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The 2021 Global Energy Innovation Index: National Contributions to the Global Clean Energy Innovation System

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To meet growing global demand for energy services while averting the worst consequences of climate change, the world must accelerate clean energy innovation. Western Europe contributes most to this global process. The United States has faltered. And China has a long way to go.

KEY TAKEAWAYS

- National governments are the most important contributors to global energy innovation. Their aggregated contributions indicate a lack of urgency, which undermines progress toward net-zero emissions by 2050.
- The 34 countries covered by the Index make widely varying contributions to the global system. As such, their rankings frequently differ dramatically across subindices measuring diverse knowledge, market, and social factors.
- Finland, Denmark, Sweden, and the United Kingdom are the pacesetters in ITIF's Global Energy Innovation Index.
- Switzerland, Belgium, the Netherlands, Germany, Canada, France, and Norway form a stable second tier of contributors behind the top four, while Japan, Austria, South Korea, Australia, the Czech Republic, and the United States are in the third tier.
- The 2021 rankings are quite similar to those for 2016.
- Together, the 34 national governments in the Index invested over $27 billion in clean energy R&D in the most recent year for which data are available—but as a share of their economies, this investment has not grown since 2015.
- The flow of early-stage venture capital into clean energy start-ups, and their ability to exit via private equity buy-out, merger or acquisition, or IPO, are bright spots for the global energy innovation system.

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Innovation is the only way that the massive global demand for energy can be met while averting the worst consequences of climate change. National governments are the most important contributors to global energy innovation. The 2021 edition of the Information Technology and Innovation Foundation's (ITIF's) Global Energy Innovation Index (GEII) provides a multifaceted assessment of national contributions to the global energy innovation system.

While public investment in clean energy research, development, and demonstration (RD&D) is essential, a host of additional steps must be taken to turn that investment into outcomes that matter in the real world. The GEII uses 20 indicators that measure both the level of the most recent year for which data is available and the change over recent years. They are aggregated into 10 functional categories and 3 subindices.

The Global Energy Innovation Index provides a multifaceted assessment of national contributions to the global energy innovation system.

European nations dominate the top ranks of the GEII, with Finland topping it. Denmark, Sweden, and the United Kingdom rank second, third, and fourth, respectively. Canada, South Korea, Japan, the United States, and Australia fill out the top half along with other European nations.

The GEII reveals the varied contributions nations make to the global innovation system. Denmark leads on the Knowledge Development and Diffusion subindex, while Finland ranks first for entrepreneurial experimentation and market formation, and the United Kingdom sets the pace for social legitimation and international collaboration. Japan, South Korea, and China contribute more through knowledge development and diffusion than other innovation system functions. The United States performs well in the entrepreneurial ecosystem category relative to its contributions to social legitimation.

A version of the Index using data that would have been available in 2016 is quite similar to the 2021 version (table 1). Half the nations moved no more than three places up or down. Norway improved the most, rising from 23rd to 11th. The United States fell the most, dropping 13 spots from 4th to 17th. Its rank fell across all three subindices, with the greatest decline (nine places) being in social legitimation and international collaboration.

THE RANKINGS

Table 1: 2021 Global Energy Innovation Index Rankings Compared with 2016

2021 Rank	Country	2016 Rank	Change
1	Finland	1	0
2	Denmark	2	0
3	Sweden	3	0
4	United Kingdom	9	+5
5	Switzerland	8	+3
6	Belgium	10	+4
7	Netherlands	5	-2
8	Germany	11	+3
9	Canada	13	+4
10	France	6	-4
11	Norway	23	+12
12	Japan	19	+7
13	Austria	12	-1
14	South Korea	22	+8
15	Australia	17	+2
16	Czech Republic	18	+2
17	United States	4	-13
18	Portugal	7	-11
19	Italy	16	-3
20	Slovak Republic	24	+4
21	Hungary	25	+4
22	Spain	21	-1
23	Ireland	14	-9
24	Lithuania	34	+10
25	China	30	+5
26	Poland	15	-11
27	Brazil	26	-1
28	Greece	31	+3
29	Mexico	27	-2
30	Estonia	20	-10
31	Chile	29	-2
32	India	33	+1
33	New Zealand	28	-5
34	Turkey	32	-2

KEY FINDINGS

- Innovation is the only way that the massive global demand for energy in the present and future can be met while averting the worst consequences of climate change. National governments are the most important contributors to global energy innovation. Their aggregated contributions indicate a lack of urgency, which is needed to accelerate progress toward net-zero emissions by 2050.
- ITIF's GEII provides a multifaceted assessment of national contributions to the global energy innovation system. The 34 countries covered make contributions that vary widely in degree and function.
- The GEII rests at its base on 20 indicators that measure both the level of the most recent year for which data is available and the change over recent years. They are aggregated into 10 functional categories and 3 subindices.
- The GEII weights the Knowledge Development and Diffusion subindex at 40 percent, the Entrepreneurial Experimentation and Market Formation subindex at 40 percent, and the Social Legitimation and International Collaboration subindex at 20 percent.
- Finland is the top-ranked contributor to the global energy innovation system. Denmark, Sweden, and the United Kingdom rank second, third, and fourth, respectively. The top four rankings are remarkably stable across differing weightings of the three subindices.
- Three different nations top the three subindex rankings. Denmark ranks first for knowledge development and diffusion, Finland is tops for entrepreneurial experimentation and market formation, and the United Kingdom sets the pace for social legitimation and international collaboration. Only Denmark and the United Kingdom rank in the top 10 across all 3 subindices.
- Other Western European countries, including Switzerland, Belgium, the Netherlands, Germany, France, and Norway, along with Canada, form a stable second tier of contributors behind the top four on the GEII.
- South Korea, Japan, the United States, and Australia, along with the Czech Republic and Austria, comprise the third tier of contributors. Japan and South Korea rank in the top five for knowledge development and diffusion, but their relatively poor scores in the other two subindices pull down their overall rankings.
- The 2016 rankings are quite similar to those for 2021. Half of the nations moved no more than three places up or down. Norway improved the most, rising from 23rd to 11th. The United States fell the most, dropping 13 spots from 4th to 17th.
- The 34 national governments included in the GEII together invested over $27 billion in clean energy research and development (R&D) in the most recent year for which data is available. This figure has grown by more than 25 percent since 2015. However, when scaled by the size of the combined economies of these countries, it has been essentially flat. Total clean energy publications are up almost 40 percent, but clean energy inventions are down almost 20 percent.
- The flow of early-stage venture capital into clean energy start-ups, and their ability to exit via private equity buyout, merger or acquisition, or initial public offering (IPO), are bright

spots for the global energy innovation system as a whole. In absolute terms, the flow of venture capital more than tripled between 2015 and 2020, and it rose as a share of the economy by an impressive 25 percent per year in that period.

- The general trends in the indicators included in the Social Legitimation and International Collaboration subindex have mostly been positive, but not by much. Effective carbon prices, for instance, rose in most nations from 2012 to 2018, but typically at low single-digit rates. While most nations have adopted more stringent regulations, national commitments under the Paris Agreement remain insufficient.
- The United States is the leading contributor to the resource mobilization, knowledge development and diffusion, and entrepreneurial experimentation functions in absolute terms, as its public investments in RD&D and venture capital dwarf the others. However, its rank fell across all three subindices, including nine places on social legitimation and international collaboration.
- China ranks 25th in the GEII, but it scores well in knowledge development and diffusion, ranking second only to the United States in the absolute level of its public RD&D investments. It has grown more rapidly on this indicator as a share of gross domestic product (GDP) than the vast majority of other nations, and its venture capital investments grew by 43 percent per year as well.
- If the European Union were ranked as a single nation, it would make the top 10 on the GEII. (We measure the European Union as the aggregate contributions of all nations that were member states during the years covered by the Index, including the United Kingdom, plus the contributions of the European Commission.)

INTRODUCTION

Energy services are a bedrock of human civilization. Nutrition, hydration, mobility, comfort—the physical requirements of a life worth living, not to mention all the activities that depend on meeting these requirements—rest on access to energy. Yet, "affordable, reliable, sustainable and modern energy," one of the United Nations Sustainable Development Goals for 2030, remains out of reach for far too many people. As of 2019, three-quarters of a billion people lacked access to electricity, and more than three times that used dangerous and inefficient cooking systems. The economic downturn brought on by the global pandemic in 2020 may have increased these numbers considerably.[1]

As the quest for universal energy access stalls, the environmental impact of the energy used is growing. Above all, climate change caused primarily by the byproducts of fossil fuel combustion is transforming the conditions of human experience and damaging natural ecosystems worldwide. The latest report of the Intergovernmental Panel on Climate Change concludes that the human influence is "unequivocal." Atmospheric concentrations of carbon dioxide, the main energy-related greenhouse gas, surpassed their highest levels in at least two million years.[2]

Fossil fuels today supply about 80 percent of global energy. Their emissions must either be captured or eliminated in the coming years if the worst consequences of climate change are to be averted. But both morality and political expediency dictate that this transition must not disrupt access to energy services. People everywhere deserve the better life that energy services make possible—and where they are able, they demand energy that is affordable, reliable, and plentiful.

Innovation—the creation and diffusion of new and improved technologies, business models, and institutions—is the only way these desires and demands can be met in a sustainable way. Energy innovators have made important progress since the beginning of this century, most notably by lowering the cost and improving the performance of solar photovoltaics, wind power, and batteries. But the pace of energy innovation is not fast enough. Emissions from fossil fuels continue to rise.[3] No clean energy options are available to provide a number of key services, and clean energy is still too expensive or performs too poorly to be acceptable for many others.

Energy innovation is a global process, with scientists, inventors, engineers, developers, and others working to advance the state of the art in nearly every country. They interact as collaborators and competitors through research institutions and markets that span international borders. These interactions are extremely valuable, allowing ideas generated in diverse settings to be combined in novel and unanticipated ways, for instance, and for field testing of options to occur in conditions far different from those in which they were created.

National governments are the most important contributors to this global energy innovation process. No global entity has the resources to fund energy innovation at the requisite scale. And no private entity will support the development of institutions that channel innovations toward solving critical problems of common interest. Through their spending, taxation, and regulatory policies, as well as through the signals they send to one another and to their citizens, national governments will determine whether clean energy becomes affordable, reliable, and plentiful through innovation.

The key role of national contributions to energy innovation was acknowledged by the creation of the Mission Innovation (MI) initiative in parallel with the Paris Agreement in 2015. Governments responsible for more than 90 percent of the world's investment in energy RD&D vowed "to reinvigorate and accelerate" clean energy innovation, in part by doubling that investment over five years.[4]

National governments are the most important contributors to the global energy innovation process. No global entity has the resources to fund energy innovation at the requisite scale.

Collectively, MI's members fell far short of this goal. MI's rebooting, which focuses on a specific set of missions (see box 3), will reduce the emphasis on this measure. While we consider public RD&D investment to be the most important indicator of a nation's contribution to the global energy innovation system, the health of the system as a whole depends on the performance of many other functions that complement that investment. National ambitions to contribute to global energy innovation, viewed as a complete system, must be enhanced in the coming years if the world is to achieve its climate goals.

The GEII provides a multifaceted assessment of national contributions to the global energy innovation system. While public RD&D investment is essential, a host of additional steps must be taken to turn that investment into outcomes that matter in the real world. Nations should be judged by the actions they take to accelerate clean energy innovation, rather than the promises they make.

Like the first version of the GEII, which ITIF published in 2019, this new edition is inevitably a work in progress.[5] While we believe that the new version is a vast improvement on the initial effort, the global energy innovation system is so complex, our understanding so limited, and measurements so sparse that our judgments are certainly open to debate. We welcome that debate, and anything else that shines a brighter spotlight on the need to accelerate energy innovation, pressures governments and other actors to take action, and informs them about which actions will really make a difference.

CORE CONCEPTS: THE SYSTEMS LENS ON CLEAN ENERGY INNOVATION

The GEII is based on a systems approach to innovation and stretches across multiple dimensions:

1. It considers the full gamut of clean energy technology possibilities.
2. It covers the entire innovation pipeline from scientific discovery to full-scale adoption.
3. It includes the broad array of functions that need to be performed for energy innovation to proceed as rapidly as possible.
4. It aspires to be global in scope, although we are unable to cover every country due to data limitations.

The global energy innovation system consists of a complex network of actors, institutions, and resources that contribute to the generation, development, diffusion, and use of innovative energy products and services. To be effective, the system must perform a broad range of functions, including mobilizing resources, developing and diffusing new knowledge, facilitating experimentation by entrepreneurs and the formation of new markets, legitimizing new technologies in society, guiding the search for new knowledge in certain directions, and guiding its spillover into other related industries. Any gaps in these functions will obstruct and curtail innovation.[6]

The GEII is organized around three baskets of functions:

- Knowledge development and diffusion
- Entrepreneurial experimentation and market formation
- Social legitimation and international collaboration

Multiple indicators for each basket, organized into functional categories, are compiled into subindices that feed into the GEII. The subindices provide insights into distinct facets of the system. Combined, they form a panoramic view of the global energy innovation system.

Without the development and diffusion of new scientific and technical knowledge, no new clean energy technologies will emerge and there will be nothing to scale up or legitimate. The process begins with the mobilization of resources to fund RD&D activities performed by companies, government laboratories, and academic institutions. The public sector plays a larger role in supporting knowledge development for energy innovation than it does in many other sectors, in large part because the transition to clean energy is being driven by the environmental threat of climate change, and markets have not been responsive to it.

RD&D funding leads to scientific discoveries and technical know-how. The quality of this new knowledge varies considerably. Most discoveries and inventions end up having little scientific or commercial value, while highly valued knowledge is ultimately recognized by and diffused through global networks of academic and professional peers. While all knowledge diffusion is important and desirable, the proper functioning of the global energy innovation system depends heavily on a healthy flow of scientific and technical knowledge across international borders.

The second facet of the system involves a different set of actors, organizations, and institutions. Start-ups, established businesses, financial institutions, and others involved in entrepreneurial experimentation and market formation comb through new ideas and inventions seeking the most promising options for commercial development to be further refined, tested, and scaled up. Entrepreneurs play a leading role by creating new ventures that carry out the high-risk technological, business, and social experiments that must be performed before innovative energy products and services can join the mainstream. These new ventures are the focal points for venture capitalists and other members of the entrepreneurial ecosystem who probe, select, and scale them up.

The global energy innovation system consists of a complex network of actors, institutions, and resources that contribute to the generation, development, diffusion, and use of innovative energy products and services.

Established businesses may also identify new opportunities and assume the risks of taking untested technologies, products, and ideas to market. Both new ventures and established businesses need to engage in an iterative process of testing, validating, and refining their innovations under real-world conditions through pilot and commercial-scale demonstrations. They also need to spot niche markets and engage with potential users and early adopters in protected learning spaces in order to receive critical user feedback before introducing their innovations in bridging markets and mass markets.[7]

The process of social legitimation depends on yet another set of actors, organizations, and institutions. Innovation is an intrinsically social process. New technology and business model options must be consistent with widely held values in the societies in which they will be deployed. Incumbent energy technologies are often buttressed by political, legal, and regulatory mechanisms and embedded in supportive national and regional cultures. Legitimation involves moving society toward a new set of rules, regulations, routines, practices, norms, beliefs, and cultural meanings.

The third facet of the system also includes international collaboration in the development of new knowledge. While competition among nations as well as firms can be healthy for energy innovation, it can also be a deterrent to investment if national governments fear that others may capture the gains made. International collaboration can realign these incentives and make the mutual benefits of energy innovation investments more transparent. Inter-governmental organizations and initiatives as well as bilateral and multilateral agreements frame many cooperative activities, although many emerge from private interactions as well.

The functions covered by these three groupings do not exhaust the possibilities for conceptualizing and understanding the global energy innovation system. We have not explored the relationships between energy and other industries, for instance, or the trade-off between diversity and specialization at the national level. In some cases, lack of data stymied our efforts. In other cases, measures that are available do not fit comfortably into a scheme aimed at ranking national contributions.

HOW THE GEII MEASURES NATIONAL CONTRIBUTIONS

At its base, the GEII rests on 20 indicators. In most cases, the indicators measure both the level of national contributions in the most recent year for which data is available and the change over the previous five years (with some exceptions as described in appendix 1). The 20 indicators are, in turn, organized into 10 functional categories, which then contribute to the 3 subindices built around the functional groupings previously described. As the indicators are aggregated from one level to the next, we standardize them and apply weights that reflect our judgments about the importance of each measurement and the quality and availability of the data.

The aggregated contributions of national governments to energy innovation indicate a lack of urgency.

This section describes the indicators and categories and explains the standardization and weighting scheme, which is summarized in table 2. Data coverage is summarized in table 3. The vast majority of nations included in the GEII have complete or nearly complete data, but missing data reduces the potential maximum scores of several. Full methodological details and data sources can be found in appendix 1. Data can be further explored and different weightings applied at the Interactive Dataviz on ITIF's website at itif.org/GEII-2021.

Table 2: Indicators and Weights in the 2021 Global Energy Innovation Index

Subindices, Categories, and Indicators	Subindex Weight	Category Weight	Indicator Weight (Category)	Indicator Weight (Overall)
Knowledge Development and Diffusion	40%			
Public Investments in Low-Carbon Energy R&D		50%	100%	20.0%
Knowledge Generation		25%		
• Number of Publications			30%	3.0%
• Share of Highly Cited Publications			70%	7.0%
Invention		25%		
• Development and Diffusion			75%	7.5%
• Attraction and Absorption			25%	2.5%
Entrepreneurial Experimentation and Market Formation	40%			
Demonstration		10%		
• Public Investment			50%	2.0%
• Number of Projects			50%	2.0%
Entrepreneurial Ecosystem		30%		
• Early-Stage Venture Capital Investments			33%	4.0%

Subindices, Categories, and Indicators	Subindex Weight	Category Weight	Indicator Weight (Category)	Indicator Weight (Overall)
• Number of High-Impact Start-Ups			33%	4.0%
• Number of Successful Company Exits			33%	4.0%
Industry and International Trade (Exports)		30%	100%	12.0%
Market Readiness & Technology Adoption		30%		
• Energy Efficiency			50%	6.0%
• Clean Energy Consumption			50%	6.0%
Social Legitimation and International Collaboration	**20%**			
National Commitments		40%		
• Global Climate Action Agenda			50%	4.0%
• Domestic Clean Energy Innovation Agenda			50%	4.0%
National Public Policies		40%		
• Standards and Regulations			50%	4.0%
• Effective Carbon Rates (ECRs)			50%	4.0%
International Collaboration		20%		
• Public RD&D Funding			40%	1.6%
• Knowledge Development (Copublications)			30%	1.2%
• Technology Development (Coinventions)			30%	1.2%

Table 3: Data Coverage

Country	GEI Index (Overall)	KD&D Subindex (40% Max)	EE&MF Subindex (40% Max)	SL&IC Subindex (20% Max)
Australia	100%	40%	40%	20%
Austria	96%	40%	36%	20%
Belgium	100%	40%	40%	20%
Brazil	96%	40%	36%	20%
Canada	100%	40%	40%	20%
Chile	90%	40%	34%	16%
China	88%	40%	32%	16%
Czech Republic	92%	40%	32%	20%
Denmark	94%	40%	34%	20%
Estonia	78%	40%	22%	16%
Finland	98%	40%	38%	20%
France	100%	40%	40%	20%
Germany	98%	40%	38%	20%
Greece	70%	20%	34%	16%

Country	GEI Index (Overall)	KD&D Subindex (40% Max)	EE&MF Subindex (40% Max)	SL&IC Subindex (20% Max)
Hungary	92%	40%	32%	20%
India	88%	40%	32%	16%
Ireland	94%	40%	34%	20%
Italy	98%	40%	38%	20%
Japan	98%	40%	38%	20%
South Korea	98%	40%	38%	20%
Lithuania	88%	40%	32%	16%
Mexico	98%	40%	38%	20%
Netherlands	100%	40%	40%	20%
New Zealand	85%	30%	36%	19%
Norway	94%	40%	34%	20%
Poland	96%	40%	36%	20%
Portugal	96%	40%	36%	20%
Slovak Republic	86%	40%	26%	20%
Spain	98%	40%	38%	20%
Sweden	100%	40%	40%	20%
Switzerland	89%	30%	40%	19%
Turkey	81%	30%	32%	19%
United Kingdom	100%	40%	40%	20%
United States	100%	40%	40%	20%

Subindex: Knowledge Development and Diffusion

Category: Public Investments in Low-Carbon Energy R&D

The energy sector is dominated by fossil fuel-based technologies and stabilized by well-entrenched political and social institutions that tend to lock in the dominant position of incumbents. The great uncertainty surrounding the viability of clean energy technologies and their high costs and risks discourage investors from making long-term investments that might disrupt this sector. Public investments in R&D are therefore the most important policy levers governments have to generate clean energy innovation—and the reason we weight this indicator most heavily in this subindex. We rely on data reported by governments to the International Energy Agency (IEA), weighted by the size of the national economy, to measure these investments.

Category: Knowledge Generation

Knowledge is ephemeral, intrinsically difficult to measure and value. Like many innovation policy researchers, we use counts of scientific and technical publications in relevant fields as our primary measures of knowledge generation. To assess the value of each country's clean energy-related publications in addition to their quantity, we consider what share is in the top 10 percent of most highly cited publications globally. Both of these indicators are scaled by national population. The knowledge generation category is weighted toward value over quantity because our interest is in knowledge that is ultimately used in practice. But we include the quantity as well since previously uncited knowledge can sometimes unexpectedly become valuable. We draw on data assembled for a European Commission study in this category.

Category: Invention

Inventions are a tangible form of knowledge, which has been (in the language of the patent law) "reduced to practice." Although patents have many flaws as measures of innovation, they remain the best widely available and internationally comparable measure for inventions. We quality-adjust the patent data by incorporating into it a measure of how widely inventors seek patent protection for the same invention around the world, presuming that wider protection will be sought for more valuable inventions. A second indicator in this category, weighted less heavily, seeks to capture a country's ability to attract inventions made abroad, so the receiving country's businesses and consumers may benefit from them. Our patent data is drawn from the Organization for Economic Cooperation and Development (OECD).

Subindex: Entrepreneurial Experimentation and Market Formation

Category: Demonstration

Pilot- and commercial-scale demonstration projects are essential for inventions and prototypes to win the confidence of investors that they can ultimately mature and succeed in the global market. But demonstration projects, particularly for complex, large-scale, clean energy technologies are often too risky and costly for private investors to fund on their own. Public investments in them, as reported to IEA and scaled by GDP, therefore provide an important measure of national contributions to the global energy innovation system. (See box 2.) However, the data for this indicator is poor, in part because the concept of demonstration is difficult to define. We therefore supplement it with an effort to count the number of demonstration projects being carried out in several key technology areas: carbon capture and storage (CCS), advanced nuclear power, hydrogen production and use, energy storage, and advanced renewables. We weight this category lightly largely due to the data limitations.

Category: Entrepreneurial Ecosystem

Successful entrepreneurship is often viewed as a triumph of individual will. In fact, extensive research shows that it depends on a complex institutional ecosystem from which start-up companies draw the resources they need to succeed. Although money is just one of these resources, it is among the easiest to measure and a useful indicator of others, such as initial markets and recruitable talent. We rely on three equally weighted indicators to assess the degree to which national entrepreneurial ecosystems are birthing viable ventures and adequately supporting them through their development. Drawn from data provided by the Cleantech Group and scaled by GDP, they are (1) the amount of venture capital flowing into clean energy start-ups, (2) the number of high-impact clean energy start-ups, and (3) the number of successful exits through initial public offering (IPO), private equity buyout, or merger or acquisition.

Category: Industry and International Trade

Incremental innovation in established products and services is a vital feature of a healthy innovation system, particularly for a sector as large and essential as energy. Direct measures of incremental innovation that are comprehensive and internationally comparable, such as private R&D spending, are unfortunately sparse. We consider the ability of a nation's enterprises to sell what they make in global markets to be a useful indicator that they are continuing to improve their products in ways that customers value. This category relies on the value of each nation's clean energy technology exports as a share of GDP, using United Nations data.[8]

Category: Market Readiness and Technology Adoption

Nations contribute to clean energy innovation by adopting new technologies quickly and on a large scale. Early adopters provide innovators with important feedback they can use to rapidly improve their offerings, while scaling up creates opportunities for innovators to learn by doing as they move into mass production. This category draws on IEA data on energy efficiency across the major end-use sectors and data on clean energy consumption as a share of total energy from the *BP Statistical Review* to measure these national contributions. We weight the rate of change more heavily for this category than for others, because the pace of turnover in durable goods is so vital to creating clean energy markets.

The flow of early-stage venture capital into clean energy start-ups, and their ability to exit via private equity buyout, merger or acquisition, or initial public offering (IPO), are bright spots for the global energy innovation system.

Social Legitimation and International Collaboration

Category: National Commitments

Public commitments to climate and clean energy policy goals send important signals to markets, citizens, and the global community about a nation's likely willingness to support clean energy innovation. The Paris Agreement is built around such commitments, which are embodied in the Nationally Determined Contributions (NDCs) they submit under it. We use Climate Analytics and NewClimate Institute's Climate Action Tracker (CAT) for this indicator's data. We also assess the depth of national commitments to clean energy innovation by using IEA data on the degree to which national governments prioritize low-carbon RD&D in their spending portfolios.

Category: National Public Policies

Carbon pricing and climate-related regulations put teeth into national commitments and provide demand-pull that accelerates the uptake of clean energy innovations. We use two indicators, which are weighted equally, to measure these policies. OECD measures effective carbon prices at the national level. The World Bank assesses the relative stringency of national regulations supporting energy efficiency and renewable energy as part of its Regulatory Indicators for Sustainable Energy (RISE) database.

Category: International Collaboration

International collaboration on clean energy innovation legitimates the shared global effort to avert the worst consequences of climate change. It can have a material effect by diversifying the range of ideas and inventions innovators around the world can draw upon. We measure international collaboration by compiling leadership, membership, and participation in formal collaborative clean energy RD&D programs and projects, such as those of the MI initiative (weighted at 40 percent); the share of relevant publications that are written with international coauthors (30 percent); and the share of relevant patents that have international coinventors (30 percent).

Standardization

In order to aggregate these diverse indicators and categories, we must first standardize them. We convert both the level of national contributions and the change in them for the 20 indicators into z-scores, with the mean set to 10 and standard deviation set to 4. The scores are capped at 0 and 20 (2.5 standard deviations from the mean in either direction) so that outliers do not carry too much weight. A nation making an average contribution to the global energy innovation system on a given indicator would receive a score of 10, while the maximum score would be 20. The z-scores are then combined and aggregated up to create the indicator, category, subindex, and index scores using the weights laid out in table 2.

Subindex Weightings

The GEII weights the Knowledge Development and Diffusion subindex at 40 percent, the Entrepreneurial Experimentation and Market Formation subindex at 40 percent, and the Social Legitimation and International Collaboration subindex at 20 percent. These weights reflect our view that the first two sets of functions are much more important to the productive operation of the global energy innovation system than the third. However, we freely admit that these weights are subjective. We explore several alternative weightings, including even weights across the three and disproportionately heavy weights on each of the first two. The rankings are surprisingly stable across these variations, which may be interpreted as sensitivity tests.

THE RANKINGS

Table 4: The 2021 GEII Overall and Subindex Rankings

2021 Rank	Country	Overall Score	2016 Rank	Change	KD&D Rank	EE&MF Rank	SL&IC Rank
1	Finland	15.59	1	0	4	1	14
2	Denmark	14.56	2	0	1	9	2
3	Sweden	14.23	3	0	10	2	19
4	United Kingdom	14.01	9	+5	8	6	1
5	Switzerland	13.74	8	+3	16	3	4
6	Belgium	13.62	10	+4	3	11	9
7	Netherlands	13.59	5	-2	14	4	3
8	Germany	13.19	11	+3	7	8	16
9	Canada	13.02	13	+4	13	5	11
10	France	12.70	6	-4	11	10	7
11	Norway	12.18	23	+12	6	16	17
12	Japan	11.81	19	+7	2	19	25
13	Austria	11.63	12	-1	15	13	10
14	South Korea	11.57	22	+8	5	21	21
15	Australia	11.22	17	+2	20	7	15
16	Czech Republic	11.02	18	+2	17	14	20
17	United States	10.82	4	-13	9	12	31
18	Portugal	10.44	7	-11	19	17	12

2021 Rank	Country	Overall Score	2016 Rank	Change	KD&D Rank	EE&MF Rank	SL&IC Rank
19	Italy	9.51	16	-3	18	27	18
20	Slovak Republic	9.41	24	+4	23	15	13
21	Hungary	8.90	25	+4	26	23	6
22	Spain	8.42	21	-1	24	26	8
23	Ireland	8.13	24	-9	25	30	5
24	Lithuania	7.83	34	+10	27	22	23
25	China	7.63	30	+5	12	31	34
26	Poland	7.32	15	-11	28	24	26
27	Brazil	7.07	26	-1	22	20	32
28	Greece	7.04	31	+3	32	18	30
29	Mexico	6.83	27	-2	33	25	24
30	Estonia	6.74	20	-10	21	32	27
31	Chile	6.59	29	-2	29	29	28
32	India	6.04	33	+1	30	33	22
33	New Zealand	5.72	28	-5	34	28	29
34	Turkey	3.59	32	-2	31	34	33

Table 4 presents the GEII rankings. They show that nations make highly varied contributions to clean energy innovation. For instance, Finland is the top-ranked contributor overall, but it leads only in entrepreneurial experimentation and market formation. It ranks 4th in knowledge development and diffusion and only 14th in social legitimation and international collaboration. Looking at the categories, Finland's only top score is in market readiness and technology adoption, which assesses a nation's demand-pull on clean energy innovation through its energy efficiency and clean energy consumption.

The three nations that follow Finland in the GEII, Denmark, Sweden, and the United Kingdom, are also uniquely strong in particular subindices. Denmark ranks first for knowledge development and diffusion, Sweden ranks second only to Finland in entrepreneurial experimentation and market formation, and the United Kingdom sets the pace for social legitimation and international collaboration. Only Denmark and the United Kingdom rank in the top 10 across all three subindices.

Variations among national energy innovation systems often complement one another when they interact across borders. Nations that excel as early adopters of new technologies provide a boost to those that are good at invention and demonstration, for example. Countries that lead in international collaboration may provide opportunity and inspiration for those that are lagging on this indicator. The global innovation system is strengthened by national diversity.

Other Western European nations, including Switzerland, Belgium, the Netherlands, Germany, France, and Norway, along with Canada, form a second tier of contributors behind the top four. If the European Union (EU) were ranked as a single nation, it would be in this group as well. (See box 1.)

Japan, South Korea, Australia, and the United States, along with the Czech Republic and Austria, comprise the third tier. Japan and South Korea rank in the top five for knowledge development and diffusion, but their relatively poor scores in the other two subindices pull down their overall rankings. Australia's performance in entrepreneurial experimentation and market formation buoys its GEII score, while the United States makes up for its very poor performance in social legitimation and international collaboration by ranking in the top third in the other two.

Developing and transition nations make up most of the lower half of the GEII. China ranks 25th, for instance, with Brazil, Mexico, Chile, India, and Turkey clustering near the bottom. These rankings are consistent with the concept of common but differentiated responsibilities embodied in the Paris Agreement, which places a heavier burden on high-income countries that have emitted a disproportionate share of greenhouse gases in the past. (Several, including China, India, and Turkey, also suffer due to poor data coverage.) It is nonetheless vital that developing and transition nations expand their contributions to the global energy innovation system in the coming years, since they will represent the fastest-growing share of emissions and thus be among the most significant markets for clean energy innovations.

Variations among national energy innovation systems often complement one another when they interact across borders.

The GEII is quite stable across differing weightings of the three subindices. Our preferred scheme places an equal 40 percent weight on knowledge development and diffusion and entrepreneurial experimentation and market formation, along with half that weight on social legitimation and international collaboration ("40/40/20"). Yet, the four tiers previously discussed are present when other schemes are applied, including equal weightings ("33/33/33") and more unbalanced ones ("50/25/25" and "30/50/20").

The rankings are stable over time as well. (2016 rankings can be found in appendix 2.) When we compare the current GEII with a 2016 version (for which the vast majority of the indicators are available), we find that half of the nations moved no more than three places up or down. Norway gained the most, rising 12 places, while Lithuania went from the very bottom of the list to 24th in this five-year period. Part of the latter's gain is artifactual, since it began reporting national RD&D spending data to IEA in 2019; but real strides are apparent in measures for which we have a steady stream of data, such as entrepreneurial ecosystem and national commitments.

The United States went the other direction, dropping 13 spots from 4th in 2016 to 17th in 2020. Its contributions declined relative to other nations across all three subindices, with the largest decline (from 22nd to 31st) in social legitimation and international collaboration, particularly the stringency of its national commitments under the Paris Agreement (from which it withdrew in 2017) as measured by the CAT.

KNOWLEDGE DEVELOPMENT AND DIFFUSION

Table 5: Knowledge Development and Diffusion Subindex Rankings

2021 Rank	Country	2021 Score	2016 Rank	Change	Public R&D Rank	Knowledge Generation Rank	Invention Rank
1	Denmark	14.67	3	+2	12	1	3
2	Japan	14.51	4	+2	3	27	1
3	Belgium	13.80	2	-1	1	17	12
4	Finland	13.71	1	-3	4	9	11
5	South Korea	13.35	5	0	13	15	1
6	Norway	12.95	23	+17	2	16	22
7	Germany	12.84	11	+4	11	18	4
8	United Kingdom	12.49	16	+8	9	5	14
9	United States	12.42	6	-3	8	14	7
10	Sweden	12.29	7	-3	10	11	8
11	France	11.63	10	-1	6	22	10
12	China	11.30	24	+12	17	10	5
13	Canada	10.81	15	+2	14	13	15
14	Netherlands	10.67	14	0	16	12	13
15	Austria	10.47	13	-2	15	21	6
16	Switzerland	10.16	19	+3	5	ND	9
17	Czech Republic	10.13	22	+5	7	25	20
18	Italy	9.65	17	-1	19	6	16
19	Portugal	9.37	2	-17	20	7	25
20	Australia	8.62	24	+4	31	2	24
21	Estonia	7.83	8	-13	33	4	17
22	Brazil	7.55	26	+3	18	30	18
23	Slovak Republic	7.11	29	+6	21	31	21
24	Spain	6.89	28	+4	27	19	31
25	Ireland	6.85	17	-7	32	8	32
26	Hungary	6.83	28	+2	23	26	29
27	Lithuania	6.54	34	+7	22	28	33
28	Poland	6.39	14	-14	29	20	23
29	Chile	6.19	26	-3	26	24	27
30	India	5.90	33	+3	30	23	26
31	Turkey	5.51	32	+1	25	ND	19
32	Greece	5.51	30	-2	ND	3	28
33	Mexico	5.33	27	-6	28	29	30
34	New Zealand	4.49	31	-3	24	ND	34

The subindex for national contributions to knowledge development and diffusion rests most heavily on public investment in clean energy R&D. This investment is an input to knowledge, and it is balanced in compiling the subindex by two output measures—publications and patents—since innovation systems do not necessarily convert inputs into outputs with the same efficiency.

The 34 national governments included in the GEII together invested over $27 billion in clean energy R&D in the most recent year for which data is available. This figure has grown by more than 25 percent since 2015. However, when scaled by the size of the combined economies of these countries, it has been essentially flat. The aggregate number of publications has risen by almost 40 percent, while patenting has slowed almost 20 percent. None of these totals indicate that the governments are imbued with the sense of urgency needed to accelerate progress toward net-zero emissions by 2050.

Table 5 presents the rankings for this subindex. Denmark is at the top. It is particularly strong in knowledge generation, taking the number one position in both total publications and highly cited publications per capita. Denmark also ranks 3rd in the inventions category and 12th in public clean energy R&D investment.

Japan and South Korea rank second and fifth, respectively. They score much better on this subindex than on the other two, raising their rankings in the GEII. The two nations tie for the top score in the inventions category. Belgium and Finland round out the top five on this subindex, coming in third and fourth, respectively.

Denmark is at the top of the rankings on the Knowledge Development and Diffusion subindex.

Like Japan and South Korea, the United States contributes far more to the global energy innovation system through knowledge development and diffusion than the other GEII subindices. In absolute terms, its investment in public clean energy R&D was over $8.4 billion in 2020, more than 25 times Norway's. Weighted by the size of its economy, though, the U.S. ranking on this indicator falls to eighth. Together with its 14th place showing in the knowledge generation category and 7th position in inventions, the United States places 9th overall in the Knowledge Development and Diffusion subindex.

China has a similar overall profile to that of the United States, ranking 12th on this subindex, well ahead of its rankings on the other two subindices. (Box 1 compares China, the United States, and the European Union.) It has ramped up its public investment in clean energy RD&D substantially, reaching over $4 billion in 2019—a near doubling since 2015. Of course, the Chinese economy also grew very rapidly during this period, so when this indicator is scaled by GDP, China drops to the middle of the pack. Within this subindex, China does best in the invention category, ranking fifth.

China is also notable for rising 12 places on the Knowledge Development and Diffusion subindex since 2016, improving across all the component categories. The United Kingdom also moved up in a big way, from 16th to 8th. On the other hand, Finland dropped from first to fourth, primarily because it cut back its public clean energy R&D investment in absolute terms, and therefore even more as a share of its economy. Portugal, Estonia, and Poland also suffered notable declines in their rankings between 2016 and 2021.

Box 1: China, the European Union, and the United States: The Big 3

China, the European Union and its member states, and the United States are by far the most important contributors to the global energy innovation system. Without their contributions, global energy innovation would essentially grind to a halt. Yet, the "Big 3" play differing roles in the system today, and each has substantial room to improve its contributions in the coming years.

Together, the Big 3 drive knowledge development and diffusion. Of the nearly $113 billion of public R&D investments reported globally since 2015, the Big 3 have contributed nearly 76 percent, accounting for around 60 percent of the world's clean energy publications and inventions as well.

Their impact on entrepreneurial experimentation and market formation is equally significant. China, the European Union and its member states, and the United States have supplied over 90 percent of the $150 billion of venture capital invested in clean energy start-ups since 2015. They account for more than 50 percent of the world's clean energy technology exports and nearly 60 percent of clean energy consumption and consumption growth.

The GEII shows unequivocally that the European Union's member states outperform China and the United States. They take 8 of the top 10 spots in the overall rankings and dominate all three subindices as well. The United States cracks the top 10 in only one subindex, in which it ranks 9th, while China's best showing is 12th. Few close observers will be surprised that European nations drive demand-pull innovation through energy efficiency and clean energy consumption, along with the associated policies. But some may not be aware that the European Union outperforms the United States in knowledge development and is competitive with China in clean energy technology exports.

The European Union's soft spot, however, is its entrepreneurial ecosystems. U.S. venture capital investments dwarf EU investments, which trail China's, too. Even though EU venture funding has grown at a 46 percent annual clip since 2015, it has been concentrated in just three countries, one of which has since Brexited the Union. If the European Union is going to capitalize on its strengths in the early and late stages of the innovation pipeline, it will need to develop these functions more fully.

The story of the United States told by the GEII is one of a dramatic fall from prominence. In the 2016 version of the GEII, it ranked fourth. Just five years later, it has fallen 13 spots, dragged down by its poor performance in functions such as trade, market readiness, and especially social legitimation. While the United States remains a very large contributor to the global energy innovation system in absolute terms, it is not contributing nearly as much, relative to its potential, as the European Union's leading members. The United States will need to take decisive action if it seeks to change its trajectory.

China, the remaining member of the Big 3, has raised its ranking over the past five years, but still has much room for continued growth. China has jumped from 24th to 12th in the Knowledge Development and Diffusion subindex by doubling its public R&D investments and rapidly accelerating growth in publications and inventions. It has improved its entrepreneurial ecosystem as well, with venture capital investments growing at an annual clip of 43 percent. While China's scores are hurt by a lack of data in some categories, its measured performance in social legitimation and international collaboration have left it last in this subindex, pulling down its overall performance.

The Big 3 bear the tremendous responsibility of ensuring that the global energy innovation system functions well. The fate of clean energy innovation rests largely in their hands. The GEII identifies strengths and weaknesses that can assist innovation policymakers in each jurisdiction to deepen and strengthen their contributions.

ENTREPRENEURIAL EXPERIMENTATION AND MARKET FORMATION

Table 6: Entrepreneurial Experimentation and Market Formation Subindex

2021 Rank	Country	2021 Score	2016 Rank	Change	Tech Demos Rank	Start-Up Ecosystem Rank	Industry & Trade Rank	Markets/ Adoption Rank
1	Finland	14.68	1	0	19	4	6	1
2	Sweden	14.01	6	+4	7	1	11	17
3	Switzerland	13.98	2	-1	11	5	10	4
4	Netherlands	13.16	5	+1	6	10	5	15
5	Canada	12.66	3	-2	1	2	24	18
6	United Kingdom	11.98	7	+2	4	6	25	10
7	Australia	11.55	14	+7	5	8	20	12
8	Germany	11.40	12	+4	21	11	9	14
9	Denmark	11.31	7	-2	3	20	1	30
10	France	11.14	9	-1	13	12	19	5
11	Belgium	11.07	13	+2	10	19	12	11
12	United States	10.64	4	-8	14	3	29	19
13	Austria	10.52	10	-3	9	34	8	8
14	Czech Republic	10.46	15	+1	ND	30	4	7
15	Slovak Republic	9.63	19	+4	ND	32	2	23
16	Norway	9.62	23	+7	2	9	27	25
17	Portugal	9.47	17	0	ND	14	23	6
18	Greece	9.30	31	+13	15	26	26	3
19	Japan	9.14	22	+3	20	22	18	13
20	Brazil	8.81	27	+7	ND	23	31	2
21	South Korea	8.80	26	+5	16	21	14	22
22	Lithuania	8.70	29	+7	18	7	15	31
23	Hungary	8.63	20	-3	ND	29	3	27
24	Poland	8.48	11	-13	ND	15	16	20
25	Mexico	8.15	28	+3	25	25	17	21
26	Spain	8.03	21	-5	17	18	22	24

27	Italy	7.96	18	-9	26	24	13	26
28	New Zealand	7.75	24	-4	12	31	30	16
29	Chile	7.74	30	+1	22	28	34	9
30	Ireland	7.19	16	-14	8	16	33	28
31	China	6.98	33	+2	24	13	21	32
32	Estonia	6.39	25	-7	23	27	7	ND
33	India	5.72	32	-1	27	17	32	33
34	Turkey	4.74	34	0	ND	33	28	29

The Entrepreneurial Experimentation and Market Formation subindex seeks to capture contributions to innovation that flow through a nation's new ventures, risk-taking by established businesses, and scale-up processes. It includes measures of funding and hosting of demonstration projects, high-potential start-ups and their early-stage and exit funding, clean energy technology exports, and demand-pull from energy efficiency and clean energy consumption across all end-use sectors. The last three categories—entrepreneurial ecosystem, trade, and market readiness—are weighted at 90 percent, with demonstration accounting for the remainder. (Box 2 discusses large-scale demonstration projects.)

The flow of early-stage capital into clean energy start-ups, and their ability to exit via private equity buyout, merger or acquisition, or IPO, are bright spots for the global energy innovation system as a whole. In absolute terms, the flow of venture capital more than tripled between 2015 and 2020, and it rose as a share of the economy by an impressive 25 percent per year in that period. (Our measure for high-potential start-ups does not lend itself to global aggregation.)

The aggregate demand-pull provided by energy efficiency and clean energy consumption, as well as public investments in demonstration reported to IEA (see box 3), also rose in the late 2010s, although at a far more modest pace than did venture capital. Clean energy exports, on the other hand, stagnated.

Table 6 displays the Entrepreneurial Experimentation and Market Formation subindex rankings. Finland ranks first, a place it also held in the 2016 ranking. It tops the chart in the market readiness category and comes in sixth in trade. Finland also places fourth in the entrepreneurial ecosystem category, where it punches well above its weight as measured by high-impact start-ups and venture capital investment as a share of GDP.

Finland ranks first in the Entrepreneurial Experimentation and Market formation subindex rankings, a place it also held in 2016.

Sweden follows Finland in the subindex ranking, leading the field in the entrepreneurial ecosystem category by a wide margin with more than three times the amount of venture capital per unit of GDP than its Finnish neighbor. Switzerland, the Netherlands, and Canada complete the top five spots on this subindex. Switzerland's performance is the most consistent across the categories, while the Netherlands excels at trade and Canada in technology demonstrations and entrepreneurial ecosystem. Canada has the highest number of high-impact clean energy start-ups and successful company exits per unit of GDP.

The United States also does well in the entrepreneurial ecosystem category. It is home to many more high-impact start-ups and far more venture capital funding in absolute terms than any other country, although these totals pale a bit when scaled by GDP, leaving it in third place in this category. The United States is pulled down to the 12th spot on this subindex, however, by its dismal rankings in trade and market readiness. It held fourth place in the subindex in 2016, when it scored much better in market readiness and came in first in entrepreneurial ecosystem.

China deploys the second-most venture capital in absolute terms, helping it perform much better in the entrepreneurial ecosystem category than the others within this subindex and rise a couple of spots since 2016. More impressive moves up between 2016 and 2021 were achieved by Greece (13 spots, improving most in market readiness) and Australia (7 spots, improving most in trade). In the 2021 GEII, both nations rank at least eight places higher on the Entrepreneurial Experimentation and Market Formation subindex than the other two.

Brazil moved up seven spots in this subindex between 2016 and 2021, bettering its rank in the market readiness category from 17th to 2nd. On the other side of the ledger, Ireland (14 spots), Poland (13 spots), and Italy (9 spots) fell the furthest. Ireland slipped from 6th to 16th and Italy from 16th to 24th in entrepreneurial ecosystems. Poland dropped from 2nd to 16th in trade and 13th to 29th in market readiness.

Box 2: Demonstration Is Still a Valley of Death, But There's New Hope

The 2019 edition of this Index identified public investment in demonstration projects as a major weakness in the global energy innovation system. The 2021 edition reinforces that finding. Many nations either invest very little in this critical stage of the innovation process or do not report their contributions in an internationally comparable fashion. This gap could derail progress on important climate solutions in the coming years. However, there is good news: New programs in the United States, the European Union, and elsewhere promise to begin bridging this "Valley of Death."

Most net-zero emissions scenarios anticipate that technologies that are today in the prototype phase will make major contributions to emissions reductions. Many of these technologies, particularly in the electric power and industrial sectors, are complex, capital-intensive systems. When scaled up for the first time, such systems typically encounter technical and integration challenges that cannot be anticipated via smaller-scale studies. These problems can only be identified and solved by running full-scale demonstration projects, which enable commercially viable follow-on projects.

But the high cost and risk of demonstrations deter private investment. Unless the public sector shares this cost and risk, developers, users, investors, and other stakeholders may never gain sufficient confidence to bring these technologies to maturity. IEA's Net-Zero Emissions scenario estimates that "around $90 billion of public money needs to be mobilised globally as soon as possible to complete a portfolio of demonstration projects before 2030."[9]

The GEII uses two indicators to try to assess national contributions to this critical phase of the energy innovation process. One is public spending on demonstration projects reported to IEA. Norway was by far the largest contributor, followed by Canada and the United Kingdom.

Unfortunately, the trend is in the wrong direction, with annual investment declining by more than 7 percent per year since 2016. However, relatively few nations reported anything at all; the data coverage for this indicator is the worst in the Index. We cannot tell whether nonreporting nations are spending nothing or failing to report a positive sum.

To try to compensate for the weakness of reporting by the public sector and also acknowledge that private actors make contributions to demonstration projects, we have sought to assemble project counts across the fields of CCS, advanced nuclear power, hydrogen production and use, energy storage, and advanced renewables. We credit the country in which the project is sited with making a contribution to the global system. This approach leads to broader coverage across countries in our database than the public spending indicator would capture on its own, with the United States, the United Kingdom, and China leading the way. We do not have complete data, however, on project size and cost, and we are unable to properly credit countries that are contributing to multinational projects outside their borders.

IEA estimated in May 2021 that only $25 billion of the $90 billion need for public investment in demonstration projects over the next decade was planned for by governments.[10] That pace would at best be roughly level with that of the past five years. But that's not good enough. Such a shortfall might well leave the world without viable emissions-reduction options in the 2030s and 2040s for major sectors that are currently hard-to-abate.

Some optimism may be found in new initiatives, however. The European Union has dedicated revenues from its Emission Trading System that could amount to about $25 billion over 10 years (depending on the carbon price and exchange rate) to support commercial demonstration of innovative low-carbon technologies. In the United States, the Senate agreed in August 2021 on bipartisan legislation that would create a new Office of Clean Energy Demonstrations, and could provide as much as $30 billion over five years for clean energy and decarbonization demonstration projects. Other nations may also up their commitments heading into the November 2021 global climate summit.[11]

SOCIAL LEGITIMATION AND INTERNATIONAL COLLABORATION

Table 7: Social Legitimation and International Collaboration subindex

2021 Rank	Country	2021 Score	2016 Rank	Change	National Commitments Rank	Public Policies Rank	Int'l Collabs Rank
1	United Kingdom	14.03	1	0	9	3	3
2	Denmark	13.49	3	+1	10	7	6
3	Netherlands	13.24	5	+2	5	10	4
4	Switzerland	12.94	8	+4	11	1	30
5	Ireland	12.91	2	-3	16	8	9
6	Hungary	12.70	15	+9	3	12	10
7	France	12.51	11	+4	6	11	18
8	Spain	12.09	10	+2	15	9	21
9	Belgium	12.06	6	-3	12	18	5

2021 Rank	Country	2021 Score	2016 Rank	Change	National Commitments Rank	Public Policies Rank	Int'l Collabs Rank
10	Austria	11.99	9	-1	8	15	12
11	Canada	11.91	27	+16	1	21	7
12	Portugal	11.90	4	-8	2	13	22
13	Slovak Republic	11.85	17	+4	4	17	14
14	Finland	11.73	13	-1	13	16	13
15	Australia	11.65	19	+4	17	22	2
16	Germany	11.50	12	-4	21	6	25
17	Norway	11.41	7	-10	23	4	20
18	Italy	11.13	14	-4	26	5	19
19	Sweden	10.70	16	-3	14	24	11
20	Czech Republic	10.47	18	-2	18	23	15
21	South Korea	10.12	28	+7	27	2	32
22	India	9.99	26	+4	25	19	8
23	Lithuania	8.94	34	+11	7	32	17
24	Mexico	8.65	24	0	29	14	23
25	Japan	8.07	30	+5	22	25	29
26	Poland	7.79	25	-1	19	30	28
27	Estonia	7.45	23	-4	20	34	1
28	Chile	7.00	33	+5	28	27	16
29	New Zealand	6.90	29	0	24	28	27
30	Greece	6.53	20	-10	32	20	26
31	United States	4.89	22	-9	30	31	24
32	Brazil	3.84	31	-1	31	33	31
33	Turkey	3.47	21	-12	33	26	34
34	China	2.93	32	-2	34	29	33

Innovation is an intrinsically social process. Technologies exert an effect on society, changing the choices available to people and organizations and often building support for themselves by doing so. But society exerts a reciprocal effect as well, obstructing some innovation pathways even as it accelerates others. The Social Legitimation and International Collaboration subindex provides insights into these complex processes as they bear on clean energy innovation by weighing what governments say (through their NDCs) a little and what they do a lot. The actions measured include public RD&D support for legacy carbon-intensive technologies, carbon-abating regulations and pricing schemes, and participation in international innovation networks.

While many of these measures do not lend themselves to global aggregation as easily as the financial flows included in the other subindices, their general trends over the past five years have mostly been positive, though not necessarily fast enough. The vast majority of NDCs, as scored by the CAT, for instance, were strengthened between Paris and Glasgow, yet remain "insufficient" or worse. Effective carbon prices, as measured by OECD, similarly, rose in most nations from 2012 to 2018, but mostly at low single-digit rates. International copublication barely budged, while international coinvention fell. A bright spot is that most countries overwhelmingly invest public energy RD&D funding in low-carbon areas.

The United Kingdom sets the pace in the Social Legitimation and International Collaboration subindex, which is displayed in table 7. It held the top spot in 2016 as well. Although the United Kingdom did not best the rest in any of the indicators that comprise this subindex, its performance is consistently strong, placing it among the top 10 in all categories.

Four European nations—Denmark, the Netherlands, Switzerland, and Ireland—follow the United Kingdom in these rankings. These results also flow from consistency across the categories rather than an outstanding performance in any one. Among the four, only Switzerland leads a category: national public policies. Canada comes in first in the national commitments category, and Estonia posts the highest score for international collaboration.

The United Kingdom sets the pace in the Social Legitimation and International Collaboration subindex.

The United States scores consistently low across the social legitimation and international collaboration categories, ranking in the bottom 5 in national commitments and public policies, and bottom 10 in international collaboration, leaving it just 3 places from the bottom on this subindex, 9 places lower than in 2016. For instance, while the United States submitted a stronger NDC in 2021 than in 2016, its target in 2020 was deemed "critically insufficient." Only five countries for which OECD had data in 2018 had lower effective carbon rates.

China fares even worse on this subindex than the United States: dead last. The two nations' public policy scores are similarly poor. The lack of data on non-low-carbon public RD&D hurts China in the national commitment category. Its very low rankings on the international copublication and coinvention indicators may also be data artifacts, given China's large domestic science and technology enterprise and the intense pressure to publish and patent within it.

Hungary, Ireland, and Spain are notable for their disproportionate contributions to the global energy innovation system through social legitimation and international collaboration. All three rank among the top 10 on this subindex, but 22nd or below on the other two. Canada's leap to the top of the national commitments category boosted its subindex ranking 16 spots from 27th in 2016 to 11th in 2021. South Korea made a similar jump from 24th to 2nd in the national policies category, but its poor showing in the other two categories kept it in the bottom half of the subindex rankings.

Turkey, Greece, and Norway all fell by 10 or more spots on this subindex between 2016 and 2021. Turkey's NDC was rated "critically insufficient." Greece and Norway both slipped dramatically in the international collaboration category. Brazil stands out for its exceptionally low commitment to the clean energy innovation agenda, with non-low-carbon projects receiving over $1 billion, or about 62 percent, of that nation's public energy RD&D funding in the most recent year for which data is available (2018), up from 52 percent a few years earlier.

Box 3: Mission Innovation Reboots

Knowledge is the most important global public good created by human beings. The same idea can be used in many places and in many ways at the same time. But this extraordinary property also leaves knowledge creation vulnerable to the free rider problem. Knowledge creation typically requires investment, but the benefits of that investment cannot easily be controlled by the investors. Yet, unless investors are confident that they will receive an acceptable return—whether pecuniary or in prestige, satisfaction, or some other value—they may be reluctant to invest in the first place.

This free rider problem exists among nations as well as individual and corporate investors. The benefits of public RD&D investments made by one nation may be realized by other nations, and the fear of such spillovers may deter investments. One important solution to this problem is international cooperation and collaboration. Mutual commitments on the part of each government to do its part to create knowledge that will be shared globally allow all governments to invest with greater confidence.

The MI initiative, which was established in 2015 in parallel with the Paris Agreement, was meant to create this sort of positive-sum game for clean energy RD&D. Governments responsible for more than 90 percent of the world's energy RD&D spending agreed to double their investments by 2020 and collaborate to tackle specific innovation challenges as well.

Unfortunately, as ITIF projected in its 2018 "Omission Innovation" report, most MI signatories did not fulfill their spending commitments. Zdenka Myslikova and Kelly Sims Gallagher (2020) estimate that the member states raised clean energy RD&D spending by only 38 percent. As we report in this Index, when scaled by the size of MI nations' economies, the results are even more dismal: Less than 1 percent annual growth over five years.[12]

Given this disappointing record, it is not surprising that MI 2.0, which was launched in May 2021, does not include a spending target. The MI reboot focuses instead on a set of specific missions, beginning with the integration of 100 percent variable renewable energy into reliable power grids, zero-emissions shipping, and low-cost clean hydrogen. The payoffs from collaboration in such efforts should be much more transparent to the participants than those from raising clean energy RD&D spending overall. Member states will also publish their own "national innovation pathways" to contribute to climate and energy goals, which will be tracked by MI in collaboration with international organizations such as IEA.[13]

MI's more modest objectives for the next five years reflect a realistic assessment of its first five. Many factors other than the fear of international free riding impact national energy RD&D budgets. A voluntary agreement with no sanctions for nonfulfillment does little to ease that fear in any case. MI's biggest champion, the United States, backed away from it soon after President Trump succeeded President Obama in 2017. In the global climate discourse since the signing of the Paris Agreement, long-term public investments in innovation have received far less diplomatic and leadership attention than more immediate emissions cuts embodied in nationally determined commitments.

That balance must be altered as MI 2.0 matures. Few goals for international cooperation are more important than accelerating clean energy innovation. Civil society, philanthropy, and the private sector must prod leading governments to contribute more to create knowledge, whether in the form of fundamental science that can underpin new climate solutions or as cumulative technological experience—learning by doing—that brings the costs of solutions down.

CONCLUSION

The world's population wants and needs a growing level of energy services now and in the coming decades. The only way this demand can be met while averting the worst consequences of climate change is through accelerated innovation—which no global entity or group of private companies will ensure occurs. Nations must take responsibility. Through a wide range of policies as well as their public statements, national governments profoundly influence the pace of progress in clean energy.

The GEII provides a wide-ranging assessment of national contributions to the global energy innovation system. The 34 countries included in it make varied contributions. Their strengths often complement one another. But national ambitions to contribute to global energy innovation, viewed as a complete system, must be enhanced in the coming years if the world is to achieve its climate goals.

APPENDIX 1: METHODOLOGY AND SOURCES

The GEII rests at its base on 20 indicators. This appendix describes the sources of these indicators, the methodologies used to construct them, and the countries and years covered by both the 2021 and 2016 editions of the GEII. It also describes the methodology used for assessing the contributions of the European Union.

In most cases, the indicators measure both the level of national contributions in the most recent year for which data is available and the change over the previous five years (with some exceptions as described in this appendix). The 20 indicators are, in turn, organized into 10 functional categories, which then contribute to the 3 subindices built around the functional groupings described in the main report.

As we aggregate indicators from one level to the next, we standardize them and apply weights that reflect our judgments about the importance of each measurement and the quality and availability of the data. We convert both the level of national contributions and the change in them for the 20 indicators into z-scores, with the mean set to 10 and standard deviation set to 4. The scores are capped at 0 and 20 (2.5 standard deviations from the mean in either direction) so that outliers do not carry too much weight. A nation making an average contribution to the global energy innovation system on a given indicator would receive a score of 10, while the maximum score would be 20. The z-scores are then combined and aggregated up to create the indicator, category, subindex, and index scores using the weights laid out in table 2.

Indicator 1: Public Investments in Low-Carbon Energy R&D

Data Sources:

- IEA Energy RD&D Statistics database
- Mission Innovation Country Highlights 2015–2021
- World Bank GDP database

Methodology: The indicator aims to assess the total amount of public investment in low-carbon energy R&D as an indicator of national contributions to the resource mobilization and knowledge development functions. IEA's Energy RD&D Statistics include data for low-carbon energy RD&D data measured in USD (2020 prices and purchase power parity (PPP)), but only offer R&D and demonstration carveouts measured in national currency (nominal). To generate data for the two carveouts that also has the benefits of the USD (2020 prices and PPP) adjustments, the percentage of low-carbon R&D and demonstration funding in total low-carbon RD&D in national currencies was determined and used to generate the same carveouts from the RD&D USD (2020 prices and PPP) data. Canada, Estonia, Italy, Norway, and Portugal had years in which the sum of R&D and demonstration did not equal the RD&D total. For those years, the difference was distributed between R&D and demonstration according to each country's average distribution ratio for the years 2010–2020. For non-IEA members that are MI members (Chile, China, and India), data for R&D and demonstration carveouts does not exist, so all clean energy RD&D funding reported to MI was considered public R&D and none was counted as demonstration funding. The index adopts IEA's taxonomy for low-carbon energy RD&D by technology, which includes CCS technologies but categorizes all other fossil energy RD&D as non-low-carbon. According to MI reporting, China invested $2.4 billion in "Cleaner Fossil Fuels" in 2018 and $1.4 billion in 2019 but did not invest any in CCS. Therefore, China's investments in "Cleaner Fossil Fuels" are not included in its low-carbon energy RD&D numbers. The level indicator is measured as low-carbon energy R&D per thousand units of GDP (R&D intensity) for the most recent year data is available during the most recent three-year period. The change indicator is measured as the 3 to 5-year compound annual growth rate (CAGR) over the previous five-year period (i.e., starting in the sixth year prior and ending with the most recent year in which data is available). The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the years 2018–2020 and the change indicator is drawn from the years 2015–2020. No data is available for Greece. For the 2016 GEII, the level indicator is drawn from the years 2013–2015 and the change indicator is drawn from the years 2010–2015. No data is available for Greece, India, and Lithuania.

Indicator 2: Number of Clean Energy Research Publications

Data Source:

- Simon Provencal, Paul Khayat, and David Campbell, *Publications as a Measure of Innovation Performance*, European Commission, Directorate General for Research and Innovation, January 2021

Methodology: The indicator aims to quantify the knowledge generated in each country as an indicator of national contributions to the knowledge development function. The level indicator measures the total number of clean energy research publications (in fractional counting) per million population for the most recent year available during the three previous years. The change indicator is measured as the 4-year CAGR for the four previous years. The total score for the indicator is given by the sum of the level indicator multiplied by 0.80 and the change indicator multiplied 0.20. For the 2021 GEII, the level indicator is drawn from the year 2019 for all countries and the change indicator is drawn from the years 2015–2019 for all countries. No data is available for New Zealand, Switzerland, and Turkey. For the 2016 GEII, the level indicator is drawn from the year 2015 for all countries. No data is available for the years prior to 2015 and therefore no change indicator is included in the score. No data is available for New Zealand, Switzerland, and Turkey.

Indicator 3: Share of Highly-Cited Clean Energy Research Publications

Data Source:

- Simon Provencal, Paul Khayat, and David Campbell, *Publications as a Measure of Innovation Performance*, European Commission, Directorate General for Research and Innovation, January 2021

Methodology: The indicator aims to assess the quality and the diffusion of knowledge generated in each country as an indicator of national contributions to the knowledge development and diffusion functions. The level indicator is measured as the share of highly cited clean energy research publications (top 10 percent) as a share of the total number of clean energy research publications. To allow for the time needed for publications to accumulate citations, the level indicator includes clean energy research publications generated two years prior to those included in the number of clean energy publication indicator. The change indicator is measured as the 4-year CAGR for the four years prior to the most recent year accounted for in the level indicator. The total score for the indicator is given by the sum of the level indicator multiplied by 0.80 and the change indicator multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2017 for all countries and the change indicator is drawn from the years 2013–2017 for all countries. No data is available for New Zealand, Switzerland, and Turkey. For the 2016 GEII, the level indicator is drawn from the year 2013 for all countries. No change indicator is used due to a lack of data availability for the years prior to 2013. No data is available for New Zealand, Switzerland, and Turkey.

Indicator 4: Development and Diffusion of Clean Energy Inventions

Data Sources:

- OECD environment-related technologies database
- World Bank GDP database.

Methodology: The indicator aims to assess the quantity, quality, and diffusion of clean energy inventions as an indicator of national contributions to the knowledge development and diffusion functions. The OECD patents database is based on "simple patent families," which are collections of patent applications filed across jurisdictions covering the same invention. The database includes statistics on categories of environment-related inventions in four different family sizes (FS): FS 1+ represents inventions filed in one or more jurisdictions (i.e., all inventions), and FS 2, 3, and 4+ represent inventions filed in 2, 3, and 4 or more jurisdictions. In other words, inventions move to higher FS's the more they are diffused across borders. They can also be presumed to be of higher value because of the additional costs of filing for protection in multiple countries. We extract and isolate the data for each of the four FS's and recombine it into one indicator. First, the total number of climate change mitigation inventions are gathered for each FS. Second, to narrow the scope to clean energy inventions, inventions in the agriculture, livestock, agroalimentary industries, wastewater treatment, and waste management categories are subtracted from the total. Third, the remaining inventions are categorized by FS. The counts for each year are then recombined by summing the patent counts for FS 4+ multiplied by 0.35, FS 3 multiplied by 0.30, FS 2 multiplied by 0.25, and FS 1 multiplied by 0.10. The combined scores are then normalized per thousand units of GDP to generate patent intensity scores for each year. The level indicator is measured as the patent intensity score for the most recent year data was available during the most recent three-year period. The change indicator is measured as the 3 to 5-year CAGR for the five years prior. The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2018 and the change indicator is drawn from the years 2013–2018. For the 2016 GEII, the level indicator is drawn from the year 2013 and the change indicator is drawn from the years 2010–2013.

Indicator 5: Attraction and Absorption of Clean Energy Inventions

Data Source:

- OECD environment-related technologies database

Methodology: The indicator aims to assess the extent to which nations are facilitating the diffusion of technical knowledge by generating domestic conditions that allow them attract and absorb clean energy inventions from abroad. The level indicator is measured using two OECD summary indicators for technology diffusion. The first is the diffusion of environment-related inventions as a percentage of all environment-related inventions worldwide. It takes the number of environment-related inventions that sought patent protection in a given geographic market (jurisdiction of a patent office) as a percentage of environment-related inventions that sought patent protection anywhere in the world during the current and three previous years. The second is the climate change mitigation inventions portion of the diffusion of environment-related inventions by domain indicator. This measures the number of climate change mitigation inventions deposited in a jurisdiction expressed as a percentage of total environment-related inventions deposited in the same jurisdiction. To maintain a focus on clean energy inventions to the greatest extent possible, climate change mitigation technologies related to wastewater treatment and waste management are not included. The first diffusion indicator is multiplied by the second diffusion indicator to generate the level indicator score for the most recent year data is available during the most recent three-year period. The change indicator is measured as the 5-year CAGR for the five years prior. The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2018 and the change indicator is drawn from the 2013–2018 period. For the 2016 GEII, the level indicator is drawn from the year 2013 and the change indicator is drawn from the 2010–2013 period.

Indicator 6: Public Investments in Low-Carbon Energy Demonstrations

Data Sources:

- IEA RD&D Statistics database
- World Bank GDP database

Methodology: The indicator aims to assess the amount of public investment in low-carbon energy demonstrations as an indicator of national contributions to the resource mobilization, entrepreneurial experimentation, and market formation functions. The level indicator is measured as the total amount of public investments in low-carbon energy demonstrations per thousand units of GDP (2020 prices and PPP) for the most recent three-year period. The change indicator is measured as the 3-year CAGR from the total amount of public investments in the previous three-year period to the recent three-year period. The total score for the indicator is given by the sum of the level indicator multiplied by 0.80 and the change indicator multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the years 2018–2020 and the change indicator is drawn from the years 2015–2020 (change from 2015–2017 to 2018–2020). No data is available for Brazil, Chile, China, Czech Republic, Finland, Germany, Greece, Hungary, India, Italy, Japan, South Korea, Mexico, Poland, Portugal, Slovak Republic, Spain, and Turkey. For the 2016 GEII, the level indicator is drawn from the years 2013–2015 and the change indicator is drawn from the years 2010–2015 (change from 2010–2012 to 2013–2015). No data is available for Brazil, Chile, China, Czech Republic, Finland, Germany, Greece, Hungary, India, Italy, Japan, South Korea, Lithuania, Mexico, Poland, Portugal, Slovak Republic, and Turkey.

Indicator 7: Low-Carbon Energy Demonstration Projects

Data Sources:

- Global CCS Institute's CO2RE database
- Third Way Advanced Nuclear Reactor database
- Pillsbury Law's The Hydrogen Map database
- U.S. Department of Energy's Portal and Repository for Information on Marine Renewable Energy (PRIMRE) database
- U.S. Department of Energy's Global Energy Storage database

Methodology: The indicator aims to account for the number of low-carbon energy demonstration projects being carried in each country as an indicator of national contributions to the entrepreneurial experimentation and market formation functions. Since demonstration projects can last many years, the level indicator is measured as the total number of pilot and commercial-scale low-carbon energy demonstration project per trillion units of GDP during the most recent five-year period. The types of demonstration projects included in the count are CCS, advanced nuclear energy, hydrogen, energy storage, and advanced renewables. No change indicator is included in the score for this indicator. For the 2021 GEII, the level indicator was drawn from the years 2016–2020. The low-carbon energy demonstration projects indicator is not included in the 2016 GEII due to limitations in data availability for certain technology areas.

Indicator 8: Early-Stage Venture Capital Investments

Data Source:

- Cleantech Group i3 database

Methodology: The indicator aims to assess the health of the entrepreneurial ecosystem, the degree to which early-stage financial resources are being mobilized to fund clean energy start-ups, and the ability of a country to create new clean energy start-ups the private sector deems as worthy of investment as an indicator of national contributions to the resource mobilization, entrepreneurial experimentation, and market formation functions. The level indicator is measured as the total amount of venture capital invested in a country's domestic clean energy start-ups per thousand units of GDP during the most recent three-year period. The change indicator is measured as the change in three-year totals measured as the 3-year CAGR from the previous three-year period to the recent three-year period. The total score is given by the sum of the level indicator multiplied by 0.80 and the change indicator multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the years 2018–2020 and the change indicator is drawn from the years 2015–2020 (change from 2015–2017 to 2018–2020). For the 2016 GEII, no data is available for the years prior to 2015. The level indicator is therefore drawn from the year 2015 only and no change indicator is used.

Indicator 9: High-Impact Clean Energy Companies

Data Sources:

- Cleantech Group Global Cleantech 100 List
- Cleantech Group 50 To Watch List
- Cleantech Group Ones To Watch List
- Cleantech Group APAC 25 List
- Cleantech Group Awards List

Methodology: The indicator aims to capture the health of the entrepreneurial ecosystem and the ability of nations to create high-potential clean energy start-up companies as an indicator of national contributions to the resource mobilization, entrepreneurial experimentation, and market formation functions. The level indicator is measured as the total number of domestic clean energy start-up companies that are honored in the Cleantech Group's various lists and awards per trillion units of GDP during the most recent three-year period. The change indicator is measured as the change in three-year totals, measured as the 3-year CAGR from the previous three-year period to the most recent three-year period. The total score is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the years 2018–2020 and the change indicator is drawn from the years 2015–2020 (change from 2015–2017 to 2018–2020). For the 2016 GEII, the level indicator is drawn from the years 2013–2015 and the change indicator is drawn from the years 2010–2015 (change from 2010–2012 to 2013–2015).

Indicator 10: Successful Clean Energy Company Exits

Data Source:

- Cleantech Group i3 database

Methodology: The indicator aims to capture the health of the entrepreneurial ecosystem and the ability of nations to create clean energy start-ups that are capable of successfully exiting as an indicator of national contributions to the resource mobilization, entrepreneurial experimentation, and market formation functions. The level indicator is measured as the total number of clean energy start-ups in a country that successfully exited from venture capital investment, either through a private equity buyout, merger or acquisition, or IPO, per trillion units of GDP during the most recent three-year period. The change indicator is measured as the change in three-year totals measured as the 3-year CAGR from the previous three-year period to the most recent three-year period. The total score is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the years 2018–2020 and the change indicator is drawn from the years 2015–2020 (change from 2015–2017 to 2018–2020). No data is available for Austria, Chile, Czech Republic, Estonia, Greece, Hungary, New Zealand, Slovak Republic, and Turkey. For the 2016 GEII, no data is available for the years prior to 2015. The level indicator is therefore drawn from the year 2015 only and no change indicator is used. No data is available for Austria, Chile, Czech Republic, Estonia, Greece, Hungary, New Zealand, Slovak Republic, and Turkey.

Indicator 11: Clean Energy Technology Exports

Data Source:

- United Nations Comtrade database

Methodology: This indicator aims to capture the relative size and competitiveness of a nation's domestic clean energy industries as an indicator of national contributions to the entrepreneurial experimentation and market formation functions. The indicator also serves an indicator of a nation's innovative and competitive capabilities, as well as a proxy indicator for private investment in clean energy R&D. Data for clean energy technology exports was gathered from the UN Comtrade database using Harmonized System (HS) Codes to the six-digit level. The method of data extraction was drawn from a European Commission report titled *Trade as a Measure of Innovation Performance*, which presents a set of HS codes that could be used to identify and extract data for a broad range of clean energy technologies.[14] The level indicator is measured as the total value in USD (2020 prices) of clean energy technology exports per unit of GDP (export propensity) for the most recent year data is available. The change indicator is measured as the 5-year CAGR over the previous five-year period. The total score is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2020 and the change indicator is drawn from the years 2015–2020. For the 2016 GEII, the level indicator is drawn from the year 2015. Data was not collected for the years prior to 2015 and so no change indicator is included.

Indicator 12: Energy Efficiency

Data Source:

- IEA Energy Efficiency Indicators database

Methodology: The indicator aims to assess the relative readiness of national markets to adopt new innovative energy efficiency technologies as an indicator of national contributions to the market formation function. IEA's Energy Efficiency Indicators database measures the energy intensity (EI) of the residential, services, industrial, and transport sectors indexed to the year 2000 with a score of 100. Lower levels of EI signal more efficient energy use. The indicator measures EI in the residential sector as per capita EI, services sector as per value-added EI (MJ/GDP PPP 2015), industrial sector as per value-added EI (MJ/GDP PPP 2015), and transport sector as the average of per passenger vehicle-kilometers EI for cars and light trucks and per ton vehicle-kilometers EI for freight trucks. The change in EI of each sector in the IEA database was inverted so that a one-point decrease in the EI was counted as a one-point increase and vice versa. This method allows improvements in energy efficiency to be counted as positive scores. Each measure is multiplied by the respective percentages of total energy consumption (PJ/GDP PPP 2015) each sector accounts for to generate an EI score for each sector. All four scores are then averaged to generate a total economy-wide EI score for each year. The level indicator is measured as the economy-wide EI score for the most recent year data is available. The change indicator aims to capture the rate of change in energy efficiency and is measured as the 4 to 5-year CAGR for the previous four-to-five-year period. While the level indicator credits countries with more efficient energy use as contributing to innovation through market readiness, we put a heavier weight on the change indicator than is typically done in the GEII in order to credit countries with higher rates of turnover, indicating more rapid adoption of new technology adoption. The total score for the indicator is therefore given by the sum of the level indicator score multiplied by 0.60 and the change indicator score multiplied by 0.40. For the 2021 GEII, the level indicator is drawn from the year 2019 and the change indicator is measured as the 4-year CAGR for the years 2015–2019. No data is available for China, Estonia, India, and Norway. For the 2016 GEII, the level indicator is drawn from the year 2014 and the change indicator is measured as the 5-year CAGR for the years 2010–2014. No data is available for China, Estonia, India, and Norway.

Indicator 13: Clean Energy Consumption

Data Source:

- BP Statical Review of World Energy database

Methodology: The indicator aims to assess the relative readiness of national markets to adopt innovative clean energy technologies as an indicator of national contributions to the market formation function. The level indicator is measured as the total amount of economy-wide clean energy consumption (consisting of the sum of nuclear, hydro, and renewable energy consumption) as a percentage of total energy consumption measured in million tons of oil equivalents for the most recent year data is available. The change indicator is measured as the 5-year CAGR for the previous five years. The indicator aims to credit countries with much higher levels of clean energy consumption as a signal of general market readiness, while putting more weight on the change indicator than is typically done in the index to credit countries with higher rates of turnover, indicating more rapid adoption of new technology. The total score for the indicator is therefore given by the sum of the level indicator score multiplied by 0.50 and the change indicator score multiplied by 0.50. For the 2021 GEII, the level indicator is drawn from the year 2020 and the change indicator is drawn from the years 2015–2020. No data is available for Denmark, Estonia, Ireland, Lithuania, and the Slovak Republic. For the 2016 GEII, the level indicator is drawn from the year 2015 and the change indicator is drawn from the years 2010–2015. No data is available for Denmark, Estonia, Ireland, Lithuania, and the Slovak Republic.

Indicator 14: National Commitments to the Global Climate Action Agenda

Data Source:

- Climate Analytics and NewClimate Institute's CAT and Climate Target Update Tracker (CTUT)

Methodology: The indicator aims to capture the stringency and commitment to upholding national contributions to the global climate action goals set out in the Paris Agreement as an indicator of the social legitimation of clean energy innovation and the clean energy transition. The indicator is measured using the CAT, which rates nations' NDCs to the Paris Agreement, 2020 pledges, and long-term targets against whether they are consistent with a country's "fair share" effort to the Paris Agreement's 1.5°C temperature goal. Countries falling in the Critically Insufficient, Highly Insufficient, Insufficient, 2 Degrees Celsius Compatible, 1.5 Degrees Celsius Compatible, and Role Model categories are scored on an ordinal scale of 0, 1, 2, 3, 4, and 5, respectively. Prior to 2017, the CAT used a different scoring system that categorized countries as Inadequate, Medium, Sufficient, and Role Model. To more accurately account for change in the change indicator, the CAT's old scoring system is roughly accounted for by scoring countries falling in each of the four categories in the prior scheme on an ordinal scale of 1.5, 2.5, 3, and 4.5, respectively, for the years prior to 2017. The level indicator is measured as the CAT score for the most recent year data is available. The change indicator is measured as the 5-year CAGR over the previous five years. Both the level and the change indicators also incorporate the CTUT, which tracks the status of the NDC update process during the years in which the Paris Agreement's ambition mechanism aims to "ratchet up" national ambitions and encourage submission of more stringent NDC targets. Countries falling in the Will Not Propose a More Ambitious Target, Did Not Increase Ambition, Proposed a Stronger NDC Target, and Submitted a Stronger NDC Target categories are scored on an ordinal scale of 0, 0, 0.25, and 0.50, respectively. The CTUT score is added to the 2020 score and is therefore accounted for in both the level and change indicators. The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the years 2020-2021 and the change indicator is drawn from the years 2016-2021. For the 2016 GEII, the level indicator is drawn from the year 2015 and the change indicator is drawn from the years 2011-2015.

Indicator 15: National Commitments to a Domestic Clean Energy Innovation Agenda

Data Sources:

- IEA's Energy Technology RD&D Statistics database
- Mission Innovation Country Highlights (2016–2021)

Methodology: This indicator aims to measure the degree to which nations are prioritizing clean energy technologies over fossil-fuel-based technologies in their energy RD&D investments as an indicator of the social legitimation of clean energy innovation. The level indicator is measured as the ratio of public investments in low-carbon energy RD&D to public investments in non-low-carbon energy RD&D in the most recent year data is available during the most recent three-year period. The change indicator is measured as the 5-year CAGR over the previous five-year period. To account for the fact that many countries have nearly reached the 100 percent clean energy RD&D limit and therefore have little room left for additional change in the direction of higher low-carbon to non-low-carbon ratios, the change indicator is given less weight than typically used throughout the index. The total score for the indicator is therefore given by the sum of the level indicator multiplied by 0.90 and the change indicator multiplied by 0.10, In the 2021 GEII, the level indicator is drawn from the years 2018–2020 and the change indicator is drawn from the years 2015–2020. No data is available for Chile, China, Greece, and India. In the 2016 GEII, the level indicator is drawn from 2015 and the change indicator is drawn from the years 2010–2015. No data is available for Chile, China, Greece, and India. No data is available for the change indicator for Lithuania.

Indicator 16: Standards and Regulations Supporting the Clean Energy Transition

Data Source:

- World Bank RISE database

Methodology: This indicator aims to assess the stringency of national policies and regulatory frameworks put in place to support the transition toward clean and sustainable forms of energy as an indicator of the social legitimation of clean energy innovation and the clean energy transition. The World Bank's RISE database uses a wide range of indicators that generate scores on a 0–100 scale and is organized around the following three pillars of sustainable energy: Energy Access, Energy Efficiency, and Renewable Energy. The indicator uses only the RISE Energy Efficiency and Renewable Energy scores. The level indicator is measured as the RISE scores for the most recent year data is available. The change indicator is measured as the 5-year CAGR over the previous five years. The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2019 and the change indicator is drawn from the years 2014–2019. No data is available for Estonia and Lithuania. For the 2016 GEII, the level indicator is drawn from the year 2014 and the change indicator is measured as the 4-year CAGR for the years 2010–2014. No data is available for Estonia and Lithuania.

Indicator 17: Effective Carbon Rates

Data Source:

- OECD Effective Carbon Rates (ECRs) database.

Methodology: This indicator aims to measure a nation's effective carbon rates as an indicator of the social legitimation of clean energy innovation and the clean energy transition. The indicator is measured using scores from the OECD Effective Carbon Rates (ECRs) database. This database provides an "effective carbon pricing score" that assesses how close countries are to pricing energy-related carbon emissions at current and forward-looking benchmark values for carbon costs. ECRs consist of three components that contribute to the overall carbon price: fuel excise taxes, carbon taxes, and tradeable emission permit prices. The database assesses carbon prices on three-year cycles covering the years 2012–2014, 2015–2017, and 2018–2020. The level indicator is measured as the ECRs score for the most recent year data is available. The change indicator aligns with the availability of the data and is therefore measured as the 3-year CAGR over the previous three years. The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2018 and the change indicator is drawn from the years 2015–2018. For the 2016 GEII, the level indicator is drawn from the year 2015 and the change indicator is drawn from the years 2012–2015.

Indicator 18: International Collaboration in Public Clean Energy RD&D Funding

Data Sources:

- Mission Innovation website[15]
- Mission Innovation Country Highlights (2017–2021)
- IEA Research Cooperation website[16]
- IEA Technology Collaboration Brochure (2019)

Methodology: This indicator aims to measure the quantity of international collaborations in clean energy RD&D funding as an indicator of the social legitimation of clean energy innovation and the importance of international collaboration. The indicator is measured by counts of membership, leadership, and participation in international clean energy RD&D collaborations, including Mission Innovation and its Innovation Challenges, Missions, Platforms, and Sub-Groups; IEA and its Research Cooperation and Technology Collaboration Programmes; and other bilateral and multilateral international energy RD&D collaborations countries have formed and engaged in. To account for variance in the size of international collaborations, the number of collaborators involved in each collaboration is counted. To put MI and IEA membership on par in terms of significance, the count of MI members is multiplied by two; and to account for different levels of membership, the membership counts for MI Observer Countries and IEA Association Countries are multiplied by 0.50. To account for the added significance of leading MI and IEA initiatives and programs, the counts for each are multiplied by three. The total counts of membership, leadership, and participation in international collaborations are summed for each year. The level indicator is measured as the total international collaboration counts for the most recent year data is available. The change indicator is measured as the 5-year CAGR over the previous five years. The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2020 and the change indicator is drawn from the years 2015–2020. For the 2016 GEII, the level indicator is drawn from the year 2015. No data was collected for the years prior to 2015 and therefore no change indicator is included in the score.

Indicator 19: International Collaboration in Knowledge Development (Copublications)

Data Source:

- Simon Provencal, Paul Khayat, and David Campbell, *Publications as a Measure of Innovation Performance*, European Commission, Directorate General for Research and Innovation, January 2021

Methodology: This indicator aims to capture the relative strength of a nation's international knowledge development networks and engagement with international partners in the development of new knowledge as an indicator of the social legitimation of clean energy innovation and the importance of international collaboration. The indicator is measured as the share of international clean energy research copublications. It is calculated based on the number of international clean energy research copublications as a proportion of the total number of publications in clean energy research. The score is normalized according to the world weighted average. The level indicator is measured as the share of international copublications score for the most recent year data is available. The change indicator is measured as the 4-year CAGR over the previous five years. The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2019 and the change indicator is drawn from the years 2015–2019. No data is available for New Zealand, Switzerland, and Turkey. For the 2016 GEII:, the level indicator is drawn from the year 2015. No data is available for the years prior to 2015 and so no change indicator is used. No data is available for New Zealand, Switzerland, and Turkey.

Indicator 20: International Collaboration in Technology Development (Coinventions)

Data Sources:

- OECD database of patent applications in climate change mitigation technologies
- World Bank GDP database

Methodology: This indicator aims to capture the relative strength of a nation's international technology development networks and degree of engagement in international collaboration in the development of new technologies as an indicator of the social legitimation of clean energy innovation and the importance of international collaboration. The indicator is measured by the share of climate change mitigation coinventions (simple patent families) developed jointly with foreign inventors in the total number of domestic climate change mitigation coinventions (in other words, the ratio of coinventions developed jointly with foreign inventors to coinventions developed jointly with other domestic coinventors.) The OECD database does not allow for subgroups of climate change mitigation technologies to be subtracted from the total for this indicator so climate change mitigation technologies related to both agriculture, livestock, and agroalimentary industries and wastewater treatment and waste management are included in the score. The level indicator is measured as the rate of international collaboration in technology development for the most recent year data is available during the most recent three-year period. The change indicator is measured as the 5-year CAGR for the prior five-year period. The total score for the indicator is given by the sum of the level indicator score multiplied by 0.80 and the change indicator score multiplied by 0.20. For the 2021 GEII, the level indicator is drawn from the year 2018 and the change indicator is drawn from the years 2013–2018. For the 2016 GEII, the level indicator is drawn from the year 2013 and the change indicator is measured as the 3-year CAGR for the years 2010–2013.

Measuring the Contributions of the European Union (EU)

Methodology: The GEII includes collected data on 19 current EU member countries, the United Kingdom, and the European Commission. We also collected data on the eight current EU member countries not included in the index (Luxembourg, Latvia, Slovenia, Bulgaria, Croatia, Romania, Cyprus, and Malta) as well as six current EU candidate countries (Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia, and Serbia). The data was too sparse to include any of these 14 countries in the Index. However, where available, data from all current EU members was included in the EU aggregate measures. Because many of the indicators used in the GEII use data from before the United Kingdom left the EU, we include its data in the EU aggregate measures.

APPENDIX 2: 2016 GEII BASELINE EDITION

Table 8: The 2016 GEII Rankings

2016 Rank	Country	Overall Score	KD&D Rank	EE&MF Rank	SL&IC Rank
1	Finland	16.47	1	1	13
2	Denmark	14.47	3	7	3
3	Sweden	13.65	7	6	16
4	United States	13.33	6	4	22
5	Netherlands	13.26	14	5	5
6	France	13.25	10	9	11
7	Portugal	13.10	2	17	4
8	Switzerland	12.97	19	2	8
9	United Kingdom	12.96	16	8	1
10	Belgium	12.91	9	13	6
11	Germany	12.89	11	12	12
12	Austria	12.51	13	10	9
13	Canada	11.97	15	3	27
14	Ireland	11.35	18	16	2
15	Poland	11.29	12	11	25
16	Italy	10.47	17	18	14
17	Australia	10.10	21	14	19
18	Czech Republic	10.09	22	15	18
19	Japan	10.04	4	22	30
20	Estonia	9.94	8	25	23
21	Spain	9.69	20	21	10
22	South Korea	9.44	5	26	28
23	Norway	9.27	23	23	7
24	Slovak Republic	8.23	29	19	17
25	Hungary	8.14	28	20	15
26	Brazil	6.52	25	27	31
27	Mexico	6.47	27	28	24
28	New Zealand	5.50	31	24	29
29	Chile	5.19	26	30	33
30	China	4.90	24	33	32
31	Greece	4.65	30	31	20
32	Turkey	3.83	32	34	21
33	India	3.53	33	32	26
34	Lithuania	3.50	34	29	34

Table 9: Indicators and Weights in the 2016 GEII

Subindices, Categories, and Indicators	Subindex Weight	Category Weight	Indicator Weight (Category)	Indicator Weight (Overall)
Knowledge Development and Diffusion	**40%**			
Public Investments in Low-Carbon Energy R&D		50%	100%	20.0%
Knowledge Generation		25%		
• Number of Publications			30%	3.0%
• Share of Highly Cited Publications			70%	7.0%
Invention		25%		
• Development and Diffusion			75%	7.5%
• Attraction and Absorption			25%	2.5%
Entrepreneurial Experimentation and Market Formation	**40%**			
Demonstration		10%		
• Public Investment			100%	4.0%
Entrepreneurial Ecosystem		30%		
• Early-Stage Venture Capital Investments			33%	4.0%
• Number of High-Impact Start-Ups			33%	4.0%
• Number of Successful Company Exits			33%	4.0%
Industry and International Trade (Exports)		30%	100%	12.0%
Market Readiness & Technology Adoption		30%		
• Energy Efficiency			50%	6.0%
• Clean Energy Consumption			50%	6.0%
Social Legitimation and International Collaboration	**20%**			
National Commitments		40%		
• Global Climate Action Agenda			50%	4.0%
• Domestic Clean Energy Innovation Agenda			50%	4.0%
National Public Policies		40%		
• Standards and Regulations			50%	4.0%
• Effective Carbon Rates (ECRs)			50%	4.0%
International Collaboration		20%		
• Public RD&D Funding			40%	1.6%
• Knowledge Development (Copublications)			30%	1.2%
• Technology Development (Coinventions)			30%	1.2%

Table 10: Data Coverage Scores for 2016 GEII

Country	GEI Composite Index (Overall)	KD&D Subindex (40% Max)	EE&MF Subindex (40% Max)	SL&IC Subindex (20% Max)
Australia	100%	40%	40%	20%
Austria	96%	40%	36%	20%
Belgium	100%	40%	40%	20%
Brazil	96%	40%	36%	20%
Canada	100%	40%	40%	20%
Chile	84%	36%	32%	16%
China	82%	36%	30%	16%
Czech Republic	92%	40%	32%	20%
Denmark	94%	40%	34%	20%
Estonia	80%	40%	24%	16%
Finland	96%	40%	36%	20%
France	100%	40%	40%	20%
Germany	96%	40%	36%	20%
Greece	68%	20%	32%	16%
Hungary	92%	40%	32%	20%
India	66%	20%	30%	16%
Ireland	94%	40%	34%	20%
Italy	100%	40%	40%	20%
Japan	96%	40%	36%	20%
South Korea	96%	40%	36%	20%
Lithuania	62%	20%	30%	12%
Mexico	92%	40%	32%	20%
Netherlands	100%	40%	40%	20%
New Zealand	85%	30%	36%	19%
Norway	94%	40%	34%	20%
Poland	96%	40%	36%	20%
Portugal	96%	40%	36%	20%
Slovak Republic	86%	40%	26%	20%
Spain	100%	40%	40%	20%
Sweden	100%	40%	40%	20%
Switzerland	88.80%	30%	40%	18.80%
Turkey	77%	26%	32%	19%
United Kingdom	100%	40%	40%	20%
United States	100%	40%	40%	20%

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