CHAPTER 5

TECHNOLOGY-SPECIFIC ANALYSIS OF ENERGY INNOVATION SYSTEMS

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The Global Innovation Index (GII) compiles and analyses quantitative metrics of innovation performance at the country level. The standardization and generalizability of the GII's metrics allow for cross-country comparisons on a like-for-like basis. The GII's metrics capture a wide range of institutional, human, infrastructural, market, and business factors that influence the efficiency with which countries convert innovation inputs into outputs. Put differently, the GII recognizes the importance of analysing 'innovation systems'. The GII's conceptual framework casts a wide net over many different elements of the innovation system, far beyond conventional measures such as research and development (R&D) expenditure and patents. As a result, 'great emphasis is placed on the climate and infrastructure for innovation and on assessing related outcomes'.[1]

Technology-specific analysis as a complement to the GII

This chapter shares the GII's foundational insight that standardized metrics of innovation systems are essential for comparative assessments of innovation performance. But whereas the GII is concerned with country-level assessments and cross-country comparisons, the approach set out here is designed for technology-specific assessments and cross-technology comparisons. This is complementary to the GII by drilling down from the broad 'climate and infrastructure for innovation' at the national level to the innovation system processes relevant and necessary for supporting specific energy technologies.[2] This in turn allows energy innovation portfolios comprising multiple technologies to be assessed, both within and across countries.

Energy innovation portfolios

There are no silver bullet solutions to the challenges facing the global energy system: mitigating climate change, providing universal access to modern energy services, and ensuring a secure and clean energy supply.[3] Instead, a 'silver buckshot' strategy is required to diffuse a wide range of affordable, low-carbon innovations throughout the energy supply and the many different energy-using sectors, from industry to transport and buildings. A portfolio approach to energy innovation recognizes specific challenges and needs in different parts of the energy system.[4]

Future uncertainties about the cost, performance, system integration, and acceptability of specific energy technologies are unavoidable. A portfolio approach to energy innovation helps diversify and manage risk: risk that one technology may fail to live up to expectations; risk that another technology may prove unpopular with potential users; and risk that a third technology may rely on changes to markets, regulations, or infrastructures that themselves prove difficult to implement.

A portfolio approach to energy innovation also raises important questions about how portfolios should be designed to deliver on desired outcomes. For example:

- How much effort should an innovation portfolio invest in supporting specific innovation processes?
- How much weight should an innovation portfolio place on specific energy technologies?

Addressing these questions requires new approaches that can analyse innovation systems for specific technologies, while retaining the generalizability to compare across technologies at the portfolio level.

This chapter sets out one such approach using the novel framework of the energy technology innovation system (ETIS) from which a standardized set of quantitative indicators applicable to specific technologies can be derived. The value of these technology-specific indicators is then demonstrated through two illustrative applications.

First, the full set of ETIS indicators is applied to examine *consistency* between innovation system processes in the European Union (EU)'s current energy innovation portfolio. The analysis reveals how certain energy technologies benefit from stronger support in some areas but much weaker support in others. This alerts innovation portfolio managers to areas of potential concern or tension within the innovation system.

Second, a reduced set of ETIS indicators is applied to consider *alignment* between global energy innovation efforts and public policy goals such as mitigating climate change. The analysis reveals a striking asymmetry between innovation inputs, which strongly emphasize energy-supply technologies, and desirable outcomes and objectives, which strongly emphasize end-use technologies. This signals a need to increase the relative share of end-use technologies in directed innovation efforts globally to address climate change.

The ETIS framework

A systemic approach to innovation is a strong predictor of successful innovation outcomes. This was the central finding of a recent synthesis of 20 historical case studies of energy innovation, ranging from wind power in Denmark and ethanol in Brazil to energy-efficient appliances in Japan and electric vehicles in China.[5] In cases where directed innovation efforts consistently strengthened a wide range of innovation system processes, new energy technologies were more likely to deploy faster, more pervasively, or with fewer adverse consequences. In cases where directed innovation efforts focused on particular innovation stages (such as R&D) or on a narrow set of innovation processes (such as scaling up production), new energy technologies were more likely to lose public policy support, fall into the valley of death between lab and market, or hit other roadblocks on the way to commercial success.

The insights from these case studies were distilled and synthesized into a framework describing the ETIS.[6] This framework identifies the necessary processes throughout the innovation system that help support successful innovation outcomes.

At the centre of the ETIS framework is a simple staged model of the technology life cycle, which runs iteratively from R&D through demonstration and market formation to deployment, diffusion, and eventual saturation and phase-out.

The ETIS framework places this life cycle within an innovation system comprising:

- processes through which *knowledge* is generated, codified, learned, shared internationally, spilled over, or potentially lost through depreciation;
- processes through which financial, human, and policy *resources* are mobilized to enable and support innovation, with a particular emphasis on public policy instruments;
- processes through which *actors and institutions* interact, exchange, network, and collaborate; and
- processes through which the *adoption and use* of technologies in market environments provide feedback and help shape innovators' expectations of future returns on investments.

Energy technologies have markedly different characteristics, maturities, and adoption environments. The ETIS framework can be applied to specific technologies to identify key processes important for innovation systems to function effectively. But, because these processes are generalizable, the ETIS framework also allows for comparative analysis across technologies in different national contexts or at different stages of the technology life cycle.[7]

Indicators for measuring the ETIS framework

Standardized indicators are needed for comparative analysis, as the GII demonstrates at the country level. Using indicators enables a wide range of 'non-observable', intangible, or tacit innovation system processes to be measured and analysed.[8] These processes extend beyond the 'usual suspects' of investments, patents, and publications for which large datasets are readily available. Directed innovation efforts stimulate knowledge spillovers and flows, are guided by strategic roadmaps and collaborations, leverage private-sector resource flows, and are reinforced by users' experiences with technologies once they have been commercialized.[9] Indicators are needed to measure these processes and more. Using quantitative metrics for each indicator opens up innovation systems analysis to transparent, replicable methods for assessing performance, effectiveness, and outcomes.

A wide range of quantitative indicators has been proposed for specific energy technologies.[10] However, few attempts have been made to apply a standardized set of indicators for comparative analyses of different energy technologies.

Table 1 shows all the indicators derived from the ETIS framework. Each indicator is designed to be applied to specific energy technologies, either individually or within an innovation portfolio. However, the indicators can also be measured at a more aggregated sectoral or country level. Table 1 therefore notes where there are conceptual linkages between the ETIS indicators and the GII indicators.

Table 1 also illustrates how the ETIS indicators can be measured, using the EU energy innovation system as an example. Data for some indicators are readily available from existing databases (e.g., the Web of Science for publications); others are collected using data-mining techniques (e.g., the International Energy Agency (IEA)'s Addressing Climate Change policy database); still others are compiled from a range of statistical sources (e.g., potential market sizes).

Using renewable energy to illustrate a technology area, the absolute value of each indicator with its corresponding metric is shown for the EU in 2015 (or 2012 for patents). The term 'technology area' is used to denote a group of related technologies serving a similar function in the energy system. Table 1 also includes a note on the availability of similar data in other countries or world regions.

To illustrate how the ETIS framework can be applied for comparative cross-technology analysis of innovation portfolios, Table 2 reports 2015 data for the top 10 EU countries on one selected indicator: public energy research, development, and demonstration (RD&D) expenditure. The data are shown for each of six technology areas: renewable energy, smart grids, energy efficiency, sustainable transport, carbon capture and storage (CCS), and nuclear power. These six technology areas are all integral to low-carbon transformation and cover both energy supply and energy end-use.

Standardized sets of key words defining each technology area ensure that its scope is consistent across different indicators. For example, 'renewable energy' is defined as comprising solar, wind, geothermal, wave, tidal, hydro, and bioenergy (excluding biofuels, which are allocated to sustainable transport). These are then mapped into search terms for querying the IEA RD&D expenditure database or for assigning pre-defined expenditure categories to the renewable energy technology area.

Analysing consistency and alignment in energy innovation portfolios

As noted above, a systemic perspective on energy innovation points to two important design criteria for innovation portfolios:

- **Consistency:** Are different parts of the innovation system working well together to support the full portfolio of energy technologies?
- **Alignment:** Is the technological emphasis of the portfolio clearly directed towards the desired outcomes?

Two examples show how the technology-specific indicators derived from the ETIS framework allow these criteria to be assessed. The first example applies the full set of ETIS indicators shown in Table 1 to six technology areas in the EU and illustrates the importance of consistency in innovation portfolios. The second example applies a subset of ETIS indicators to two much broader technology areas globally to illustrate the importance of alignment. Each is discussed in turn below.

Table 1: Technology-specific indicators of innovation system processes

Innovation system processes in the ETIS framework	Technology-specific indicators (illustrated for the EU)	Absolute values for renewable energy in the EU in 2015 (with units)	Data availability	Main data source	Similar indicators in the GII 2017 conceptual framework (GII Annex 1)
KNOWLEDGE					
Generation	Public energy RD&D expenditure	880 (euros, millions)	Country*	1	2.3.2 Gross expenditure on R&D
	Demonstration budgets	91 (euros, millions)	Country*	1	None
Codification	Scientific publications	16,030 (number of articles)	Country	2	6.1.4 Scientific & technical articles
	Citation-weighted publication counts	123,372 (number of articles)	Country	2	6.1.5 Citable documents H index
	Patents ^	2,422 (number of patents)	Country	3	6.1.2 PCT patent applications
	Citation-weighted patent counts ^	1,414 (number of patents)	Country	3	5.2.5 Patent families filed in 2+ offices
Spillover	Energy technology imports	12,810 (euros, millions)	Country	4	5.3.2 High-tech imports less re-imports
International Flows	Publication co-authorships between EU and non-EU actors	598 (number of co-authorships)	Country	2	5.2.2 State of cluster development
	Patent co-inventions between EU and non-EU actors ^	1,088 (number of co-inventions)	Country	3	5.2.2 State of cluster development
Learning	Learning-by-doing	17 (% learning rate)	Global†	5	None
Depreciation	Volatility in energy RD&D expenditure	7.1 (coefficient of variation)	Country*	1	None
RESOURCES					
Mobilisation of Finances	Public energy RD&D expenditure (as % of GDP)	0.006 (percent)	Country*	1	2.3.2 Gross expenditure on R&D, % GDP
Mobilisation of Innovators	Patent activity (as % of total patents) ^	0.54 (percent)	Country	3	None
Policy Density†††	Policy instruments: innovation, regulatory, market-based	145 (number of instruments)	Country*	6	None
Policy Durability†††	Policy instruments: innovation, regulatory, market-based	13.05 (cumulative number of instruments, average)	Country*	6	1.1.2 Government effectiveness
Policy Mix	Diversity of policy instruments	0.98 (Shannon index)	Country*	6	None
Policy Stability	Stability of policy instruments	0.03 (cumulative years of all instruments adjusted by revisions, average)	Country*	6	1.2.1 Regulatory quality
Legacy of Failure	Decline in interest following failures	3,390 (exponent of decline function fitted to Google search frequency)	Global†	7	None
Regulatory Capture	Public RD&D expenditure on fossil fuels	164 (euros, millions)	Country*	1	None

(Continued)

Consistency in the EU's energy innovation portfolio

The EU's Strategic Energy Technology (SET) Plan identifies six priority areas for energy innovation: renewable energy, smart grids, energy efficiency (in buildings and industry), sustainable transport (including electric vehicles), CCS, and nuclear power (emphasizing safety).[11] In each of these technology areas, the SET Plan provides strategic planning

Table 1: Technology-specific indicators of innovation system processes *(continued)*

Innovation system processes in the ETIS framework	Technology-specific indicators (illustrated for the EU)	Absolute values for renewable energy in the EU in 2015 (with units)	Data availability	Main data source	Similar indicators in the GII 2017 conceptual framework (GII Annex 1)
ACTORS AND INSTITUTIONS					
Capacity	Top 100 Clean-tech funds	56 (euros, millions)	EU††	8	2.3.3 Global R&D firms. avg. exp. top 3
Heterogeneity	Diversity of types of organisation in European Energy Research Alliance	0.79 (Shannon index)	Country/EU	9	None
	Diversity of types of organisation in publication activity	1.46 (index constructed by authors)	Country	2	None
	Diversity of types of organisation in patenting activity ^	0.99 (index constructed by authors)	Country	3	None
Exchange & Interaction	European Energy Research Alliance activities involving different EU actors	26 (number of activities)	Country/EU	9	5.2.1 University/industry research collaboration
	Publication co-authorships between different EU actors	662 (number of co-authorships)	Country	2	5.2.1 University/industry research collaboration
	Patent co-inventions between different EU actors ^	396 (number of co-inventions)	Country	3	5.2.1 University/industry research collaboration
Shared Expectations	Policy instruments: targets, roadmaps, action plans	112 (number of instruments)	Country*	6	None
	Policy instruments: targets, roadmaps, action plans	1.77 (cumulative number of instruments, average)	Country*	6	None
ADOPTION AND USE					
Market Size	Potential market size (total number of physical units multiplied by cost per unit)	1,809,328 (euros, millions)	Country	5	None
Market Share	Actual market size as percentage of potential market size	34 (percent)	Country	5	

Main data sources: 1 IEA energy RD&D statistics, available at http://wds.iea.org/WDS/Common/Login/login.aspx; 2 Web of Science, available at https://login.webofknowledge.com/; 3 United States Patent and Trademark Office (USPTO) PatentsViews database, available at http://www.patentsview.org/web/; 4 Eurostat EU trade statistics, available at http://ec.europa.eu/eurostat/web/international-trade-in-goods/data/database; 5 Secondary data from peer-reviewed studies; 6 IEA Addressing Climate Change policy database, available at https://www.iea.org/policiesandmeasures/climatechange/; 7 Google Trends, available at https://trends.google.com/trends/?geo=; 8 Global Cleantech 100, available at https://www.cleantech.com/; 9 European Energy Research Alliance (EERA), available at https://www.eera-set.eu/.

Notes: A single GII indicator may map to more than one ETIS indicator, and vice versa. A 'learning rate' is the % reduction in cost per doubling of cumulative experience. The Shannon index is a common measure of diversity. Indicators, metrics, and absolute values in 2015 (or 2012 for patents) are illustrated for renewable energy in the EU (see text for details). ETIS = energy technology innovation system; IEA = International Energy Agency; OECD = Organisation for Economic Co-operation and Development.

^ Data are from 2012 because of truncation issues with more recent patent data.

* Data are readily available for IEA or OECD member countries but may not be available for developing economies.

† Data are not available for specific countries, but only on an aggregated basis at a regional or global level.

†† Data are specific to the EU (used here to illustrate how the ETIS framework indicators can be measured). Alternative data may be available for other regions.

††† This comprises three separate indicators per type of policy instrument: innovation, regulatory, and market-based.

and coordination of research and innovation activities within the EU.[12]

The ETIS indicators can be used to assess consistency in the SET Plan portfolio. 'Consistency' in this case means that a similar level of emphasis is placed on different innovation system processes within each technology area. This helps determine whether different parts of the innovation system are acting in concert to shape innovation outcomes. Consistency is therefore linked to careful

Table 2: Public energy RD&D expenditure in six technology areas for the top 10 countries in the EU ranked by total expenditure, 2015 euros, millions

Country	Renewable energy	Smart grid	Energy efficiency	Sustainable transport	Carbon capture & storage	Nuclear power	Total
Germany	211	102	66	40	7	226	652
France	101	55	45	148	21	76	446
United Kingdom	50	52	43	53	12	153	364
Netherlands	74	11	30	31	2	7	156
Finland	11	17	69	27	—	21	145
Belgium	12	8	30	7	2	77	136
Denmark	47	21	18	31	0	1	118
Austria	12	37	21	11	3	1	86
Spain	43	25	—	2	7	3	80
Sweden	15	22	18	22	0	1	78

Source: IEA energy RD&D statistics, available at http://wds.iea.org/WDS/Common/Login/login.aspx.
Notes: See text for details. RD&D = research, development, and demonstration; — = missing data.

coordination of directed innovation efforts. As the EU states: 'the mobilisation of public and private resources in a coordinated and targeted way . . . is and will continue to be at the SET Plan's centre'.[13]

Figure 1 shows the relative share of different innovation system processes across the six technology areas in the SET Plan portfolio. All the ETIS indicators shown in Table 1 are used to describe the innovation system processes relating to knowledge, resources, and actors and institutions.

Consistency in Figure 1 is shown by narrow variation within a technology area; inconsistency is shown by wide variation. Inconsistency means that, for any given technology, there is a strong emphasis on some innovation system processes but only a weak emphasis on others.

Taking the top panel of Figure 1 as an example, the relatively narrow variation for renewable energy and smart grids across all the knowledge-related indicators shows a consistent emphasis on different innovation system processes. Conversely, the relatively wide variation for sustainable transport shows a rather inconsistent emphasis on knowledge-related processes: some are strongly weighted in the SET Plan's innovation portfolio (e.g., publications); others have a disproportionately low share (e.g., amount and stability of R&D investments).

Overall, Figure 1 shows that the SET Plan's innovation portfolio is most clearly consistent in resources-related processes (including the durability and stability of public policy instruments), with a similar level of emphasis across the six technology areas. This implies that the level of financial, human, and policy resources being mobilized are working in concert to support innovation system functioning. Conversely, Figure 1 shows less consistency in the generation, codification, spillover, and international flows of knowledge in the sustainable transport and energy efficiency areas because they are weighted differently as innovation system processes within the SET Plan portfolio. This helps draws portfolio managers' attention to areas of possible tension or weakness where innovation efforts could be strengthened.

Alignment in global energy innovation portfolios

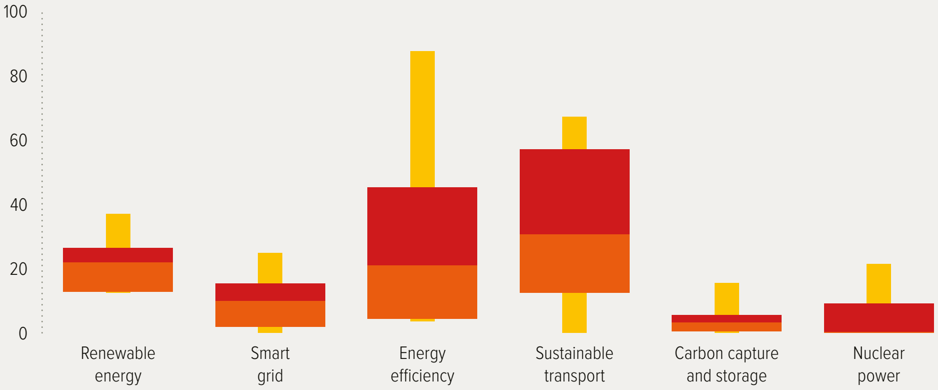
Mission Innovation is a commitment by 22 countries as well as the EU to double energy R&D investments over five years in order to 'accelerate a clean energy revolution'.[14] This increased investment is spread over diverse innovation challenges, ranging from carbon capture, biofuels, and solar energy to smart grids and heating and cooling in buildings. Like the EU's SET Plan, the Mission Innovation portfolio encompasses both energy-supply technologies and energy end-use technologies.

Besides Mission Innovation, there are many other important publicly supported initiatives for directing global energy innovation. A subset of the ETIS indicators adapted for global-scale analysis can be used to assess alignment between directed innovation efforts on the one hand (inputs), and public policy objectives on the other (desired outcomes).

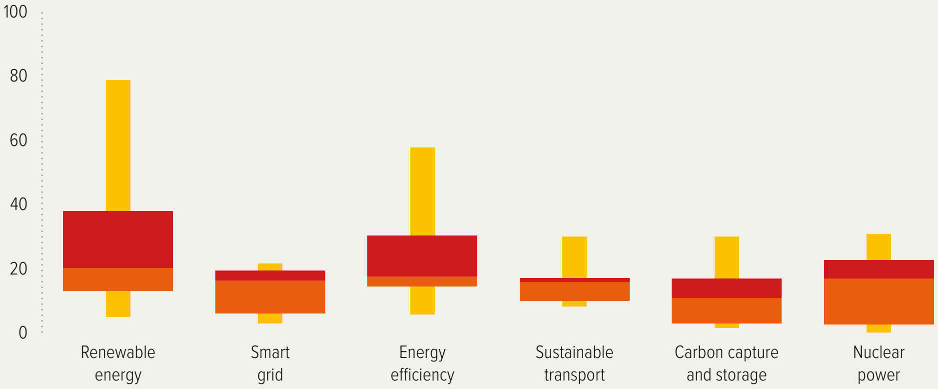
Figure 1.
Consistency of emphasis on innovation system processes in the six technology areas of the SET Plan

▲ Relative share within SET Plan portfolio

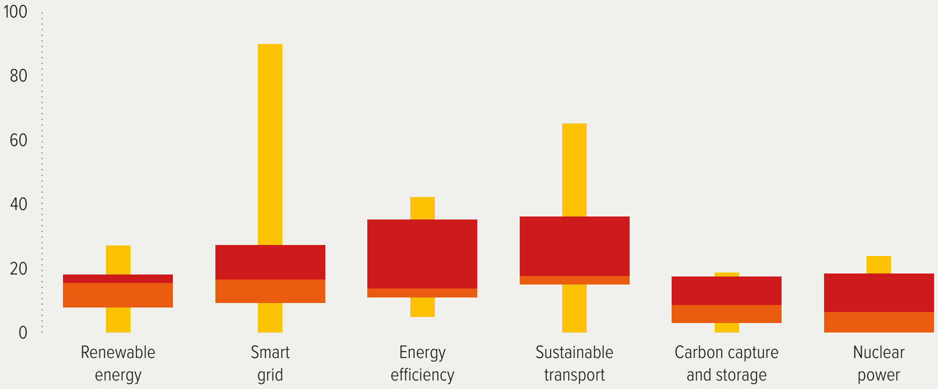
Variation in 11 knowledge-related indicators



Variation in 12 resources-related indicators



Variation in 9 actors and institutions-related indicators



Data source: Kim and Wilson, 2017.

Notes: Red and orange bars show interquartile ranges for all indicators related to *knowledge, resources,* and *actors and institutions.* Yellow bars show the minimum and maximum shares of innovation system processes within each type. For details of processes, indicators, and data sources, see Table 1. Indicators relating to adoption and use are not shown because of their small sample sizes.

Figure 2 summarizes the data for both input and outcome indicators characterizing a select set of global, regional, and national innovation efforts. For each indicator, the relative share (percent) of energy-supply technologies and energy end-use technologies is shown.

The input indicators describe both tangible and intangible contributions to the energy innovation system. They are similar to those shown in Table 1, but are more limited in scope in this example. Input indicators in the top panel of Figure 2 are summarized here:

- *modelling* studies of energy-system transformation for climate change mitigation;[15]
- scientific *research articles* related to energy technologies and system integration challenges;[16]
- technology *roadmaps* and international *collaborations* to strengthen shared expectations and knowledge exchange in key technology areas;[17]
- innovation funding programmes targeting high-risk high-gain *breakthrough projects* as well as more conventional *public R&D* expenditure on energy innovation;[18]
- private-sector *venture capital* leveraged by public funds into energy technologies.[19]

The desired outcomes describe broader sectoral or economy-wide impacts of energy innovation. Outcome indicators in the bottom panel of Figure 2 are summarized here:

- *capital investment* in energy technologies both in financial terms (in U.S. dollars) and in terms of *physical capacity* (in megawatts);[20]
- *cost reductions* as a result of learning-by-doing;[21]
- *economic returns* on innovation investments (e.g., increased economic productivity) as well as *social returns* (e.g., reduced pollution and greater energy security);[22]
- future *expected benefits* from innovation investments (in both economic and social terms);[23] and
- contribution to climate change *mitigation* (i.e., greenhouse gas emission reductions) at both global and national levels.[24]

Technology-specific data on each indicator were compiled from a wide range of sources. An example for each indicator is provided in the endnotes to the list above; full details on all the indicators, data, and sources are available in Wilson et al. (2012).

Figure 2 shows that the global energy innovation portfolio is misaligned. Whereas innovation inputs are strongly weighted towards energy-supply technologies, innovation outcomes that are in line with public policy objectives are dominated by energy end-use technologies. Energy end-use technologies make up a greater share of energy-system investments, leverage higher levels of private-sector activity, reduce more in costs as a result of market deployment, return larger social benefits, and offer greater potential for mitigating climate change.

Why do directed innovation efforts privilege energy-supply technologies? Several explanations are possible. End-use technologies are smaller in scale, larger in number, highly dispersed, and varied in form. This makes analysis harder, data less readily available, and innovation efforts less visible and tangible. End-use innovation also lacks the coherent political economic influence of the well-capitalized and long-established energy-supply industry.[25] The heterogeneous and distributed nature of end-use technologies also means there are greater perceived difficulties in scaling up deployment to make step-change reductions in emissions.[26]

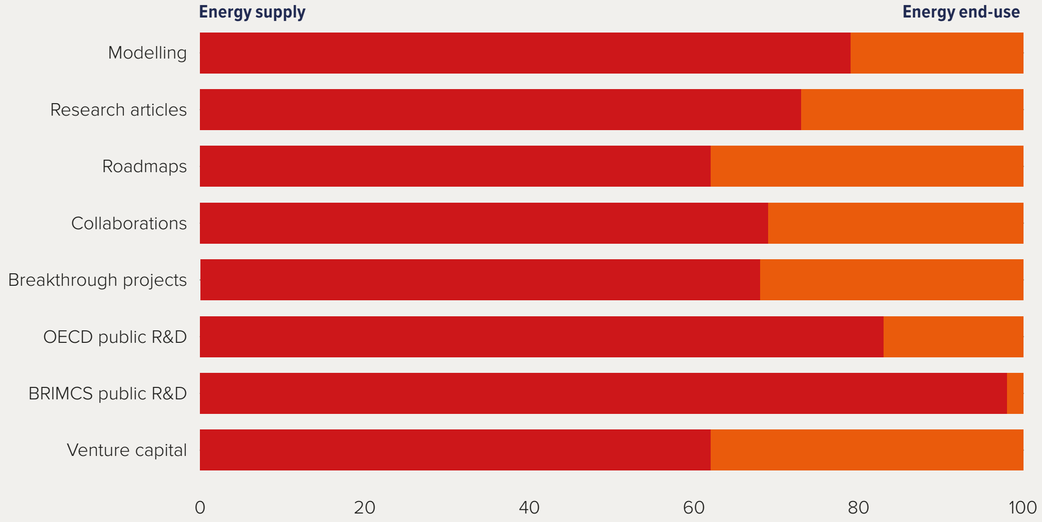
The indicators alone cannot establish which of these possible explanations of misalignment is correct. But the technology-specific analysis shown in Figure 2 helps draw policy makers' attention to potential weaknesses within directed energy innovation efforts globally.

This is one example of how the ETIS framework and its derived indicators can be used to assess alignment. A similar approach could be used to examine alignment between technology-push and market-pull drivers of innovation,[27] between near-term and long-term innovation outcomes,[28] and between breakthrough and incremental innovation efforts.[29]

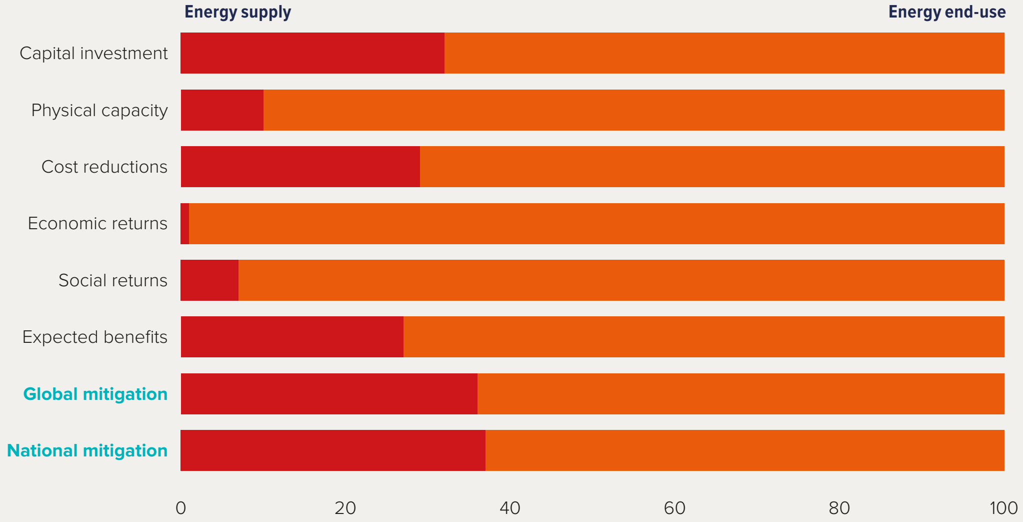
Figure 2.

Alignment of directed innovation efforts with outcomes and objectives for climate change mitigation: Energy-supply technologies vs energy end-use technologies

Innovation efforts (inputs)



Innovation outcomes and **objectives**



Source: Adapted from Wilson et al., 2012.

Notes: For details of indicators, data, and data sources, see Wilson et al., 2012. BRIMCS = Brazil, Russia, India, Mexico, China, South Africa; OECD = Organisation for Economic Co-operation and Development.

Conclusions

A systemic view of energy innovation captures the wider conditions that enable successful innovation outcomes. Actors, institutions, policies, finance, and markets all play important roles in energy innovation, so they all need to be measured, tracked, and analysed. The GII's conceptual framework sets out a diverse set of quantitative indicators applicable at the national level to enable cross-country analysis. The ETIS framework sets out a similarly diverse set of indicators applicable to specific energy technologies to enable cross-technology and portfolio-level analysis.

Two important design criteria for energy innovation portfolios at national, regional, and global scales are *consistency* and *alignment*.

A proportionately similar emphasis on related innovation system processes is an indication of consistency. This was illustrated in Figure 1 for the EU's current innovation portfolio across six technology areas ranging from renewable energy to sustainable transport. There is good evidence that different parts of the innovation system need to work in concert to deliver successful outcomes.[30] For example, technology-push and market-pull forces act together to shape innovators' expectations, stimulate innovation investments, and align technology development with users' needs.[31] Evidence of inconsistency in an energy innovation portfolio calls for a redirection of support towards weaker innovation system processes to ensure that the system as a whole works effectively.

Innovation system inputs that are directed, enabled, leveraged, or directly invested by public policy can also be tested for alignment. This was illustrated in Figure 2 for global energy innovation portfolios across two broad technology areas: energy supply and energy end-use. Technology-specific indicators help identify hidden biases within directed innovation efforts. Evidence of misalignment calls for a redirection of support towards technologies within the portfolio that can best deliver on public policy goals.[32]

The ETIS framework and its derived set of indicators are versatile in their applicability. Technology-specific analyses of energy innovation systems provide important insights for policy makers and portfolio managers directing innovation efforts towards a clean, efficient, low-carbon future energy system.

Notes

1 Cornell University et al., 2017, p. 47 (Annex 1).

2 The GII 2017 places a great deal of emphasis on the 'climate and infrastructure for innovation'; see Cornell University et al., 2017, p. 47, Annex 1.

3 Johansson et al., 2012.

4 Grubler and Riahi, 2010.

5 Grubler et al. 2012; Grubler and Wilson, 2014.

6 Gallagher et al., 2012.

7 Grubler et al., 2012; Grubler and Wilson, 2014.

8 Freeman and Soete, 2000.

9 Chan et al., 2017.

10 Borup et al., 2008; Borup et al., 2013; Hu et al., 2018; Klitkou et al., 2012; Miremadi et al., 2018; Truffer et al., 2012; Wilson, 2014.

11 EC, 2015; EC, 2017.

12 Carvalho, 2012.

13 EC, 2017, p. 86.

14 For further information about Mission Innovation, see http://mission-innovation.net.

15 For an example, see Edenhofer et al., 2010.

16 For an example, see D'Agostino et al., 2011.

17 For an example, see IEA, 2010.

18 For an example, see US DoE, 2011.

19 For an example, see UNEP et al., 2009.

20 For an example, see Wilson and Grubler, 2014.

21 For an example, see Grubler et al., 2012.

22 For an example, see NRC, 2001.

23 For an example, see NRC, 2007.

24 For an example, see Riahi et al., 2007.

25 Moe, 2010; Unruh, 2000.

26 Wilson et al., 2012.

27 Nemet, 2009.

28 Sandén and Azar, 2005.

29 Davis et al., 2013; Pacala and Socolow, 2004.

30 Gallagher et al., 2012.

31 Grubler et al., 2012; Nemet, 2009.

32 Grubler and Riahi, 2010.

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