, easier, and more comfortable".* Here, we reason that extreme answers can be taken as indicators of either utopian (and hence likely uncritical) or dystopian (and hence likely dismissive) views on the potential of science and technology to address the problems created by the First Deep Transition and facilitate the second one. Hence, the higher share of extreme views on science and technology contributes to a higher score on the Ideas index.

3.1.2 Institutions

In the Institutions dimension, we measure the extent to which the country prioritizes societal vs. environmental concerns in its institutions and the extent to which the country's institutions are geared towards addressing the consequences of technological change (rather than attempting to anticipate them).

For the institutions*environment cell, we combine data from Global Innovation Index and Environmental Performance Index. Global Innovation Index (GII) measures innovation performance in 131 countries and ranks world economies based on their innovation capabilities (Cornell University, INSEAD & WIPO, 2020). It relies on two sub-indices—the Innovation Input Sub-Index and the Innovation Output Sub-Index. We use the Institutions pillar of the Innovation Input Sub-Index that captures the capability of an economy to nurture "an institutional framework that attracts business and fosters growth by providing good governance and the correct levels of protection and incentives is essential to innovation" (*ibid*.: 204). Environmental Performance Index (EPI) uses 32 indicators to rank 180 countries on environmental health and ecosystem vitality (Environmental Performance Index, 2021). We combine these two composite indicators by calculating the geometric mean of the GII Institutions' pillar and EPI and then finding the arithmetic mean of the resulting geometric mean and EPI. This approach allows us to assess the balance between innovation-supporting and environment-protecting institutions while also penalizing for lower-performing environmental institutions. Thus, countries with 1) higher GII to EPI geometric mean, and 2) lower EPI, score higher on the Institutions index. We use the most recent scores (2020) for both GII and EPI.

For the institutions*STI cell, we use country-level data on environmental regulations and legislative acts from ECOLEX, a global environmental law database. Each database entry has been tagged with particular keywords. We extracted 421 tags that occurred more than 30 times and, where possible, allocated them to one of the following categories: 1) reactive, directed at alleviating environmental impacts; 2) conservation-oriented, directed at preventing the current situation from getting worse; 3) proactive, directed at preventing the emergence of harmful environmental impacts (see Kanger et al., 2020 for more detail). Based on the presence of the reactive, conservation-oriented, and proactive tags, each document was coded as fully proactive, 1/2 proactive, if 2 categories were present, or 1/3 proactive, if 3 categories were present. The higher combined share of reactive and conservation-oriented laws contributed to a higher score on the Institutions index. To guarantee a sufficient amount of entries, legislative acts and regulations from 2007 to 2017 were used (data beyond 2017 was sporadic and thus excluded from the analysis). Since there were not enough entries (N < 50) for Estonia, Japan, Romania, Singapore, and Thailand, the Institutions index for these countries only reflects the value of the variable calculated based on GII and EPI. This is in line with our assumption of substitutability (see 3.3).

3.1.3 Practices

In the Practices dimension, we assess the extent to which the country's socio-metabolic profile exhibits the common characteristics of industrial societies, the overall directionality of innovative activities as well as the use of technology.

For the practices*environment cell, we use the U.S. Energy Administration 2019 data on primary energy consumption, in particular the share of oil, gas, nuclear energy, biomass, and biofuels in countries' energy mixes as an indicator of dependence on energy sources characteristic to industrial modernity. Although many see biomass and biofuels with carbon capture and sequestration or other carbon capture technologies as a major potential contributor to climate mitigation (IPCC, 2018; van der Hilst et al., 2019), there are also strong concerns about these energy sources regarding land competition, food security as well as the current non-availability of many necessary technologies to achieve these gains (Calvin et al., 2021). For these reasons, we have decided to currently count biomass and biofuels as energy sources characteristic of industrial modernity. We also use the most recent available data (2015) from the Global Material Flows database (UNEP, 2016) for direct material input per capita, a metric that combines domestic materials extraction with import. A high relative share of fossil energy and a high DMI both contribute to high IMI scores.

For the practices*STI cell, we assess the share of new passenger vehicles with diesel, gasoline, natural gas, and hybrid engines as opposed to electric vehicles, battery electric vehicles, hybrid electric vehicles, and plug-in hybrids. Here, we did not aim to attain the latest available data but data from earlier than 2020 because of the effect COVID-19 had on the automotive and mobility industries (Furcher et al., 2021). Where possible, we use data on new passenger vehicle registrations. However, due to data availability constraints, we substitute new passenger vehicle registrations with passenger vehicle sales for some countries (see the full list in Appendix A). For country totals, we use the latest available data from Knoema Data Portal and for passenger vehicle sales data from the MarkLines Information Platform. A higher share of new passenger vehicles with diesel, gasoline, natural gas, and hybrid engines increases the Practices index.

As an additional indicator, we use OECD data from 2018 on the share of non-environment-related technologies (e.g. technologies related to environmental management and climate change mitigation) of all domestic patents. The OECD patent statistics rely on the Worldwide Statistical Patent Database (PATSTAT) maintained by the European Patent Office. A higher share of non-environment-related technologies translates to a higher score on the Practices index.

3.1.4 Strength of association between variables

To assess the association between the variables selected for the IMI, we use Spearman's rank correlation coefficient (Spearman's rho). We apply Spearman’s rho to avoid any disproportionate effects from either extreme values or skewness of the data. The rank correlation coefficients are available in Table 2. While most variables display low to moderate correlations, Innovation-supporting vs. environmental institutions and per capita DMI have a strong positive monotonic relationship ($\rho = 0.71$) indicating countries with worse-performing environmental institutions have higher per capita DMI. Because the variables selected in the IMI reflect different aspects of industrial modernity that are interrelated but differentiated by dimensions of it, we do not consider the existence of correlations as something to be corrected for but as a feature of industrial modernity. This is in line with recommendations by Nardo et al. (2005).

Table 2. The Spearman's rank correlation coefficients of variables chosen for the IMI.

	Attitudes towards economic growth	Attitudes towards science and technology	Innovation-supporting vs. environmental institutions	Environmental regulations	Per capita DMI	Energy consumption	Passenger vehicles	Non-environment related technologies
Attitudes towards economic growth	**1.00**	0.10	0.16	0.12	0.41	0.47	0.09	0.20
Attitudes towards science and technology	0.10	**1.00**	0.54	-0.40	0.50	0.22	-0.26	0.09
Innovation-supporting vs. environmental institutions	0.16	0.54	**1.00**	0.10	**0.71**	0.37	-0.54	0.17
Environmental regulations	0.12	-0.40	0.10	**1.00**	0.23	0.20	0.19	0.22
Per capita DMI	0.41	0.50	**0.71**	0.23	**1.00**	0.42	-0.39	0.19
Energy consumption	0.47	0.22	0.37	0.20	0.42	**1.00**	-0,17	0.34
Passenger vehicles	0.09	-0.26	-0.54	0.19	-0.39	-0.17	**1.00**	0.33
Non-environment related technologies	0.20	0.09	0.17	0.22	0.19	0.34	0.33	**1.00**

3.2 Normalization

Multiple indicators in IMI (ideas*environment, ideas*STI, institutions*STI, energy consumption part of practices*environment, practices*STI) are measured as percentages meaning they are comparable and can be aggregated. However, the share of regulations in the institutions*STI cell and the share of patents in the practices*STI cell cannot be interpreted in the same manner because both of these shares lack a logical and theoretically justifiable maximum value. For example, while an economy can depend entirely on non-renewable or renewable energy, it would be far-fetched to expect all environmental regulations to be either reactive, conservation-oriented, or proactive. Similarly, it is not feasible to expect all patents to be environment-related. Thus, even though these indicators are measured as percentages, we standardize them using z-scores to have similar dispersion across countries (Nardo et al., 2005) and use cumulative distribution function to find the countries' position regarding each other in a normal distribution where the value attained communicates the probability of another element in the distribution taking a value less than or equal to the value attained (Wang & Chen, 2012). We multiply the value attained by 100 to get a value ranging from 0-100 allowing us to assess countries' performance. We standardize the only other variable (per capita DMI), not naturally ranging from 0 to 100, using the same method.

We calculate the z-scores using the formula:

$$z = \frac{(x-\mu)}{\sigma},$$

where x is the variable, μ is the population mean, and σ is the population standard deviation.

The position in the normal distribution is obtained using the formula:

$$p(Z \leq z) = F(z) = 100 \times \left(\frac{1}{2}\left[1 + erf\left(\frac{z-\mu}{\sigma\sqrt{2}}\right)\right]\right),$$

where z is the z-score, μ is the mean (μ = 0), and σ is the population standard deviation (σ = 1).

3.3 Aggregation

Following the DT framework, the different traits of industrial modernity (i.e. each cell in the ideas/institutions/practices*environment/STI matrix) are deemed equally significant. Thus, we give equal weight (0.33) to all dimension indices (Ideas, Institutions, Practices) in the IMI. We also give equal weight to variables within a particular cell (e.g. energy consumption contributes 25% to the environment*practices cell). We aggregate the normalized indicators first for each dimension index and then aggregate across the three dimension indices to attain the IMI score. We use additive aggregation for the score of each dimension index and the overall IMI score. Table 3 summarizes the main components of IMI, including information on standardization and ascribed weights.

Table 3. The components, standardization, and aggregation of IMI.

Indicator	Standardization	Weights	Dimension	Weights
Attitudes towards economic growth	No	0.5	Ideas	0.33
Attitudes towards science and technology	No	0.5		
Innovation-supporting vs. environmental institutions	No	0.5	Institutions	0.33
Environmental regulations	Z-score, cumulative distribution function	0.5		
Per capita DMI	No	0.25	Practices	0.33
Energy consumption	Z-score, cumulative distribution function	0.25		
Passenger vehicles	No	0.25		
Non-environment related technologies	Z-score, cumulative distribution function	0.25		

3.4 Work-through example: Colombia

Since this study is the first to introduce IMI, we demonstrate how the index is calculated based on Colombia as an example. Table 4 provides an overview of the values used in the calculation as well as the aggregated scores. The steps of calculation are described below.

Table 4. IMI values for Colombia.

Indicator	Value	Dimension	Dimension index score	IMI
Attitudes towards economic growth (WVS 7th wave, 2017-2020)	29.5	Ideas	42.85	40.36
Attitudes towards science and technology (WVS 7th wave, 2017-2020)	56.2			
Innovation-supporting vs. environmental institutions (GII and EPI, 2020)	44.21	Institutions	22.6	
Environmental regulations (ECOLEX, 2007-2017)	0.99			
Per capita DMI (Global Material Flows, 2015)	21.91	Practices	55.62	
Energy consumption (EIA, 2019)	75.81			
Passenger vehicles (Knoema and MarkLines, 2019)	99.3			
Non-environment related technologies (OECD, 2018)	25.49			

Ideas dimension

- Attitudes towards economic growth (%) = 100 – 70.5 (all the other answers, including "Other answer" and "Don't know") = 29.5
- Attitudes towards science and technology (%) = 16.8 + 2.3 + 4.9 + 32.2 = 56.2
- **Total score = (29.5 +56.2) / 2 = 42.85**

Institutions dimension

- Innovation-supporting vs. environmental institutions:

  100 - (√(52.9 (EPI) * 65.1 (GII)) + 52.9 (EPI)) / 2 = 44.21

- Environmental regulations and legislation:

  Share of non-proactive documents = 100 – (100*(731.17 (proactive document part sum) / 1652 (all documents classified reactive, conservation oriented and/or proactive))) = 55.74

  z = 55.74 – 76.02 / 8.72 = -2.33

$p(Z \leq z) = F(z) = 100 \times \left(\frac{1}{2}\left[1 + erf\left(\frac{-2.33-0}{1\sqrt{2}}\right)\right]\right)$= 0.99

- **Total score = (44.21 + 0.99) / 2 = 22.6**

Practices dimension

- Per capita DMI (tonnes per capita) = 9.3

  z = 9.3 – 22.8 / 17.4 = -0.78

  $p(Z \leq z) = F(z) = 100 \times \left(\frac{1}{2}\left[1 + erf\left(\frac{-0.78-0}{1\sqrt{2}}\right)\right]\right)$= 21.9
- Energy consumption (EJ)

  100 – (128.08 (renewables) * 100 / 529.46 (total consumption)) = 75.8
- Passenger vehicles (%)

  100 – (1550 (new electric etc. passenger vehicles) * 100 / 220581 (new passenger vehicles)) = 99.3
- Non-environment-related technologies (%) = 87.49

  z = 87.49 – 89.89 / 3.63 = -0.66

  $p(Z \leq z) = F(z) = 100 \times \left(\frac{1}{2}\left[1 + erf\left(\frac{-0.66-0}{1\sqrt{2}}\right)\right]\right)$= = 25.49
- **Total score = (21.9 + 75.8 + 99.3 + 25.49) / 4 = 55.62**

Industrial Modernity Index = (42.85 + 22.6 + 55.62) / 3 = 40.36

4. Results

In this section, we present the main results of our study. Section 4.1 provides the IMI scores, distinguishing between three groups of countries ranked according to their likelihood of enacting the Second Deep Transition. Section 4.2 explores correlations between IMI and other selected indicators and indices.

4.1 IMI scores

The values of the IMI index for 30 countries (with a mean score of 50.59) have been presented in Figure 2. In terms of dimension indices, we find Ideas to have the lowest mean value (36.71, Figure 3), followed by Institutions (43.92, Figure 4) and Practices (71.04, Figure 5). In terms of domains, we find the mean value for the natural environment to be lower than that of science, technology, and innovation (52.14 and 60.02 respectively). The various descriptive statistics have been summarized in Table 5.

Figure 2. Industrial Modernity Index scores by country.

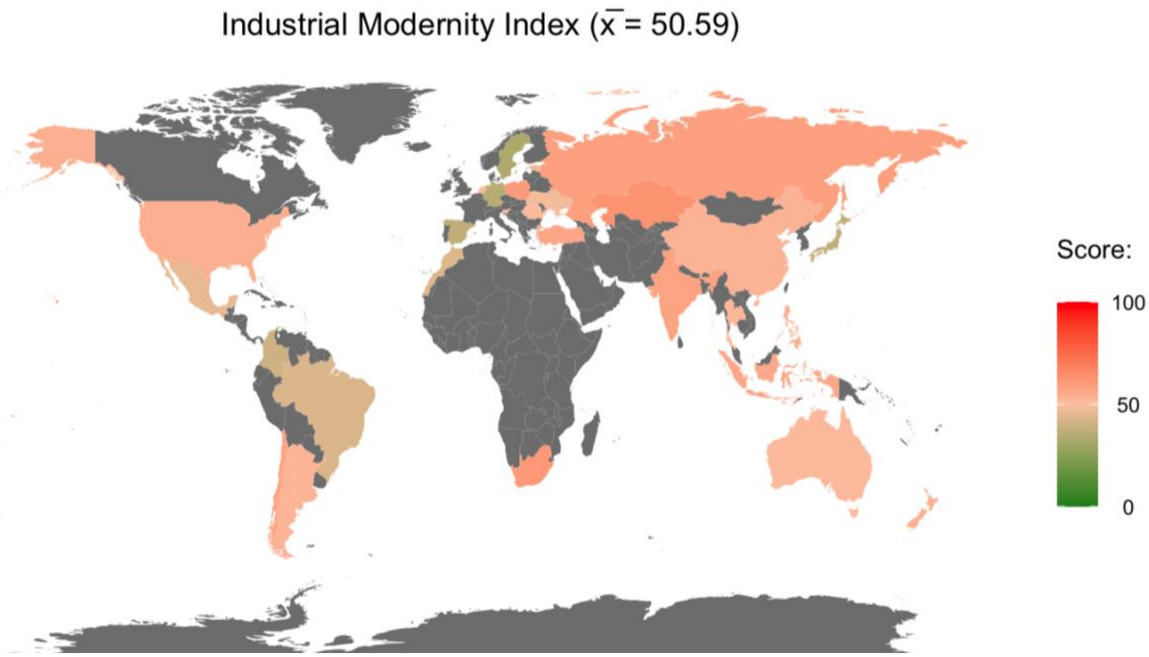


Figure 3. Industrial Modernity Index: Ideas dimension index scores by country.

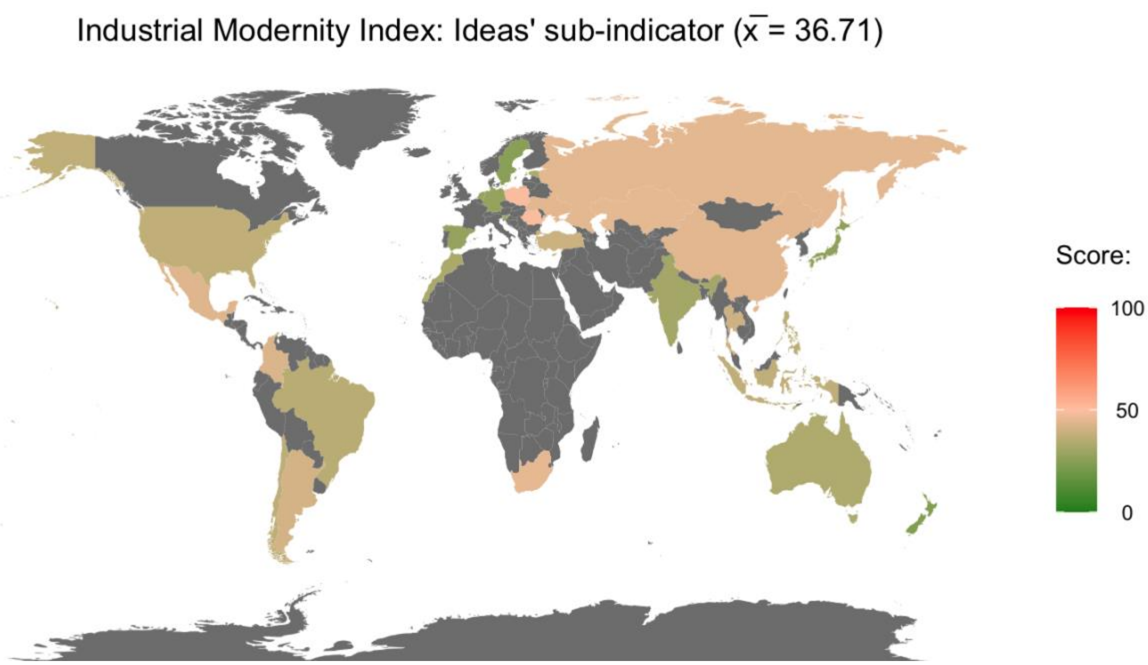


Figure 4. Industrial Modernity Index: Institutions dimension index scores by country.

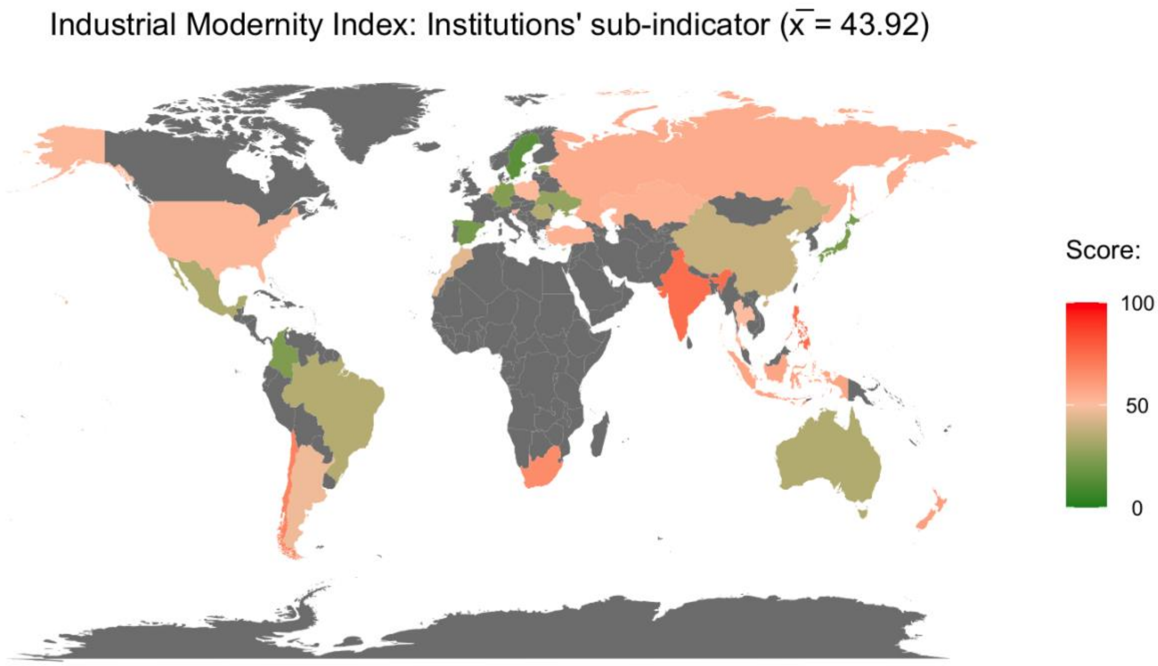


Figure 5. Industrial Modernity Index: Practices dimension index scores by country.

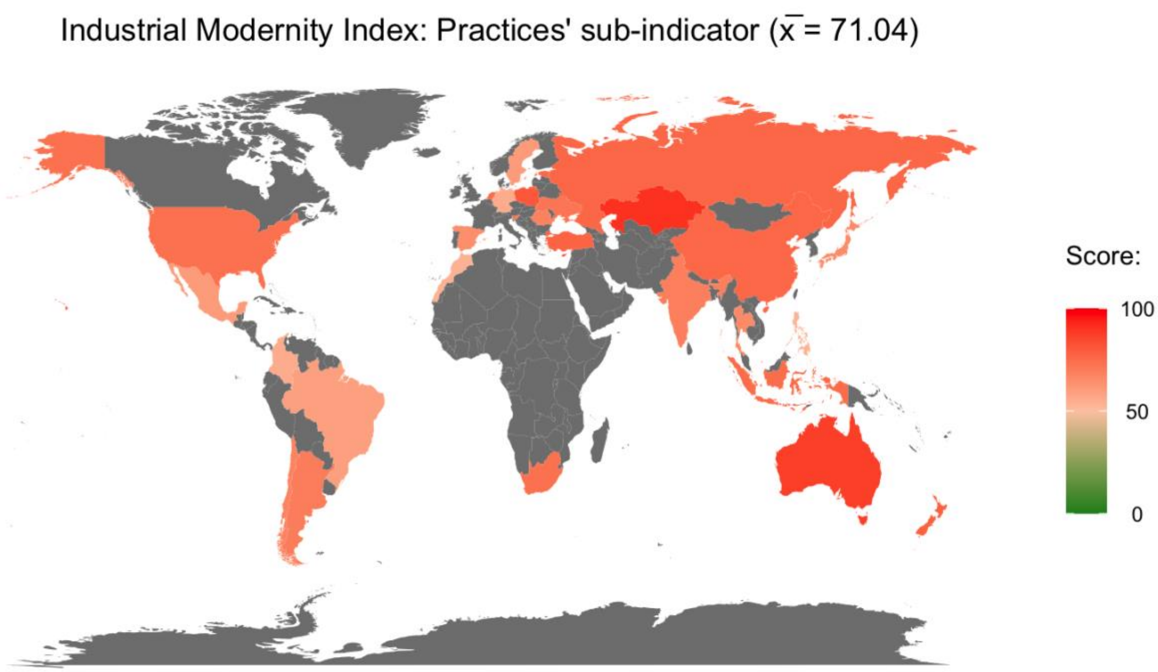


Table 5. Descriptive statistics for the IMI by dimension and by domain.

	N	Mean	SD	Median	Min	Max
Ideas	30	36.71	7.44	36.72	23.20	49.45
Institutions	30	43.92	16.30	45.91	13.70	74.44
Practices	30	71.04	10.70	71.64	53.07	92.62
Natural environment	30	52.14	7.51	52.74	38.05	66.96
Science, technology, and innovation	25*	60.02	11.49	60.53	38.17	74.95
IMI	30	50.56	7.93	52.52	33.11	63.06

**The countries with missing data are excluded from the calculation of the descriptive statistics.*

The countries with the most favourable preconditions for the Second Deep Transition include Sweden, Germany, Spain, Japan, and Colombia (Table 6), which display relatively low levels of industrial modernity in all three dimensions. The countries that populate the end of the range are India, Russia, Poland, South Africa, and Kazakhstan (Table 6). These countries have higher structural constraints across all three dimensions. The only exception is India with an Ideas sub-indicator score (30.9) that outperforms one of the frontrunners, Colombia. India is dragged to the bottom of the IMI rankings by its Institutions sub-indicator score that is the highest in the sample (74.44) and a relatively high Practices sub-indicator score (68.96). Both, the countries at the top of the list as well as the bottom of the list display diverse geographical settings. While the wealthy European countries at the top might not come as a surprise, the South American countries following them are less frequently discussed as frontrunners regarding climate mitigation. Similarly, the bottom of the list is not reserved for the Global South but also for countries like Poland and Russia. These findings are in line with what has been proposed by the proponents of the DT framework: the Second Deep Transition demands a transnational response discarding the conventional North-South divide (Kanger and Schot, 2019).

Table 6. The IMI, dimension, and domain scores by country.

Rank	Country	IMI	Sub-Indicators			Domains	
			Ideas	Institutions	Practices	Environment	STI
1	Sweden	33.11	24.85	13.70	60.77	38.05	42.00

2	Germany	35.35	27.40	23.52	55.12	42.41	38.17
3	Spain	37.33	27.45	20.20	64.33	43.01	45.15
4	Japan*	37.78	26.40	21.50	65.43	40.12	49.26
5	Colombia	40.36	42.85	22.60	55.62	42.86	45.50
6	Brazil	43.04	35.60	34.59	58.92	45.52	48.49
7	Morocco	43.55	32.55	44.51	53.59	46.95	45.17
8	Mexico	45.90	43.90	33.36	60.43	51.41	47.65
9	Estonia*	46.62	32.95	31.03	75.87	58.20	49.66
10	Ukraine	48.08	44.85	27.40	72.00	55.73	52.40
11	Romania*	50.75	49.45	34.49	68.33	48.93	61.36
12	Netherlands	50.82	27.25	50.09	75.12	53.26	60.53
13	Australia	51.46	33.35	33.81	87.23	61.49	59.31
14	Slovenia	51.76	31.90	52.10	71.29	44.63	68.65
15	Thailand*	52.21	40.45	50.33	65.84	55.22	56.01
16	Singapore*	52.84	32.05	33.84	92.62	66.11	59.45
17	Argentina	52.84	41.50	47.31	69.71	54.42	59.69
18	China	53.13	44.55	38.77	76.06	55.89	61.83

19	New Zealand	53.51	23.20	59.03	78.31	44.47	74.95
20	United States	54.28	37.10	52.18	73.55	52.22	65.97
21	Philippines	54.44	35.95	74.30	53.07	49.82	58.38
22	Cyprus	55.14	36.85	40.43	88.13	56.00	70.77
23	Indonesia	56.51	37.45	57.38	74.70	50.10	72.02
24	Turkey	56.83	39.55	53.61	77.31	54.68	69.21
25	Chile	57.34	36.60	67.70	67.71	62.09	57.77
26	India	58.10	30.90	74.44	68.96	49.78	71.85
27	Russia	58.93	44.75	55.60	76.45	57.25	69.38
28	Poland	60.30	49.25	51.06	80.59	55.81	74.93
29	South Africa	61.32	45.35	65.30	73.32	60.86	67.79
30	Kazakhstan	63.06	45.00	53.47	90.72	66.96	72.99

Notes: Countries marked with an asterisk have missing data in the Institutions sub-indicator.

To further investigate countries' profiles, we use k-means clustering (Hartigan and Wong, 1979) with the IMI and dimension scores (Table 7). The three k-means clusters (k = 3, N = 30) with respective mean IMI scores of 39.55, 51.15, and 56.15 (Table 7) are interpreted as the most to least likely loci for the Second Deep Transition. With varying absolute levels, both 'Most likely' (N = 8) and 'Moderately likely' (N = 7) loci for Second Deep Transition are characterized by a particular sequence where the Institutions score is the lowest, followed by the Ideas and Practices. However, the countries classified as 'Least likely' (N = 15) loci for major transformative change display a pattern where the Ideas score is the lowest, followed by the Institutions and Practice. Similarly, the Environment and STI domain means for the 'Most likely' and 'Moderately likely' loci have a ratio of 0.97 while the domain means for the 'Least likely' loci have a ratio of 0.81.

Table 7. K-means clustering of the IMI score.

Likeliness	Countries		Mean IMI	Dimensions			Domains	
				Ideas	Institu-tions	Practices	Environ-ment	STI
Most likely (N = 8)	Sweden Germany Spain Japan Colombia Brazil Morocco Mexico		39.55	32.63	26.75	59.28	43.79	45.17
Moderately likely (N = 7)	Estonia Ukraine Romania Australia Singapore China Cyprus		51.15	39.15	34.25	80.03	57.48	59.26
Least likely (N = 15)	Netherlands Slovenia Thailand Argentina New Zealand United States Philippines Kazakhstan	Turkey Chile India Russia Poland South Africa Indonesia	56.15	37.75	57.59	73.11	54.11	66.68

The cluster describing the most likely loci of the Second Deep Transition consists of countries with varying scores from the Ideas, Institutions, and Practices dimensions further affirming previous theoretical claims. For example, Sweden and Morocco both classify as most likely loci for the Second Deep Transition. While, on one hand, Sweden is in the lead with Ideas score of 24.85 that is 1.59 standard deviations lower than the sample mean ($\bar{x}$ = 36.71, Table 6) and Institutions score of 13.70 that is 1.85 standard deviations lower than the sample mean ($\bar{x}$ = 36.71). Morocco, on the other hand, exceeds Sweden with a Practices score of 53.39 that is 1.63 standard deviations lower than the sample mean ($\bar{x}$ = 71.04) with Sweden scoring 60.77; 0.96 standard deviations lower than the sample mean. This indicates that while Sweden might be a trailblazer regarding rupturing the ideational and institutional dimensions of industrial modernity, the country is not a frontrunner regarding practices.

Furthermore, some of the countries scoring among the worst in Practices, still classify as 'Moderately likely' loci for major transformative change. Examples here include Singapore, Cyprus, and Australia, with respective Practices scores of 92.62, 88.13, and 87.23 (Table 6). In spite of the performance regarding practices, all of the three countries score 0.21-0.62 standard deviations lower than the sample mean for both Ideas and Institutions (the only exception being Cyprus' Ideas score that is 0.02 standard deviations higher than the sample mean). On the flip side, the Philippines score 1.68 standard deviations lower than the sample mean in Practices while scoring 1.86 standard deviations higher than the sample mean on Institutions, placing the country to the 'Least likely' cluster. Moreover, both Chile and India are countries that are classified as 'Least likely' loci for the transformative change with Practices scores respectively 0.31 and 0.19 standard deviations lower than the sample mean and Ideas score 0.01 and 0.78 standard deviations lower than the sample mean. Where both countries are lagging behind is Institutions score: Chile's is 1.46 and India's 1.87 standard deviations higher than the sample mean. Thus, while the Ideas dimension can imply a potential for ideational change and change in practices, it is not a prerequisite.

4.2 IMI and other indicators

According to the DT framework, the challenges posed by the First Deep Transition are global yet the traits of industrial modernity are unevenly spread. Furthermore, as industrial modernity is a configuration of ideas, institutions, and practices, the high or low total values in the IMI index can be achieved in a number of ways. This means that the favourable conditions for the Second Deep Transition might not be correlated much with the ranking of countries along with other, more common measures of societal progress. Indeed, we find that IMI does not have statistically significant correlations with per capita GDP, Human Development Index, Gini index, and Sustainable Development Index (see Appendix B). In other words, countries with similar levels of development or countries facing similar environmental and social challenges exhibit notable variance in terms of their capability to enact the Second Deep Transition.

We also compare the IMI index values for each country with the most recent Climate Action Tracker report (2021) that evaluates countries' climate targets and policy actions against the Paris Agreement goal of keeping global warming below 1.5°C (Table 8). This is an instructive exercise as it allows to juxtapose the countries' current potential for transformative change (expressed by the IMI) to their future commitments. We find that the assessments of the IMI and CAT match for 11 countries. For 11 countries IMI overestimates CAT values, underestimating them for 6 countries. Note, however, that with the exception of Germany, CAT assesses the average performance of European countries (EU27) as a whole. This means that CAT does not distinguish between the performance of countries that differ considerably in their IMI values (e.g. Sweden and Poland). As a result, the mismatch between the two metrics might be somewhat exaggerated.

Table 8. Climate Action Tracker evaluations vs. the IMI clusters.

	Sufficient/almost sufficient	**Insufficient**	**Highly/critically insufficient**
Most likely	Morocco	Japan Germany Spain Sweden	Brazil Colombia Mexico
Moderately likely		Estonia Cyprus Romania	Australia China Singapore Ukraine
Least likely		Chile Netherlands Poland Slovenia South Africa USA	Argentina Indonesia India Kazakhstan New Zealand Russia Thailand

Notes:
1 CAT classifies countries on a 5-point scale. In the table, we have merged the extremes of the scales ("sufficient/almost sufficient" and "highly/critically insufficient") to create a match with the IMI grouping.
2 The cells marked with green indicate where the k-means classification of the IMI and CAT overlap; the cells marked with orange represent differences.
3 CAT does not evaluate the climate targets of the Philippines and Turkey hence these countries are missing from the table.

5. Discussion and conclusion

Our findings demonstrate that favourable preconditions for the Second Deep Transition can be found in economically, politically, and culturally diverse countries, covering multiple continents. The same applies to the timing of industrialization with the 'most likely' group including first (Germany, up to the 1880s), second (Japan, Sweden, 1880-1950), and third wave countries (Brazil, Colombia, Morocco, Spain, 1950s and onward) (Stearns, 2013). Notably, our results show that scoring low on the Practices sub-indicator does not automatically equal good prospects for major transformative change as the combined weight of countervailing ideas and institutions may well offset this advantage (the Philippines provides an extreme case here). Finally, our index was not significantly correlated with any standard metrics of societal welfare such as GDP, human development, or inequality. Taken together, the findings back up claims made in the existing literature that the Second Deep Transition is not about the South supplying all the problems and North all the solutions. Instead, there are pockets of experimentation with new technologies, social innovations, and transformative policymaking all over the world, with different regions making piecemeal contributions to major transformative change and enabling deep mutual learning in an international arena (Schot and Steinmueller, 2018; Kanger and Schot, 2019).

A comparison of our index with Climate Action Tracker (2021) suggests that the transformative potential of many countries is higher – much higher in the case of Brazil and Colombia – than reflected in their current commitments to averting climate change. This underscores the role of agency, power, and politics of Deep Transitions: although the low values of IMI can be viewed as an open door, they do not compel countries to enter. In many instances, the potential but highly uncertain long-term gains may be offset by short-term political considerations. As stressed by Cohen: *"Especially during the period when the rise of authoritarianism poses pronounced threats to democratic governance and political legitimacy remains inexorably tethered to customary measures of economic growth, it is imperative to inquire whether sustainability is actually a globally salient objective"* (2021: 93). Insights from Global Political Economy (Newell, 2020) might help to explain why certain countries may purposefully choose to delay or even block the path to the Second Deep Transition - even when they are characterized by a fairly high degree of transformative potential.

Our snapshot comparison of 30 countries also seems to be in line with the results on historical time-series. First, the difference between the mean values for the ideational, institutional, and practice-related components of IMI (36.71, 43.92, and 71.04 respectively) matches empirical observations on time-lagged shifts, beginning with a change in public discourse in the 1960s, followed by institutional reforms in the 1980s, followed, in turn, by far more modest changes in practices from the 1990s (Kanger et al., 2020; Kanger et al., forthcoming). Second, the mean value for the domain of the environment in IMI is lower than that of science, technology, and innovation (52.14 and 60.02 respectively) – despite the fact that many countries have extremely high levels of material input and fossil fuel based energy consumption. Again, this matches with historical evidence, showing more rupture in the first pillar of industrial modernity (environment as a blind spot) than in the second one (overconfidence in science and technology) (ibid.).

This leads us to the final point. Although the dramatic impacts of climate change and loss of biodiversity dominate the newsfeed and public imagination, our results indicate that much more attention should be paid to rethinking the ways in which societies think about, regulate, and develop science and technology. Continuing on the historically dominant path of largely uncritical, overconfident, and exclusionary application of technoscientific knowledge would only result in the repetition of age-old problems of industrial societies such as continuous techno-fixes aimed at symptoms instead of root causes, pervasive rebound effects where increases in technological efficiency are offset by a corresponding growth in demand or gross overestimations of the promises of new technologies. In times when various highly risky Earth System Interventions are increasingly advocated with minimal accountability (Reynolds, 2021), the need to rethink science and technology is nothing short of an existential one.

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Appendix A

Data table with all the relevant sources that differ from what is described in the Methods and data section.

Country	Variable	Year	Source
Argentina	Passenger vehicles	2019	Statista, available at: https://www.statista.com/statistics/1208501/argentina-electric-hybrid-vehicles-unit-sales
Australia	Passenger vehicles	2019	Statistics Office Australia, available at: https://www.abs.gov.au/statistics/industry/tourism-and-transport/motor-vehicle-census-australia/31-jan-2019#data-download
Brazil	Passenger vehicles	2019	IEA Global EV Outlook 2020, available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf
Chile	Passenger vehicles	2019	IEA Global EV Outlook 2020, available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf
	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
China	Passenger vehicles	2019	IEA Global EV Outlook 2020, available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf
Cyprus	Passenger vehicles	2019	ACEA, available at: https://www.acea.auto/figure/new-passenger-car-registrations-in-eu/
Estonia	Passenger vehicles	2019	Transport Administration, available at: https://www.mnt.ee/et/ametist/statistika/soidukite-statistika

	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
India	Attitudes towards economic growth	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
	Passenger vehicles	2019	IEA Global EV Outlook 2020, available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf
Japan	Passenger vehicles	2019	IEA Global EV Outlook 2020, available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf
Kazakhstan	Passenger vehicles	2019	Informburo, available at: https://informburo.kz/kaz/elektromobilderd-tken-bgn-zhne-bolashay-azastan-lemdk-trendten-nege-kende-aldy.html
Morocco	Passenger vehicles	2019	Saudi British Research and Marketing Company, available at: https://aawsat.com/home/article/1680741/«تيسلا»-الأميركية-تمثل-نصف-سوق-السيارات-الكهربائية-في-المغرب
	Attitudes towards economic growth	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp

New Zealand	Passenger vehicles	2019	Transport Administration, available at: https://www.transport.govt.nz/statistics-and-insights/fleet-statistics/monthly-ev-statistics/
Poland	Passenger vehicles	2019	ACEA, available at: https://www.acea.auto/figure/new-passenger-car-registrations-in-eu/
	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
Slovenia	Passenger vehicles	2019	Eurostat, available at: https://ec.europa.eu/eurostat/databrowser/view/ROAD_EQR_CARPDA__custom_1017182/default/table?lang=en
	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
South Africa	Passenger vehicles	2019	IEA Global EV Outlook 2020, available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf
	Attitudes towards economic growth	2010-2014	WOrld Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
Spain	Passenger vehicles	2019	Eurostat, available at: https://ec.europa.eu/eurostat/databrowser/view/ROAD_EQR_CARPDA__custom_1017182/default/table?lang=en
	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
Sweden	Passenger vehicles	2019	IEA Global EV Outlook 2020, available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-

			bad21fa844fd/Global_EV_Outlook_2020.pdf
	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
United States	Passenger vehicles	2019	IEA Global EV Outlook 2020, available at: https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf
Germany	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
Netherlands	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp
Ukraine	Attitudes towards science and technology	2010-2014	World Values Survey 6th wave, available at: https://www.worldvaluessurvey.org/WVSOnline.jsp

Appendix B

Spearman's rank correlation coefficient (Spearman's rho) for the IMI and Human Development Index (HDI), Gini index, Sustainable Development Index (SDI), and GDP per capita

	Human Development Index	Gini index	Sustainable Development Index	GDP per capita
IMI	-0.33	0.12	0.04	0.06

Data sources: United nations (HDI), World Bank (Gini index, GDP per capita), www.sustainabledevelopmentindex.org (SDI).