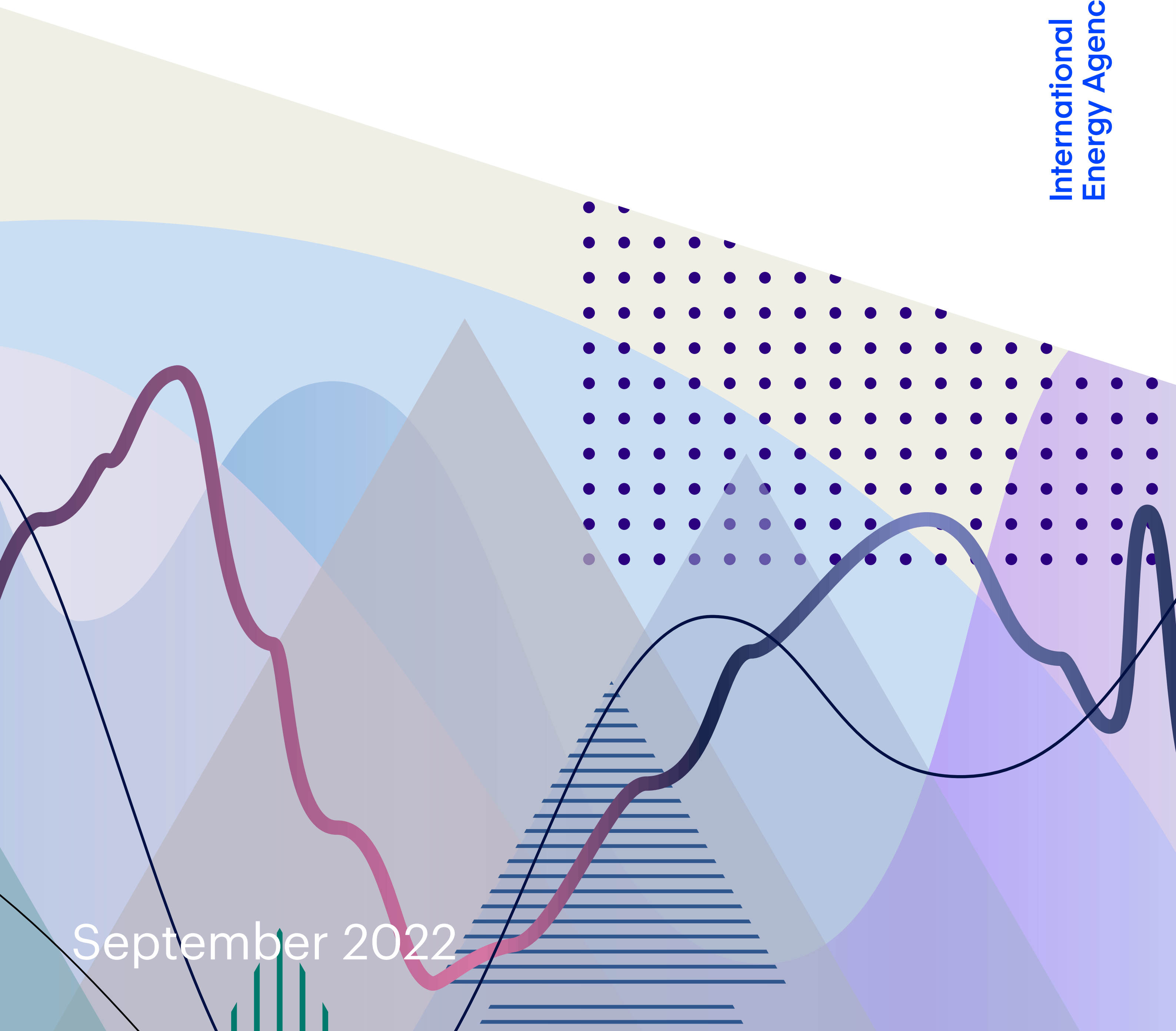
Tracking Clean Energy Innovation in the Business Sector: an Overview

International Energy Agency



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Abstract

Acceleration of clean energy innovation, supported by effective innovation policies, is critical for achieving net-zero emissions by 2050, and the technology development in the business sector will be to success. As their ambitions for technological change rise, governments are increasingly asking how they can measure the performance of their energy innovation systems, prioritise technologies and benchmark progress internationally. However, in most countries, information about private energy innovation is much less readily available and less reliable than that for the public sector. In addition, the available approaches to filling this gap have never before been compiled in a single place.

By presenting a wide variety of different approaches to tracking clean energy innovation in the business sector, this Overview demonstrates that governments and other analysts already have a range of practical options open to them. For example, the wealth of existing experience with surveys of business sector innovation, including R&D, has been applied to questions of energy by several countries. The different approaches that have been followed provide invaluable insights into their advantages, as well as the main challenges of gathering reliable energy-related innovation data from the private sector. These challenges can include the need for upfront investment, institutional capacity building and consistent classification of technologies. However, the advantages in terms of policy-relevant insights can outweigh the drawbacks, especially when data is complemented by other sources of quantitative and qualitative information.

This Overview reviews a range of such sources including financial fillings, venture capital deals, patents, scientific publications, marketed products and firm-level perceptions. It recommends that governments seek to develop and share effective practices in this area and adopt a portfolio of indicators suited to their own context. Six insights are presented for governments wishing to strengthen their energy innovation tracking efforts. The insights highlight the value of increased international cooperation on methodologies, which echoes the importance of cross-border collaboration to accelerate clean energy innovation more generally.

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Executive summary

Clean energy innovation must be accelerated, but if you cannot measure it then you cannot reliably improve it

Accelerating the innovation process is critical for achieving net-zero emissions by 2050 and policies will play a crucial role. Almost half of the emissions reductions needed in 2050 in a future with net-zero emissions from fossil fuels will come from technologies not yet past the demonstration stage today. This is especially true in sectors that remain stubbornly dependent on fossil fuels, such as long-distance transport and heavy industry. The goal of net-zero emissions by 2050 will be out of reach without major innovation efforts to improve and commercialise known technologies this decade, and quickly bring less mature ideas to market as soon as possible to minimise the costs of energy transitions.

There is considerable uncertainty about the extent to which countries' energy transitions are on track. For innovation, there are few reliable and high-quality metrics available in most countries to support evidence-based policy decisions on energy technologies. Around the world, governments are asking more questions about technology progress, innovation gaps, national strengths and the effectiveness of energy and climate innovation policies.

For public spending on energy research, the IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics provides a reference manual for governments, including state-owned enterprises. The resulting unique dataset shows that global government energy R&D and demonstration spending was around USD 38 billion in 2021, 5% higher than the previous year and continuing a growth trend over the past five years.

No equivalent manuals or handbooks exist to guide countries efforts to understand progress in energy innovation in the business sector. The business sector is nonetheless a major player and tracking its activities is vital to any overview of the clean energy innovation landscape. The IEA estimates that companies active in energy technologies spent almost USD 120 billion on energy R&D in 2021, three time more than governments. Among sectors, the automotive sector is the highest spender on energy-related R&D, much higher than other "hard-to-decarbonise" sectors. Beyond these headline estimates, however, information on the energy innovation activities of firms – whether freely or commercially available; at technology level or highly aggregated – is frustratingly scarce.

This overview presents a summary of the options available to governments for measuring the clean energy innovation activities of the business sector. It

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illustrates the options with examples from around the world and lists some of the advantages, disadvantages and inherent trade-offs. While it is not intended as a comprehensive guidance document and does not reflect a process of international consensus, we hope it can serve as an inspiration for practitioners and experts to enhance their tracking of energy transitions.

There is a wealth of existing experience in tracking innovation metrics for the business sector

Experts from governments and the research community have for decades discussed innovation, its place in policy, and the importance of measuring it and its impacts. Today, a common international vocabulary and set of practices exists for measuring certain innovation indicators consistently and comparably. For example, the Frascati Manual and Oslo Manual are the basis for collecting and using R&D spending data from the public and private sectors, as well as metrics related to products and jobs. Both manuals have been adopted by governments all over the world. Other approaches exist to track innovation in the business sector, including canvassing opinions and expectations and analysing patent data.

While few of these methodologies have so far been applied to energy in a consistent manner, there are opportunities to do so. Existing methods can potentially be adapted to track the specificities of clean energy technology innovation by the business sector in ways that answer key uncertainties facing policy makers in areas including hydrogen, smart grids, energy efficiency, electrification and many more.

Surveys allow data to be tailored to policy objectives, and can be internationally standardised

Surveys are a reliable means of gathering data on corporate innovation and can overcome the lack of publicly available information. Experience over four decades shows that well-designed R&D and innovation surveys can be highly valuable and unique resources for understanding trends. They demonstrate the importance of investing upfront to determine the appropriate scope, respondents and institutional processes to ensure durability, timeliness and practical value to decision-makers over many years. For example, good survey design must account for the limitations of common sectoral classifications when it comes to mapping firms to energy technologies. The efforts of countries such as Austria, Canada and Italy to incorporate international energy technology classifications illustrate what is possible.

Surveys can be used to develop a range of indicators. Existing government innovation surveys include a mix of questions about the recent past – such as those on levels of spending or personnel – and expectations of the near future -

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such as perceptions on how the innovation system is changing. Governments are increasingly interested in the effectiveness of clean energy innovation policies and surveys can also ask about so-called "outputs" and "outcomes" of innovation, in addition to financial inputs. These can include metrics relating to the adoption and use of new or improved technologies in specific fields. Taken together, these indicators can help gauge the health of a relevant innovation system and identify opportunities for early policy interventions.

The time needed to develop energy surveys can be reduced by "piggybacking" on existing business surveys. A common feature of the more detailed government surveys of corporate energy R&D is that they build on the statistical architecture of existing surveys. Typically, they are integrated within broader business sector R&D surveys that have already established the trust of respondents and have a legal framework in place (sometimes conferring an obligation to respond). Such an approach decreases the time and effort needed to receive the first results and maximises the chances of long-term durability. Similarly, relevant questions have been added to innovation surveys in some cases: since 2008, the EU Community Innovation Survey has included a question on new or improved products and services with environmental benefits and asks about the factors that shaped them.

Other sources of available information can be mined to provide a more complete picture of energy innovation

This Overview also presents several examples of how governments and analysts creatively use existing data sources to generate insights about business sector clean energy innovation. Some of these data sources have much shorter time lags than surveys and therefore provide information closer to real time. At times of rapid technological change and uncertainty, such as today, shorter turnaround times can be very advantageous.

Among data sources with time lags of less than a year, administrative financial data can help shed light on R&D spending in energy-related sectors or on different energy technologies. Individual financial fillings are publicly available, or can be accessed in aggregate from commercial providers. They may even be combined with patent data to yield deeper insights, as demonstrated by the European Commission. Data from tax returns, state-owned enterprises, regulated companies or recipients of public funding are not public but can be accessible to government analysts under certain conditions that vary by country. Datasets of venture capital investments are generally updated within days of each new deal and offer powerful insights into the expectations of investors, including business sector investors via corporate venture capital funds.

Some data sources have longer time lags, but yield trends about earlier-stage research efforts and breakthroughs. Publicly available data on patents and

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scientific articles are routinely used to reveal technology-specific trends in early-stage clean energy innovation, including insights into the status of knowledge flows between businesses and their partners in academia, research institutes and overseas.

There is considerable scope for international cooperation to build consistency and comparability

While this Overview identifies examples of effective practices from many countries, comprehensive frameworks for tracking multiple indicators are rare. It is also uncommon for individual national efforts to be comparable with their peers overseas, making it harder to measure the global status of clean energy innovation, whether for specific technologies or more generally. In part, this reflects the significant challenges and data limitations facing even the most well-resourced teams of analysts in this area, but it also arises from infrequent interactions among policy makers and experts in different countries.

Despite this, two of the most critical policy questions that governments seek to answer in this area are inherently international in nature, namely: "are businesses in our jurisdiction well positioned to create wealth as energy transitions proceed?" and "is the global portfolio of clean energy technologies getting cheap enough and performing well enough to get adopted faster?" Furthermore, the number of countries that are making impactful contributions to improving the global energy technology portfolio is expanding to include nations with less established routines for innovation data collection. As with innovation itself, progress in answering these questions will be faster if experiences are shared internationally and effective practices evolve into global standards.

Six insights for governments who wish to strengthen business sector energy innovation tracking

1. **Start soon.** All governments have different levels of resources and access to data, but that should not prevent them from starting to track what is feasible now and improving the measurement framework over time.
2. **Be patient to obtain results.** Few of the methodologies covered by this overview can be implemented immediately and new surveys may take several years to generate results, but today's established processes are now reaping the benefits (in terms of time series data) of effort invested upfront.
3. **Integrate energy questions into existing surveys.** Existing tools provide a solid foundation that could be adapted to more targeted purposes, such as clean energy by integrating a range of energy-specific questions and targeting the right stakeholders.

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4. **Develop frameworks for tracking innovation that align with user needs**. Any new approach to tracking business sector energy innovation must be carefully tailored to the needs of relevant decision makers, which will influence which suite of indicators is chosen.
5. **Be consistent with related national and international activities and reporting commitments**. To maximise the value of the effort directed to tracking business sector activities, attention should be paid to consistency with comparable data on public sector spending and tracking efforts in other countries.
6. **Participate in international efforts for building consensus and sharing practices.** Forums such as Mission Innovation and IEA committees and expert groups are platforms for sharing experiences and aligning the implementation of effective practices among different countries with the aim of informing better policies and faster.

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Chapter 1. Introduction

Why track energy innovation in the business sector?

Accelerating the innovation process is critical for achieving net zero emissions, and major innovation efforts are vital for bringing the technologies needed to market as soon as possible. As the world needs more, better and cheaper technologies, reliable and high-quality data must support evidence-based decisions to enhance policy making for energy innovation, properly track the progress of clean energy innovation and inform investment decisions.

The IEA's Tracking Clean Energy Innovation report introduces a framework and set of metrics to support the tracking and evaluation of clean energy innovation systems under four pillars: resource push, knowledge management, market pull and sociopolitical support. The scope of these indicators is broad because effective energy innovation policies cover a range of important measures. Taken together, indicators can help identify gaps and opportunities, evaluate the effectiveness and efficiency of programmes and understand the market readiness of key technologies.

While there is no single indicator for tracking clean energy innovation progress, public and private R&D funding generally receive the most attention. Estimations of both government and corporate contributions to R&D are important because public and corporate spending are not directly substitutable. Compared with government funds, corporate capital tends to focus more on incremental improvements and product development and the later stages of bringing emerging technologies to market. Governments, on the other hand, play an outsized role in funding and supporting early-stage, high-risk R&D. While companies do undertake basic research and fund first-of-a-kind projects, much of what they do is complementary and not in competition with publicly funded research. Studies typically find that public funding, when used to co-fund projects to which companies bring their own resources, stimulates additional corporate R&D and directs it towards longer-term societal challenges and opportunities, such as tackling climate change.

The IEA estimates that global government energy R&D and demonstration spending was USD 38 billion in 2021. For companies active in energy technologies, the estimate for total energy R&D and demonstration spending was around USD 120 billion, suggesting that global corporate spending exceeds public spending by at least threefold. However, in most countries, information about

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private energy R&D spending is much less readily available and less reliable than that for the public sector.

Furthermore, innovation goes beyond R&D, and the health of the corporate energy innovation system cannot be understood through R&D spending data alone. As the world accelerates energy innovation efforts across many sectors and seeks to manage the uncertainties associated with disruptive change, other indicators can give further insights. A variety of metrics can help to understand the state of the transition as innovation moves away from the unabated use of fossil fuels and towards clean energy. Data on corporate energy innovation may help governments to answer and track questions such as these:

- Are the resources that companies devote to clean energy innovation increasing?
- Is the allocation of corporate resources to clean energy innovation aligned with national strategic priorities?
- Are companies responding to policy changes in the desired manner, and how effective are the policies that are in place?
- What and where are the weaknesses and underserved gaps in the energy innovation system?
- How is the interaction of the public science and research base with the business sector?
- How does the country or region compare with international peers?
- Is innovation spending leading to outputs and outcomes aligned with national clean energy objectives, such as the development, manufacturing or deployment of new or improved clean energy technologies?

Purpose of this overview

Governments often struggle to understand what data are available to track progress in energy innovation. Currently, there are no manuals or handbooks to guide countries when navigating these trade-offs. In addition, developing a comprehensive framework for tracking energy innovation would take several years and would require the allocation of human and budget resources. The purpose of this overview is to collect a summary of the options available to governments, with their advantages and disadvantages, and examples of the activities that already exist around the world and provide resources for further information. While this complements the 2011 IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics for governments, including state-owned enterprises, it is not intended as a guidance document of the same stature, nor does it reflect a process of international consensus. Rather, this overview is a broader introduction to the topic based on examples from around the world that demonstrate the opportunities and limits of tracking private sector activities. It is aimed primarily at government officials looking to enhance their tracking frameworks for energy transition,

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including innovation. We hope that it will serve as a reference for practitioners and experts in the public, private and research sectors.

The nature of energy innovation is such that a range of indicators is always needed to assess the nature of business sector activity and progress, and this overview deliberately introduces a broad set of indicators. In Chapter 2, the overview starts by setting out some key definitions and primary resources before moving to summaries of the main indicators and approaches. Chapter 3 presents different approaches to estimating R&D spending in the business sector through surveys, and Chapter 4 through financial filings and other administrative data. Chapter 5 looks at funding allocated to young innovative companies, or start-ups, including corporate venture capital. Chapter 6 reviews a range of non-financial indicators, such as R&D personnel, patents, scientific publications, demonstration projects, new products, and opinions and expectations. Chapter 7 concludes with a summary of the insights for policy makers based on the findings of the report.

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Chapter 2. A framework for tracking energy innovation in the business sector

Experts from governments and the research community have for decades discussed innovation, its place in policy, and the importance of measuring it and its impacts. Today, a common vocabulary and set of practices exist to guide the measurement of some innovation indicators in a way that is reproducible over time and that provides results comparable across jurisdictions. Worldwide recognised standards have been developed to measure indicators such as R&D spending. However, using these standards to track the specifics of clean energy technology innovation by the business sector requires some adaptation, especially to collect data with detailed granularity by energy area and in a way that is meaningful in relation to the different levels of maturity of energy technologies.

Two key guidance documents for standardising measurement efforts: The Frascati and Oslo Manuals

When countries first began measuring innovation in the 1960s, they encountered theoretical difficulties when starting R&D surveys, and differences in scope, methods and concepts made international comparisons difficult. To address the technical challenges in measuring R&D, the OECD Working Party of National Experts on Science and Technology Indicators (NESTI) published the first edition of the Frascati Manual in 1963. The “Frascati Family” of documents, including the 2015 update of the Frascati Manual, still provides the basis for the main statistics and indicators on science and technology and is approved by government delegates to NESTI. The Oslo Manual joined this family in 1992 to provide broader coverage than R&D alone, including guidance on collecting and interpreting innovation data. As the United Nations Education, Scientific and Cultural Organization (UNESCO) uses both manuals as their standards for measuring R&D and innovation, their utilisation is now considered to be global.

R&D: The Frascati Manual

The Frascati Manual is the central resource for collecting and interpreting data on R&D by the public and private sectors. Originally published by the OECD as Proposed Practical Standard for Surveys of Research and Experimental

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Development, it is now in its seventh edition, entitled Guidelines for Collecting and Reporting Data on Research and Experimental Development. It provides a methodology for collecting and using R&D statistics, including standard definitions of basic concepts, data collection guidelines and classifications for compiling R&D statistics on expenditures, personnel and government budgets. The definitions provided in the Frascati Manual now constitute a common language to ensure internationally comparable statistics on R&D. It has become an acknowledged standard in R&D analysis beyond OECD countries and has been adopted by governments all over the world.

Other parts of the innovation process: The Oslo Manual

The Oslo Manual focuses on the business sector. The fourth edition, published in 2018, is entitled Guidelines for Collecting, Reporting and Using Data on Innovation. It addresses the need to understand and measure how innovation systems operate beyond the spending statistics gathered by adopters of the Frascati Manual or patent statistics covered by the OECD Patent Statistics Manual. Today, the OECD and other international organisations, such as the UNESCO Institute for Statistics, the Ibero-American and Inter-American Network for Science and Technology Indicators and the African Union Development Agency, use the Oslo Manual for their standards for collecting and publishing statistics on business innovation.

The main unit of measurement of the Oslo Manual is “a new or improved good or service that differs significantly from the firm’s previous goods or services and that has been introduced on the market”. That is, it focuses on the stages of innovation related to developing new products or services from inventions arising from prior in-house or external R&D. To be of interest to followers of the Oslo Manual, the product or service need not yet be “a commercial, financial or strategic success at the time of measurement”.

Mapping the terms “energy” and “clean energy”

The available data sources for tracking corporate energy innovation are limited. While there are a small number of relevant third-party public and private data sources for certain areas, such as patenting and the capital expenditures of selected companies, it is unusual to be able to piece together the full picture of the business sector’s energy research trends using readily available information. However, that does not mean there is no “low-hanging fruit”. Existing government databases might contain valuable data points, and existing government surveys can sometimes be expanded to cover more energy-related content.

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The collection of corporate data on energy R&D and demonstration spending faces diverse challenges. These challenges range from identifying the firms conducting innovation to obtaining information on R&D and demonstration with the granularity required to assess progress on the development of specific clean energy technologies.

Most of the indicators and approaches reviewed in this overview have established methodologies for data collection but are generally applied without a well-defined energy technology focus, such as on clean energy. A core challenge for analysts of clean energy innovation progress is to identify whether energy-relevant insights can be extracted from existing datasets, for example whether they use a classification system for companies or activities that maps well onto energy topics of interest. It is, therefore, imperative to understand the definitions employed in such classification systems and the differences between them. In most cases, the match with clean energy is imperfect, and further details on the companies and their innovation areas must be identified, for example via surveys.

Corporate data sources generally classify companies by their main sector of economic activity or their sectors of revenue. Several such classifications exist and are maintained by public and private entities. Common public classifications include the International Standard Industrial Classification of All Economic Activities (ISIC) Rev.4, the Statistical Classification of Economic Activities in the European Community (NACE) and the North American Industry Classification System (NAICS). ISIC Rev.4 and NACE have a very high degree of compatibility but differ slightly in numbering. All classifications include some sectors that can be analysed for their direct relevance to energy. In some categories, the energy-relevant part of the sector is split into a more detailed level of hierarchy. In others, an energy-relevant area is further split into sectors that relate to clean energy and fossil fuel energy separately when moving down the hierarchy. While the Frascati Manual recommends using the ISIC class level, i.e. four digits, it is common for companies to be assigned only to the most aggregated level of activity when they have multiple activities (two digits), for example in different areas of manufacturing, which does not allow the energy companies of interest to be isolated.

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Examples of energy-relevant sectors defined separately in ISIC Rev.4 and NACE

ISIC Rev.4		NACE	
05	Mining of coal and lignite	2121	Coal mining
06	Extraction of crude petroleum and natural gas	211	Oil and gas extraction
0721	Mining of uranium and thorium ores	-	-
0910	Support activities for petroleum and natural gas extraction	213111	Drilling oil and gas wells
		213112	Support activities for oil and gas operations
		213113	Support activities for coal mining
1920	Manufacture of refined petroleum products	3241	Petroleum and coal products manufacturing
		325193	Ethyl alcohol manufacturing
2710	Manufacture of electric motors, generators, transformers, and electricity distribution and control apparatus	332410	Power boiler and heat exchanger manufacturing
		3353	Electrical equipment manufacturing
2720	Manufacture of batteries and accumulators	335910	Battery manufacturing
2740	Manufacture of electric lighting equipment	3351	Electric lighting equipment manufacturing
2811	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	3336	Engine, turbine and power transmission equipment manufacturing
2815	Manufacture of ovens, furnaces and furnace burners	333414	Heating equipment (except warm air furnaces) manufacturing
		333415	Air-conditioning and warm air heating equipment and commercial and industrial refrigeration equipment manufacturing
-	-	333132	Oil and gas field machinery and equipment manufacturing
2910	Manufacture of motor vehicles	3361	Motor vehicle manufacturing
		336310	Motor vehicle gasoline engine and engine parts manufacturing
		336320	Motor vehicle electrical and electronic equipment manufacturing
-	-	336412	Aircraft engine and engine parts manufacturing
35	Electricity, gas, steam and air conditioning supply	2211	Electric power generation, transmission and distribution
		2212	Natural gas distribution
		221330	Steam and air-conditioning supply
4220	Construction of utility projects	237120	Oil and gas pipeline and related structures construction
		237130	Power and communication line and related structures construction
4930	Transport via pipeline	486	Pipeline transportation

Sources: United Nations (2008), International Standard Classification of All Economic Activities (ISIC), Rev.4; Executive Office of the President of the United States (2022), North American Industry Classification System.

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In contrast, the UN Comtrade Database uses a different classification system, the Harmonized Commodity Description and Coding System (HS), for reporting import and export goods. It was developed by the World Customs Organization and comprises more than 5 300 commodity groups, called “sub-headings”, each identified by a six-digit code. The latest update, released in January 2022, aimed for “the recognition of new product streams and addressing environmental and social issues of global concern”. For example, solar PV and LEDs were under the same sub-heading of “photosensitive semiconductor devices” (HS 8541.40), making it impossible to differentiate trade in each of the goods. In the 2022 HS update, PV cells were separated from LEDs, and different subheadings for each technology were created. Meanwhile, in the 2017 HS update, a subheading for electric and hybrid-electric motor cars and motorcycles was introduced, and in the 2022 HS update, a category on “fully or partially electrified road tractors for semi-trailers” was added.

Private data suppliers sometimes use their own, more detailed classifications, such as the Bloomberg Industry Classification System and the Thompson Reuters Business Classification System used by Refinitiv, whose correlation with NACE is available from the EU Technical Expert Group on Sustainable Finance.

While some of these sectoral classifications may be more adequate than others to provide a comprehensive view of clean energy, it may still be difficult to perform systematic tracking. Certain types of important energy R&D are impossible to extract from broader categories, such as building energy efficiency from real estate, renewable energy equipment from manufacturing or smart energy management from telecommunications in the industrial classification system. This means that energy-specific technology classifications may need to be applied to understand the trends. Such classifications sometimes require approaches that go beyond the publicly available data and request self-categorisation by companies of their technology interests.

In addition, another major shortcoming is that companies are given only one industrial classification system, such as ISIC or NACE, considering the activity that contributes the most to their value added. However, the activity that contributes the most to their value added may only represent 10% or 20%, and there may be other activities that are also generating and adding value. This can lead to significant problems of false positives – counting innovation that is unrelated to energy if a firm has an energy industrial classification – and false negatives – not counting energy-related innovation activities if a firm is not identified by an energy classification. There are relatively few countries that compile “multi-product firm” data, with Belgium being an example.

The IEA manages one such detailed classification of energy technologies that is unrelated to the industrial classification system. It covers seven main categories

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(energy efficiency, fossil fuels, renewables, nuclear, hydrogen and fuels cells, other power generation and cross-cutting technologies or research) and 131 subcategories. The Annual Survey of Research and Development in Canadian Industry took inspiration from the classification, which has allowed them to gain more insights into energy-relevant activities.

Regarding patents, in 2010, the European Patent Office launched the first version of a dedicated classification system for climate change mitigation technologies, now known as Y02-Y04S, which allows users to search quickly for technologies related to climate change mitigation and adaptation in a user-friendly way. The Y02 scheme applies to technologies or applications that contribute to reducing greenhouse gas emissions in the atmosphere. It covers seven main categories within GHG mitigation: buildings (Y02B), GHG capture and storage (Y02C), energy (Y02E), industry and agriculture (Y02P), transportation (Y02T) and waste management and wastewater treatment (Y02W). Y04S is a spin-off of Y02 for smart grids. If the patenting entities can be successfully mapped to the databases of companies, then patents can be a powerful means of identifying the specific energy technology areas in which companies are becoming more active and for creating a representative sample of companies engaged in energy-relevant R&D (see Chapter 6 for further insights on the use of patents for tracking innovation). The IEA is currently undertaking an exercise to map these variations in industrial, patent and IEA classifications to help analysts work across datasets and avoid drawing false equivalence between similarly titled categories.

What is clean energy technology innovation?

Technology innovation is the process of generating ideas for new or improved products or production processes and guiding their development all the way from the laboratory to their mainstream diffusion into the market.

Energy technology includes any device, component of a device or process related to the production, storage, transmission, distribution or consumption of energy services or commodities, including for end uses such as heat, light or as a moving force. Energy technologies seek to satisfy a new or existing energy service or commodity at a lower cost or with an increase in quality, or to reduce the environmental impact and increase the social welfare associated with its production and use.

The IEA report, How Governments Support Clean Energy Start-Ups, introduces a broad definition of a “clean energy technology”: any device, component of a device or process for its use dedicated to producing, storing or distributing energy with low CO_2 emissions intensity; or a novel device that provides a new or improved

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energy service or energy commodity that enables users to minimise their contribution to atmospheric CO_2 concentrations in line with net zero CO_2 emissions globally. While the focus here is on climate change mitigation, clean energy technologies also address other environmental concerns, such as air pollution, water quality or mineral resource depletion, or do not unduly exacerbate them. Clean energy technologies overlap considerably with the range of technologies frequently grouped together as “cleantech” or “climate tech”. However, these other classifications are broader and can include recycling, air monitoring, mobility services and land use in addition to energy applications.

Energy technology innovation is an evolutionary process that takes place through four main stages of development: prototype, demonstration, early adoption and maturity. Each stage requires different policy support programmes and stakeholders, and the technology’s path from idea to market is influenced by feedback loops and spillover effects at different stages of maturity.

Identifying the relevant set of innovating energy companies

One of the first steps towards measuring aspects of energy innovation is to identify those companies that have an impact on the development or deployment of clean energy. While traditionally, R&D and other innovation activities tended to be concentrated around relatively few companies, the nature of energy innovation is evolving rapidly, and incumbents as well as newly created companies can contribute. Large corporations have a long-standing tradition of incremental innovation. However, some of the most disruptive innovations may come from young and small companies, also known as start-ups, and it is valuable to identify them to keep track of energy innovation progress in key technology areas. Furthermore, the breadth of clean energy technologies implicates many companies outside the traditional energy sector, including companies in real estate, heavy industry and mobility, whose products are major sources of energy consumption.

Directories of potential R&D and innovation performers in the private sector can be highly valuable, justifying the upfront effort required to establish them. Governments can tailor the choice of companies to be included based on their specific needs and the questions they are trying to answer. In some cases, especially in larger economies, it will not be immediately obvious which companies should be included within the scope for the directory to be as comprehensive or representative as possible. Some approaches to identifying the relevant sample are:

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- companies reporting R&D or innovation activities in any business survey, or through the inclusion of a question on energy-related activities in broader business innovation surveys
- companies having filed for a patent application in an energy field in the past several years
- companies benefiting from public research or innovation grants, as well as companies claiming tax relief for R&D activities
- publicly traded company listings, such as national stock exchanges
- extracts from third-party cleantech and climate tech databases that list small innovative companies by country and technology area
- asking relevant chambers of commerce and industries or professional associations, etc.

Governments may not have the same definition of which types of companies to include, but common sectoral and technology classifications can help ensure comparability. In all cases, there is a strong argument for including energy-relevant firms that are outside the traditional energy sectors and those with activities split across multiple sectors. Chapter 4 describes the use of financial filings for estimating R&D spending and presents some suggestions on how to allocate the R&D of these firms by technology area, including using revenues and patents. For consistency in the use of energy technology areas, the IEA's ETP Clean Energy Technology Guide and Energy Technology RD&D Budgets provide a framework.

Selecting relevant metrics to track business sector energy innovation

The effective tracking of energy innovation progress can help governments identify gaps and understand good policy practice to incentivise energy innovation by the business sector. However, the business sector is neither independent of other actors nor monolithic in character. The energy innovation system comprises a set of interdependent actors – large companies, medium-sized enterprises, start-ups, state-owned enterprises, universities, research institutes, public institutions and civil society. These actors interact with one another to different extents and with arising knowledge, policy and regulation, and markets for goods and services. This complexity means that a range of indicators is needed to generate insights into different facets of the performance of an energy innovation system, but selecting the right metrics for a given policy question is not straightforward. After all, each metric is only a proxy for a real-world activity or impact, which means it rarely tells whether any factor is improving or not without additional assumptions and approximations.

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Indicators to assess energy technology innovation are commonly categorised as:

- Inputs: resources that enable the growth of the energy innovation system, including R&D spending and R&D personnel, as well as other resources, such as infrastructure.
- Outputs: results of R&D projects and other innovation processes, which can be subsequently applied to commercial products and services or otherwise have societal or environmental consequences. Patent and publication data are examples that tend to relate to the earlier phases of energy innovation, such as R&D.
- Outcomes: the short and long-term effects of innovation, such as the adoption and use of new or improved energy technologies.[1] Indicators such as new energy technologies launched or energy technology trade can reflect the immediate outcomes for technologies reaching the market, whereas deployment, economic, emissions and other aggregated social indicators reflect longer-term effects.

Input indicators dominate most analytical and tracking exercises, especially R&D spending. This is the case for analyses by companies and governments alike: firms and their investors typically assess competitiveness in innovation using the ratio of R&D spending to revenue and R&D personnel. There are other inputs to the energy innovation system that may be more difficult to quantify, such as new business strategies or marketing campaigns that are key for an innovation to be implemented and succeed, and these can be assessed qualitatively. However, input indicators are insufficient on their own for assessing trends in business sector energy innovation performance, as not all R&D will lead to a tangible innovation outcome, and innovation may arise from unknown and unmeasured inputs. Some firms, therefore, also track output and outcome metrics, such as royalties from intellectual property, technical performance improvements, costs and output volumes, but these are generally not available to governments or external analysts. Across the three categories, a wide variety of metrics can potentially be employed, each with its own strengths, weaknesses and level of maturity. Governments can make informed choices about the development of a tracking framework for their own needs.

The following chapters do not intend to provide an exhaustive description of the different types of indicators and how to use them. Instead, they present an overview of some of the most common metrics to assess the inputs and outputs of the energy innovation system for the business sector and proxy metrics for the outcomes.

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[1] These include technologies that satisfy new energy services, new technologies that satisfy a demand at a lower cost and new or improved technologies that satisfy a demand with lower GHG emissions, lower environmental impact and/or a lower use of critical resources.

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Chapter 3. Surveys for estimating R&D spending in the business sector

Introduction

The most frequently cited indicator of energy innovation in the business sector is money spent on R&D, as its measurement is well established through the OECD Frascati Manual and the IEA, which has collected data on government funding of research, development and demonstration (RD&D) since 1974. Along with patents, spending data are the main means by which companies benchmark themselves against one another. Expenditure data are an attractive indicator because it uses a single metric (usually USD) across all technologies and sectors. This common basis facilitates easy aggregation and comparison, as well as the creation of other intuitive statistics that are used by financial analysts, such as a company's ratio of R&D spending to revenue.

However, the use of R&D spending data also suffers several shortcomings, which include the following:

- It is an input metric that is usually uncoupled from the efficiency with which companies are able to turn money into new or improved ideas, solutions and products.
- It does not differentiate between technologies that have different resource intensities for the development of new and impactful technologies. The costs of bringing a novel digital technology to market can be much lower than those for a biotechnology-based product.
- It is common for part of the funds spent on energy R&D by companies to be derived from government grants. Unless this portion can be isolated, for example via surveys, there can be double counting when estimates of public and private spending are aggregated. However, the overlap tends not to be large – in Canada, the share of corporate energy R&D spending funded by governments at different levels was 8% in 2019. In line with IEA guidance, some countries include state-owned enterprise R&D within their definition of public R&D, which can create a similar challenge for analysts.
- It is rare for companies to publish forward expectations of R&D budgets, which makes the use of R&D spending data limited in terms of its insights into future innovation directions.

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- It needs to be complemented by other data sources if it is to shed light on the reallocation of funds between in-house R&D, R&D contracting, the purchase of new technologies and the investment of equity in start-ups.

Existing data sources for corporate spending on energy R&D are limited, especially for efforts directed toward clean energy, but methodologies have been developed to improve availability. The two main approaches are based on surveys and analyses of public financial filings. While financial filings are often already in the public domain, not all energy businesses submit annual financial reports that declare R&D spending, including unlisted companies, such as start-ups or small and medium-sized enterprises. As discussed in the previous chapter, there are also challenges related to identifying the relevant businesses to include in the scope and to allocating their spending to technology areas of interest. Surveys can provide more in-depth insights but tend to be more expensive to set up and maintain.

Defining R&D

When designing a framework for tracking corporate energy innovation, understanding the different ways in which some key terms are defined is of central importance. R&D is a common term that is defined differently depending on the data source. Its definition can also vary among countries in some cases.

The Frascati Manual's definition of R&D is: "Research and experimental development (R&D) comprise creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge." For an activity to be an R&D activity, it must be novel, creative, uncertain, systematic and transferable and/or reproducible.

According to the Frascati Manual, the term R&D covers three types of activity: basic research, applied research and experimental development. **Basic research** is "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view". **Applied research** is "original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective". **Experimental development** is "systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes". The

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Frascati Manual's concept of R&D excludes **demonstration**[2] and deployment. However, the IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics, which focuses on energy-related programmes only, includes demonstration projects as they are an important part of the development of new energy technologies, but also excludes deployment. Demonstration is defined by the IEA as the "design, construction, and operation of a prototype of a technology at or near commercial scale with the purpose of providing technical, economic and environmental information to industrialists, financiers, regulators and policy makers".

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[2] The concept of "technical demonstration" is included in R&D in the Frascati Manual, while "user demonstration", which takes place when a prototype is operated at or near full scale in a realistic environment to aid the formulation of policy or the promotion of its use, is not considered to be R&D.

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Surveys

Questions that surveys can help answer: How much are companies spending annually on energy R&D, and in which energy technology areas? What are the trends in other relevant indicators, such as R&D personnel dedicated to energy and company perceptions?

Strengths: Surveys allow the collection of more comprehensive and robust data that can be directly tailored to government priorities and needs on energy technology innovation without generally requiring additional modelling or estimation.

Limitations: It can take time to develop surveys, especially surveys, sections and questions dedicated to energy, particularly the first time they are put in place, and it also takes time for companies to fill them in. There is usually a time lag of up to two years or more between when data are collected and published. It can be challenging to achieve high response rates for non-mandatory surveys, and it can be hard to validate company inputs.

Surveys can be one of the most reliable and comprehensive means of gathering data on corporate R&D spending, and they can also include questions on other valuable energy innovation indicators. They can overcome the lack of publicly available information, and existing national examples demonstrate a range of different approaches and levels of detail. Achieving high response rates and informative results over a series of years requires careful planning, a clear mandate and administrative resources. The best surveys require institutional and financial commitments and can take several years to establish but can deliver high-quality information and insights over long periods.

The good news is that most countries do not need to begin from scratch. Most countries already survey companies that are active within their borders about their R&D activities. These surveys are usually part of international efforts to collect standardised and comparable data following guidelines that governments have agreed upon under the auspices of the OECD and UNESCO. The main examples of surveys of corporate energy R&D build on these foundations rather than creating an entirely new exercise.

Among the differences between national surveys of private energy R&D spending are their approaches to tackling several key considerations:

- Ensuring a high response rate. Companies typically consider the breakdown of their R&D spending to be confidential, which means that surveyors either need to make the survey mandatory by law or provide an incentive for participation.

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Privileged access to results might be one such possible incentive. Perhaps the most straightforward means of launching new mandatory questions is to integrate them into an existing mandatory survey. Surveyors can also raise response rates by combining different methods, including online questionnaires, phone calls and face-to-face data collection. Building trust between public administrations and the business surveyed is also key to ensure better responsiveness and accuracy.

- Coverage. The level of effort required to obtain exhaustive data can be much higher than that required for a representative sample. Therefore, most surveyors include only companies above a certain size threshold or only companies that are known to be active in energy R&D. The total expenditure across a country can be estimated by extrapolating from the sample where necessary. However, because companies active in energy-relevant research are not only in the so-called “energy sectors”, it can be challenging to identify the right recipients. One approach is to include a question about energy research in economy-wide R&D surveys to identify the relevant subset.
- Confidentiality. While government-conducted surveys generally give government analysts access to the full survey results, companies’ confidentially concerns are normally respected when publishing any data. This usually means that the results for any sub-category of respondent in which a single firm represents an outsize share of the data are not shared. They are only included in more aggregated categories from which individual firms cannot be recognised. In general, competitiveness concerns also mean that raw data cannot be shared for the purposes of cross-country analysis, although the OECD microBeRD project conducts a coordinated multi-country analysis of R&D microdata that allows data owners to preserve the confidentiality of disclosed results while ensuring comparability.
- Confidence. To ensure that the results can be trusted, different levels of effort should be devoted to checking for errors and clarifying responses. Surveyors take various approaches to these tasks using automated and manual processes.

The Frascati Manual advises governments to keep surveys as short and logical as possible. This includes separating R&D aspects from those related to product commercialisation (which are covered by the related Oslo Manual) and including the following indicators in the R&D questions: R&D expenditure by funding source (internal business enterprise funds; external funds received from other companies, the government, the higher education sector and private non-profit institutions; flows of funds from the rest of the world; or funds from the business sector to these other actors to perform R&D) and type of R&D (basic research, applied research or experimental development), and the number of R&D personnel. The OECD recognises that there is interest in the distribution of R&D funds by specific technology areas but does not provide dedicated guidelines for this.

The Frascati Manual also stresses giving consideration to electronic questionnaires that can embed definitions and instructions in their questions and

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ensure consistency in the data reported. It recommends testing surveys to ensure that content is well understood and that application is functional.

Dedicated energy R&D surveys and survey sections

In response to policy needs, a number of countries have developed surveys that include dedicated questions on energy R&D or, in some cases, ask all respondents for a more detailed breakdown of the technology areas to which their spending is allocated. Typically, these dedicated energy surveys build on the statistical architecture and legal framework of existing business sector R&D surveys and are distributed as an annex or section of the broader questionnaire.

Canada

The **Annual Survey of Research and Development in Canadian Industry** (RDCI) is a mandatory survey whose completion is a legal requirement under the Statistics Act, Revised Statutes of Canada, 1985, Chapter S-19.

The survey sample comprises all businesses and industrial non-profit organisations in Canada that are believed to perform or fund R&D based on their previously reported R&D expenditures (either from questionnaires or administrative tax data) in the prior two years or that continue to make or receive technology payments. These entities are classified according to NAICS codes, and the exercise is otherwise definitionally consistent with the OECD’s Frascati Manual 2015. The requested information covers in-house and outsourced R&D expenditures, R&D personnel and technology payments. The in-house R&D expenditures are broken down by type of R&D expenditure, funding source and subnational location of the R&D performed, field of R&D and the nature of the R&D activity.

Since 2014, the RDCI has included an embedded survey on energy-related R&D by area of technology, which includes a technology breakdown adapted from the IEA’s RD&D classification. This Energy Research and Development Expenditures by Area of Technology survey is executed by Statistics Canada (the manager of the RDCI) for the Department of Natural Resources of the Government of Canada. Prior to 2014, this additional survey was standalone and was sent to all companies receiving the RDCI, plus an extra group of companies not in the RDCI sample that were believed to perform energy-related R&D based on reporting in prior years or from publicly available information. The intention was to create a census of all companies performing or funding energy-related R&D.

For a given fiscal year (April to March) of expenditure (Y), data are usually collected approximately in June to November (Y+1), validated in September (Y+1) to February (Y+2) and finally published in May to June (Y+2).

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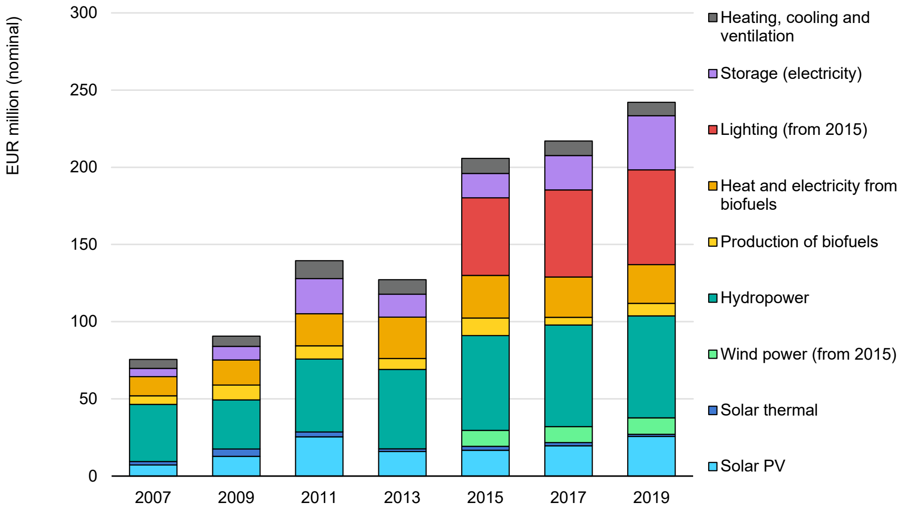
Key features of Canada’s Energy Research and Development Expenditures by Area of Technology survey

Feature	Design approach
Frequency	Annual
First and last available data years (as of August 2022)	1996-2020
Approach to response rates	Mandatory
Survey client	Natural Resources Canada
Survey performer	Statistics Canada
Number of surveyed companies in the last cycle	8 750
Coverage	All businesses and industrial non-profit organisations that perform or fund R&D in Canada
Means of identifying relevant recipients	All NAICS codes except 61131 (universities) and 91 (public administration)
Energy technology breakdown	Classification of energy technologies
Questionnaire	2020 Annual Survey of Research and Development in Canadian Industry
Public outputs	Database 2020 report

Corporate energy R&D expenditure by technology reported to the Annual Survey of Research and Development in Canadian Industry, 2014-2020



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Notes: This analysis is based on publicly available data from Statistics Canada. However, because Statistics Canada has a responsibility to ensure that corporate confidentiality is maintained in the aggregate figures published, the publicly available dataset may not be representative of the full spending reported by all companies. Separate analysis by Natural Resources Canada has identified higher spending in 2015-2017, which indicates a shallower slump in spending in those years.

Source: Statistics Canada (2022), Industrial energy research and development expenditures by area of technology, by industry group based on NAICS and country of control, accessed 11 August 2022.

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Example question from the 2019 Annual Survey of Research and Development in Canadian Industry

In 2019, did this business’s total in-house and outsourced (contracted out or granted) R&D expenditures include energy-related R&D in the following categories?

1. Fossil fuels
2. Renewable energy resources
3. Nuclear fission and fusion
4. Electric power
5. Hydrogen and fuel cells
6. Energy efficiency
7. Other energy-related technologies

If yes, please provide details below

Energy-related R&D by area of technology	2019 in-house energy-related R&D expenditures					2019 outsourced energy-related R&D expenditures		
	A	B	C	D	Total	E	F	Total
	CAN$ ‘000							
1. Fossil fuels								
a) Crude oils and natural gas exploration	$	$	$	$	$	$	$	$
b) Crude oils and natural gas production and storage	$	$	$	$	$	$	$	$
c) …	$	$	$	$	$	$	$	$
2. Renewable energy resources								
a) Solar PV	$	$	$	$	$	$	$	$
b) Solar thermal-power and …	$	$	$	$	$	$	$	$
c) Solar heating and cooling	$	$	$	$	$	$	$	$
d) Wind energy	$	$	$	$	$	$	$	$
e) Bio-energy – biomass production …	$	$	$	$	$	$	$	$
f) …	$	$	$	$	$	$	$	$

Total in-house R&D, include sources of funds from: (A) funds from the business; (B) funds from federal provincial or territorial governments; (C) all other Canadian sources of funds and (D) all foreign sources of funds.

Total outsourced R&D include: (E) outsourced within Canada and outsourced outside Canada (F).

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Structure of the energy technology classifications in the Annual Survey of Research and Development in Canadian Industry

Fossil fuels	Crude oils and natural gas exploration Refining, processing and upgrading of fossil fuels	Crude oils and natural gas production and storage Coal production, preparation and processing	Oil sands and heavy crude oil surface and sub-surface production	Transportation of fossil fuels
Renewable energy sources	Solar PV Solar thermal-power and high-temperature applications Solar heating and cooling	Wind energy Small hydro Large hydro	Bio-energy – biomass production and transportation Bio-energy – biomass conversion to transportation fuel	Bio-energy – biomass conversion to heat and electricity Other bio-energy Other renewable energy
Nuclear fission and fusion	Nuclear materials exploration, mining and preparation, and tailings management	Nuclear reactors	Other fission	Fusion
Electric power	Generation in utility sector	Combined heat and power in industry, buildings	Electricity transmission, distribution and storage	
Hydrogen and fuel cells	Hydrogen production for process applications	Hydrogen production for transportation applications	Hydrogen transport and storage Other hydrogen	Stationary fuel cells Mobile fuel cells
Energy efficiency	Energy efficiency applications for industry	Energy efficiency for residential, institutional and commercial sectors	Energy efficiency for transportation	Other energy efficiency
Other energy-related R&D	Carbon capture, transportation and storage related to fossil fuel production and processing	Carbon capture, transport and storage related to electric power production	Carbon capture, transport and storage related to industry in end-use sector	Energy system analysis All other energy-related technologies

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Source: Statistics Canada (2022), 2019 Annual Survey of Research and Development in Canadian Industry, accessed 11 August 2022.

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Italy

Italy's **Statistical Survey on Research and Development in Enterprises** (Italian: Rilevazione Statistica sulla Ricerca e Sviluppo nelle Imprese) is a mandatory annual survey of enterprises. Its completion is a legal requirement under the National Program 2017-2019 - Update 2019 (Code IST-02698). The Italian National Institute of Statistics collects and publishes the data annually. Since 2007, the survey has included questions on energy R&D, and since 2013, these have taken the form of a thematic section on energy-related R&D that is aligned with the seven broader categories of the IEA's RD&D classification.

Italy's survey is consistent with the Frascati Manual approach to data gathering and also complies with the European Commission's Regulation (EU) 995/2012 requiring EU member states to report on the research activities of their companies. Data are collected on intramural R&D expenditures, extramural R&D expenditures and R&D personnel. Companies potentially active in R&D across all sectors receive the questionnaire, and a similar survey is distributed to non-profit organisations and public institutions but is managed separately.

The survey takes place from February to April each year, with the final data published three years later.

Key features of Italy's Statistical Survey on Research and Development in Enterprises

Feature	Design approach
Frequency	Annual
First and last available data years (as of March 2022)	2007-2019
Approach to response rates	Mandatory
Survey client	Italian National Institute of Statistics
Survey performer	Italian National Institute of Statistics
Number of surveyed companies in the last cycle	-
Coverage	All Italian companies active in R&D
Means of identifying relevant recipients	-
Energy technology breakdown	IEA classification (two highest levels)
Questionnaire	Statistical Survey on Research and Development in Enterprises
Public outputs	2020 National Energy Situation

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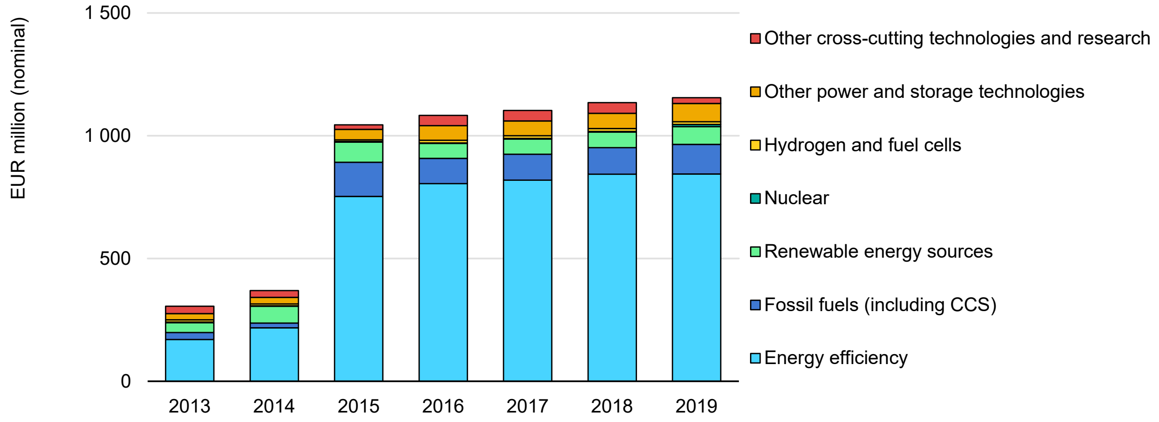
Corporate energy R&D expenditures reported to Italy's survey, by technology, 2013-2019



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Source: IEA (2022), Energy technology RD&D budgets database, accessed 11 August 2022.

Energy technology classification in Italy's Statistical Survey on Research and Development in Enterprises

Energy Efficiency	Industry On-road and off-road transport Residential and commercial appliances (including batteries) Other energy efficiency
Renewable energy sources	Solar energy Wind energy Other renewable energy sources Geothermal energy Biofuels
Use of hydrogen and fuel cells for power generation	Hydrogen Fuel cells
Nuclear fusion and fission	Nuclear fusion Nuclear fission
Production, processing, storage and utilisation of fossil fuels: oil, gas and coal	Oil and natural gas Coal Carbon capture and storage
Other technologies for the conversion, transmission, distribution and storage of energy	Electricity generation Electricity transmission and distribution Electricity storage
Other energy-related R&D	Cross-cutting technologies and basic research

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Source: Information provided by the Italian National Institute of Statistics.

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Economy-wide surveys with a highly aggregated treatment of energy

To generate data on energy R&D spending by companies across all sectors – and not total R&D spending by companies classified as being in energy sectors – a minimal approach is to include a single question asking how much R&D spending is directed to energy. This approach is followed by Austria, Germany and the United States and has been used by governments participating in the OECD Research and Development Statistics database.

Austria

The **Survey on Research and Experimental Development** (German: *Erhebung über Forschung und experimentelle Entwicklung*) is a mandatory survey that has been carried out once every two years since 2002 (with the exception of 2006-2007). Its completion is a legal requirement under the R&D Statistics Regulation 2003. Energy is one of the socio-economic objectives included in the survey since 2015.

Austria's survey is consistent with the Frascati Manual approach to data gathering and also complies with the European Commission's Regulation (EU) 995/2012 requiring EU member states to report on the research activities of their companies. Statistics Austria manages the survey, which asks about intramural R&D expenditures and R&D personnel. The sources of funding are broken down by business enterprise sector, government sector, higher education sector, private non-profit sector and whether from the rest of the world.

All enterprises with 100 or more employees are required to complete the survey, and enterprises with fewer than 100 employees are surveyed if included in a register of R&D performing enterprises maintained by Statistics Austria. Relevant companies are also identified using the results of previous R&D surveys, information from the Austrian Research Promotion Agency on applicants to R&D funding programmes and sources such as media, funding agency reports and patent applications. The companies are classified according to NACE Rev.2 codes A to S (excluding O, public administration and defence). The Austrian Energy Agency further groups around 200 companies into nine energy technology areas: PV; solar heating and cooling; wind energy; hydropower; production of biofuels; heat and electricity from biofuels; lighting; electricity storage; and heating, cooling and ventilation. In 2019, around 8 000 enterprises were surveyed, and around 500-600 reported R&D expenditure on the socio-economic energy objective.

For a given calendar year of expenditure, the results are published online two years later. They are reported to the IEA and the detailed data are also disseminated in reports.

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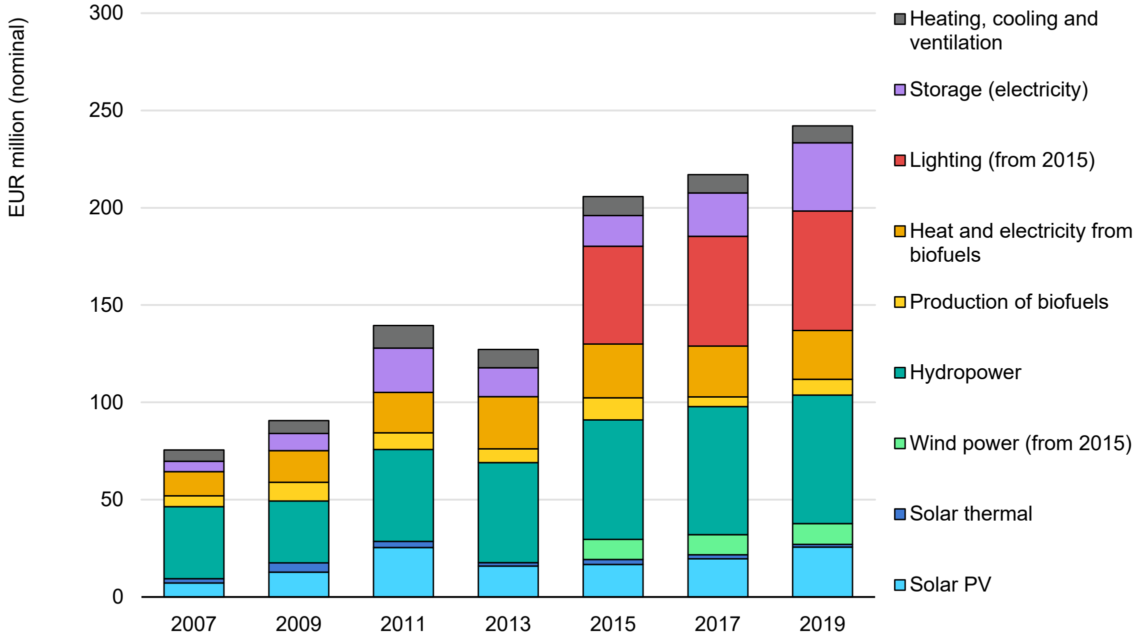
Key features of the Austrian Survey on Research and Experimental Development

Feature	Design approach
Frequency	Every two years
First and last available data years (as of July 2022)	2002-2019 (total) 2015-2019 (energy)
Approach to response rates	Mandatory
Survey client	Statistics Austria
Survey performer	Statistics Austria
Number of surveyed companies in the last cycle	8 000 (total), 500-600 (energy)
Coverage	All enterprises with more than 100 employees All enterprises with fewer than 100 employees active in R&D
Means of identifying relevant recipients	Previous R&D surveys Published company information in media Funding agency reports Patent applications
Energy technology breakdown	One sector: energy
Questionnaire	-
Public outputs	Energy research spending in the corporate sector Austria 2019

Corporate energy R&D expenditures reported by selected energy-relevant companies in Austria's survey, by technology, 2007-2019



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Source: Austrian Energy Agency (2021), Energy R&D: Private Sector Spending in Austria 2019.

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Germany

The **Survey on Research and Development** (German: *Erhebung über forschung und entwicklung*) was started in the 1970s. It is executed not by a government agency but by the Stifterverband's Research Data Centre FDZ Wissenschaftsstatistik, an association of companies and foundations, on behalf of the Federal Ministry of Education and Research. Since 2013, the survey has included a question on the share of R&D expenditures for different research fields, including a category on energy research and energy technologies.

The survey is consistent with the Frascati Manual's approach to data gathering and also complies with the European Commission's Regulation (EU) 995/2012 requiring EU member states to report on the research activities of their companies. It follows a two-year cycle, whereby the sample in odd-numbered years comprises all eligible companies and in even-numbered years is a smaller, representative sample.

The survey collects internal and external R&D expenditures, broken down by the use of funds and the funding source. It also gathers data on R&D personnel by type of work and gender. It is distributed to around 30 000 companies known to be active in R&D. It has previously included focus sections on the co-operation behaviour of companies in the field of R&D (2011), scientific R&D personnel (2013), R&D product and service innovation (2015) and international R&D (2017).

The data are not freely available to the public but may be purchased.

Key features of Germany's Survey on Research and Development

Feature	Design approach
Frequency	Annual (all companies in odd years; a representative sample in even years)
First and last available data years (as of March 2022)	2013-2020 (energy R&D) 1970s to 2020 (R&D)
Approach to response rates	Survey conducted by an association of companies and foundations on behalf of the government
Survey client	Federal Ministry of Education and Research
Survey performer	SV Wissenschaftsstatistik, a part of Stifterverband, an industry association
Number of surveyed companies in the last cycle	-
Coverage	All companies active in R&D
Means of identifying relevant recipients	-

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Feature	Design approach
Energy technology breakdown	One research field: energy research and energy technologies
Questionnaire	2020 Survey on Research and Development in Germany
Public outputs	2019 Analysis Database Energy research spending in the corporate sector Austria 2019

United States

The **Business Enterprise Research and Development (BERD) Survey** is a mandatory annual survey that has been undertaken since 1953, firstly as the Survey of Industrial Research and Development until 2007, then the Business R&D and Innovation Survey until 2016 and then the Business Research and Development Survey in 2017 and 2018. From the beginning of 2019, the survey name was changed again for international comparability. Its completion is a legal requirement under *Title 13, Section 8 of the United States Code*.

The BERD survey is distributed by the US Census Bureau and the National Science Foundation's National Center for Science and Engineering Statistics to a sample of companies with ten or more employees. These companies are identified using the Census Bureau's Business Register, with classifications according to the NAICS.[3] Only those spending more than USD 50 000 on R&D in a given year are included in the tabulations. For a given calendar year of expenditure, the results are published online three years later and featured in analytical reports.

From 1973, the United States collected data on industrial expenditures on energy R&D disaggregated by the primary energy source: fossil fuels (oil, gas, shale, coal and others), nuclear, geothermal, solar and others. Since 2008, the survey does not ask for disaggregated data on industrial R&D expenditures but has a broader coverage, including distribution, storage and energy efficiency, asking specifically about the share of domestic R&D paid for and performed by the respondent company with energy applications, including energy production, distribution, storage and efficiency (excluding exploration and prospecting). The survey also asks companies to report whether the energy R&D was self-funded or paid for by others. In 2019, the sample included 42 500 companies out of a population size of 1 124 000 companies,[4] of which 3 880 replied to the question on energy R&D.

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[3] However, the NAICS categories of agriculture, forestry, fishing and hunting (11), postal service (491), educational services (61), private households (814) and public administration (92) are excluded.

[4] The target population for the BERD Survey consists, among other criteria, of all for-profit companies that have 10 or more paid employees in the United States and that are classified in certain industries based on the 2012 NAICS.

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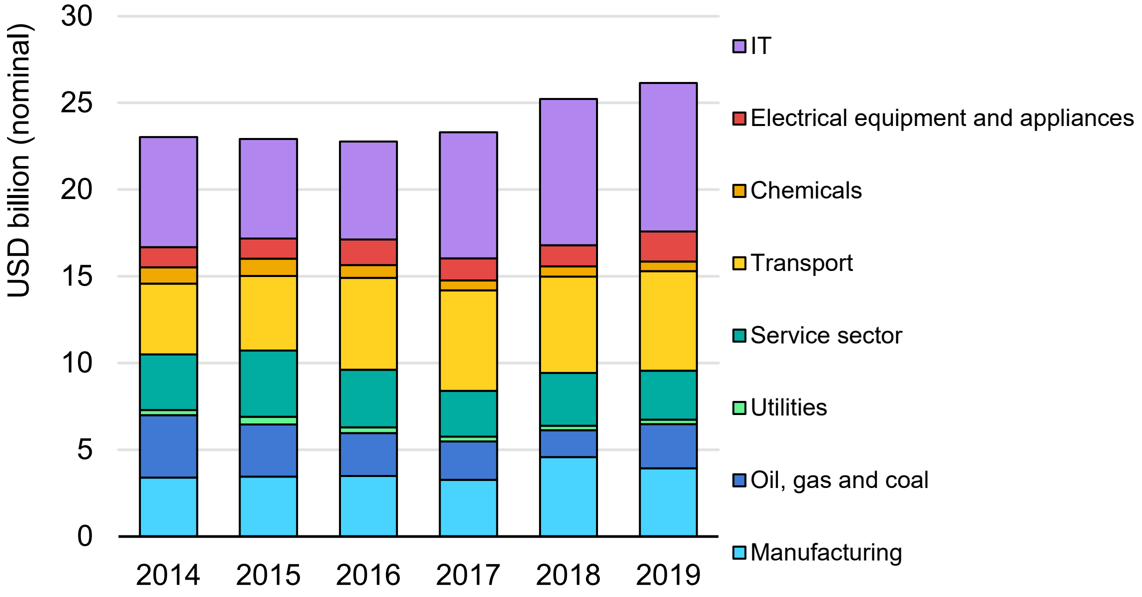
Key features of the US BERD survey

Feature	Design approach
Frequency	Annual
First and last available data years (as of May 2022)	1973-2019 (energy R&D) 1953-2019 (R&D)
Approach to response rates	Mandatory
Survey client	National Center for Science and Engineering Statistics and National Science Foundation
Survey performers	US Department of Commerce and US Census Bureau
Number of surveyed companies in the last cycle	42 500 (3 880 energy R&D)
Coverage	Sample of all companies operating in the United States with 10 or more employees and spending more than USD 50 000 on R&D in a given year
Means of identifying relevant recipients	Information on the number of employees and industry classification extracted from the Census Bureau's Business Register All NAICS codes except 11, 491, 61, 814 and 92
Energy technology breakdown	One sector: energy
Questionnaire	2020 Business Enterprise Research and Development Survey
Public outputs	Database The State of US Science and Engineering 2022 National Patterns of R&D Resources

Corporate energy R&D expenditures reported to the US BERD survey, 2015-2019



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Source: National Science Foundation, Business Enterprise Research and Development Survey, accessed 11 August 2022.

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Other countries

Japan's Survey of Research and Development for Business Enterprises asks about the total intramural expenditure on R&D in the energy field, which includes research relating to exploration, production, conversion, transportation, consumption and safety in relation to the development and reasonable use of energy resources.

Switzerland's Survey on R&D Spending and Staffing in Private Business Enterprises also has a question on intramural expenditure on R&D on energy, including production, conversion, transportation, and its efficient use, but excluding R&D related to prospection, and vehicles and engine propulsion systems.

Australia's Research and Experimental Development survey for the business sector asks about the share of R&D expenditure according to the area in which the respondent perceives the purpose or the outcome of the R&D, including energy and mineral resources (excluding energy resources). The Australian Bureau of Statistics provides a detailed description of the type of R&D activities included and excluded in both fields.

OECD Research and Development Statistics

From 1981 to 2015, the OECD Research and Development Statistics survey included, for some countries, a breakdown of gross domestic expenditure on research and experimental development by 14 socio-economic objectives, of which one was energy. The annual survey collected responses on the financial resources (national and foreign) used for the execution of research and experimental development work in a given country by the public sector, business enterprises, higher education and private non-profit entities. However, following low response rates to this section, it was decided in 2016 that the socio-economic breakdown would be restricted to governments and exclude business enterprises as it had not provided meaningful information.

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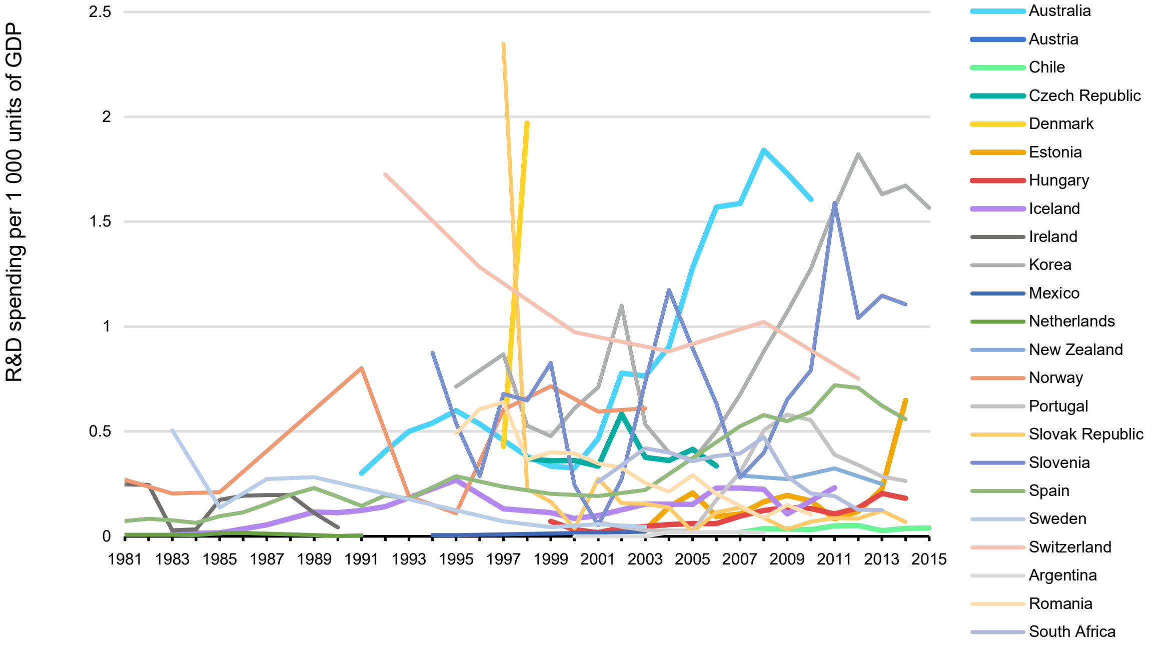
Gross domestic expenditure on R&D performed by Business Enterprise in Energy, 1981-2015



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Note: Energy is one of the 14 socio-economic objectives that was measured in the expenditure section of the Research and Development Statistics until 2015.

Source: OECD (2022), Gross domestic expenditure on R&D by sector of performance and socio-economic objective, accessed 11 August 2022.

Non-government surveys

Third parties outside the government may conduct confidential surveys or engage in activities that seek to raise awareness of technology innovation, especially related to climate change mitigation.

The Carbon Disclosure Project is a not-for-profit organisation that runs the global climate disclosure system, a voluntary approach that seeks to raise corporate awareness through the measurement and disclosure of environmental data, creating peer pressure for transparency. Via a questionnaire, the organisation requests information on low-carbon opportunities from some of the world's largest companies, who may answer voluntarily or at the request of their investors.

Some companies share selected data on their low-carbon energy R&D, including the shares of their R&D budgets allocated to low-carbon technologies. The Carbon Disclosure Project discloses the data using ranges: "no R&D budget for low-carbon technology"; "<20% of R&D budget in low-carbon technology"; "20-60% of the R&D budget in low-carbon technology"; and ">60% of R&D budget in low-carbon technology". The companies are also classified by industry sector: cement, transport, electric utilities, capital goods, oil and gas, chemicals, coal, real estate, construction, metals and mining, steel, general, and food, beverages and tobacco. The Carbon Disclosure Project estimated EUR 65 billion in low-carbon R&D in Europe in 2019.

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Chapter 4. Use of administrative data for estimating R&D spending in the business sector

Surveys are a powerful tool for reliably estimating R&D spending in the business sector, especially as they can be tailored to specific (clean) energy technologies. However, building a new survey is time-consuming, and ensuring adequate response rates without a legal mandate is challenging. Nevertheless, there are some administrative data that can provide information on R&D spending. These data are either publicly available, such as financial filings, or available to governments, such as tax returns, state-owned enterprises, regulated companies or recipients of public funding.

Financial filings

Questions that financial filings can help answer: How much do listed companies spend on R&D and in what sectors of the economy? How much are R&D expenditures compared to other company expenditures, and what share are they of revenues?

Strengths: Data from listed companies made available in annual reports are audited and are generally more accurate or reliable. The data are provided in a timelier manner than survey-based data, which can suffer from a time lag of several years, so financial filings can complement survey data. Users can purchase third-party datasets that compile global reporting and access individual company data freely on public investor websites. Data can be correlated with other datasets, such as those on patenting.

Limitations: Non-listed companies are not included. It can be challenging to get high levels of sectoral granularity or identify the shares of energy technologies in R&D budgets. Budgets are aggregated in the country where a company's headquarters are located, not necessarily where innovation takes place. Requires analytical knowledge and effort to manipulate datasets, particularly expertise in finance, accounting and databases. Companies may report R&D expenditures in different ways and may not disclose some of them.

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Energy innovation information from financial filings

Many companies track and report R&D spending data to meet the needs of shareholders and regulators. This information may be made public, most notably in the case of companies that are listed on public stock exchanges. These companies must file periodic financial statements that can be used by finance professionals to inform investment decisions.

Corporate financial filings include several documents that seek to provide a genuine and fair view of the company’s operations and budgets, such as audited financial statements. Income statements and balance sheets list all operating expenses, including R&D spending, and the broader filing generally includes short sections on innovation and metrics relating to R&D budgets to put these in context with the company’s activities and strategy. In some cases, such as when companies seek to showcase their in-house technology innovation capabilities to appeal to investors, they may also report optional metrics, such as those related to R&D personnel and patents.

Where can financial filings and related documents be found?

There are several ways to find the information reported in corporate financial filings:

- Companies may publish freely accessible annual reports on their websites’ investor relations pages or quarterly reports.
- Some countries hold a central database for public company filings, managed by the local regulator, such as EDGAR in the United States, SEDAR in Canada and CorpFiling in India.
- Commercial databases by companies such as Bloomberg or S&P Global Ratings provide indicators drawn from corporate financial and regulatory filings, including those relating to R&D spending.

How companies account for R&D costs

Although accounting practices can change from one country to another, there are commonalities in terms of what counts as R&D activities and how companies can account for the associated costs.

“Research” is defined as activities aimed at discovering new knowledge that may be used for new or improved products or processes. “Development” is defined as the translation of this stock of knowledge for the purpose of discovering and developing new or improved products or processes. The Frascati Manual and the System of National Accounts use relatively similar definitions of R&D. However, the Frascati Manual is clear in defining R&D as an activity, and its methodological

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guidance focuses on capturing the resources dedicated to that activity. In contrast, in the System of National Accounts, R&D may refer not only to an activity but also "to the assets resulting from the R&D activity, e.g. knowledge, resulting from R&D as evidenced by the existence of intellectual property rights", which could be objects of further transactions, such as sales or licencing. Regulators and auditors typically publish more specific guidance alongside concrete examples to help accountants and finance experts report R&D costs (e.g. Accounting Standards Codification 730 in the United States).

In theory, R&D spending should be reported separately from capital expenditures because the future benefits of R&D are uncertain and so their future value cannot be accurately assessed. This means that the costs associated with R&D should be reported as expenses rather than assets. In practice, however, companies may consider that some of their R&D expenses should be accounted for as assets instead. Depending on the jurisdiction in which companies operate, publicly reported R&D spending can include a range of capitalised and non-capitalised costs, from basic research to product development and in some instances even resource exploration. However, these expenses can also be reported inside other expenses. As a general rule of thumb, there is no obligation to report R&D expenses – of any kind – unless the regulator deems that such information is necessary.

For example, according to the Accounting Standards Codification 730 in the United States, expenditures on materials, equipment and facilities that have an alternative future use beyond R&D may be capitalised. The International Financial Reporting Standards (IFRS), on the other hand, differ from US standards. According to the International Accounting Standard (IAS) 38, some R&D activities may be considered as internally generated intangible assets, which are business assets with no physical form. Expenditures relating to intangible assets can be capitalised if future economic benefits are probable and the costs can be measured reliably. While research costs should still be considered as expenditures, some development costs can be capitalised as intangible assets if certain criteria are met, at the discretion of company management. For example, development expenses related to a prototype of a car or an energy company can be amortised under IAS 38 but should be expensed under US standards. Companies in the European Union prepare financial statements abiding by the International Financial Reporting Standards. In the United Kingdom, companies have the option to capitalise some of their development expenditures if similar criteria are met as well.

As a result of these differences across jurisdictions – and taking into consideration that company management retains some degree of independence, such as deciding whether or not to capitalise equipment or intangible assets or to allocate a share of time for personnel to spend on R&D activities – it can be challenging to

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compare R&D expenditures across firms, relative to examining trends or aggregate numbers at the sectoral level. More detailed information about what is being reported may be available in companies' annual reports.

Financial filings as a resource to track corporate energy R&D spending

Various methods have been used to translate company annual reports into estimates of corporate energy R&D spending by technology area. These approaches generally rely on commercial databases that aggregate corporate filings.

The IEA estimates global corporate energy R&D spending by sector, based on data extracted from Bloomberg. The methodology includes reallocating reported spending not already assigned to specific technologies based on companies' industrial classifications and sectoral revenue shares. For example, if a company develops both electric vehicles and renewables, its R&D budgets will be split across those two sectors based on how much revenue is being generated in each. In 2021, the IEA estimated global corporate energy R&D spending to be about USD 120 billion. This covered companies active in the automotive business; renewables; electricity generation, supply and networks; nuclear; oil and gas; thermal power and combustion equipment; batteries, hydrogen and energy storage; and coal. Spending by companies outside the energy sector but with increasing relevance to the energy transition can also be tracked, such as in heavy industry (e.g. cement, iron and steel, chemicals, and pulp and paper) and transportation (e.g. aviation, shipping and trucks).

There are limitations to this methodology.

- Only listed companies are covered, which excludes from the dataset non-listed state-owned enterprises and family-owned, privately held, or small and medium businesses. Yet, these may bring meaningful contributions to global energy R&D efforts. In fact, Asian Development Bank Institute research suggests that non-reporting firms may have substantial R&D expenditures in some instances.
- Furthermore, in some regions, the reporting requirements for listed firms may be less stringent or less thoroughly implemented, which can create imbalances in the geographical coverage of the dataset. Excluding certain exceptions (e.g. Chinese companies that typically carry out much of their R&D domestically), regional breakdowns under this approach can be imprecise because companies do not report where they innovate, whereas their R&D budgets are entirely attributed to where they are headquartered.
- In the case of commercial databases compiling data on financial filings, there can be methodological inconsistencies as to what counts as R&D. For example, financial documents may not contain metadata that describes budget lines,

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leading analysts to label broader development budgets as "R&D spending" when they actually relate to later-stage product development.

- It can be challenging to estimate how much R&D spending is associated with specific energy technologies of interest. This is because companies typically keep this information confidential, and databases provide sectoral values at the aggregate level as a result. For example, assumptions are made to estimate the share of carmakers' R&D spending that may be allocated to alternative drivetrain development versus non-energy-related vehicle components. Similarly, only a fraction of R&D spending in industry is typically allocated to energy technology development or improvement, or to energy efficiency.

In 2017, the European Commission's Joint Research Centre followed another methodology that couples similar data on spending with details of clean energy technology patents filed in the European Union for different clean energy technologies (grouping renewable energy technologies, smart energy systems, efficient energy systems, sustainable transport, carbon capture utilisation and storage, and nuclear safety). The combination of these datasets, coupled with more detailed information on the values of different energy technologies in companies' overall business activity and other factors, enables the calculation of average research costs per patent, per technology and per year. With this approach, the Joint Research Centre estimated about EUR 24 billion in private R&D spending in 2018 across the 28 EU member states, which covered the significant aggregate efforts of non-listed companies, such as small and medium-sized enterprises.

While the method provides the most comprehensive estimate available for Europe, it has some drawbacks for tracking purposes. For example, patent statistics are published with a time lag, meaning that the most recent complete dataset at the time of analysis can date back up to three years. Constructing and maintaining a quality, coherent and consistent dataset is a labour-intensive exercise. Also, the method assumes that the patenting strategies of companies that report annual R&D spending are the same as those that do not, and that these strategies do not change over time.

Given the various challenges associated with using commercial databases (e.g. the cost of purchase, knowledge and time required to process and analyse the data), it can be easier to select a sample of major companies as a starting point and extract information from annual reports. For a limited sample of domestic firms, it is, therefore, possible to track R&D budgets using only freely available sources. This may be appropriate in countries with a relatively small number of relevant companies.

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Tax returns

Questions that tax returns can help answer: How much energy R&D or innovation spending was submitted in claims for tax relief each year, by sector? How do companies respond to fiscal incentives relating to innovation?

Strengths: The data are, in theory, highly reliable and under government ownership.

Limitations: Data availability is dependent on the extent to which companies claim tax relief and time series data will be influenced by policy changes. Confidentiality concerns can make access to the raw data challenging. It can be challenging to get high levels of sectoral granularity or to identify the shares of energy technologies in R&D budgets.

As of 2021, 34 of the 38 OECD countries, 22 of the 27 EU member states and countries including Argentina, Brazil, the People's Republic of China ("China" hereafter), South Africa and Thailand offer tax relief for R&D expenditure at the central or subnational government levels. Since 2000, the number of countries offering R&D tax relief and the share of innovation support offered as tax relief have both increased significantly. Consequently, many of the world's finance ministries and tax offices receive corporate submissions detailing annual firm-level R&D expenditure in tax returns.

In the United Kingdom, which publishes summary statistics on its R&D tax credits, around GBP 47.5 billion in R&D expenditures were used to claim tax credits in the financial year to March 2020. Most of these claims were by larger companies rather than small and medium-sized enterprises. However, UK data are not further classified by sectors that reflect energy transition priorities but are presented only for highly aggregated categories, such as mining and quarrying; electricity, gas, steam and air conditioning; and manufacturing. With a dedicated reclassification of firms in terms of their energy-related activities, governments could nonetheless gain much more detailed insights from this data source.

Tax return data in most cases are not perfectly compatible with surveys of business R&D conducted under the Frascati framework. For example, tax relief can often be claimed on R&D conducted overseas. It may also be measured based on financial rather than calendar years, and business surveys may exclude sectors including higher education and finance. Some of these factors may underpin the large and growing discrepancy between estimates of business R&D expenditure in the United Kingdom via these two approaches: in 2015, around 20% more R&D expenditure was used to claim tax credits than was reported via the business survey, and in 2020 this had risen to over 80% more, even when

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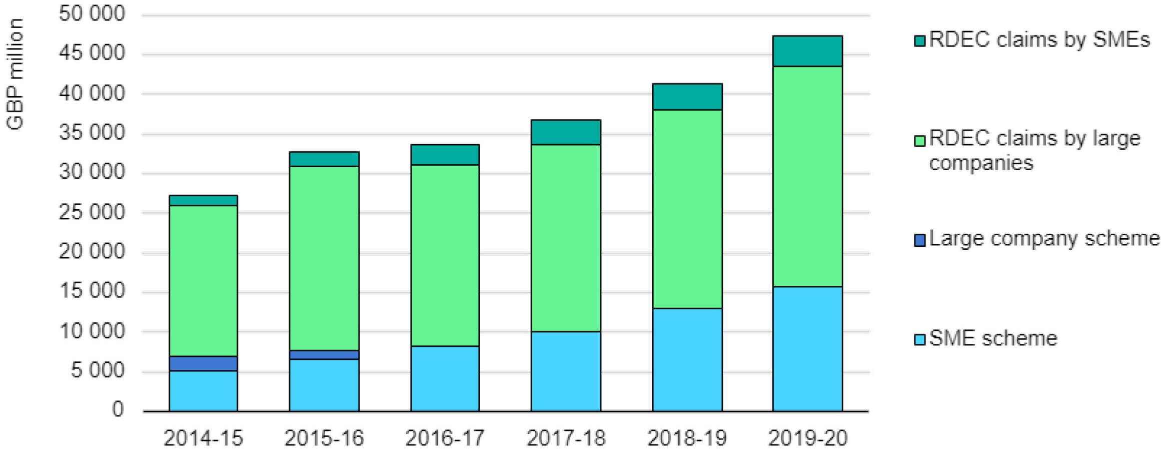
based on a consistent set of sectors. This counter-intuitive finding has prompted the United Kingdom to include a question in its business R&D survey about whether the reported R&D spending (whether in-house or externally contracted) was the basis for a tax relief claim.

R&D expenditure used to claim R&D tax credits by scheme in the United Kingdom, 2015-2020



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Note: RDEC = Research and Development Expenditure Credit scheme; SME = small and medium-sized enterprise.
Source: UK National Statistics (2022), Research and Development Tax Credits Statistics: September 2021, accessed 11 August 2022.

Given the confidential nature of tax return data, accessing sufficient details to learn about trends in corporate energy R&D spending would likely require close cooperation between ministries of finance or tax agencies and those government entities responsible for energy innovation. It is probable that those institutions themselves would need to undertake data analysis and aggregation before sharing their findings with the government institution responsible for energy innovation. Just as in the case of cooperation with statistical agencies on surveys, this naturally raises questions about resource and budget allocation for innovation tracking that a country would need to resolve in a sustainable manner to generate time series data. One interesting approach to collecting consistent tax relief data while respecting confidentiality concerns is the OECD's microBeRD project, although not related to energy.

However, it is difficult to estimate whether general R&D tax incentives are allocated to energy or not. Therefore, if there is no additional information on the sector in which the R&D was performed, this approach can only be used with companies that are well known to be active in energy innovation. In France, when requesting tax relief for their R&D expenditures in the form of a research tax credit (French: crédit impôt recherche), companies have to report an R&D field code in addition to their NACE industry code. The fields of research include energy (French: *énergétique*) and thermal (French: *thermique*). Combining an R&D field

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code with the industry code can provide information on the amount of expenditures that go to energy-related research, but this information may be of limited value if only one activity code is attributed to a company. More information could be gained by allowing companies to disaggregate their R&D into different fields of research. Although France's Ministry for Higher Education and Research publishes statistical reports on the tax relief data provided by the Ministry of Economy and Finance, no data are currently published by field of research. However, the French example could potentially extend to further distinctions relating to clean energy technologies, using classifications aligned with the IEA's for R&D spending data.

The OECD microBeRD and SwiFTBeRD projects

To overcome some of the challenges for policy makers in fully gauging the impact of R&D tax incentives across different types of firms, the OECD established the microBeRD project to extract and analyse comparable national data.

The project uses a unique distributed approach to analysing microdata held in separate enclaves within different government databases by means of a common, centrally designed computer code (routine). This routine is automated and flexible enough to run on different data sources in different countries while accounting for their idiosyncrasies. Furthermore, with this approach, national experts can generate aggregated results (so-called "harmonised, non-confidential micro-aggregates"), overcoming confidentiality concerns. Twenty countries have participated in this collaborative exercise to date: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, France, Germany, Hungary, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The first phase (2016-2019) was successful in investigating the structure, distribution and concentration of business R&D and sources of R&D funding across countries. The second phase (2020-2023) explores the effect of R&D support policies on innovation outputs (e.g. on introducing new products and services and filing patents) and economic outcomes (e.g. employment and productivity growth). It also explores the relationship between tax incentive design, additionality and the innovation support policy mix over time.

As an illustration of the results, it was found that R&D tax incentives help increase R&D activity, and this effect does not seem to be driven by increases in R&D wages. The tax incentives increase the level of R&D activity among existing R&D performers and entice firms to start or continue investing in R&D, but there are substantial variations in the R&D input additionality of R&D tax incentives and direct funding across countries. To build on this work, it may be possible in future

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to apply the analysis only to firms identified as active in clean energy technology development.

The OECD has established the SwiFTBeRD initiative to provide timely data on business R&D spending and total revenues based on publicly available company financial statements. It covers data on the world's largest R&D performers, with broader coverage and sectoral insights for companies in the automotive and aerospace, pharmaceutical and biotechnology, and ICT sectors.

Data are updated quarterly, semi-annually and annually, with only a few months' delay after their publication. These data are published in the SwiFTBeRD dashboard, which complements the publication of official statistics derived from R&D surveys. While official statistics illustrate the recent past and provide rigorous information, the use of the SwiFTBeRD platform aims to counterbalance the time lag by providing near real-time data and "nowcasts" on R&D expenditure based on reported investment plans.

Existing formal relationships with businesses

Data on private sector energy R&D expenditures are sometimes available via the formal relationships that governments have with some of the major performers of the relevant research. A salient example is information on the activities of state-owned enterprises (SOEs), to which governments have access through ownership. In certain countries, such as China, this spending is included as a component of public R&D expenditure, indicating that the data can be gathered but also that not all countries allocate to the same side of the boundary between public and private spending. Other examples include regulated entities and recipients of policy support. In these cases, formal interaction with the government can provide an opportunity for data collection.

State-owned enterprises

According to IEA reporting guidelines, for the purposes of energy RD&D, state-owned companies should be considered as public bodies but shown separately. However, in the Frascati Manual and the System of National Accounts 2008 the term "business enterprise" includes both private enterprises and public enterprises to the extent that the principal activity is the production of goods or services for a market at a "significant" price.

The IEA provides governments with a template for collecting and sharing the energy R&D spending of their SOEs as part of its public RD&D data collection. The format follows the template used to classify other public budgets for energy

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RD&D, enabling comparability and the option of including extensive detail where possible. Most countries that share RD&D budget data with the IEA do not also complete the section on SOEs, sometimes because they do not have any relevant SOEs in their energy sectors.[5] In some cases, SOE data are not gathered and shared for confidentiality reasons, often because the number of SOEs is small – sometimes a single company – and the technology breakdown of their R&D spending is not otherwise in the public domain. In such situations, the IEA recommends that the amounts are transparently reported alongside other public RD&D data, although there can be data access constraints in instances where SOEs are external to the government budget and operate as standalone publicly led entities. However, even if SOE R&D spending data cannot be shared publicly, this does not prevent them from being available for analysis and aggregation by the national governments.

Over time, SOE energy R&D spending reported to the IEA, including seven countries, has decreased from around USD 900 million in 2012 to around USD 400 million in 2019 (both in USD [2021]). In China, where the public sector is bigger, a more significant share of public sector R&D is conducted by SOEs than in other countries. Until 2016, China's National Bureau of Statistics published the Statistics Yearbook on Science and Technology Activities of Industrial Enterprises, which presented aggregated SOE R&D spending across industrial sectors.

Recipients of public funding

Many corporate entities interact with the government to apply for R&D grant funding support and negotiate the resulting funding contracts. These contracts usually detail the shares of the total project costs for which the public and private sectors are responsible, potentially providing a source of information about this specific area of project spending. Furthermore, this information can be correlated with other sources of data on companies' research and patenting activities as part of efforts to assess the impact of public funding programmes. The interaction with grant recipients potentially offers an additional opportunity to solicit additional insights, the provision of which could be introduced into the contractual process. Valuable information for understanding the landscape of corporate energy R&D might accrue from relatively undemanding and confidential questions about R&D spending plans, priorities and expectations.

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[5] The OECD defines SOEs as enterprises for which the state is the ultimate beneficiary owner of the majority of voting shares or otherwise exercises an equivalent degree of control.

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Regulated companies

Governments usually have a role in approving the spending plans of regulated entities such as utilities and energy network operators. This role provides governments with insight into the corporate budgets for R&D and innovation and could potentially be an opportunity to request further details of R&D plans by technology for tracking purposes.

Research certification processes

Some countries have existing systems for accrediting private sector research activities. In India, the Department of Scientific and Industrial Research's Recognition of In-House R&D Units scheme certifies private sector R&D centres, making them eligible for tax relief and certain types of finance. Although they are generally not specific to energy, such systems can provide an opportunity to analyse the activities and interests of companies applying for certification in energy-relevant areas, which can potentially be correlated with information on actual R&D spending for these centres against which tax relief is claimed.

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Chapter 5. Tracking finance to fund innovation by start-ups

This chapter presents two indicators that use data on venture capital investments: total equity investments in start-ups and corporate venture capital. In the context of tracking business sector clean energy innovation, corporate venture capital is a complement to corporate R&D spending data. It reveals how larger companies devote investment funds to learning about potential new solutions and, in some cases, buying an option for integrating them into their businesses rather than developing them in-house using R&D budgets.

Questions that venture capital data can help answer: How much do companies invest in start-ups to support their innovation strategy? Are energy companies venturing outside their traditional lines of business by acquiring start-ups in new strategic fields? What is the share of non-energy companies investing in clean energy start-ups?

Strengths: Some sources of information and data are freely available and updated regularly, providing up-to-date information.

Limitations: Purchasing and processing commercial databases require an understanding of start-up ecosystems and resources. The value of some transactions may not be disclosed.

Tracking venture capital investments

In addition to R&D spending, which covers a narrow set of expenditures on innovation projects, the pace and direction of business energy innovation can be tracked in terms of the money allocated to innovative young companies aiming to bring new technologies to market. A large share of the finance raised by these companies to cover their scale-up expenses is dedicated to prototype testing and refinement, which are key parts of the innovation process phases of R&D, demonstration and early adoption. Most venture capital investment is by dedicated venture capital funds that generally have a broader investment remit than clean energy alone. Some venture capital investment is by funds that specialise in clean energy, a subset of which are managed by corporations such as utilities or carmakers, and a smaller subset is funded by the public sector.

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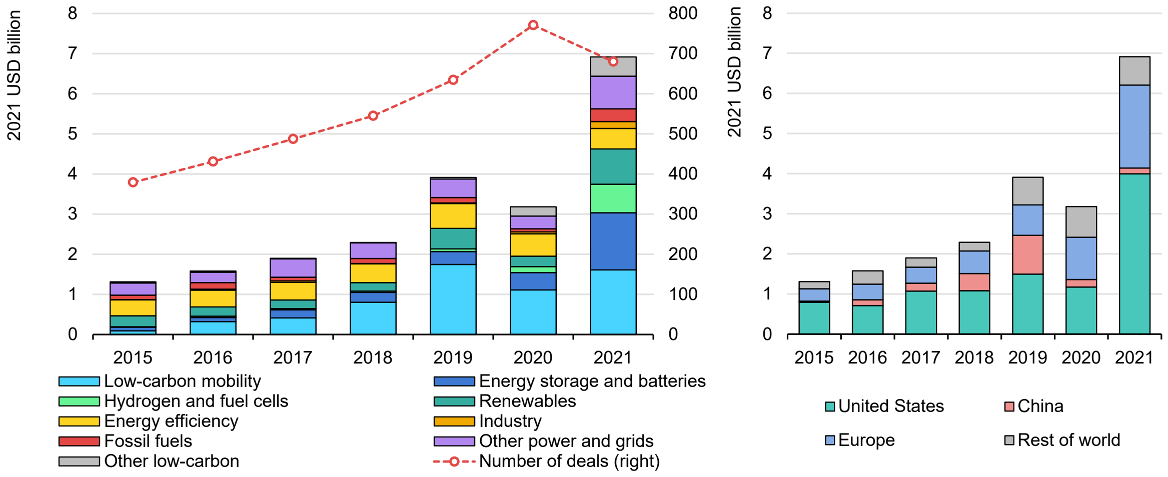
Venture capital financing for energy technology innovation provides important complements to R&D budgets. The funding typically supports technology testing and design, playing a critical role in honing good ideas and adapting them to market opportunities. This generally fits technologies with lower upfront capital needs, although data in recent years have shown more investor appetite for "asset-heavy" technologies, including in aviation and heavy industry. The tracking of early-stage deals may be used as a proxy for nascent technologies, and growth equity for the ability to scale up and diffuse in larger markets. The IEA tracks global venture capital investments using a third-party data source (Cleantech Group), and other providers, including Crunchbase, Dealroom and Pitchbook, offer data services with different characteristics. These sources show that investments have been increasing in recent years despite the coronavirus (Covid-19) pandemic. However, to extract these trends, the data must be cleaned by analysts with some subject matter expertise, and decisions about technology categorisations are required because commercial data rarely maps perfectly onto the clean energy categories of interest.

Early-stage venture capital investments in clean energy start-ups, by technology area (left) and start-up location (right), 2015-2021



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Notes: Early-stage deals are defined as seed, Series A or Series B deals. Very large deals in these categories – above a value equal to the 90th percentile growth equity deals in that sector and year – are excluded and reclassified as later-stage investments. Low-carbon mobility includes technologies specific to alternative powertrains, their infrastructure and vehicles but not generic shared mobility, logistics or autonomous vehicle technology. Within renewables, bioenergy includes transport biofuels but not biochemicals. Other low-carbon includes carbon capture, utilisation and storage, nuclear and heat generation. Fossil fuels cover fossil fuel extraction and use, fossil fuel-based power generation and fuel economy for hydrocarbon combustion vehicles.

Sources: IEA analysis based on Cleantech Group (2022), i3 database, accessed 11 August 2022; published in IEA (2022), World Energy Investment 2022.

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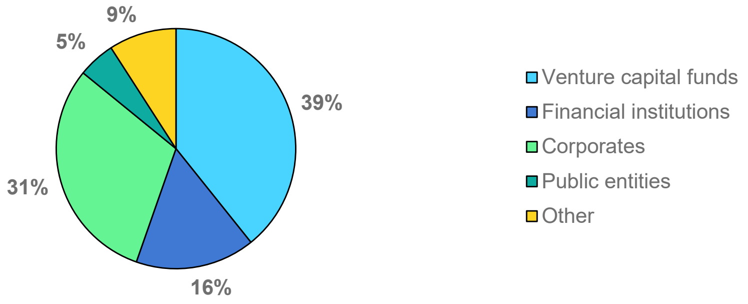
Early-stage venture capital investments in clean energy start-ups, by type of investor, cumulative over 2019-2021



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Notes: Early-stage deals are defined in the previous figure. Financial institutions include private equity and debt funds, investment banks and related firms, angel investors, and pension funds. Public entities include public-private investors and quasi-governmental actors. Corporates include private companies and state-owned enterprises. Other includes angel networks, crowdfunding, family offices, foundations, incubators and universities.

Source: IEA analyses based on Cleantech Group (2022), i3 database, accessed 11 August 2022; published in IEA (2022), World Energy Investment 2022.

Corporate venture capital as a complementary indicator of companies' innovation spending

While traditional investors, such as venture capital funds and other financial institutions, still account for the bulk of investments, companies have been increasingly investing in energy start-ups as well through corporate venture capital. Many major energy companies have set up dedicated venture capital branches that operate as investment funds and identify strategic investments in start-ups, with the view to supporting overall business strategy.

For companies, investing in start-ups can be a valuable complement to in-house R&D. It opens opportunities to acquire knowledge, talent, new technologies, concepts and processes, either to strengthen and modernise existing lines of business or to diversify and expand. For example, carmakers regularly invest in electric vehicle and battery start-ups. A number of oil and gas companies have been investing in a range of other energy segments, including renewables, hydrogen, and carbon capture, utilisation and storage. Industrial conglomerates with chemical industry activities have been investing in battery start-ups to strengthen their position as electric vehicle markets expand. Airlines have been investing in new companies that are developing small electric aircraft concepts.

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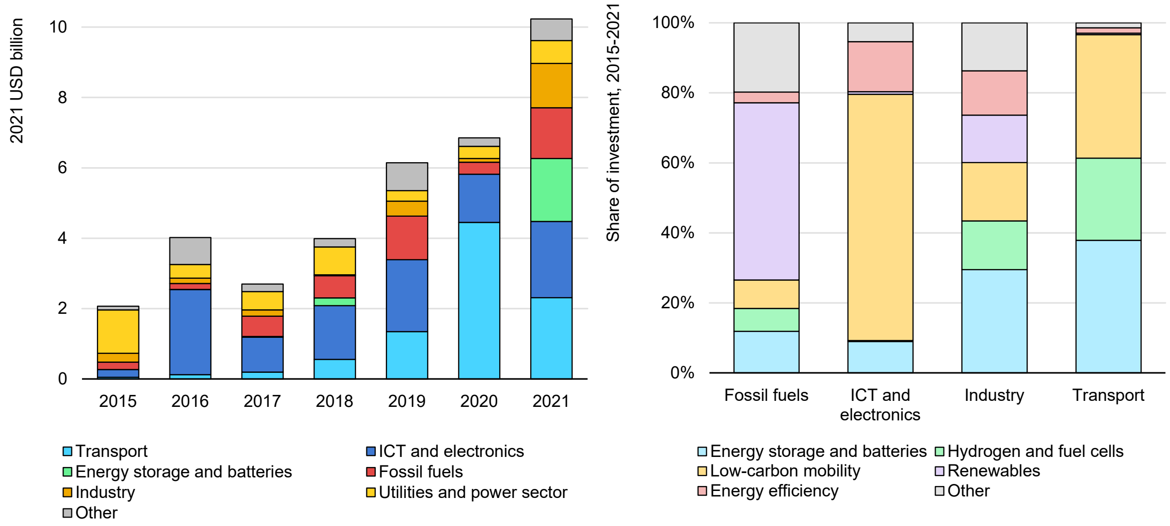
Corporate venture capital investment in clean energy start-ups, by sector of corporate investment (left) and start-up technology area of investment (right), 2015-2021



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Notes: ICT = information and communications technology. Investment includes seed, Series A, Series B, growth equity, private equity, buyouts and private investment in public equity deals. The result include only investment by private-sector investors. Where there are several investors, the deal value is evenly split across them. Left graph: industry = chemicals, cement, commodities, construction (excluding real estate), iron and steel, and other equipment suppliers; utilities and power sector = independent power producers, and electricity and renewables equipment and services. Right graph: low-carbon mobility includes technologies specific to alternative powertrains, their infrastructure and vehicles but not generic shared mobility, logistics or autonomous vehicle technology. Within renewables, bioenergy includes transport biofuels but not biochemicals. Other low-carbon includes carbon capture, utilisation and storage, nuclear and heat generation. Fossil fuels cover fossil fuel extraction and use, fossil fuel-based power generation and fuel economy for hydrocarbon combustion vehicles.

Source: IEA analyses based on Cleantech Group (2022), i3 database, accessed 11 August 2022; published in IEA (2022), World Energy Investment 2022.

There are several possible approaches to compiling data on corporate venture capital investments, including:

- Purchasing commercial databases (e.g. Cleantech Group and Crunchbase) and processing the data to filter for company investors in targeted sectors.
- Tracking news articles for targeted companies and extracting information relating to start-up investments.
- Examining annual reports by listed companies, which can sometimes contain information about start-up investments.

Commercial databases generally offer comprehensive coverage and high-quality data but acknowledge that a number of investors do not disclose critical data, such as deal values, for confidentiality, and that data can be harder to collect in some jurisdictions where there is lower reporting or availability of technology and innovation news. Processing and analysing such datasets can be costly and time-consuming, particularly for in-depth sectoral analysis.

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Chapter 6. Non-financial indicators for tracking energy innovation

A variety of indicators can give insights into the energy innovation activities of the business sectors, and these can be tracked over time for a more complete picture of how research topics, efforts and expectations are changing. Whereas financial indicators typically give information on past *inputs* to the innovation process, the complementary indicators summarised in this chapter can be designed to reveal trends in *outputs* and *outcomes*, plus perceptions of the future. This chapter covers a range of quantitative indicators on personnel, patents, publications, projects and products. These data are available via surveys and, in some cases, publicly available databases. In addition, we review questions about opinions and expectations that can be added to business innovation surveys.

R&D personnel

Questions that R&D personnel data can help answer: Is the business sector workforce for energy R&D increasing over time in certain technology areas, and how does energy compare with other sectors? Are women adequately represented in this workforce?

Strengths: R&D personnel data are a good indicator of the level of skills and effort being applied to innovation challenges in society, complementing data on financial inputs to innovation. There is an existing global framework and methodology for collecting this type of data that can provide a basis for energy-specific data collection.

Limitations: As R&D headcounts are generally based on survey data, the limitations are similar to those for surveys more generally.

Data on R&D employment in the energy sector is an *input* indicator of energy innovation efforts. There are well-established methodologies for gathering this type of data, usually via surveys, and some countries, such as Austria, are already collecting data on R&D personnel for energy technologies by the private sector. In its latest survey on energy research expenditure in the business sector, Austria estimated that around 3 900 people (full-time equivalent) were employed in R&D in the companies surveyed in 2019, of which 1 990 were working in one of its nine focus technology areas.

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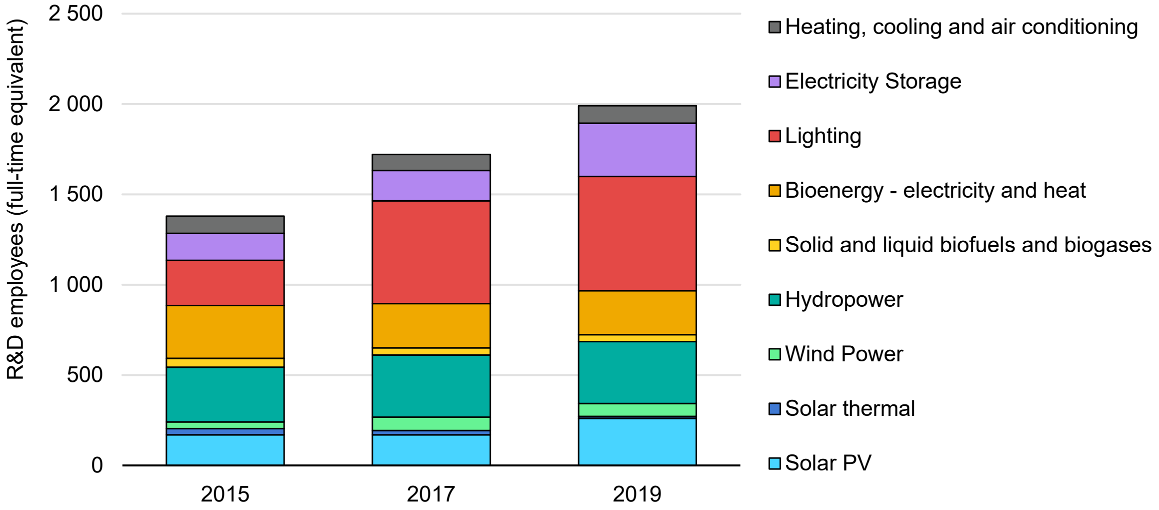
R&D personnel in selected technology areas in surveyed companies in Austria



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Note: This figure only includes those R&D employees assigned to one of the nine technology areas under research by the Austrian government, which also measures additional R&D employees beyond these focus technologies.

Source: Austrian Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology (2021), Energy Research Expenditure – Business Sector in Austria 2019.

The collection of R&D personnel data for the energy sector is in any case scarce. However, the United Nations Sustainable Development Goals provide an incentive for all countries to consider improving the sectoral details of their surveys. Agenda 2030, adopted in 2015 by all United Nations member states agreeing to work towards the Sustainable Development Goals, aims to substantively improve national statistics reporting capabilities.

Sustainable Development Goal 9, to “build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation”, includes a target to enhance “scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people”. UNESCO has the responsibility of monitoring indicator 9.5.2 (full-time equivalent researchers per million inhabitants).

Several international organisations – including UNESCO, the OECD, the Statistical Office of the European Union, the Ibero-American and Inter-American Network for Science and Technology Indicators, and the African Science Technology and Innovation Indicators Initiative – manage surveys on business R&D that include questions on R&D personnel in accordance with the guidelines in the OECD’s Frascati Manual.[6] For example, a UNESCO Institute for Statistics

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[6] Chapter 5 of the Frascati Manual defines R&D personnel as highly trained researchers, specialists with high levels of technical experience and training, and other supporting staff who contribute directly to carrying out R&D projects and activities, i.e. to create new knowledge.

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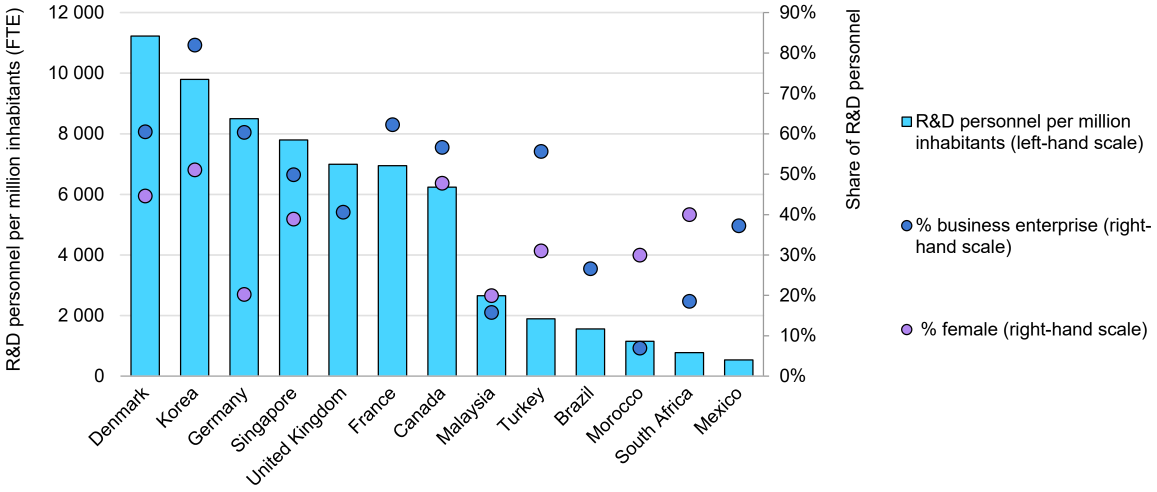
annual questionnaire is sent to around 125 countries that are not covered by the data collections of other international organisations. The survey requests headcounts in full-time equivalent or person-years, broken down by sex, R&D function, age and level of formal qualifications. Most recipients are in national ministries of science and technology or national statistical offices. As per the collection of R&D spending data in the same survey, ISIC Rev.4 is used. The UNESCO Institute for Statistics processes the questionnaires, communicating with the countries in case of questions, then calculates indicators and releases the data and indicators. The Guide to Conducting an R&D Survey provides advice that could be valuable to any country wishing to extend these survey approaches to ask about energy R&D in particular.

R&D personnel by enterprise and gender composition in selected countries



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Notes: FTE = full-time equivalent. The latest available data from 2018 have been used, but where not available, older data from 2017 or 2016 have been used. The UNESCO database does not report data for all countries for the share of female R&D personnel, and in those cases, the information has not been completed.

Source: UNESCO Institute for Statistics (2022). Science, technology and innovation: Research and experimental development, accessed 22 August 2022.

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Patents

Questions that patent data can help answer: Which companies are filing new inventions and in which detailed technology areas? Which partners are companies collaborating with on inventions? What are the national strengths and technology advantages among a country's businesses compared with other countries?

Strengths: Detailed data are publicly available, and historical analysis is possible over long time periods. Technology breakdowns can be more granular, and there are existing classifications to identify clean energy technology areas. Personnel in local patent offices have the required skills to navigate such datasets.

Limitations: Companies do not patent all inventions. Patents do not indicate whether they have led to the commercialisation of new or improved products or processes. There is a time lag of up to three years between when research is conducted, patents are filed and data become available. Manipulating detailed patent data may require dedicated knowledge and effort.

Patents are one indicator of the *outputs* of the innovation process, and there is a strong tradition of research on patent trends, thanks to the availability of rich data on all the applications made by companies to protect their inventions. Given the information that applicants are required to submit for a patent, analysts can derive insights into firm-level technology priorities, geographical variations, inventor gender, collaborations between different types of organisations and, sometimes, funders. The type of inventors most active in a specific technology area, for example whether a university, public research institution, corporate laboratory or start-up, can also shed light on the progress of a technology.

Not all patents are equal in their value or innovativeness, which has led to the development of two approaches to tracking inventions that are more likely to be impactful. The first considers only so-called "international patent families" for which patent applications have been filed in two or more patent offices worldwide. Multiple applications entail more effort and costs for the applicant, suggesting that the inventor perceives sufficient value to seek protection in at least two jurisdictions. The second approach uses citations, i.e. the citation of prior art by a new patent, to identify high-value patents that generate a lineage of new ideas. Citations can also enable the quantification of the diffusion of citations into other industries and the reliance of a technological class on prior research in the same area. In some cases, patent citations can reveal high-value inventions by a company, even if those inventions were never commercialised.

A significant advantage of clean energy patent analysis is the availability of a dedicated patent classification for climate and energy, managed by the European

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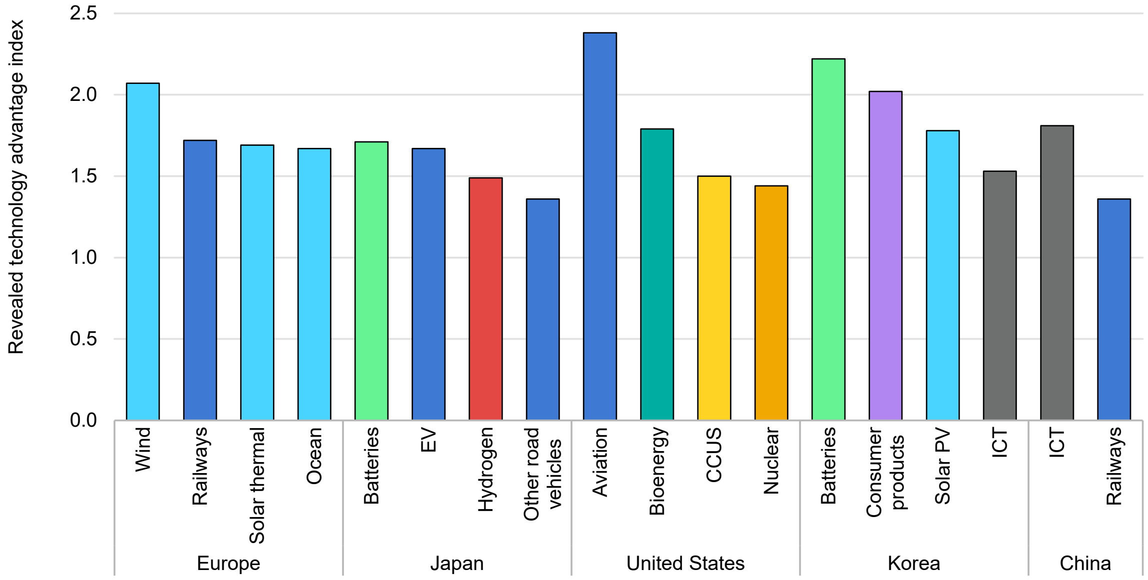
Patent Office (Chapter 2). The Y02/Y04S classification includes over 3.5 million documents and 372 cross-sectional classes that have been designed to cover technologies related to climate change with a high level of granularity. It is an integral part of the Cooperative Patent Classification and is freely available in the European Patent Office's patent information products, such as Espacenet, or to subscribers to the Global Patent Index and the PATSTAT database. The Y02/Y04S scheme provides a standardised global benchmark for tracking trends in the field of climate change mitigation technologies, with a considerable number of articles published in peer-reviewed journals. The European Patent Office and the IEA have further mapped the Y02/Y04S classification to a subset of low-carbon energy technologies and created a fossil fuel technology patent classification. The World Intellectual Property Organization, the OECD, the European Commission and the International Renewable Energy Agency have also made use of the Y02/Y04S scheme for their research and policy-making purposes.

Main revealed technology advantages of global innovation centres



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Notes: CCUS = carbon capture, utilisation and storage. The revealed technology advantage index indicates a country's specialisation in terms of clean energy technology innovation relative to its overall innovation capacity. It is defined as a country's share of international patent families in a particular field of technology divided by the country's share of international patent families in all fields of technology. A revealed technology advantage index score above one reflects a country's specialisation in a given technology. Only the highest revealed technology advantages (with scores of approximately 1.5 or more) are reported in the chart.

Source: European Patent Office and International Energy Agency (2021), Patents and the Energy Transition.

One downside of patent studies is that data are rarely available up to the present date. Published patent data in databases such as PATSTAT are often only available a year or more after an application is filed, and it can take up to two years to receive approval for an application. Approval is important because it confirms that the patent is unique and eligible. For citation analysis, it can take even more

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time for a patent to accumulate citations after being published, and the most reliable citation analyses might only reveal high-value patents a decade or more after application. Nonetheless, techniques have been developed for extracting the most up-to-date trends from patent data, based on historical patterns. Another consideration for governments seeking to track clean energy patent data is that manipulating the data available in most databases requires specialist analytical skills. However, this knowledge is generally already available in government patent offices, which could potentially collaborate on tracking projects.

Nonetheless, patent data present several upsides that can enrich innovation assessment, as individual technologies can have multiple classifications. Unlike surveys or administrative data, if a definition in the technology classification system is changed, the time series can be reconstructed (as illustrated for the Y02/Y04S classification updates) and the analyses can be very detailed, allowing for studies on international collaboration, the demographics of inventors, knowledge spillovers (e.g. through citations) and cross-organisation cooperation, etc.

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Scientific publications authored by, or co-authored with, the business sector

Question that scientific publications can help answer: For which technologies is the business sector cooperating and exchanging knowledge with academia?

Strengths: Scientific publications can provide insights into technologies at low maturity levels. They can also inform on knowledge flows between academia and the business sector over time and some of their linkages within the clean energy technology innovation system.

Limitations: Few companies engage in academic publications. There may be significant lags between research and publication. It is difficult to define clear system boundaries for energy technology innovations or consider whether complementary technologies, such as materials or emission control systems, should be included.

Peer-reviewed publications (academic journals and conference proceedings) are sometimes used to measure research performance and evaluate public research funding efforts. Often referred to as bibliometrics, these analyses generally use databases of indexed scientific publications that include metadata on the affiliations of authors.

However, while these publications in aggregate can shed light on certain innovation *outputs*, they are a less robust indicator of business sector efforts than patents. This is because scientific publications tend to report earlier-stage R&D than patents as business sector researchers have much lower incentives to publish than their peers in academia. Exceptions to this latter consideration are the outputs of collaborative R&D projects between the business sector and universities and other research institutions, and publicly funded projects undertaken by businesses that incentivise the grant recipient to publish results. The use of open source publishing and public-private cooperation are both priorities of the European Strategic Energy Technology Plan.

A study by the European Commission found that in 2019, more than 10% of clean energy-related publications were borne out of collaboration between the public and private sectors, and in the European Union, this share rises to 14%. The study sourced data from Scopus, which has a broad coverage of scientific literature, including regional and non-English-language journals and conference proceedings. Likewise, Scopus has been used to evaluate in various clean energy topics of relevance in recent years in Finland. In a separate study, the same authors used SciVal, in which affiliations are classified as belonging to the

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academic, corporate, government, medical, or other sectors. SciVal allows for the analysis of international co-publications – including those with multiple authors with affiliations from multiple countries – and, analogously, academic-corporate publications. Web of Science is another source of data used by analysts.

Bibliometrics can, therefore, be a direct means of tracking private sector research collaborations. An understanding of the interactions between academia and companies, such as the technologies in which there is a significantly higher or lower rate of co-publications, can help to design policies that enhance knowledge diffusion between sectors.

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Demonstration projects

Questions that data on demonstration projects can help answer: How much do companies spend on demonstrating priority energy technologies? What corporate capabilities are available in a given country for large-scale demonstration projects? What are companies' key near-market energy technology priorities?

Strengths: There are typically not a large number of projects to track in any given country or part of the energy sector. Public funding generally provides leverage for accessing information.

Limitations: Demonstration projects give a narrow view of the overall innovation process. Projects in one country may not be representative of the global portfolio of demonstration projects.

The innovation process involves successive demonstrations of scientific concepts, working prototypes, and consumer demand. The IEA has estimated a global need for around USD 90 billion in public funding by 2026 for large-scale demonstration projects for certain key net zero energy emissions technologies.[7] Such a level of funding would need to trigger a comparable amount of investment from the business sector. The IEA provides a standardised set of definitions and practices to enable countries to track their investments. However, most countries are not yet tracking their public investments in demonstration projects in an internationally comparable fashion.

Tracking companies' contributions to demonstration projects can provide information on whether the business sector is responding to the challenge of commercialising some of the most critical technologies for achieving net zero emissions. Key technologies like advanced biofuels, low-emissions cement production and synthetic aviation fuels are still at the pre-commercial stage with significant gaps between project costs and market value for low-carbon products. The willingness of the business sector to accept some of the costs and risks of early projects in order to gain a first-mover advantage is a test of their expectations and the effectiveness of government policy. Information on demonstration projects can also reveal useful updates on the capabilities of the business sector in important technology areas. Tracking individual projects is generally feasible, with the number of such technologies and projects being relatively small in any given

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[7] A "demonstration project", according to common usage in the energy sector, is typically one of the first few examples of a new technology being introduced onto a given market at the size of a single full-scale commercial unit. Demonstration projects in clean energy technologies have a pronounced innovative effect, as they enable technical (e.g. costs, efficiency, reliability and safety), organisation, policy, and market learning of the people who participate. They also perform important commercial and regulatory functions by showing customers that the technology is effective at scale, reducing the perception of risk for financiers and insurers; and informing regulators about costs and market deployment needs.

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country. In some areas, such as carbon capture, utilisation and storage and hydrogen, lists of demonstration projects in the planning and construction stages already exist.

Information on business sector activity in the area of large-scale demonstration projects can be gathered by governments in the process of their provision of public support. As demonstration projects generally require public support, especially for those technologies where economies of scale favour large installations, governments are often involved at several stages. These include:

- Issuing calls for expressions of interest. This sometimes precedes calls for proposals in order to gauge the level of interest.
- Evaluating applications for funding. Although confidential, this information can be processed and used for internal tracking.
- Contracting with projects for the funding of a defined project scope. Some of this information will also be confidential but potentially can be processed and used for internal tracking.
- Monitoring project progress and ensuring knowledge sharing. Some governments have developed means of ensuring the publication of as much technical output resulting from the public funding as possible – including performance improvements and cost reductions – without compromising commercial interests.

Furthermore, business surveys could also include specific questions on demonstration projects and related details, such as:

- Expenditures (split between different partners).
- Technology and strategic priorities.
- Technology upgrades.
- Time scales for moving from project announcement to engineering design to investment decision and then operation.

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New or improved technologies launched

Question that data on new or improved technologies launched can help answer: How successfully are the inputs to business sector innovation being translated into products on the market?

Strengths: This is one of a relatively small set of available firm-level indicators or innovation process *outcomes*.

Limitations: Establishing the boundary of what constitutes a new or improved product may be challenging. It cannot capture those technology processes based on tacit or non-codified knowledge (e.g. energy efficient building design).

Tracking the appearance of new or improved clean energy technologies on the market can provide an indicator of the *outcomes* of the innovation process. This information can be accessed via surveys or trademark databases, and analysts have successfully paired it with firm-level data on R&D spending and stock market reactions to provide insights into the effectiveness of business sector innovation. While the existence of a new product or service does not mean that it is necessarily innovative or successful, it is nonetheless a proxy that gets closer to the intended outcomes of innovation than innovation *output* indicators.

The launch of new or improved energy technologies could be measured through tracking firm announcements, especially for those technology areas that are a priority for governments. Knowing whether the product is new to the world, new to the firm's market or just new to the firm can provide additional insights into the pace of technological change. However, for a large range of technologies, this type of tracking may not be practical and may also encounter issues relating to firms' propensity to publicly announce new product launches. If certain types of companies are more likely to make such public announcements than others, the results may be biased.

The most common way to collect data on new products is via surveys, and guidelines are provided in the Oslo Manual. Specifically, the Oslo Manual includes suggested questions on the "share of sales accounted for by product innovations", broken down into those sales that can be attributed to products that have different levels of novelty: new to the world, new to the firm's market or just new to the firm. It also contains a suggested question about the number of product innovations introduced by a respondent within defined numerical ranges. However, it includes a note of caution about the reliability of results from such self-reporting. Usefully, the Oslo Manual also defines the minimum requirement for a new product or

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process to be considered innovative: "having one or more characteristics significantly different from those contained in the product or processes previously offered by the firm".[8]

Building on existing surveys that are consistent with the Oslo Manual, governments could include in their business innovation surveys specific questions on new or improved clean energy technologies and whether they target mostly lower production costs or higher energy efficiency. As one example of such a question, India's Annual Survey of Industries includes a question about the energy consumption of new products launched. Since 2008, the Community Innovation Survey, a survey of innovation activity in enterprises in EU member states and some European Free Trade Association countries, has included a question on innovations with environmental benefits[9]. The latest Community Innovation Survey version asks enterprises whether they introduced new products or services during the three years from 2020 to 2022 that reduce the energy use or CO_2 footprint of the user. The survey also asks about addressing other types of pollution and the facilitation of recycling and product durability, as well as a rough self-assessment of the significance of these contributions to environmental protection.

Another means of tracking novelty in the market is through trademark filings,[10] for which information can be found from local patent agencies, such as the Japan Patent Office and the United States Patent and Trademark Office; intellectual property offices, such as the European Union Intellectual Property Office; and third-party databases, such as LexisNexis or Dialog. Trademarks exist to indicate the company origin of a product and highlight to consumers that those offerings are different from competing offerings. Importantly, trademarks have to prove actual use, and non-use typically results in cancellation. Therefore, trademark registration data can complement patent data to show not only that a firm has invented a potential new product or a new production method but also introduced a new product or service to the market.

However, as a drawback, trademark classification is made according to an international classification of goods and services, the Nice Classification, which is less detailed than the Y02/Y04S scheme for patent classification. The relevant trademarks for each technology area have to be identified by looking for keywords in the trademark description. The OECD has applied such an approach to the emerging business of hydrogen supply for the energy sector, indicating that "while patenting activity on hydrogen production technologies is growing at a very slow

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[8] A "significant" difference excludes minor changes and enhancements and could also result from a series of minor improvements provided that the sum of these minor improvements results in a significant difference in the final product or process. The Oslo Manual contains an acknowledgement that some subjectivity will shape responses to the question.

[9] An innovation with environmental benefits is defined as a new or improved product or process that generates a lower environmental impact during its production or use compared to previous products or processes.

[10] The World Intellectual Property Organization defines a trademark as "any sign capable of distinguishing the goods of or services of one enterprise from those of other enterprises".

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pace, the number of hydrogen trademarks recently took off, suggesting that companies are focusing on commercialisation rather than on innovation, and anticipate a growing hydrogen market pulled by government subsidies”.

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Opinions and expectations

Questions that information about opinions and expectations can help answer: How much do companies expect to invest in R&D and innovation in the coming years? How do companies perceive the strength of the innovation ecosystem and current business environment? How do companies expect energy technology innovation priorities to evolve in the near future?

Strengths: Opinions and expectations can offer valuable insights about what is affecting the innovation ecosystem and trends in company perceptions, complementing quantitative data sources. Requesting data ranges or growth rates rather than precise numbers can help overcome confidentiality challenges.

Limitations: It can be challenging to draw macro-level conclusions from subjective data, and responses may be highly dependent on the personnel providing the information within the company. Surveys are generally voluntary, hence achieving high response rates and collecting representative data can be difficult.

The previous sections of this chapter presented different quantitative indicators, such as R&D personnel, patent counts or academic publications, that are built using numeric and verifiable data. However, their correlation with innovation inputs and outcomes remains a matter of proper interpretation. While quantitative indicators offer a historical snapshot, qualitative indicators may provide complementary insights into how innovation is actually happening in a company and how it may evolve in the coming years. This section reviews some quantitative and qualitative metrics that have been gathered by surveys of opinions and expectations. All of these examples could be oriented to energy companies or technologies specifically. Typically, where quantitative information is requested, ranges and relative comparisons (such as, "Do you expect better performance for product innovations compared to your other products?") are preferred to precise requests in order to navigate confidentiality concerns and increase response rates.

Company characteristics

The 2022 Innovation Research Interchange annual survey asks respondents about their revenue, R&D spending, the location of their R&D labs and the portion of R&D spending outside a given jurisdiction.[11] Respondents are given predefined

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[11] Since 1984, the Innovation Research Interchange (formerly the Industrial Research Institute) has surveyed R&D and innovation leaders, with the primary goal of mapping expectations for R&D investment levels, activities, budgets and other important factors for the year ahead. This voluntary survey provides qualitative and perception-based inputs that allow

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ranges, such as R&D spending “less than USD 1 million”, “USD 1-5 million”, “USD 6-10 million”, “USD 11-50 million”, “USD 51-100 million”, “USD 101-500 million”, “USD 501-1 000 million, “more than USD 1 billion” and “I don’t know”.

In the Oslo Manual, the OECD authors recommend asking companies about their general performance expectations, such as the direction of future sales or profits, and particularly the expected performance of newly launched products. The intention is to try to establish a link between innovation and performance. Predefined ranges are also recommended here, for example “0%”, “more than 0% to less than 25%”, “25% to less than 50%”, “50% to less than 75%”, “75% to less than 100%” and “100%”.

Since 2020, the Community Innovation Survey asks about the degree of importance (“high”, “medium”, “low”, “not relevant”) of a series of factors related to climate change for a business: “government policies or measures related to climate change”, “increasing customer demand for products that help mitigate or adapt to climate change (e.g. low carbon products)”, “increasing costs or input prices resulting from climate change (e.g. higher insurance fees, higher prices for water, adaptation of processes or facilities)”, “impacts of extreme weather conditions (e.g. damages/disturbances)”.

Innovation spending outlook

The 2022 Innovation Research Interchange survey asks respondents about the difference between their projected and actual R&D budgets for the previous year, which allows for better contextualisation of the annual forecast. To explain the variances between projected and actual spending, the survey asks respondents to choose the top three factors behind the budget changes from a list of options: “changing business/market conditions (including Covid-19)”, “strategy change”, “changed emphasis on growth”, “workforce change”, “schedule days” and “technical success or lack thereof”.

The 2022 survey asks about the level of increase or decrease in R&D spending the respondent expects in a given year with respect to the previous year: “increase more than 10%”, “increase 5% to 10%”, “increase 3% to 5%”, “increase 1% to 3%”, “little to no change”, “decrease 1% to 3%”, “decrease 3% to 5%” or “decrease more than 5%”. It also asks about the five-year forecast but provides broader response ranges: “significant increase”, “slight increase”, “stable”, “slight decrease” or “significant decrease”. The survey also asks about the staffing outlook and respondents’ hiring plans using a response scale to indicate an increase, decrease or no change, differentiating between new graduates,

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nowcasting, i.e. getting insights about the very near future and upcoming trends. For example, the 2022 Innovation Research Interchange survey contained 25 questions: two open-ended questions and 23 questions with defined response sets, sometimes with the option to add comments when appropriate.

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professional R&D staff, retiring senior staff and temporary or contract staff. This information can be used to nowcast metrics on energy innovation and identify potential bottlenecks to innovation before they become obvious in the statistics.

Innovation management and outlook

The 2010 McKinsey Global Survey on Innovation and Commercialisation employed a series of metrics to explore how a company manages innovation and how the innovation processes are rooted in the company. These can provide valuable insights into the formalisation of the innovation process in the business sector. The survey asked, “How effective is your organization at using each of the following tactics to drive innovation?”, allowing answers in four categories (“extremely/very effective”, “somewhat effective”, “not at all effective” and “don’t use”) for each of the following items:

- corporate venture capital
- global centres of innovation
- outsourced R&D and innovation (e.g. to another organisation or geography)
- formal accountability to business leaders for innovation
- partnerships and open innovation
- traditional R&D in business lines
- centralised innovation initiatives at the corporate centre or for specific projects.

The 2022 Innovation Research Interchange survey asked about the expected changes in collaboration by type using a response scale to indicate an increase, decrease or no change, including if there is no activity, and differentiating between the following types of collaboration: “participation in R&D alliances”, “participation in R&D consortia”, “acquisition of IP through M&A”, “acquisition of IP through direct purchase of patents”, “inbound IP licensing”, “contracts/grants with academia”, “contracts with government labs”, “crowdsourcing/open innovation competitions”, “creation of spinoffs based on developed technology”, “contracts with start-ups” and “corporate venture capital”.

Innovation strategy and outlook

An opinion survey can also be used to get insights into the innovation strategies of the companies surveyed. Answers to these questions can provide relevant insights into the degree of technological disruption versus incremental improvements expected from the companies. For example, the 2008 Boston Consulting Group Senior Executive Innovation Survey covered questions such as: “Are you satisfied with your company’s return on innovation spending” or “Where does innovation rank among your company’s strategic priorities (“top priority”, “top-three priority”, “top-ten priority” or “not a priority”)? The McKinsey survey asked about the statements that best describe a company’s primary growth

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challenge, with respondents choosing from options indicating growth in the existing core business, growth through opportunities adjacent to the core business, or growth in new business beyond the boundaries of the existing core business or indicating that they are in the early stages of growth as a new business.

Since 2008, the Community Innovation Survey asks about the importance ("high", "medium", "low" or "not relevant") of each of the following factors in driving a firm's decision to introduce innovations with environmental benefits: "existing environmental regulations", "existing environmental taxes, charges or fees", "environmental regulations or taxes expected in the future", "government grants, subsidies or other financial incentives for environmental innovations", "current or expected market demand for environmental innovations", "improving your enterprise's reputation", "voluntary actions or initiatives for environmental good practice within your sector", "high cost of energy, water or materials" and "need to meet requirements for public procurement contracts". While countries do not have to collect information exactly as presented in the document for harmonised data collection for the Community Innovation Survey, some countries, such as Luxembourg, uses this question in their Combined Survey on R&D 2020 and Innovation 2018-2020.

The Boston Consulting Group Senior Executive Innovation Survey also asked about the biggest obstacles companies face when it comes to generating a return on their innovations. Likewise, the Innovation Research Interchange survey asks respondents to identify the factors most likely to influence their companies' innovation success. This question is asked in a rank-order format, where respondents identify their first, second and third priority areas from among a list of options. The options include "balancing long- and short-term R&D objectives", "attracting, developing and retaining talent", "building and maintaining an innovation culture", "identifying disruptive technologies", "measuring R&D effectiveness", "managing innovation globally", "complying with regulatory changes" and "improving knowledge management".

The Innovation Research Interchange survey also asks which tactics organisations expect to employ to develop new technologies over the next three years. Respondents can select from responses that include "in-house development", "academic collaborations", "hiring new staff", "industrial collaborations/partnerships", "increasing R&D funding", "working with start-ups", "licencing technology from others", "open innovation competitions", and "outsourcing".

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Sectoral innovation landscape

Surveys can provide insights into companies' perceptions of a sector and their competitors. For example, the 2022 Innovation Research Interchange survey asks an open-ended question about the greatest technological challenges that respondents believe their industries will face over the next three years. The 2008 Boston Consulting Group Senior Executive Innovation Survey asked about the three global companies that respondents considered were the most innovative in a given industry and why.

Surveys can also provide information about the general regulatory challenges companies face to innovate in a given area. For example, the 2022 Innovation Research Interchange survey asks respondents to note any regulatory or legislative actions by local, national or international governing bodies in 2021 that they believed were likely to affect their R&D organisations significantly.

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Chapter 7. Insights for governments

Examples throughout this overview illustrate that methodologies for tracking business sector innovation have been developed for a wide range of indicators. However, there is often no uniformity with regard to the collection of innovation data specific to energy. Individual governments have mostly developed these indicators to better inform their policies. The examples shown provide guidance, inspiration and information on where to find more details or even directly contact experienced practitioners, although the report cannot provide detailed instructions on how to collect energy innovation data in the business sector. While some of these methodologies have been developed for or applied to energy as a distinct technology field, there are also many good examples of how more general approaches could be adapted to energy topics.

There is clearly a strong appetite among governments and stakeholders for more information in this area, and the efforts to integrate it into evidence-based policy are growing.

Governments can select indicators for their tracking framework based on their resources, willingness to invest in the creation of new data sources and ability to cover as much of the innovation process – from inputs to outcomes – as possible. Clean energy innovation outcomes are particularly hard to track and attribute to the business sector, and we hope more research in this area will be forthcoming.

Based on the summaries in this overview, we propose six main insights for governments:

- **Start soon**. Despite the challenges related to tracking clean energy technology innovation in the business sector, governments can improve their current efforts by adopting effective existing practices across a range of indicators. While the work being done by some countries is very advanced in certain areas, other countries should not be discouraged from starting to measure energy innovation in the business sector, even if they cannot do so in a way that is as comprehensive or if they have to use proxies or assess a smaller subset of companies (e.g. the largest ones or those working on priority energy technologies).
- **Be patient to obtain results**. Few of the methodologies covered by this overview can be implemented without some investment of effort. In a number of cases, it might take several years to generate results and, unless historical data are readily available (such as for financial filings, patents and venture capital), will usually take more time to create a useful time series. However, most countries have

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already invested heavily in high-quality systems, including mandatory business sector R&D and innovation surveys. These existing tools generally meet international standards and provide a solid foundation that can be adapted to more targeted purposes, such as clean energy. The Canadian and Italian dedicated energy R&D surveys for businesses are good examples of this.

- **Integrate energy questions into existing surveys on R&D spending and other innovation-related topics**. Surveys offer the most powerful tool for generating reliable and targeted data on business sector energy innovation. They can be tailored to appropriate energy technology scopes that reduce the reliance on industrial classification systems, which can poorly reflect clean energy activities. They can include a range of metrics, from R&D spending and personnel to project products and opinions. Not including questions across a range of indicators is a missed opportunity, as R&D spending is not the only input leading to innovation, and it is uninformative about outputs and outcomes without additional metrics on these. A small number of additional questions dealing quantitatively or qualitatively with other inputs to innovation can be complementary and highly insightful. While R&D spending and personnel data reflect historical values, opinions can illustrate short-term future trends and help to identify issues in advance.
- **Develop frameworks for tracking innovation that align with user needs**. Any new approach to tracking business sector energy innovation must be carefully designed with the end product in mind. The insights from the methodologies covered in this overview are only valuable if they can be disseminated to decision makers as an accessible and reliable source of information on the evolution of national business sector innovation performance. Furthermore, effective dissemination and impact are vital to gain the trust of the business sector to help improve tracking efforts, by providing robust data in particular. Surveys require a significant amount of upfront effort, such as consulting with businesses and public institutions, designing the questionnaires, obtaining approvals and carrying out implementation. Over the past four decades, the results of well-designed R&D surveys have been a unique and influential resource for understanding trends. They demonstrate the value of investing upfront to ensure that data will cover a range of priority indicators, include the right set of company respondents from the outset, continue to be insightful in the medium-to-long term, be maintained by sufficiently resourced statisticians over time, produce timely results and use the latest data techniques (for example, microBeRD).
- **Be consistent with related national and international activities and reporting commitments**. To maximise the value of a tracking framework for business sector clean energy innovation activities, attention should be paid to consistency with comparable data on the public sector and on other countries.
- **Participate in international efforts for building consensus and sharing practices**. International cooperation will be an important factor in raising this type of tracking to the level of authoritative guidance available for public sector energy RD&D spending (from the IEA) and general R&D and innovation surveys (from the OECD's Frascati and Oslo Manuals). International efforts should be encouraged

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to establish some degree of uniformity in the type of data collected and their technological disaggregation. Similarly, efforts should aim to align the implementation of best practices among different countries to improve the tracking of energy innovation in the business sector, which will ultimately lead to better policies.

Overview of energy innovation indicators in the business sector

Indicator	Stage of the innovation process	Existence of a well-established method	Existing examples of applications to energy*	Publicly available data	Effort required
R&D spending	Input	Surveys: mature	Yes	Poor	Significant (to create or adapt surveys)
		Financial filings: needs refinement	Yes	Good	Medium (data processing)
		Tax returns: unproven	No	Poor/good	Medium (establish systems)
		Via relationships: unproven	No	Poor	Medium (establish systems)
Venture capital	Input/output	Mature	Yes	Good	Low (data processing)
Corporate venture capital	Input	Mature	Yes	Good	Low (data processing)
R&D personnel	Input	Mature	Yes	Upfront effort required to generate survey data	Significant (to create or adapt surveys)
Patents	Output	Mature	Yes	Good	Medium (data processing)
Scientific publications	Output	Mature	Yes	Good	Medium (data processing)
Demonstration projects	Input/output	Needs refinement	In development	Poor	Significant (establish systems)
New or improved products launched	Output/outcome	Mature	Yes	Poor	Significant (to create or adapt surveys)
Opinions and expectations	Input/output/ outcome	Mature	-	Poor	Medium (to create or adapt surveys)

* To the best of the authors' knowledge.

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