GLOBAL ENERGY INNOVATION INDEX

National Contributions to the Global Clean Energy Innovation System

Colin Cunliff and David M. Hart

August 2019

INFORMATION TECHNOLOGY & INNOVATION FOUNDATION

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KEY FINDINGS

- Without more and faster clean energy innovation it will be virtually impossible to meet global climate emission goals.
- The 23 countries covered by ITIF's Global Energy Innovation Index make highly varied contributions to clean energy innovation, but all can and should increase their contributions considerably.
- Norway, Finland, and Japan make the most significant contributions to the global clean energy innovation system relative to the size of their economies.
- Norway and Finland are the only countries that invest as much as experts recommend in public clean energy research, development, and demonstration (RD&D).
- Despite announcing its intent to withdraw from the Paris climate agreement, the United States continues to make major contributions to global clean energy innovation, ranking fourth on a per-gross-domestic-product (GDP) basis.
- On an absolute basis, the United States invests more than any other nation to support clean energy innovation. It invests more in total clean energy RD&D ($6.8 billion in 2018) than the next two countries (China and Japan) combined, and more in basic energy science than all other nations combined.
- Australia, Italy, and the Netherlands rank the lowest of the developed countries, owing primarily to their limited contributions to clean energy option generation.
- Despite joining the Paris Agreement and committing to double their public clean energy RD&D investments within five years in the Mission Innovation (MI) initiative, nine countries—South Korea, France, Italy, Netherlands, Australia, Sweden, Denmark, Norway, and Finland—and the EU invest less now in absolute terms than they did in 2015.
- Public funding for demonstration of capital-intensive clean energy technologies, such as carbon capture and storage (CCS) and advanced nuclear energy, appears to be a major weakness in the global energy innovation system.
- The rate at which nations produce high-impact clean energy start-ups, which are important for scaling up some clean energy technologies, varies widely. The global system is dependent on a few countries, led by the United States in absolute terms, to perform this function.
- Although most nations target clean energy with their public RD&D investments, six nations—Mexico, China, Australia, Norway, Italy, and Canada—still spend at least a sixth of their investments on legacy fossil fuel RD&D programs.
- Seven nations—China, Saudi Arabia, United Arab Emirates, Indonesia, India, Mexico, and South Korea— subsidized fossil fuel consumption by $171 billion in 2018, spending far more for this purpose than all 23 nations and the EU combined invested in clean energy RD&D ($22.7 billion in 2018).
- Because fossil fuel subsidies in a few high-emissions countries outweigh the generally modest carbon prices many countries have imposed to curb carbon dioxide (CO_2) emissions, the weighted average effective carbon price across all MI countries is -$3.44 (*negative*) per ton of CO_2.

INTRODUCTION

To sustain global prosperity and expand energy access while meeting the challenge of climate change, energy must become more reliable, more affordable, and cleaner. Fossil fuel combustion, the primary source of climate-warming emissions, still supplies about 80 percent of global energy needs—and total consumption is rising.[1] These emissions must either be captured or eliminated in the coming years if the worst consequences of climate change are to be averted.

If dramatic emissions cuts cannot be achieved without raising energy costs or degrading performance, the energy transition will fall short. Few countries will accept higher costs or poorer performance. Yet, right now, no viable clean energy substitutes are available for many essential purposes. [2] For many others, such substitutes are still too expensive or perform too poorly to be acceptable.[3] The transition to a global clean energy system cannot be accomplished without innovation on a massive scale to provide these solutions.

Energy innovation is a global process. The relevant research communities, industries, and financial institutions span nearly every border. Such global interactions are extremely valuable. They allow diverse ideas to be combined in novel ways, for instance, and for field testing of options to occur in settings far from where they originate.

Despite energy innovation's global scope, national governments are its most important contributors. There is no global entity that can sufficiently provide funding to fuel the process at the requisite scale, guide the application of those resources to key problems, or support the development of problem-solving institutions. National governments have the biggest impact on energy innovation, through their spending, taxation, and regulatory policies, as well as through the signals they send to one another and to their citizens.

The importance of both innovation and the centrality of national contributions to energy transition were acknowledged by the creation of the MI initiative in parallel with the Paris Agreement in 2015. Twenty-four nations and the EU committed to both double their public investments in energy RD&D and collaborate in tackling key innovation challenges.[4] (As we show, most are falling short of fulfilling this commitment in practice.)

MI was a bold declaration. But it will amount to little more than hot air unless the member nations both follow through on their commitments and build on them aggressively, with increasing ambition. Nations should be judged by the actions they take to accelerate clean energy innovation.

This report seeks to provide accountability for these commitments, and to lay the foundation for more ambitious measures by assessing national contributions to the global energy innovation system made by the MI member nations and the EU.

CORE CONCEPTS: THE SYSTEMS "LENS" ON ENERGY INNOVATION

This report is based on an assessment of three essential functions of an innovation system: option generation, scale-up to widespread use, and social legitimation.[5]

Options are new technologies and practices that have the potential to change the way energy is produced or consumed on a large scale while reducing greenhouse gas emissions per unit of energy service supplied. **Option generation** encompasses many of the activities associated with corporate research and development (R&D) divisions, academic institutions, and government laboratories. In order to perform this function, these institutions must have access to funding and talent as well as to one another. Governments frequently fund exploration of options that markets do not support, and shape the flows of talent, finance, and terms of collaboration among institutions. A healthy innovation system generates a steady flow of options, in part to guard against the risk of failures of incumbent and emerging technologies, as well as to identify the most promising opportunities for significant improvement.

Options are typically refined, **scaled up**, and weeded out by a different set of organizations and institutions than those that generate the options in the first place. An innovation must not merely work in an optimized laboratory setting to make a difference at climate scale, it must be cheap, durable, and flexible enough to be applied in a diverse array of applications and settings. When investment flows to innovators who are seeking access to large markets, downstream users become key actors in refining, weeding out, and scaling energy innovations. Users' feedback, as well as their revenue, helps determine which technology pathways are followed and which are not. Scale-up can accelerate significantly when a virtuous cycle of adoption, reinvestment, cost reduction based on economies of scale, process innovation, and further product innovation takes hold. Governments can play a variety of roles in nurturing such virtuous cycles, notably by sharing the risk of innovation through direct investments in pilot and demonstration projects, guarantees of private investments in first-few-of-a-kind commercial projects, and tax incentives for early adopters.[6]

Options that scale must be acceptable to the society in which they will be deployed. Innovation is an intrinsically social process, and options that are inconsistent with widely held values, which may include—and always extend beyond—environmental sustainability, may be blocked. This process of **social legitimation** of energy innovations depends on yet another set of organizations and institutions beyond those involved in option generation and scale-up. Incumbent energy technologies—even those that impose great environmental costs—are often buttressed by political, legal, and regulatory mechanisms, and may be embedded in supportive regional or national cultures as well. Lower costs and better reliability, along with environmental benefits such as reduced carbon emissions, provide an innovation with a measure of legitimacy. Yet if the innovation is perceived to put other values, such as reliability and security, at risk, or is seen to unfairly displace established businesses and workers, societal forces may withhold the "license to operate" needed for an innovation to scale up.

GLOBAL ENERGY INNOVATION INDEX BUILDING BLOCKS

The Global Energy Innovation Index is built from three component indexes, each of which measures one of the functions sketched in the previous section. The 3 indexes are, in turn, built from a total of 14 components, which carry different weights. This section describes these building blocks and explains the weighting scheme. For full details, see the methodological appendix. To further explore the data and apply your own weightings, please download the spreadsheet from our website.

OPTION GENERATION

Public investment in clean energy RD&D is the most important policy lever governments have to create new clean energy options, and therefore is weighted most heavily. The private sector is generally unwilling to make large, long-term investments that provide highly uncertain returns. Public investments are essential if the world is to fully break its dependence on dirty energy resources, as the MI initiative acknowledges.

Public investment in basic energy science is essential to generate new options and pathways for advancing clean energy innovation. All clean energy technologies would benefit from fundamental breakthroughs in catalysts and materials discovery, and require better control and understanding of structures and functions at atomic and subatomic scales. MI implicitly recognizes the importance of basic energy science research to innovation with its inclusion of clean energy materials as one of the eight core "Innovation Challenges."[7]

The Option Generation Index also credits nations that are **growing their clean energy RD&D budgets** and **building diverse clean energy RD&D portfolios.** Growth demonstrates responsiveness to the challenge of climate change and the shared commitments expressed in MI. More-diverse portfolios are more likely to cover all sectors of the economy and sources of emissions, as well as insure against the risk of any one technology failing to perform or scale as hoped for.

SCALE-UP

Although their value varies across technology fields, patents often foster investment in the companies that hold them and thereby facilitate the further refinement of the inventions they protect, aiding their progress toward commercial scale. National policy plays a central role in the patent system, defining legal rights and shaping the quality of enforcement. The level of **high-value patent applications for climate change mitigation technologies** therefore provides a measure of a nation's ability to turn options into products or services of commercial value, and to weed out options that have little chance of being commercialized.

Demonstration projects are often required to refine and validate technologies that are not quite ready for commercial use, and to create confidence among their potential buyers, users, and investors. As the International Energy Agency noted, demonstration projects often contain "an element of risk that is too large for the private sector to assume," requiring **public investment in clean energy demonstration projects** to complement private-sector investment.[8] If demonstrations provide convincing evidence of a technology's reliability, safety, and economic viability, it is far more likely to scale rapidly.

The demonstration phase is particularly important for capital-intensive technologies, because of the greater risk investment in these technologies poses. Two groups of capital-intensive technologies that are particularly important are **carbon capture and storage** (CCS) and **advanced nuclear power**. CCS plays a role in nearly all pathways identified by the Intergovernmental Panel on Climate Change as having a reasonable chance of limiting global average temperature rise to 2 degrees Celsius or less. Similarly, advanced nuclear power is a promising source of clean energy that can provide low-carbon electricity and may be able to provide other energy services that solve challenging emissions problems, such as process heat and hydrogen production. We include binary variables to indicate the presence of an advanced nuclear industry and CCS demonstration projects.

The number of **high-impact cleantech start-ups** indicates the degree to which a nation's entrepreneurs are likely to take innovations to scale. The Ernst & Young (EY) **Renewable Energy Country Attractiveness Index** (RECAI) incorporates additional factors that help renewable energy scale up, including energy demand growth, renewable energy resource availability, access to investors and capital, and other policy and economic factors.

SOCIAL LEGITIMATION

A **carbon price** incorporates some or all of the costs climate change imposes on society into the cost of unabated fossil fuel energy and other climate-unfriendly products and services, thereby signaling a societal preference for clean energy and enhancing the price competitiveness of clean energy options. A carbon price may be implemented through a carbon tax or a cap-and-trade system and may cover some or all of a nation's emissions. Fossil fuel consumption subsidies slow the adoption of clean energy technologies and deter investment in clean energy companies by lowering the cost of fossil fuels below their market value. These subsidies are incorporated into this component as a negative carbon price.

Fuel taxes such as gasoline taxes, which are often imposed for non-climate-related reasons, can increase the price of high-carbon fuels relative to low- and zero-carbon fuels. This differential encourages energy users to go for low- or zero-carbon options.[9] However, this does not mean implicit carbon prices imposed by fuel taxes are sufficient, or that fuel taxes are the best way to address the external costs of climate change. Fuel taxes are often intended to fund transportation infrastructure, or incorporate the costs of other (non-climate) negative side effects such as congestion, accidents, and local air pollution.

Many nations continue to invest a portion of their total public energy RD&D budget in unabated **fossil fuel energy RD&D**. RD&D that lowers the cost or improves the performance of dirty energy technologies strengthens them in markets where they compete with clean alternatives. This investment also sends mixed signals to the energy industry and investors about a nation's commitment to clean energy. And, like subsidies, dirty energy RD&D spending represents a lost opportunity for clean energy innovation.

The last component of the Social Legitimation Index highlights **international cooperation in clean energy RD&D**. It is measured by leadership of and participation in the MI Challenges, which are "calls to action aimed at catalyzing global research efforts." International cooperation could dramatically accelerate progress in clean energy innovation with big payoffs in these eight areas: smart grids, off-grid access to electricity, carbon capture, sustainable biofuels, converting sunlight to fuels, clean energy materials, heating and cooling of buildings, and clean hydrogen.[10] A nation's engagement in these challenges signals to its citizens and the global community that it is committed to the fight against climate change.

STANDARDIZATION AND WEIGHTING

The Global Energy Innovation Index is built in these three steps from diverse components. First, we standardize each component as a set of z-scores, with the mean set to 10 and standard deviation to 4. The scores are capped at 0 and 20 (2.5 standard deviations from the mean in either direction), so outliers do not carry too much weight. A nation contributing to the global system at an average level on any component would receive a score of 10, while the maximum score would be 20.

The second step is to create the Option Generation, Scale-Up, and Social Legitimation Indexes by combining the z-scores for the 14 components using the weights in table 1. Finally, the three indexes are aggregated to create the Global Energy Innovation Index. In this step, we weight option generation more heavily than the other two functions, because we believe it is the most essential function for the global energy innovation system to perform at a high level.

The Global Energy Innovation Index captures, to the best of our abilities given the available data and our considered expert judgment, each country's contributions to the global energy innovation system.

Table 1. Indicators and weights in the Global Energy Innovation Index

Innovation Indicator	Data Type	Category Weight	Indicator Weight
Option Generation		50%	
Public Investment in Clean Energy RD&D	Raw Number		60%
Public Investment in Basic Energy Science	Raw Number		25%
Change in Clean Energy RD&D	Raw Number		10%
Diversity of RD&D by Technology Type	Raw Number		5%
Scale-Up		25%	
Climate Change Mitigation Patent Applications	Raw Number		30%
Clean Energy Demonstration Funding	Raw Number		30%
CCS Demonstrations	Binary Variable		10%
Adv. Nuclear Industry	Binary Variable		10%
High-Impact Cleantech Start-Ups	Raw Number		10%
EY Renewable Energy Country Attractiveness Index	Raw Number		10%
Social Legitimation		25%	
Effective Carbon Price, Incl. Fossil Fuel Subsidies	Raw Number		50%
Fuel Taxes	Raw Number		20%
Percent Clean RD&D	Raw Number		20%
International Cooperation in Clean Energy RD&D	Binary Variable		10%

OVERALL RANKINGS

Table 2. The Global Energy Innovation Index and component categories

Rank	Country	Total Score	Option Generation		Scale-Up		Social Legitimation	
			Rank	Score	Rank	Score	Rank	Score
1	Norway	15.5	2	14.1	4	11.8	4	13.0
2	Finland	14.8	1	15.1	14	9.2	5	12.9
3	Japan	13.7	4	12.6	2	12.1	12	10.1
4	United States	13.3	3	13.5	8	10.8	15	9.1
5	France	13.2	5	12.2	10	10.1	2	13.3
6	Canada	12.7	6	11.7	3	12.0	13	9.2
7	Germany	12.5	10	10.7	6	11.5	6	12.0
8	South Korea	12.3	9	10.8	5	11.6	10	11.1
9	United Kingdom	12.2	7	11.2	13	9.6	3	13.2
10	Denmark	12.1	11	9.5	1	12.6	7	11.9
11	Sweden	12.0	13	9.2	7	11.4	1	14.4
12	Austria	10.7	8	11.0	15	8.7	11	10.6
13	Netherlands	10.3	14	9.0	11	10.1	8	11.7
14	Italy	9.2	12	9.2	19	8.1	9	11.3
15	China	9.0	15	8.7	9	10.3	19	7.8
16	Australia	8.3	17	7.6	12	9.9	14	9.2
17	Brazil	7.0	18	7.3	16	8.6	18	8.2
18	Mexico	6.6	16	8.6	21	7.3	20	5.9
19	India	6.5	21	6.4	18	8.4	16	9.1
20	Chile	5.1	20	6.4	23	6.3	17	8.4
21	United Arab Emirates	5.0	23	5.9	17	8.6	21	5.0
22	Indonesia	4.3	22	6.1	20	8.0	22	3.3
23	Saudi Arabia	3.7	19	6.7	22	6.9	23	2.1

Norway tops the overall Index, making the most significant contribution of any nation to the global clean energy innovation system relative to the size of its economy, and ranks among the top four nations across all three subsidiary indexes. Norway and Finland are the only countries that invest as much as experts recommend in public clean energy RD&D, the most heavily weighted component in the Index. Japan ranks third and is particularly strong in scale-up.

Despite declaring its intent to withdraw from the Paris Agreement, the United States is making major contributions to the global clean energy innovation system, placing fourth in the overall Index. In absolute terms, the United States invests vastly more in clean energy RD&D than any other nation, and its contributions to basic energy science research are an order of magnitude larger than any other nation, even on a per-GDP basis. However, the United States ranks 15th in the Social Legitimation category, dragged down by the lack of a national carbon price and low fuel taxes.

As the rankings of the United States show, national contributions vary across the three functions measured by the subsidiary indexes. Finland is best at generating clean energy options, but lands in the bottom half in the Scale-Up Index due to poor scores for demonstration and patenting. China, by contrast, ranks above the median in scale-up due to its support for CCS, advanced nuclear projects, and attractiveness for renewable energy development, but places only 19th in social legitimation due to its fossil fuel consumption subsidies. While currently ranked last, Saudi Arabia appears to be on track to double its investment in clean energy RD&D from a baseline of $75 million in 2015 to $150 million by 2021—which is dwarfed by the $44.7 billion it spent in fossil fuel consumption subsidies last year.

Other notable findings include:

- Public funding for demonstration of capital-intensive clean energy technologies, such as CCS and advanced nuclear energy, appears to be a major weakness in the global energy innovation system. Only ten nations reported any spending in this category, while six nations reported no spending, and another seven nations did not provide any data.
- Nine countries and the EU invest less now in clean energy RD&D than they did at the launch of MI in 2015. Most countries have not fulfilled their MI commitment to substantially increase investment in this important global public good.
- Only 7 nations undermine the social legitimacy of clean energy by subsidizing fossil fuel consumption, but the amount these nations spend for this purpose is more than 7 times the total amount all 23 nations in the Index invested in clean energy RD&D.
- The rate at which nations produce high-impact start-ups, which are important for scaling up clean energy technologies, varies widely. The capacity of a national innovation system to generate such firms depends on many factors, some of which are difficult for public policies to influence. The global system may be dependent on a few countries to perform this function.
- Although most nations target clean energy with their public RD&D investments, six nations—Mexico, China, Australia, Norway, Italy, and Canada—still allocate at least a sixth of their investment to legacy fossil fuel RD&D programs. China devotes nearly 40 percent of its energy RD&D budget to such a program. Improving the efficiency of fossil fuel combustion would at best yield marginal emissions reductions while imposing an opportunity cost by diverting innovation resources away from clean energy.
- Carbon prices, generally at modest levels, are imposed on a small albeit growing fraction of emissions. Fourteen nations impose a carbon price at the national or subnational level or participate in the EU Emissions Trading System. However, fossil fuel subsidies—which act as a negative carbon price—overwhelm carbon prices, resulting in a weighted average effective carbon price of -$3.44 (*negative*) per metric ton of carbon dioxide (-$3.44/t$CO_2$).

The Global Energy Innovation Index may not do full justice to all national contributions, due to incomplete or inadequate data. Data for the basic science and demonstration components, for example, are incomplete. Since the Index relies primarily on national reporting to the International Energy Agency (IEA), nations can and should fill these gaps by reporting their efforts more fully and consistently, using internationally agreed upon definitions and measures. We hope to issue a future Global Energy Innovation Index 2.0 report that draws on improved data. Our full methodology and data is available for public use.

Mission Innovation

While this report focuses on national contributions to the global energy innovation system, it also begs the question of the health of the system as a whole. We report on this question in detail elsewhere.[11] The short answer is the global clean energy innovation system is not yet up to the climate challenge. A wide array of indicators lead us to the conclusion that the pace of clean energy innovation is too slow, and the system needs strengthening.

For instance, patent applications for climate change mitigation technologies nearly tripled globally between 2000 and 2011. But, after peaking at 27,800 in 2011, the total declined by 27 percent over the next 4 years. The decline was consistent across all the major nations, except China. The decline in filings has been most pronounced in nuclear power and renewable energy technologies.[12] Weak patent applications portend weakness in the global scale-up of clean energy innovations.

Similarly, growth in global public investment in clean energy RD&D is much less robust than it should be. MI is far off track from achieving its goal of doubling this investment in five years.[13] This finding differs dramatically from MI's May 2019 announcement that its members had increased their spending by 55 percent.[14] The reason for the discrepancy is many MI member nations lowballed the baselines against which their doubling pledges are assessed, thereby enabling them to take credit for clean energy RD&D they were already supporting before MI.

A third key global data point is an effective carbon price. The vast majority of global carbon emissions are not priced at all. For the small fraction of emissions that are subject to pricing schemes, the estimated average price is paltry, although it has been rising. The World Bank suggests a carbon price of \$40–\$80/tCO_2 is required to be on track to meet the goals of the Paris Agreement. The price paid on the average ton of carbon emissions globally is roughly 3 percent of the lower limit of this range.[15]

Inadequate national policies are a major cause of this global failure. Only national governments are in position to both make long-term, high-risk investments in key areas such as energy-related basic science and energy technology demonstration projects that generate clean energy options and help bring them to scale. National governments are central players in pricing carbon and eliminating fossil fuel subsidies, which help to legitimate the adoption of clean energy innovations.

If the world is to avoid the worst consequences of climate change, and its societies are to enjoy energy that is affordable, reliable, safe, and secure, it needs a much better energy innovation system. National governments must commit more resources, improve their approaches, and exercise greater public leadership.

CATEGORY 1: OPTION GENERATION

Table 3. The option generation score and component indicators

Rank	Country	Option Generation Score	Clean Energy RD&D		Energy Science		Growth in RD&D		Portfolio Diversity	
			Rank	Z-score	Rank	Z-score	Rank	Z-score	Rank	Z-score
1	Finland	15.1	1	20.0	4	10.6	23	0.0	13	8.5
2	Norway	14.1	2	18.1	6	9.4	22	1.7	5	13.3
3	United States	13.5	10	11.3	1	20.0	6	12.2	12	9.4
4	Japan	12.6	3	14.5	12	8.3	9	11.6	6	12.8
5	France	12.2	4	13.2	3	11.2	16	9.7	11	9.7
6	Canada	11.7	5	12.6	8	8.8	4	12.3	4	14.2
7	United Kingdom	11.2	9	11.3	9	8.5	1	17.7	9	10.6
8	Austria	11.0	6	12.1	10	8.5	8	11.8	14	8.3
9	South Korea	10.8	7	11.5	12	8.3	15	10.6	3	14.4
10	Germany	10.7	11	10.6	5	9.5	5	12.3	1	14.5
11	Denmark	9.5	8	11.4	12	8.3	21	3.2	17	5.4
12	Italy	9.2	13	9.0	12	8.3	17	9.6	2	14.5
13	Sweden	9.2	12	10.3	12	8.3	20	6.3	15	6.0
14	Netherlands	9.0	14	8.9	7	8.9	18	8.9	10	10.3
15	China	8.7	15	7.9	12	8.3	3	13.4	8	11.4
16	Mexico	8.6	17	6.5	2	12.1	2	13.7	16	6.0
17	Australia	7.6	16	6.8	11	8.4	19	8.6	7	11.9
18	Brazil	7.3	18	6.5	ND	ND	7	12.0	ND	ND
19	Saudi Arabia	6.7	19	5.9	ND	ND	10	11.2	ND	ND
20	Chile	6.4	21	5.3	12	8.3	11	11.1	18	0.0
21	India	6.4	20	5.6	ND	ND	12	11.0	ND	ND
22	Indonesia	6.1	22	5.3	ND	ND	13	11.0	ND	ND
23	United Arab Emirates	5.9	23	5.1	ND	ND	14	10.9	ND	ND

Finland takes the top spot on the Option Generation Index, doing more than any other nation, relative to the size of its economy, to generate new clean energy options for the world. It shines particularly on the most heavily weighted component, investing more than three times the average nation in clean energy RD&D. However, a different component is "flashing a warning signal" for the leader, as its investments in clean energy RD&D have shrunk, rather than grown, since 2015, declining more than any other country in that period.

Norway has a similar profile, ranking second. Like Finland, it scores well in public clean energy RD&D spending, not as well in energy science and portfolio diversity, and poor in its public clean energy RD&D spending trend, which is negative.

The United States ranks third on the Option Generation Index, owing to its top spot as a funder of basic energy-related science research and a reasonably strong showing in the other components. In absolute dollars, the United States is by far the largest funder of clean energy RD&D, investing $6.8

billion in 2018, but comes in near the average when measured as a share of GDP. The United States has also grown its public clean energy RD&D budget more than most of the MI countries.

The United Kingdom and Mexico are notable for the dramatically positive trend in their spending. The United Kingdom has increased its clean energy RD&D budget at a faster rate more than any other country in the Index. This movement is consistent with the U.K.'s Industrial Strategy, launched in 2018, which aims to increase total combined public and private R&D (including non-energy sectors) to 2.4 percent of GDP.[16] Similarly, Mexico has rapidly increased its clean energy RD&D budget and ramped up investments in basic energy sciences, although this trend may be reversed by the current national government.

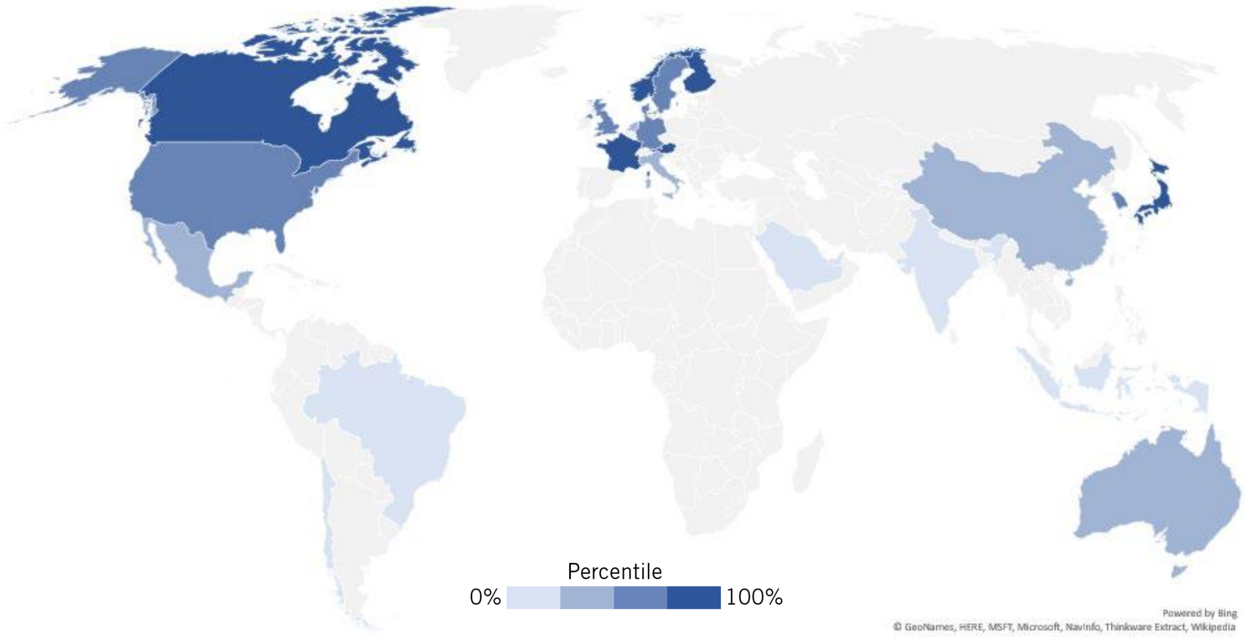
On the other hand, nine high-income countries—South Korea, France, Italy, Netherlands, Australia, Sweden, Denmark, Norway, and Finland—invest less now than they did when MI was launched in 2015. This is true of the EU as a whole as well. While these countries are making robust contributions to the global system now, these investments are to some extent a legacy of past investments and bode ill for a future in which energy innovation must accelerate to meet the climate challenge.

China is the second-largest funder of clean energy RD&D in absolute dollars, investing $3.8 billion. And China has grown its clean RD&D budgets faster than all but two countries in the Index, indicating its intent to expand its contribution to the global system. But two important caveats should be noted. First, the funding levels we use, drawn from internationally comparable sources, do not include investments from state-owned enterprises. Adding these might increase contributions significantly, but the data is murky.[17] Second, China continues to make major investments in non-CCS fossil fuel RD&D, as we show in the Social Legitimation Index. Such investments offset some of the contributions it is making in clean energy innovation.[18]

The non-IEA member countries (Brazil, Chile, China, India, Indonesia, Saudi Arabia, and the UAE) generally have lower per capita incomes than the other countries in the Index, an important factor leading them to make relatively low investments in clean energy RD&D. However, the contributions of these countries as a group are growing rapidly, and most are on track to double public clean energy RD&D spending by 2020 or 2021. Many of them are also partnering with countries with more established innovation systems to identify needs, develop roadmaps, hold joint technology workshops, and even engage in collaborative research projects. India, for example, recently launched funding opportunities in carbon capture, biofuels, and converting sunlight to fuels, each of which require participation from more than one MI member.[19]

Data availability is a concern for non-IEA member countries. Of the seven non-IEA members, only Chile and China have adopted IEA's accounting standards and provide a breakdown of their energy RD&D investments.

INDICATOR 1: PUBLIC INVESTMENT IN CLEAN ENERGY RD&D



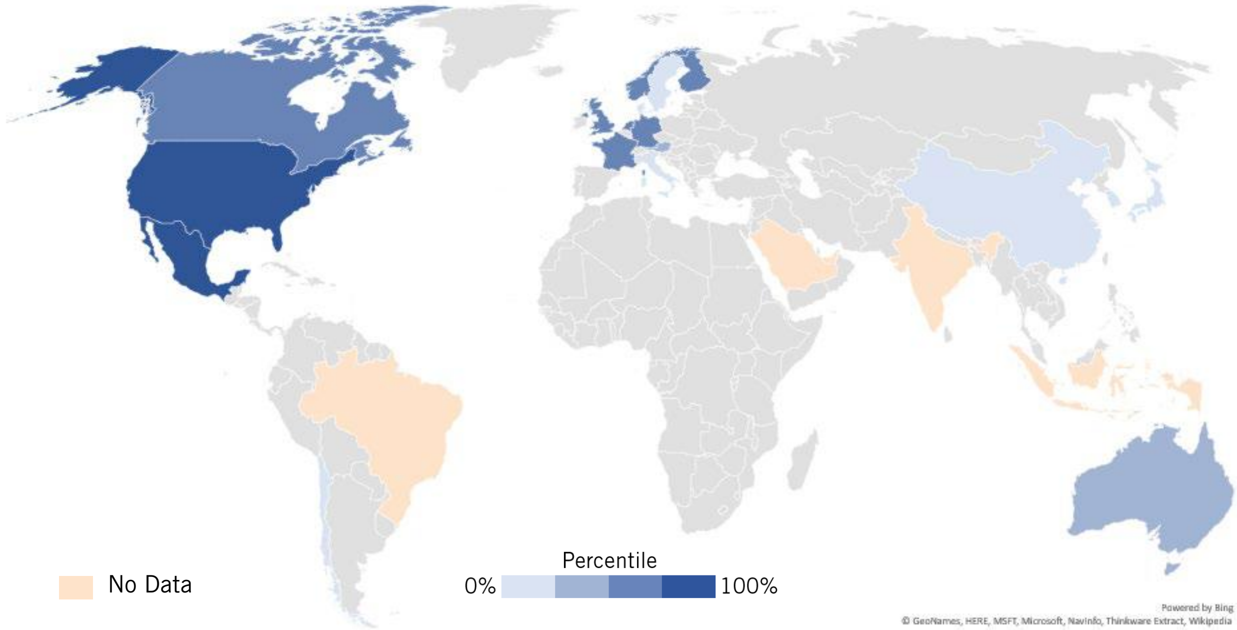
Finland tops the list on this indicator, investing the equivalent of $0.81 in clean energy RD&D for every $1,000.00 of GDP, followed by Norway at $0.69. The United States is the largest source of public funding for clean energy RD&D in absolute terms, investing about $6.8 billion, more than Japan, Germany, France, and the United Kingdom combined. As a share of its economy, this investment puts the United States in 10th place. China's investment displays a similar pattern: It is the second-largest funder of clean energy RD&D in total, having invested $3.8 billion in 2018, but comes in 15th when that figure is scaled by the size of its national economy.[20] The bottom 5 countries invest less than $0.05 per $1,000.00 of GDP in clean energy RD&D.

Experts recommend governments invest as much as Norway and Finland do (roughly $0.60 to $0.80 per $1,000.00 of GDP) in clean energy RD&D.[21] All other countries fall short of this standard, with an average of just $0.26.

Table 4. Option generation, Indicator 1: Public investment in clean energy RD&D, per GDP and total amount

2019 Rank	Country	RD&D per 1,000 units GDP	RD&D amount (millions)	2019 Rank	Country	RD&D per 1,000 units GDP	RD&D amount (millions)
1	Finland	0.81	$212	13	Italy	0.21	$536
2	Norway	0.69	$234	14	Netherlands	0.20	$194
3	Japan	0.50	$2,756	15	China	0.15	$3,809
4	France	0.43	$1,301	16	Australia	0.09	$120
5	Canada	0.40	$707	17	Mexico	0.08	$200
6	Austria	0.37	$180	18	Brazil	0.08	$255
7	South Korea	0.34	$718	19	Saudi Arabia	0.05	$90
8	Denmark	0.34	$109	20	India	0.03	$109
9	UK	0.33	$1,023	21	Chile	0.02	$8
10	US	0.33	$6,775	22	Indonesia	0.01	$30
11	Germany	0.29	$1,311	23	UAE	0.004	$12
12	Sweden	0.28	$149		**MI Average**	**0.26**	

INDICATOR 2: PUBLIC INVESTMENT IN BASIC ENERGY SCIENCE RESEARCH



The United States is by far the largest funder of energy-related basic science research, both in absolute terms and as a percent of GDP. It invested over $3 billion in 2018, or $0.16 per $1,000.00 GDP, more than 10 times the international average. Mexico has increased its investments in energy science in recent years, moving into second place at more than $0.03, followed by France and Finland at $0.03 and $0.02, respectively. Only 11 countries and the EU report any spending in this category; 7 countries report no funding in this category; and 5 countries do not include basic research in their breakdown of total energy RD&D. However, 15 countries and the EU are members of the Clean Energy Materials Innovation Challenge (IC6), which supports basic research in materials discovery and falls firmly in the basic research end of the innovation spectrum.[22]

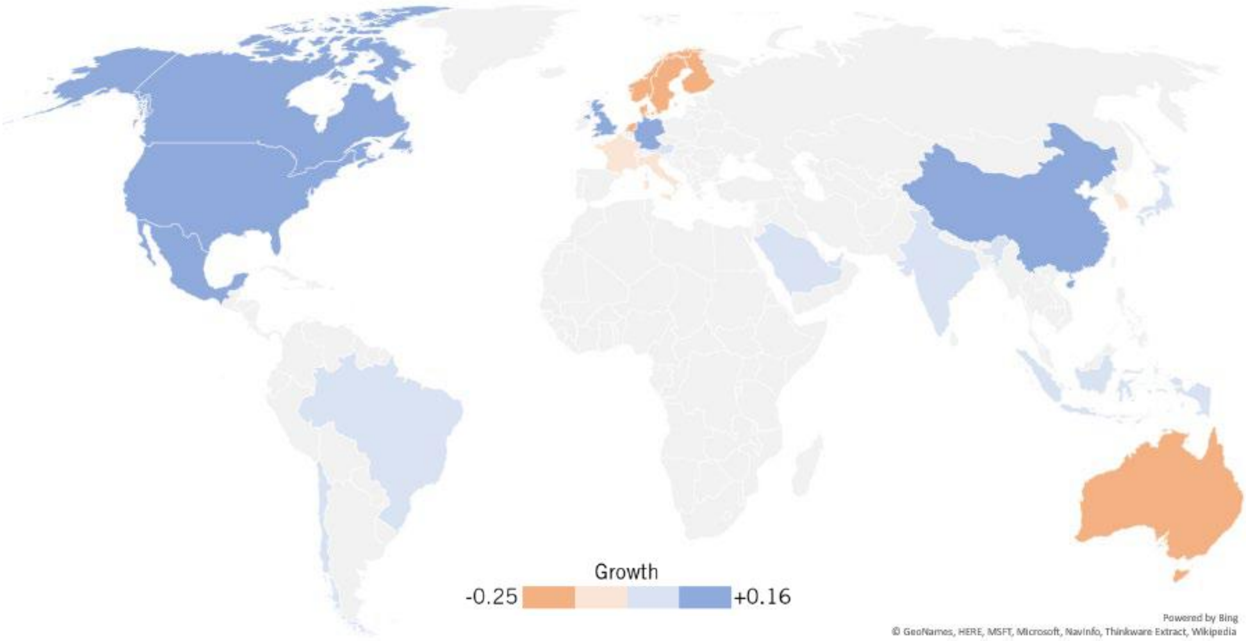
Either countries are not investing in energy science at levels that are commensurate with the energy innovation challenge, or they are not tracking their investments in an internationally comparable fashion.

Table 5. Option generation, Indicator 2: Public investment in basic energy science research, per GDP and total amount

2019 Rank	Country	Energy science per 1,000 units GDP	Energy science amount (millions)	2019 Rank	Country	Energy science per 1,000 units GDP	Energy science amount (millions)
1	United States	0.159	$3,253	10	Austria	0.002	$1
2	Mexico	0.034	$85	11	Australia	0.000	$0.32
3	France	0.026	$77	12	Chile	0	0
4	Finland	0.020	$5	12	China	0	0
5	Germany	0.011	$49	12	Denmark	0	0
6	Norway	0.010	$3	12	Italy	0	0
7	Netherlands	0.005	$5	12	Japan	0	0
8	Canada	0.004	$7	12	South Korea	0	0
9	United Kingdom	0.002	$5	12	Sweden	0	0
					MI Average	**0.015**	**$194**

Note: Brazil, India, Indonesia, Saudi Arabia, and United Arab Emirates have not provided information on their funding for basic energy science.

INDICATOR 3: GROWTH IN PUBLIC CLEAN ENERGY RD&D SINCE 2015



Nine countries and the EU invest *less* now than they did at the launch of MI in 2015. At the other end of the spectrum, the United Kingdom and Mexico have increased their clean energy RD&D budgets by the largest amount when weighted by GDP, investing $0.15 and $0.06 more per $1,000.00 GDP, respectively, than they did in 2015. In terms of absolute growth, China leads the pack, increasing its investment in clean energy RD&D by $1.4 billion, followed by the United States, which grew its clean energy budget by $640 million.

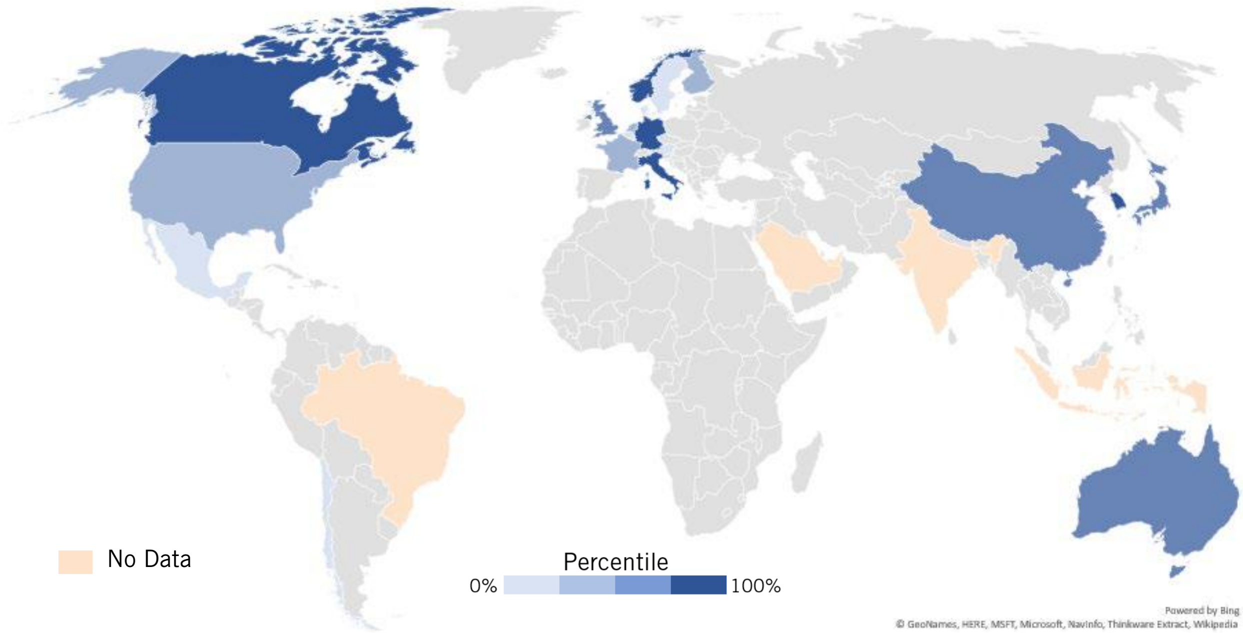
MI was launched in December 2015 to reverse declining public investment in clean energy RD&D.[23] Unfortunately, most countries have not fulfilled their MI commitments to substantially increase investment in public clean energy RD&D.

Table 6. Option generation, Indicator 3: Growth in public investment in clean energy RD&D since 2015, per GDP

2019 Rank	Country	Change in RD&D per GDP	2019 Rank	Country	Change in RD&D per GDP
1	United Kingdom	0.146	13	Indonesia*	0.005
2	Mexico	0.061	14	United Arab Emirates*	0.003
3	China	0.056	15	South Korea	-0.003
4	Canada	0.032	16	France*	-0.022
5	Germany	0.031	17	Italy	-0.024
6	United States	0.031	18	Netherlands	-0.039
7	Brazil	0.027	19	Australia*	-0.045
8	Austria*	0.022	20	Sweden	-0.094
9	Japan	0.019	21	Denmark	-0.160
10	Saudi Arabia*	0.009	22	Norway	-0.191
11	Chile	0.008	23	Finland*	-0.248
12	India	0.005		**MI Average**	**-0.016**

* Data from 2018 not yet available. Growth shown from 2015 to 2017.

INDICATOR 4: DIVERSITY OF PUBLIC CLEAN ENERGY RD&D INVESTMENT



The EU has the most diverse portfolio of clean energy RD&D spending, investing nearly equal amounts across seven broad fields of science and technology IEA and MI track, which include energy efficiency, renewables, nuclear, hydrogen, CCS, and two cross-cutting categories. A Diversity Index of 1 indicates countries are investing in equal amounts across all seven technology categories. Germany and Italy, both EU members, are the top two individual countries. Chile has the least diverse portfolio, with 98 percent of its funding going to just two fields: renewables and hydrogen. Five countries do not share information about the breakdown of their clean energy RD&D spending across these fields.

Most nations are investing in a fairly diverse RD&D portfolio. Those that are not are small nations, which may reasonably choose to focus their limited resources on taking advantage of particular technological strengths or local resources. Diversity is more important at the system level than the national level, which is why this component has a very low weight—but national diversity is nonetheless a useful contribution to the global system.

Table 7. Option generation, Indicator 4: Diversity of public clean energy RD&D investment

2019 Rank	Country	Diversity Index	2019 Rank	Country	Diversity Index
1	European Union	0.91	11	Netherlands	0.75
2	Germany	0.89	12	France	0.73
3	Italy	0.89	13	United States	0.72
4	South Korea	0.89	14	Finland	0.69
5	Canada	0.88	15	Austria	0.68
6	Norway	0.85	16	Sweden	0.61
7	Japan	0.83	17	Mexico	0.61
8	Australia	0.80	18	Denmark	0.59
9	China	0.79	19	Chile	0.37
10	United Kingdom	0.76		**MI Average**	**0.74**

Note: Brazil, India, Indonesia, Saudi Arabia, and the United Arab Emirates have not provided data.

CATEGORY 2: SCALE-UP

Table 8. The scale-up score and component indicators

Rank	Country	Scale-Up Score	Clean Patents		Demo Funding		CCS & Adv Nuc		Cleantech Start-Ups		EY RE Attractiveness	
			Rank	Z-score	Rank	Z-score	Rank	Z-score	Rank	Z-score	Rank	Z-score
1	Denmark	12.6	3	17.0	4	10.2	1	12.8	10	8.5	11	9.7
2	Japan	12.1	2	17.5	11	8.0	1	12.8	17	7.0	7	11.7
3	Canada	12.0	12	8.9	2	12.9	1	12.8	1	20.0	12	9.0
4	Norway	11.8	15	7.9	1	20.0	12	8.8	7	11.2	18	5.1
5	South Korea	11.6	1	20.0	11	8.0	12	8.8	14	7.3	16	7.1
6	Germany	11.5	4	13.7	11	8.0	1	12.8	9	11.1	6	13.6
7	Sweden	11.4	6	11.8	5	9.9	1	12.8	3	16.7	17	6.1
8	United States	10.8	10	9.9	10	8.0	1	12.8	5	12.1	2	16.9
9	China	10.3	16	7.0	ND	ND	1	12.8	15	7.2	1	18.3
10	France	10.1	8	10.7	9	8.7	12	8.8	8	11.2	3	14.5
11	Netherlands	10.1	9	10.0	3	10.6	12	8.8	6	11.4	9	10.4
12	Australia	9.9	14	8.0	7	9.2	1	12.8	11	8.2	5	13.9
13	United Kingdom	9.6	11	9.3	8	8.7	12	8.8	4	13.4	8	11.1
14	Finland	9.2	5	12.2	11	8.0	21	3.6	2	19.4	19	4.8
15	Austria	8.7	7	11.6	6	9.4	21	3.6	12	8.0	ND	ND
16	Brazil	8.6	20	6.4	ND	ND	1	12.8	16	7.2	13	8.4
17	United Arab Emirates	8.6	22	6.3	ND	ND	1	12.8	17	7.0	ND	ND
18	India	8.4	19	6.6	ND	ND	12	8.8	13	7.3	4	14.3
19	Italy	8.1	13	8.1	11	8.0	12	8.8	17	7.0	14	8.2
20	Indonesia	8.0	23	6.2	ND	ND	1	12.8	17	7.0	20	4.7
21	Mexico	7.3	21	6.3	11	8.0	20	7.6	17	7.0	15	8.2
22	Saudi Arabia	6.9	18	6.6	ND	ND	12	8.8	17	7.0	21	4.0
23	Chile	6.3	17	6.7	ND	ND	21	3.6	17	7.0	10	10.0

The Scale-Up Index includes some components that are directly controlled by governments, such as funding for energy demonstration projects and patent applications, that are largely subject to indirect influence. Few countries score well across all of the components. The difference between the top and bottom of this Index is smaller for option generation or social legitimation, with many nations clustered in a dense middle tier.

Denmark scores highest, due largely to its score on high-value climate change mitigation patent applications and its participation in CCS and advanced nuclear demonstration projects. However, Denmark scores below the mean on the cleantech start-ups component, indicating that incumbent firms dominate its contributions to the global energy innovation system.

Japan and South Korea come in second and fifth, respectively, on the Scale-Up Index, with similar profiles across the components. Both countries apply for patents at a high rate, while neither hosts a large number of high-value cleantech start-ups. A contradiction in our data is neither Japan nor South Korea reports public funding of energy demonstration projects, yet both support CCS demonstration projects. This discrepancy highlights the need for countries to track demonstration investments using harmonized or standardized definitions.

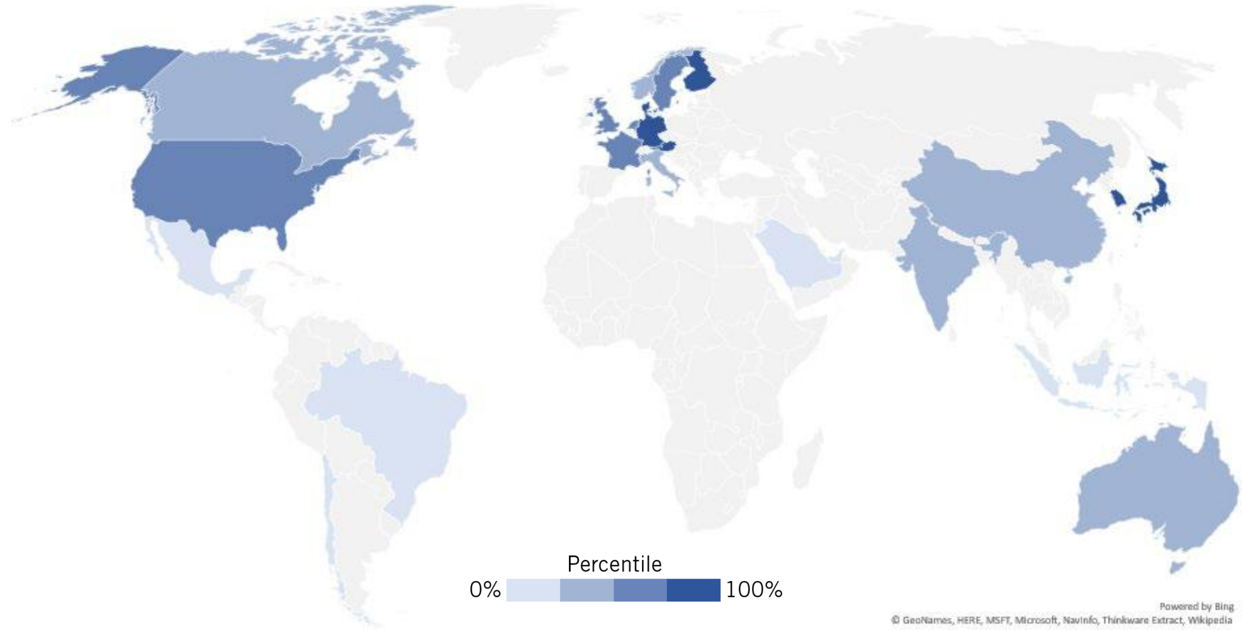
Norway places fourth on the Index, primarily due to its support for energy demonstration projects. It spends more on demonstration projects as a share of its economy than most countries, including the United States, spend on their entire clean energy RD&D portfolios. Norway has a long history of supporting CCS demonstration projects, having launched the world's first CO_2 geological storage site in 1996 and more recently supporting pilot and demonstration carbon capture projects for cement and oil refining plants.[24]

In absolute numbers, the United States tops the list in both high-value climate mitigation patent applications and high-impact cleantech start-ups, accounting for 27 percent of the former and nearly 50 percent of the latter. Measured against its large economy, however, the United States is at or near the middle of the pack on both of these components. As with most high-income nations, its rate of patenting in climate mitigation technologies has declined since 2011, a potentially significant drop in its contribution to the global system that may slow diffusion in the future.

China is one of the few countries that have bucked this trend; high-value climate mitigation patent applications from China have increased 2 percent since 2011. Relative to the size of its economy, China's score on this component remains below average, but will climb in the future if current trends continue. China is also investing heavily in CCS and advanced nuclear energy technologies, and takes the top spot for attractiveness to renewable energy investment.

Of our three subsidiary indexes, the Scale-Up Index is the one that would be most improved by better data in a future update of the Global Energy Innovation Index. The data on demonstration funding is particularly bad, plagued not only by gaps but also by questions about quality. It is unclear to what extent nations that report on this component have actually adopted harmonized standards and definitions. Yet, we feel compelled to include this component, because demonstration funding is one of the few tools nations have to help promising clean energy technologies bridge the "valley of death" that inhibits global scale-up. We try to ameliorate this problem by including CCS and advanced nuclear activity as well as reported public funding for demonstration projects.

INDICATOR 5: HIGH-VALUE CLIMATE CHANGE MITIGATION PATENT APPLICATIONS



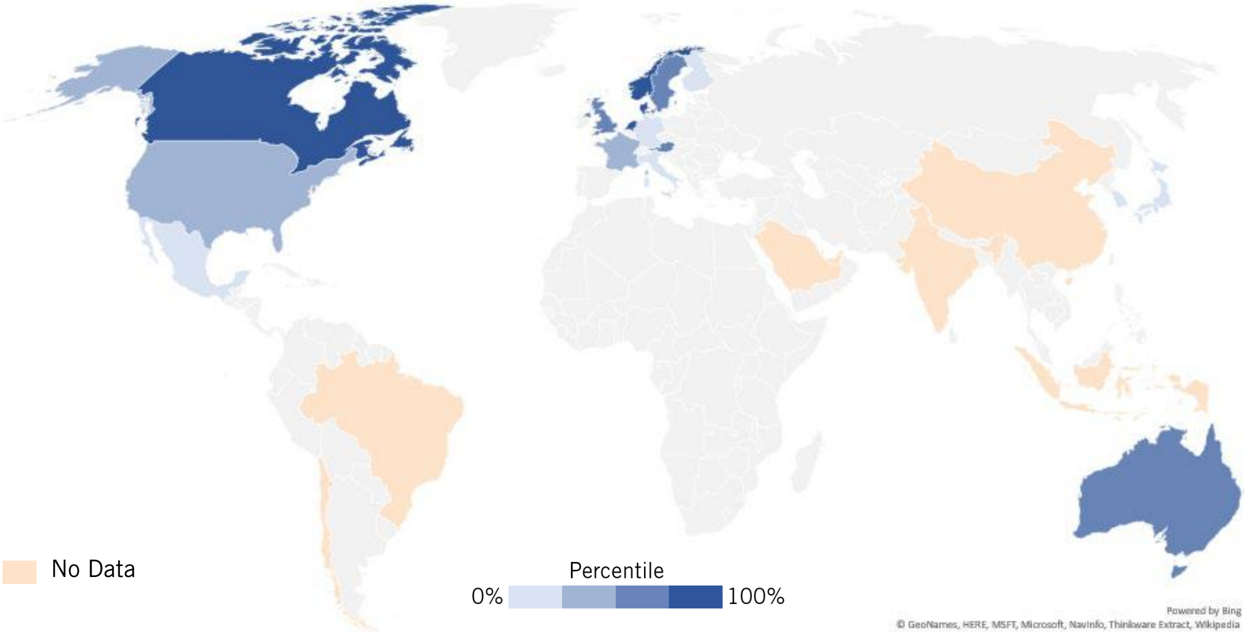
Four countries—the United States, Japan, Germany, and South Korea—account for the vast majority of high-value climate change mitigation patent applications in the world. However, the rankings are quite different when the data is scaled against GDP. South Korea and Japan take the top two spots, generating 1.34 and 1.02 applications per $1 billion of GDP, respectively, followed closely by Denmark with 0.97 patents per $1 billion GDP. Even though the United States ranks first in aggregate, accounting for 27 percent of all high-value patent applications, its score on this component is below average when weighed by GDP. Norway fares worse, producing only 0.15 applications per $1 billion GDP, despite having a robust RD&D portfolio, indicating its contributions to scale up are more limited than to option generation. The non-IEA countries and Mexico come in toward the bottom of these rankings, suggesting they are followers in clean energy scale-up.

Innovators apply for high-value climate change mitigation patents at widely varying rates across countries. Although interpretation of this indicator is subject to debate, this variation suggests some national systems are much more efficient than others in bringing energy innovations to scale.

Table 9. Scale-up, Indicator 5: High-value climate change mitigation patent applications, per GDP

2019 Rank	Country	Patents per GDP	2019 Rank	Country	Patents per GDP
1	South Korea	1.34	13	Italy	0.17
2	Japan	1.02	14	Australia	0.16
3	Denmark	0.97	15	Norway	0.15
4	Germany	0.68	16	China	0.07
5	Finland	0.54	17	Chile	0.05
6	Sweden	0.51	18	Saudi Arabia	0.04
7	Austria	0.49	19	India	0.03
8	France	0.40	20	Brazil	0.02
9	Netherlands	0.34	21	Mexico	0.01
10	United States	0.33	22	United Arab Emirates	0.01
11	United Kingdom	0.27	23	Indonesia	0.00
12	Canada	0.25		**MI Average**	**0.34**

INDICATOR 6: PUBLIC INVESTMENT IN CLEAN ENERGY DEMONSTRATION PROJECTS



Norway ($0.39 per $1,000.00 of GDP), Canada ($0.12), and the Netherlands ($0.06) spend the most on clean energy demonstration projects as a share of their economies. Seven other IEA countries report spending less than $0.05 per $1,000.00 of GDP. Six countries—Finland, Germany, Italy, Japan, Mexico, and South Korea—and the EU report spending nothing on such projects, and the remaining countries did not break out demonstration as a separate stage of innovation in their reporting.

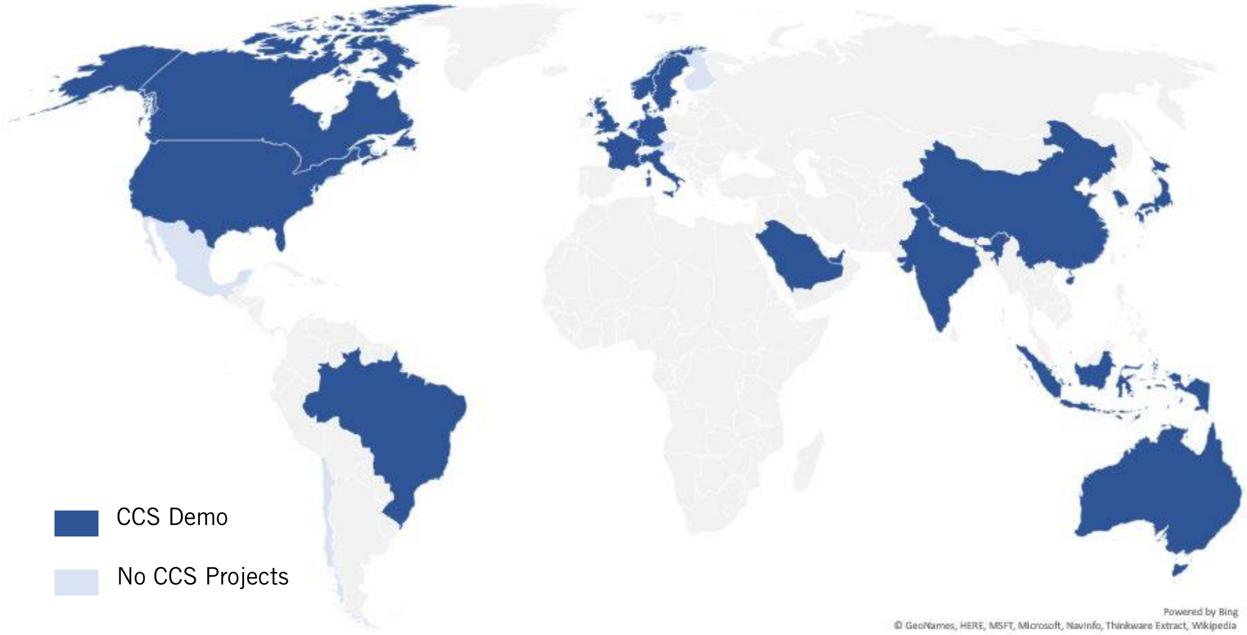
The IEA recognizes demonstration as an important—and often essential—stage in the evolution of energy technologies, and provides a standardized set of definitions to enable countries to track their investments. Yet, most countries are either investing little or nothing in demonstration projects—or else they are not tracking their investments in an internationally comparable fashion. We contend public investment in demonstration projects is an important gap, and the global energy innovation system would benefit from greater contributions from nations.

Table 10. Scale-up, Indicator 6: Public investment in clean energy demonstration projects

2019 Rank	Country	Demo per 1,000 units GDP	2019 Rank	Country	Demo per 1,000 units GDP
1	Norway	0.39	9	France	0.02
2	Canada	0.12	10	United States	0.001
3	Netherlands	0.06	11	Finland	0
4	Denmark	0.05	11	Germany	0
5	Sweden	0.05	11	Italy	0
6	Austria	0.03	11	Japan	0
7	Australia	0.03	11	Mexico	0
8	United Kingdom	0.02	11	South Korea	0
				MI Average	**0.05**

Note: No data is available for Brazil, Chile, China , India, Indonesia, Saudi Arabia, and the United Arab Emirates.

INDICATOR 7: CCS DEMONSTRATION PROJECTS



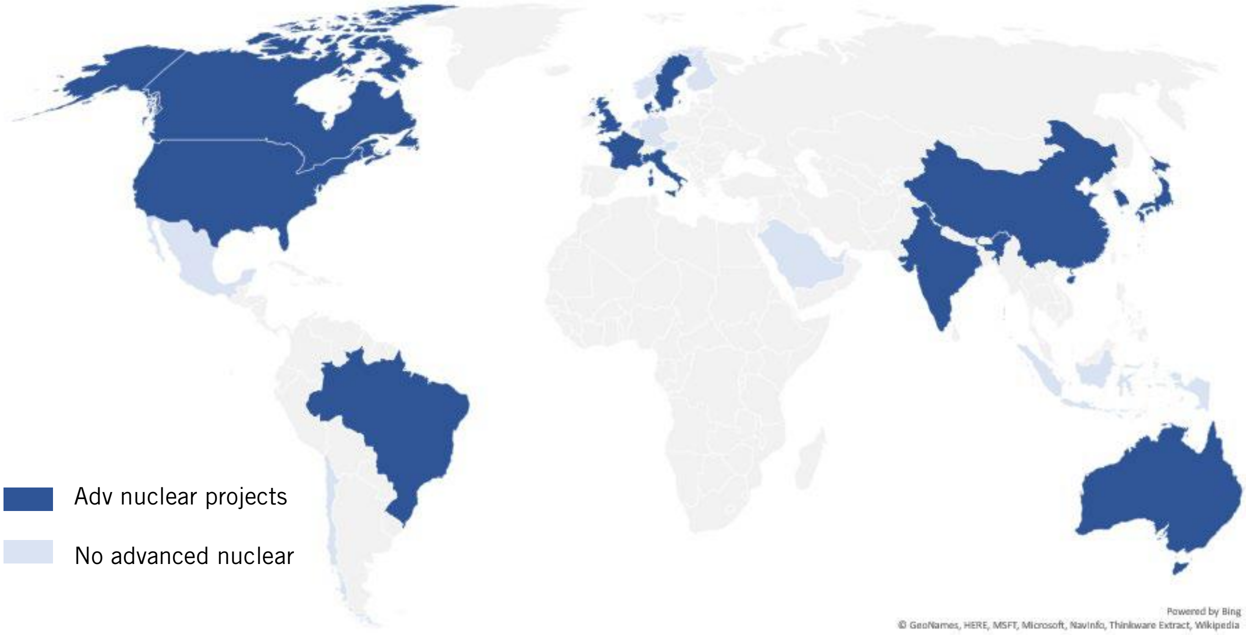
A large majority of countries are participating or planning to participate in CCS demonstration projects and therefore score positively on this component of the Scale-Up Index. Only Austria, Chile, Finland, and Mexico are not doing so.[25]

The breadth of international involvement in CCS demonstration projects is encouraging. However, IEA rates CCS is "Not on Track" to make adequate progress to reach the level of deployment needed for deep decarbonization by 2050.[26] Even countries that do not have suitable geology for CO_2 storage will need to be able to capture and transport this gas, which is emitted as a chemical byproduct of major industrial processes as well as through fossil fuel combustion. Using CO_2 for enhanced oil recovery offers a lower-cost opportunity for early deployment of CCS projects and could provide a glide path for developing the technologies, infrastructure, and regulatory tools to enable large-scale geologic CO_2 storage.[27]

Table 11. Scale-up, Indicator 7: CCS demonstration projects

2019 Rank	Country	CCS Demo
1	Australia, Brazil, Canada, China, Denmark, France, Germany, India, Indonesia, Italy, Japan, Netherlands, Norway, Saudi Arabia, South Korea, Sweden, United Arab Emirates, United Kingdom, United States	Yes
20	Austria, Chile, Finland, Mexico	No

INDICATOR 8: ADVANCED NUCLEAR POWER INDUSTRY



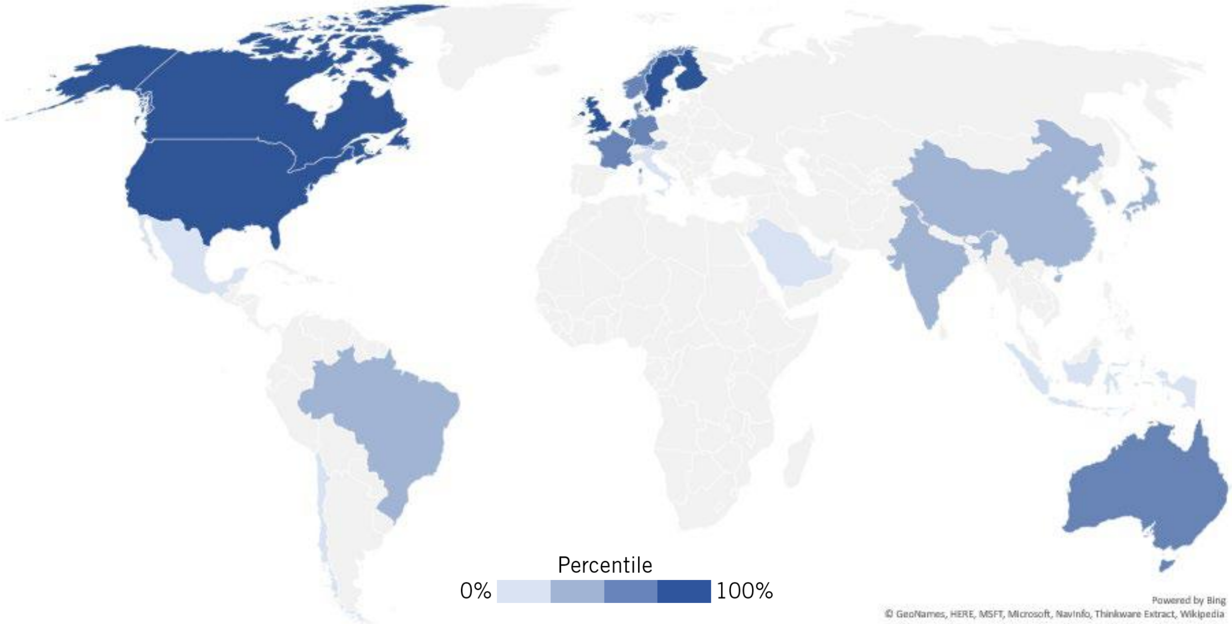
Just over half of the nations in our dataset are home to an advanced nuclear industry, including such major non-IEA members as Brazil, China, and India. Ten nations do not appear to be supporting the technology, including those that lead in other areas of technology such as Germany, Norway, and the Netherlands.

Advanced nuclear power is another capital-intensive technology that plays a role in most deep decarbonization pathways, providing firm, low-carbon electricity and potentially other energy services (e.g., heat, hydrogen production), including for hard-to-abate sources of emissions. But advanced nuclear power is far from being commercialized, and must be demonstrated at full-scale before reaching the market. While this technology has support from a diverse array of governments, further progress is far from guaranteed. Not only has nuclear power long faced significant opposition in countries where it is already in use, but in addition, some governments that supported it in the past, such as South Korea's, have called for phasing it out, citing safety concerns.

Table 12. Scale-up, Indicator 8: Advanced nuclear power industry

2019 Rank	Country	Adv Nuclear
1	Australia, Brazil, Canada, China, Denmark, France, India, Italy, Japan, South Korea, Sweden, United Kingdom, United States	Yes
14	Austria, Chile, Finland, Germany, Indonesia, Mexico, Netherlands, Norway, Saudi Arabia, United Arab Emirates	No

INDICATOR 9: HIGH-IMPACT CLEANTECH START-UPS



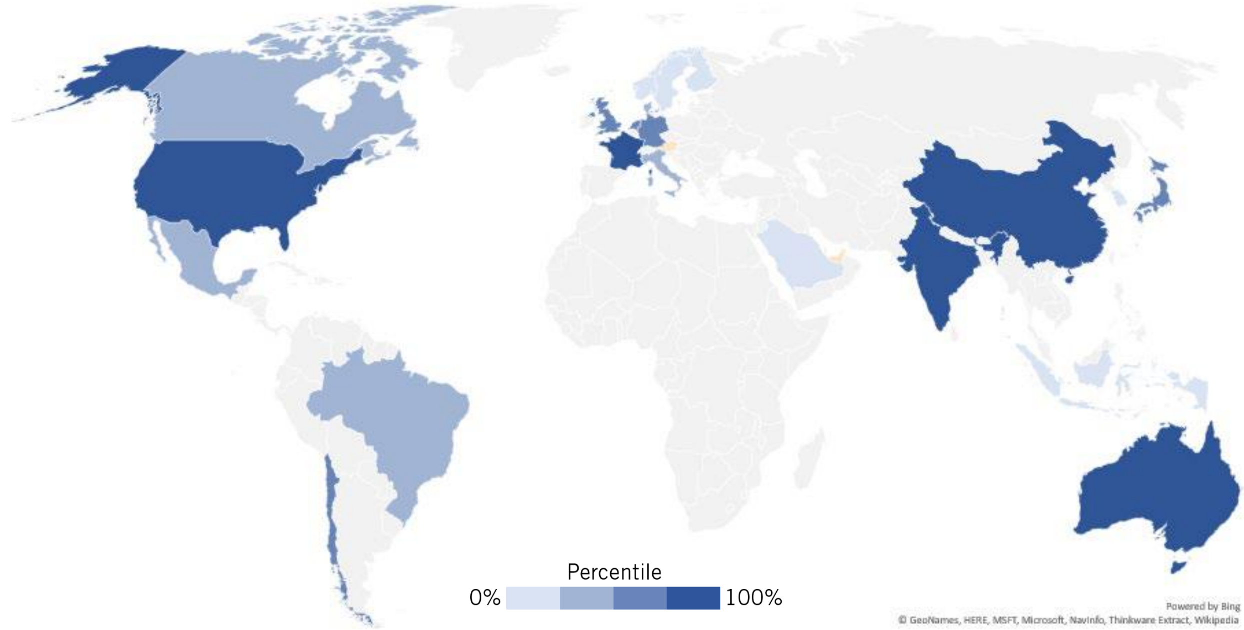
Canada and Finland top the list of countries producing the largest number of high-impact cleantech start-ups appearing in the Global Cleantech 100, with 10.0 and 9.2 cleantech start-ups per $1 trillion GDP, respectively. The United States accounts for nearly half of all high-impact cleantech start-ups, and ranks fifth when this figure is scaled against its economy. More than half of the countries, particularly non-IEA countries and countries with nationalized energy systems, score very poorly on this component, tallying less than one clean tech start-up per $1 trillion GDP.

This component has a wider range of variation than others in the Scale-Up Index. Some countries that score high on other components, such as South Korea and Japan, receive grades that are well below average on this one. The capacity of an innovation system to generate high-impact start-ups depends on many factors, including some that are difficult for public policies to influence, such as entrepreneurial culture. The global system may be dependent on relatively few countries to perform this function.

Table 13. Scale-up, Indicator 9: High-impact cleantech start-ups, per GDP

2019 Rank	Country	High-Impact Start-Ups	2019 Rank	Country	High-Impact Start-Ups
1	Canada	9.99	13	India	0.31
2	Finland	9.16	14	China	0.23
3	Sweden	7.12	15	South Korea	0.17
4	United Kingdom	4.74	16	Brazil	0.10
5	United States	3.77	17	Japan	0.06
6	Netherlands	3.23	18	Chile	0
7	Norway	3.09	18	Indonesia	0
8	France	3.05	18	Italy	0
9	Germany	3.01	18	Mexico	0
10	Australia	1.64	18	Saudi Arabia	0
11	Denmark	1.08	18	United Arab Emirates	0
12	Austria	0.70		**MI Average**	**2.24**

INDICATOR 10: EY RENEWABLE ENERGY COUNTRY ATTRACTIVENESS INDEX



China tops the rankings on this component, due to rapidly growing electricity demand and its plan to invest $363 billion in renewables by the end of 2020.[28] The United States comes second, while France has moved into third place, thanks in part to four new demonstration projects for floating offshore wind power. Saudi Arabia first made the list in 2018 after announcing plans to develop 9.5 gigawatts of renewables by 2023.

Many countries in our dataset are highly attractive for renewable energy investment, which is important because renewables account for a majority of current and expected investment in electricity-generation facilities globally. Scaling them rapidly is one of the most important elements in the near term for pathways that lead to deep decarbonization, even though, as their penetration rises, additional technologies will be required to remain on these pathways.

Table 14. Scale-up, Indicator 10: EY Renewable Energy Country Attractiveness Index

2019 Rank	Country	EY RECAI	2019 Rank	Country	EY RECAI
1	China	68.7	11	Denmark	56.3
2	United States	66.7	12	Canada	55.2
3	France	63.2	13	Brazil	54.3
4	India	63.0	14	Italy	54.1
5	Australia	62.4	15	Mexico	54.0
6	Germany	61.9	16	South Korea	52.4
7	Japan	59.2	17	Sweden	51.0
8	United Kingdom	58.3	18	Norway	49.5
9	Netherlands	57.2	19	Finland	49.1
10	Chile	56.6	20	Indonesia	49.0
			21	Saudi Arabia	48.0

Note: Austria and the United Arab Emirates do not appear in the last three editions of the EY Index; Saudi Arabia's score is taken from the 2018 edition of the EY Index.

CATEGORY 3: SOCIAL LEGITIMATION

Table 15. The social legitimation score and component indicators.

Rank	Country	Social Legit. Score	Effective CO_2 Price		Fuel Taxes		Percent RD&D Low-Carbon		International Collaboration	
			Rank	Z-score	Rank	Z-score	Rank	Z-score	Rank	Z-score
1	Sweden	14.4	1	18.6	12	8.5	1	13.0	14	8.5
2	France	13.3	4	14.4	5	12.4	9	12.1	7	12.4
3	United Kingdom	13.2	7	10.9	1	18.4	8	12.5	2	15.4
4	Norway	13.0	2	16.2	6	12.2	14	7.7	11	9.4
5	Finland	12.9	3	14.8	11	10.7	7	12.7	14	8.5
6	Germany	12.0	8	10.6	4	13.8	3	12.9	6	13.4
7	Denmark	11.9	5	12.5	7	12.2	5	12.7	17	6.5
8	Netherlands	11.7	8	10.6	2	16.0	2	12.9	17	6.5
9	Italy	11.3	8	10.6	3	15.8	13	8.0	7	12.4
10	South Korea	11.1	6	11.4	8	12.1	11	11.5	17	6.5
11	Austria	10.6	8	10.6	9	11.8	6	12.7	21	4.5
12	Japan	10.1	13	9.8	10	11.2	4	12.8	21	4.5
13	Canada	9.2	12	10.0	18	5.1	12	8.4	2	15.4
14	Australia	9.2	16	9.5	13	8.2	15	7.6	7	12.4
15	United States	9.1	15	9.6	19	4.9	10	11.5	11	9.4
16	India	9.1	19	8.3	17	6.3	ND	ND	1	18.3
17	Chile	8.4	14	9.7	14	7.6	ND	ND	23	3.5
18	Brazil	8.2	16	9.5	21	4.2	ND	ND	11	9.4
19	China	7.8	18	9.0	15	7.3	16	2.0	4	14.4
20	Mexico	5.9	20	6.1	16	7.1	17	0.0	4	14.4
21	United Arab Emirates	5.0	21	4.5	ND	ND	ND	ND	16	7.5
22	Indonesia	3.3	22	2.5	20	4.3	ND	ND	20	5.5
23	Saudi Arabia	2.1	23	0.2	ND	ND	ND	ND	10	11.4

Sweden performs highest on this Index, due to its high effective carbon price and elimination of government support for legacy fossil fuel energy RD&D. It has relatively low fuel taxes—though they are less relevant, as the environmental costs of transportation are already incorporated into a carbon price—and it lags in international collaboration in clean energy RD&D.

France and the United Kingdom have similar profiles, scoring above average on all of the individual components and ranking just below Sweden on the Index. France has a higher effective carbon price, which is high enough to be in the range recommended by the World Bank to meet the goals of the Paris Agreement. The United Kingdom has a lower carbon price, but partially compensates for it with a much higher transportation fuel tax. It also places near the top in international engagement and collaboration on clean energy RD&D, participating in all eight MI Challenges, leading two, and hosting the MI Secretariat.

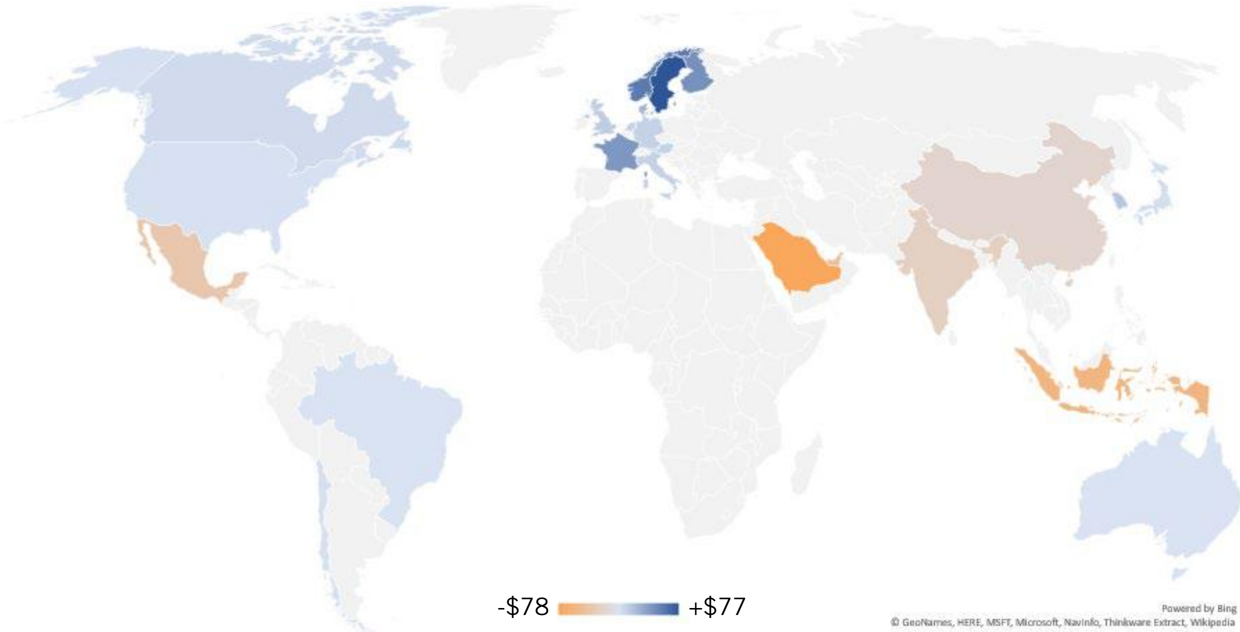
India receives the highest score on international cooperation in clean energy RD&D, participating in all eight Innovation Challenges, and leading three. India has also hosted international workshops on smart grids, clean energy materials, and off-grid access to electricity through the MI platform—and even issued calls for proposals for collaborative R&D with other MI member nations.[29]

The United States scores much lower in the Social Legitimation Index than the other two component categories in the Global Energy Innovation Index. It has no national carbon pricing policy, though state and regional carbon pricing schemes, such as the California Cap-and-Trade Program and the Regional Greenhouse Gas Initiative, cover a portion of the nation's emissions. It falls near the bottom in terms of fuel taxes, and has reduced its international cooperation in clean energy RD&D in recent years.

Seven countries—China, India, Indonesia, Mexico, Saudi Arabia, South Korea, and United Arab Emirates—continue to subsidize fossil fuel consumption. Collectively, these nations spent more than $171 billion on fossil fuel subsidies in 2018, nearly 8 times more than the total amount ($22.7 billion) all MI members invested in clean energy RD&D that year. Four of the countries—India, Indonesia, Saudi Arabia, and the United Arab Emirates—have fossil fuel subsidies and no carbon price. Mexico has both a national carbon tax and fossil fuel subsidies, but the value of the subsidies is greater than the carbon tax, resulting in a net-negative effective carbon price. China also has fossil fuel subsidies that overwhelm the modest city-level carbon prices. These nations appropriately fill out the bottom slots on the Social Legitimation Index, due to the high barriers to clean energy adoption imposed by these subsidies. South Korea has a small legacy fossil fuel subsidy, but has a national emissions trading system with a total value greater than the cost of its fossil fuel subsidies, resulting in a net-positive effective carbon price.

IEA does not have data on dirty energy RD&D investments for the seven MI countries that are not members of IEA—Brazil, Chile, China, India, Indonesia, Saudi Arabia, and United Arab Emirates. A crude estimate can be made for China based on its own reporting to MI, but this estimate would not include RD&D made by state-owned enterprises and could overestimate the percent of total energy RD&D China invests in clean energy. The situation in the other six non-IEA countries is even more opaque, with no information available in IEA or other international datasets on non-clean energy RD&D.

INDICATOR 11: EFFECTIVE CARBON PRICE (INCL. FOSSIL FUEL SUBSIDIES)



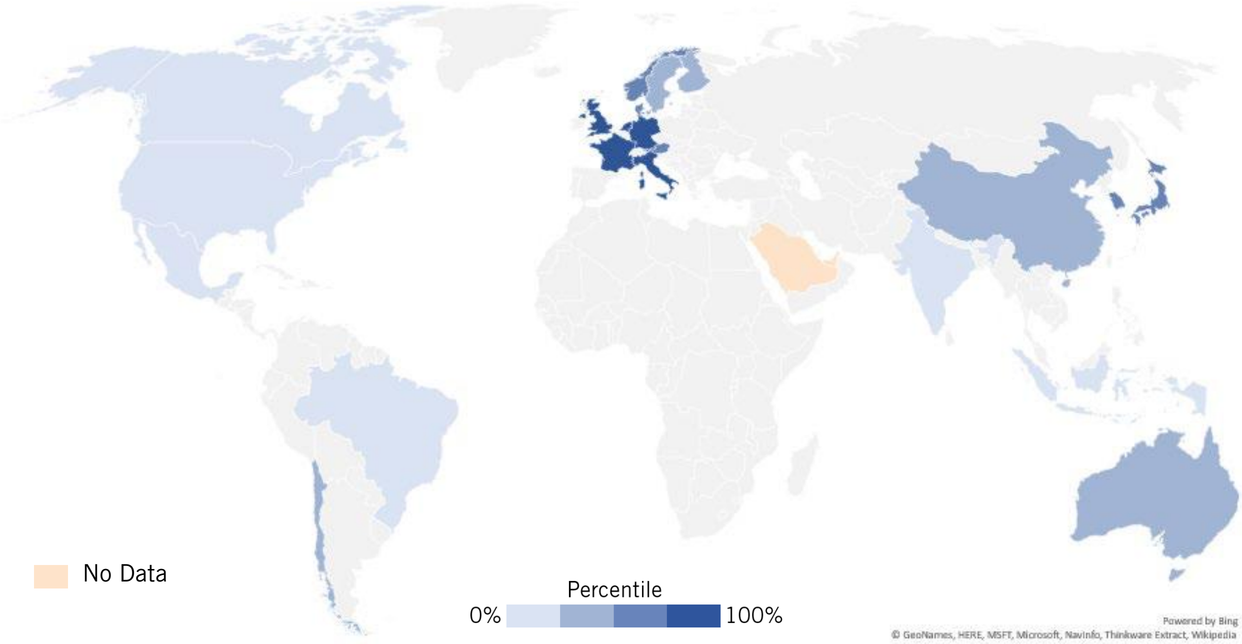
The top four countries on this component—Sweden, Norway, Finland, and France—have an effective carbon price within a range ($40–$80/tCO_2) the World Bank recommends for the world to be on track to meet the goals of the Paris Agreement.[30] Ten other countries have either imposed national carbon prices or participate in the EU Emissions Trading System. Even though Canada and the United States have not imposed carbon prices nationally, provincial and state-level policies result in effective carbon prices of $4.13 and $1.13/t$CO_2$, respectively, for these two countries.[31]

Seven MI members continue to subsidize fossil fuel consumption, undermining the legitimacy of clean energy innovation. Saudi Arabia and Indonesia rank lowest, both as a percentage of GDP and in terms of effective carbon prices. Several Chinese cities have pilot carbon pricing programs, but China's fossil fuel subsidies outweigh its city-level programs, leading to a net-negative effective carbon price.[32] The weighted average effective carbon price across all MI countries is a net-*negative* $3.44/t$CO_2$, because the value of fossil fuel subsidies outweighs the total value of all carbon prices.

Table 16. Social legitimation, Indicator 11: Effective carbon price, including fossil fuel subsidies

2019 Rank	Country	Carbon Price ($/ton)	2019 Rank	Country	Carbon Price ($/ton)
1	Sweden	76.59	13	Japan	2.17
2	Norway	56.23	14	Chile	1.51
3	Finland	44.06	15	United States	1.13
4	France	40.68	16	Australia	0.00
5	Denmark	25.39	16	Brazil	0.00
6	South Korea	15.76	18	China	-4.25
7	United Kingdom	12.05	19	India	-10.23
8	Austria	9.13	20	Mexico	-28.49
8	Germany	9.13	21	United Arab Emirates	-42.14
8	Italy	9.13	22	Indonesia	-58.58
8	Netherlands	9.13	23	Saudi Arabia	-78.23
12	Canada	4.13		**MI Weighted Average**	**-3.44**

INDICATOR 12: FUEL TAXES



European countries, led by the United Kingdom, impose the highest fuel taxes. Ten of these countries, along with Japan, impose taxes that equate to effective carbon prices surpassing \$100/tCO_2. The lowest fuel taxes are found in the Americas (Brazil, Chile, Mexico, United States, and Canada) and Asian/Pacific countries (Australia, Indonesia, India, and China).

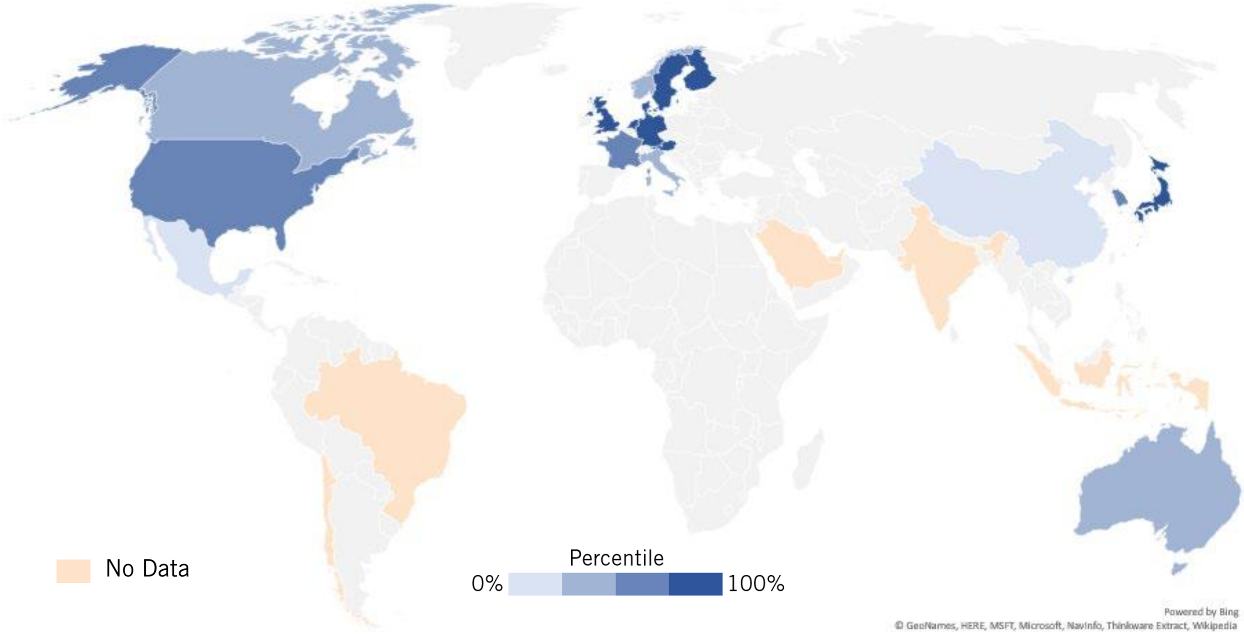
The large variation in the range on this component reflects and reinforces differences in national attitudes toward dirty and clean energy technologies, particularly in transportation. Very low fuel taxes strengthen dependence on petroleum-powered vehicles, whereas the transition to electric vehicles is eased when fuel taxes make them more attractive options.

Table 17. Social legitimation, Indicator 12: Fuel taxes, expressed as an effective carbon price.

2019 Rank	Country	Fuel taxes (\$/tCO_2)	2019 Rank	Country	Fuel taxes (\$/tCO_2)
1	United Kingdom	281.47	12	Sweden	87.70
2	Netherlands	216.26	13	Australia	83.67
3	Italy	219.26	14	Chile	73.46
4	Germany	189.46	15	China	65.59
5	France	162.29	16	Mexico	61.37
6	Norway	155.07	17	India	45.73
7	Denmark	146.92	18	Canada	21.55
8	South Korea	153.67	19	United States	17.80
9	Austria	143.92	20	Indonesia	7.12
10	Japan	135.49	21	Brazil	4.50
11	Finland	127.34		**MI Average**	**114.27**

Note: No data is available for Saudi Arabia and United Arab Emirates.

INDICATOR 13: PERCENT CLEAN ENERGY RD&D



Of the 17 countries where we have data on this component, 8 spend 98 percent or more of their energy RD&D budgets on clean energy technologies, and 3 countries and the EU invest 100 percent. Near the bottom of the rankings, Norway, Australia, Italy, and Canada still invest almost 20 percent of their energy RD&D investments toward non-low-carbon technologies. China fares worse, devoting nearly 40 percent of its energy RD&D budget—more than $2.5 billion in 2018—to "cleaner fossil fuel" technologies other than CCS.[33] Mexico comes in last on this component, investing more than half of its budget on legacy fossil fuel programs—although this share has declined in recent years.[34]

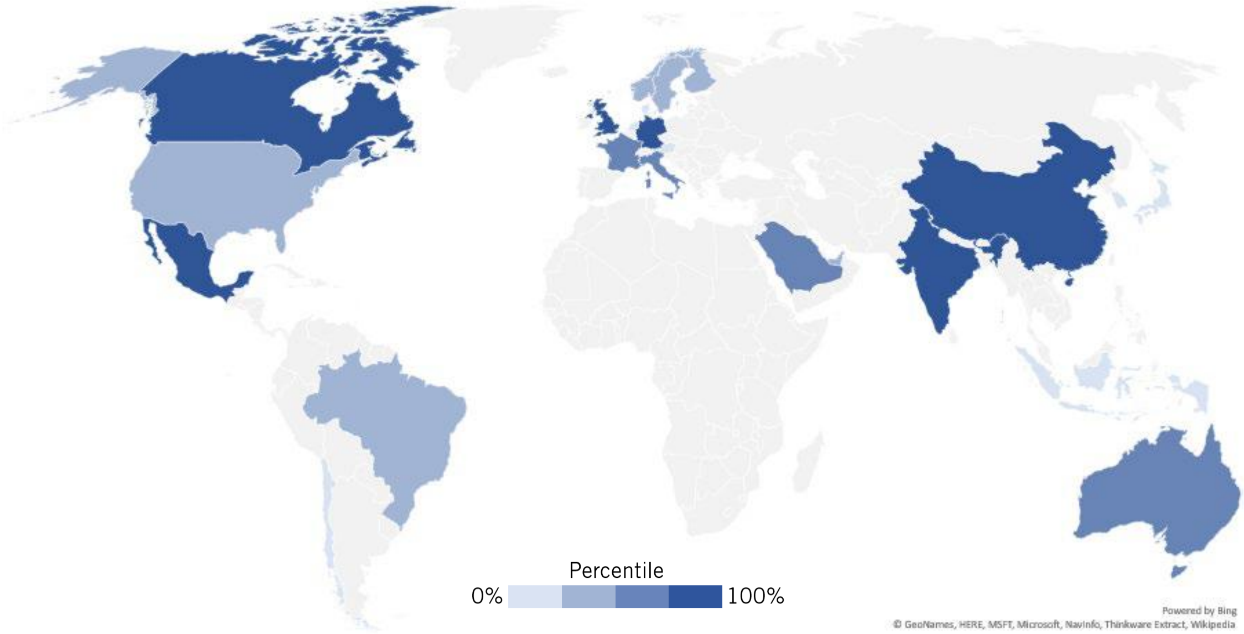
While technologies that improve the efficiency of fossil fuel combustion may result in marginal emissions reductions, they do not expand the set of zero-carbon energy options available for adoption in the future. Most countries are prioritizing clean energy technologies over dirty ones, but legacy fossil RD&D programs that fail to advance the global clean energy innovation agenda persist in too many MI countries.

Table 18. Social legitimation, Indicator 13: Share of public energy RD&D investment in clean energy technologies

2019 Rank	Country	% Low-Carbon*	2019 Rank	Country	% Low-Carbon*
1	Sweden	100	10	United States	95
2	Netherlands	100	11	South Korea	95
3	Germany	100	12	Canada	83
4	Japan	99	13	Italy	82
5	Denmark	99	14	Norway	81
6	Austria	99	15	Australia	81
7	Finland	99	16	China	60
8	United Kingdom	98	17	Mexico	49
9	France	97		**MI Average**	**89**

* No data is available for Brazil, Chile, India, Indonesia, Saudi Arabia, and United Arab Emirates.

INDICATOR 14: INTERNATIONAL COOPERATION IN CLEAN ENERGY RD&D



The MI Challenges have become a prominent forum for international collaboration in recent years. Countries are hosting joint technology workshops, collaboratively identifying innovation gaps, and developing shared research priorities. For example, as part of the Clean Energy Materials Challenge, Mexico, Canada, and the United States cohosted an international workshop and produced a joint report that identifies goals and priority research directions—such as autonomous materials discovery and artificial intelligence for materials—that are now informing members' research programs.[35] According to IEA, "International collaboration can increase effectiveness, bring efficiency benefits, and maximize the impact of energy technology innovation efforts."[36]

The eight MI Challenges are led by two to four countries each, with a total of 22 leadership roles in all. India and the EU hold three of these leadership roles each and are participating members in all of the other challenges. Five countries lead two Innovation Challenges, and six lead one. Eleven countries, including the United States, are not leading any of the challenges.

Table 19. Social legitimation, Indicator 14: International cooperation in clean energy RD&D, measured by participation in MI Challenges

2019 Rank	Country	Lead	Member	2019 Rank	Country	Lead	Member
1	European Union	3	5	12	United Arab Emirates	1	2
1	India	3	5	13	Norway	0	8
2	Canada	2	6	13	United States	0	8
2	United Kingdom	2	6	15	Finland	0	7
4	China	2	5	15	Sweden	0	7
4	Mexico	2	5	17	Denmark	0	5
6	Germany	2	4	17	Netherlands	0	5
7	Australia	1	7	17	South Korea	0	5
7	France	1	7	20	Indonesia	0	4
7	Italy	1	7	21	Austria	0	3
10	Saudi Arabia	1	6	22	Japan	0	3
11	Brazil	1	4	23	Chile	0	2

APPENDIX: INDEX METHODOLOGY AND SOURCES

To combine these disparate indicators into comparable scores, variables were transformed into z-scores. Z-scores indicate the distance in standard deviations from a sample mean, and are calculated by subtracting the sample mean from a country's score on the indicator, then dividing by the standard deviation for that indicator. This allows for metrics with different units of measurement and different scales to be standardized. The mean is set to 10 and the standard deviation is set to 4, which allows the z-scores to be compared and combined in a meaningful way. For this report, z-scores are capped at 2.5 and -2.5 standard deviations from the mean (scores of 20 and 0, respectively), so outliers would not carry too much weight.

Within each category, indicators are assigned weights according to each indicator's relative importance and uniqueness. To produce the overall category scores, the standardized indicator scores are multiplied by their respective indicator weights and summed, and then standardized again to retain matching means and standard deviations among categories.

For countries with data gaps, new weights are chosen proportional to the weights in table 1, such that the sum of the new weights is 1.

OPTION GENERATION

TOTAL PUBLIC INVESTMENT IN CLEAN ENERGY RD&D

Data Sources: IEA Energy RD&D Statistics Database. Mission Innovation Country Highlights 2019. World Bank GDP Database.

Methodology: Raw scores are given by the clean energy RD&D intensity, or clean energy RD&D per thousand units GDP. We adopt IEA's taxonomy for clean energy RD&D by technology, which includes carbon capture and storage (CCS) as a low-carbon energy technology, but categorizes all other fossil energy RD&D as non-low-carbon. According to MI reporting, China invested $2.5 billion in "Cleaner Fossil Fuels" but did not invest any funding in CCS. Therefore, China's fossil fuel investments are not counted toward its clean energy RD&D numbers.

PUBLIC INVESTMENT IN BASIC ENERGY-RELATED SCIENCE

Data Sources: IEA Energy RD&D Statistics Database. Mission Innovation Country Highlights 2019. The World Bank GDP Database.

Methodology: For IEA countries, this is reported in field 72BASICUN in the IEA Energy RD&D Statistics Database. Non-IEA countries have the option of reporting this in field "7.2 Basic energy research that cannot be allocated to a specific category" in the Annex of the Country Highlights report. Basic Energy Science funding is weighed by GDP.

No data is available for Brazil, India, Indonesia, Saudi Arabia, and the United Arab Emirates.

GROWTH IN CLEAN ENERGY RD&D

Data Sources: IEA Energy RD&D Statistics Database. Mission Innovation Country Highlights 2019.

Methodology: Raw scores are the change in a country's clean energy RD&D from 2015 to the present, weighted by GDP. For IEA countries, the baseline year is taken to be 2015, since many countries used 2015 as the baseline year for MI.

DIVERSITY OF CLEAN ENERGY RD&D

Data Sources: IEA Energy RD&D Statistics Database. Mission Innovation Country Highlights 2019.

Methodology: The IEA/MI classification breaks down clean energy RD&D investment across seven technology areas: energy efficiency; renewable energy; nuclear energy; hydrogen and fuel cells; carbon capture and storage; other power and storage technologies; and other cross-cutting technologies and research. Diversity is measured using the Shannon-Wiener Diversity Index.

No data is available for Brazil, India, Indonesia, Saudi Arabia, and the United Arab Emirates.

SCALE-UP

HIGH-VALUE CLIMATE CHANGE MITIGATION PATENT APPLICATIONS

Data Sources: Organization for Economic Cooperation and Development (OECD) database of high-value (patent family size equal to or greater than 2) patent applications in climate change mitigation technologies.[37] The World Bank database for national GDP.

Methodology: The quality of patents varies widely: Some inventions are extremely valuable, whereas others have little commercial value. And some countries, such as China, have incentives for researchers to patent that may inflate the number of patent applications without increasing the commercialization of new technologies. This report uses "high-quality" inventions—additional filings of the same patent application in two or more countries—to control for the quality of the invention. Because of the additional costs of filing for patent protection in multiple countries, only the most valuable inventions are filed in several countries.[38]

The Patent Indicator is given by the number of high-quality inventions per $1 billion GDP, averaged over the years 2013 through 2015.

PUBLIC FUNDING OF CLEAN ENERGY DEMONSTRATION PROJECTS

Data Sources: IEA RD&D Statistics Database.

Methodology: Because demonstration projects may span multiple years, demonstration funding is aggregated over the years 2015 through 2018 to get a full snapshot of nations' spending on demonstration projects. Demonstration funding per GDP is calculated from the ratio of demonstration funding in national currency to total energy RD&D funding in national currency, multiplied by the RD&D intensity (RD&D funding per thousand units GDP).

No data is available for Brazil, Chile, China, India, Indonesia, Saudi Arabia, and United Arab Emirates.

PARTICIPATION IN CCS DEMONSTRATION PROJECTS

Data Sources: CO_2RE Database, Global CCS Institute.[39]

Methodology: Countries are assigned a score of 1 if they have an operating or planned CCS project.

ADVANCED NUCLEAR ENERGY PROJECTS

Data Sources: Third Way Advanced Nuclear Reactor Database.[40]

Methodology: Countries are assigned a score of 1 if they have an advanced nuclear reactor project (includes non-light-water fission designs and fusion designs).

HIGH-IMPACT CLEANTECH START-UPS

Data Sources: Cleantech Group Global Cleantech 100[41]

Methodology: The list of high-impact cleantech start-ups is compiled from the Global Cleantech 100 for the years 2017 through 2019, the Global Cleantech Ones to Watch for the years 2016 to 2018, and the 2018 APAC-25. The number of high-impact cleantech start-ups in each country is weighted by GDP.

EY RENEWABLE ENERGY COUNTRY ATTRACTIVENESS INDEX

Data Sources: EY Renewable Energy Country Attractiveness Index.[42]

Methodology: This indicator uses scores from the 53rd edition of the EY RECAI, which measures the market attractiveness driving renewable energy investments in each country. Saudi Arabia does not appear on the 53rd edition, so its score from the 52nd edition is used.

SOCIAL LEGITIMATION

EFFECTIVE CARBON PRICE

Data Sources: Carbon pricing information provided by the World Bank Carbon Pricing Dashboard.[43] Fossil fuel consumption subsidies provided by the International Energy Agency.[44] Emissions data were obtained from BP Energy Outlook.[45]

Methodology: For countries with national carbon prices, the effective carbon price is determined by the total value raised by the policy divided by the nation's CO_2 emissions in 2018. For countries that participate in the EU Emissions Trading System (EU ETS), the effective carbon price is given by the sum of the EU ETS effective carbon price (total value raised in EU ETS divided by total EU CO_2 emissions in 2018) and any national effective carbon price. The United States and Canada do not have national carbon pricing policies but have subnational (state, province, or city) carbon prices. For these nations, the total value raised by all subnational policies is summed and divided by national CO_2 emissions.

For countries with fossil fuel subsidies, the effective carbon price is given by the negative of the total value of the subsidies, divided by the nation's CO_2 emissions in 2018.

FUEL TAXES

Data Sources: OECD Taxing Energy Use, 2018.[46]

Methodology: OECD converts fuel taxes into carbon price equivalents by dividing taxes per unit of fuel by the carbon content of the fuel.

PERCENT LOW-CARBON RD&D

Data Sources: IEA's Energy Technology RD&D Budget Database.[47] MI Country Highlights.[48]

Methodology: Percent low-carbon RD&D is given by the ratio of low-carbon energy RD&D to total energy RD&D (low-carbon plus non-low-carbon). We adopt IEA's taxonomy for clean energy RD&D by technology, which includes CCS as a low-carbon energy technology, but categorizes all other fossil fuel energy RD&D as non-low-carbon. According to MI reporting, China invested $2.5 billion in "Cleaner Fossil Fuels" but did not invest any funding in CCS. Therefore, China's fossil fuel investment is classified as non-low-carbon energy RD&D.

No data is available for Brazil, Chile, India, Indonesia, Saudi Arabia, and United Arab Emirates.

INTERNATIONAL COLLABORATION IN CLEAN ENERGY RD&D

Data Sources: Mission Innovation website.[49]

Methodology: International collaboration is measured by participation in the MI Challenges. Leadership of an innovation challenge counts as 1 point, while participation counts as 0.25 points. Scores for each nation were determined by their participation level in each innovation challenge.

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