Global Innovation Needs Assessment

System flexibility

October 12, 2021

Funded by:

climateworks FOUNDATION

Foreign, Commonwealth & Development Office

Analytics by:

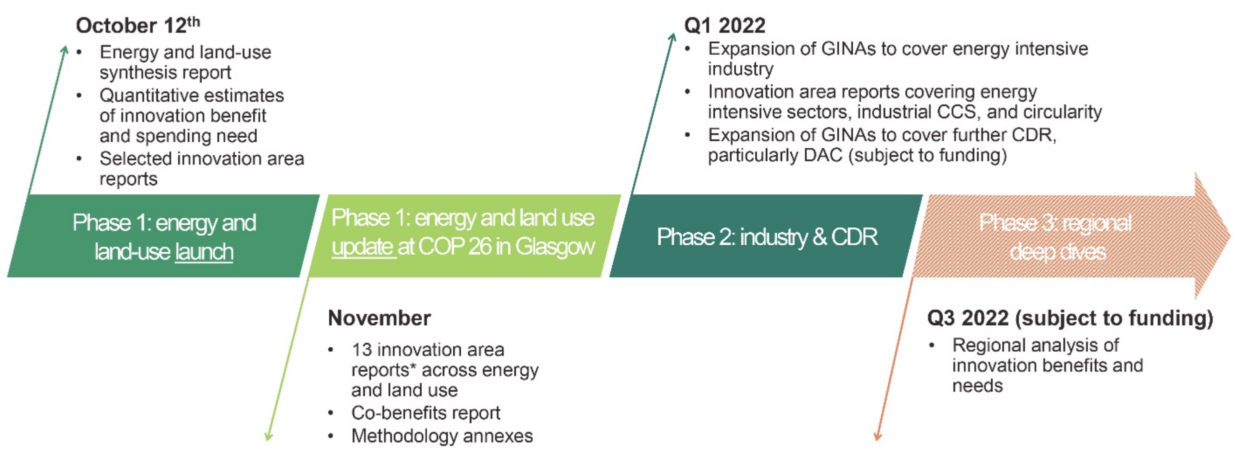
:vivideconomics

The Global Innovation Needs Assessments

The Global Innovation Needs Assessments (GINAs) is a first of a kind platform for assessing the case for low carbon innovation. The GINAs take a system wide perspective, explicitly modelling the impact of innovations across the global economy. Uniquely, the analysis quantifies the economic benefits of low carbon innovation and identifies the public investment levels — from research and development to commercialization — needed to unlock these benefits. The analysis is divided into 3 Phases: Phase 1 on global energy and land use, Phase 2 on global industry, and Phase 3 on regional deep dives. This synthesis report forms part of Phase 1.

The analyses do not assess all relevant technologies, nor do they evaluate all relevant factors for policy judgements. Instead, the work is intended to provide a novel evidence base to better inform policy decisions. The Phase 1 analysis looks across a broad range of climate mitigation technologies in energy and land-use, ranging from demand response to protein diversification, to model the economic value of related innovation investment. Later phases expand the research. As with all technologies, there are risks and potential downsides to their adoption, and some remain controversial. Which innovations to invest in is ultimately a policy judgement, and this analysis does not provide policy recommendations to invest in any specific technologies.

Phases of the Global Innovation Needs Assessments



The Global Innovation Needs Assessments project is funded by the ClimateWorks Foundation and the UK Foreign, Commonwealth & Development Office. Analysis was conducted by Vivid Economics. Thank you to the UK Department for Business, Energy and Industrial Strategy (BEIS) analysts and the Mission Innovation Secretariat who were consulted on aspects of the work, and for BEIS support for the 2017-2019 Energy Innovation Needs Assessments which developed the methodological approach taken here.

The findings and views expressed across this project do not reflect the view of ClimateWorks, the Government of the United Kingdom or Mission Innovation.

Phase 1 GINA outputs

The suite of reports across innovation areas methodological annexes and a synthesis report for GINAs are available on the GINA website at: https://www.climateworks.org/report/ginas/.

The suite of outputs for Phase 1 of the Global Innovation Needs Assessments

1. **Energy and land use synthesis report –** *slide based summary for policymakers and executives*
   Synthesis of the findings across the innovations considered in energy and land use

2. **Energy and land use & agriculture innovation reports –** *in depth quantitative analysis for industry and policy analysts*

   - **Wind power**
     Offshore and onshore wind turbines
   - **Low carbon hydrogen**
     Electrolysers and gas reforming with CCS
   - **Solar power**
     Utility-scale and distributed PV
   - **Low carbon fuels**
     2nd generation biofuels, synthetic fuels (H_2 + CO_2)
   - **Nuclear power**
     Small modular and large-scale advanced reactors
   - **System flexibility**
     Battery storage, power-to-X, demand response
   - **Buildings**
     Heat pumps, building fabric
   - **Power CCS**
     CCS in power generation (coal, gas and biomass)
   - **Zero-carbon road transport**
     Battery electric vehicles, fuel cell electric vehicles
   - **Protein diversity**
     Replacement food and novel vegan food
   - **Decarbonizing agrochemical inputs**
     Innovative fertilisers and pesticides
   - **Yield enhancing technologies**
     Digital agriculture and vertical farming
   - **Irrigation**
     Improved irrigation methods and systems

   The selected innovation areas were selected for their potential for further innovation and the potential magnitude of the associated system benefits. Their selection here is because they could play a key role in a net zero pathway but does not imply that an optimal net zero pathway necessarily includes them. Further notes on the rationale behind their selection is provided in the methodology annex on the GINA website

3. **Co-benefits of innovation report –** *qualitative analysis of the environmental and other non-economic benefits of net-zero innovation*
4. **European case study –** *Analysis of jobs and growth benefits in Europe specifically*
5. **Methodology annex–** *A description of the modelling approach taken for analysts*

Executive Summary

Improved power system flexibility is essential to decarbonising the power system. All power systems have some inherent level of flexibility, designed to balance supply and demand at all times, despite their variability and uncertainty. Historically, flexibility has been provided mainly by thermal power plants by adjusting power output up and down to meet real time demand. However, this will be increasingly challenging as power systems decarbonize via variable renewable energy (VRE), with solar and wind power potentially supplying 70% of electricity by 2050. Although solar and wind are already the cheapest forms of new-build electricity generation in many regions, their supply is inherently variable and unpredictable. To ensure that energy supply is sufficient to meet demand and maintain stable grid operations at all times, there needs to be greater flexibility in the power system.

Innovation in system flexibility can expand the ability and reduce the cost of system resources to ramp up and down in response to system needs (e.g., changes in solar generation as the weather changes). Innovation can occur both in the physical sources of system flexibility as well as the way that they are integrated within the power system. Physical sources of system flexibility include all forms of power generation, energy storage, and demand response. Demand response can come from different flexible loads on the power system, such as smart appliances, industrial processes, electric vehicles, hydrogen electrolysers ('power-to-gas'), and heating ('power-to-heat'). Meanwhile, the physical integration of all these resources would rely on the rollout of smart meters, sensors, improved data management techniques, and grid upgrades. Innovation can make these technologies and applications more widely available and at lower costs. Finally, better market platforms need to be established for emerging sources of flexibility to exploit their full potential and remunerate them for the system value they provide.

Stronger innovation in system flexibility could reduce global energy system costs by $180 billion per year (1.6% of total) on average between now and 2050. Improved system flexibility would help power systems integrate increasing amounts of solar and wind power, thus reducing the total cost of power system decarbonization. This will further translate into cost savings for electricity consumers in industry, transport, and buildings. By 2050, the value of cost savings from innovations in system flexibility could reach $490 billion per year in a high-innovation scenario. This represents an 80% increase in storage capacity relative to a low-innovation scenario, allowing solar and wind penetration in 2050 to go beyond 70% and approach 80%.[1]

To unlock these substantial benefits, global public RD&D and commercialization needs to increase to $4.3 billion per year and $5.6 billion per year, respectively. Public RD&D spending on energy storage, power transmission, distribution, and grid control systems is estimated to be $1.1 billion in 2019. The analysis presented in this report estimates that this amount should be at least tripled. The amount of RD&D spending *related* to system flexibility will span a wider range of power system resources and overlaps with many technologies covered in separate GINAs reports, such as heat pumps, hydrogen

[1] There are contrasting views on what and how much flexibility is feasible within the power system. For example, it is unclear what is the percentage of electric vehicles that could be expected to provide grid services in any given hour of the day. This report quantifies the benefits of system flexibility innovations at a high level without getting into specific assumptions for each source of flexibility.

electrolysers, EV batteries and fuel cells – all of which could be configured to provide demand side flexibility for the power system.

Commercialization spending should be accompanied by reforms in electricity market designs to remove barriers and enable new business models. Commercialization spending could focus on technologies that have been demonstrated but require extra support to achieve scale and become cost competitive – this likely focuses on capital-intensive projects such as utility scale short-/long-term energy storage and HVDC transmission. As an example, $1 billion in spending could already support dozens of 100MW scale battery storage projects, helping to establish the supply chains needed to unlock further growth. However, improvements in system flexibility also depend on whether electricity markets reward innovations in flexible resources and enable the participation of new business models such as aggregators. Currently, many electricity markets lack scarcity pricing and have limits on who can participate as suppliers in energy and ancillary services markets, therefore, failing to engage and remunerate flexible resources in the power system. Reforms could focus on opening up electricity markets to new participants and provide efficient price signals that accurately reflect system value in different times and locations.

As the market value for system flexibility could increase by over 20 times by 2050, this creates substantial business opportunities in the value chain. This report has quantified the market size associated with aggregators, utility scale batteries, and smart charging stations for electric vehicles. Their combined turnover could reach $260 billion per year in 2050, a 20-fold increase from the current scale. At that point, these industries could provide $82 billion per year in GVA and support 760,000 direct jobs in high-value economic activities. Beyond the scope of these three industries, many more manufacturers and service providers will benefit from growing demand associated with system flexibility, such as smart meters, HVDC transmission cables, and load optimization. Innovative companies supplying these highly traded goods and services will benefit from a rapidly growing global market.

Public benefits (i.e., energy system cost savings)	Cumulative 2021-50, undiscounted: $5,9 trillion Cumulative 2021-50, discounted at 5% p.a.: $1,9 trillion Annual average 2021-50, undiscounted: $190 billion
Business opportunities	2035: GVA $41 billion, supporting 650,000 direct jobs 2050: GVA $82 billion, supporting 760,000 direct jobs
Public spending required	Commercialization, annual average 2021-35: $5.6 billion per year RD&D, annual average 2021-35: $4.3 billion per year

1. System flexibility and the energy system

1.1. Current role in the energy system

Power system flexibility is crucial to lowering the costs of meeting electricity demand and maintaining stable grid operations. All power systems have some inherent level of flexibility, designed to balance supply and demand in real time, despite their variability and uncertainty. To do so, the power system could draw on different power system resources, such as power plants or batteries, to ensure sufficient supply is available to meet demand at all times, and to maintain a stable voltage and frequency on the grid. A lack of system flexibility brings severe consequences, such as increased frequency of load losses or blackouts, increased need for expensive peaking capacity and grid reinforcement, and greater curtailment of solar and wind power, resulting in lower returns for developers and higher costs for consumers.

Box 1 Meaning of system flexibility

Power system flexibility can be defined as the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long-term security of supply (IEA 2019).

Historically, system flexibility mainly came from thermal power plants, adjusting power supply to meet demand and maintain grid stability. Two properties of thermal power plants are particularly relevant for their ability to provide system flexibility: ramping and inertia. Thermal power plants provide system flexibility by *ramping* their power output up and down in response to system needs – when energy is scarce, spare generation capacity could be deployed and ramp up output in short periods of time.[2] Thermal power plants also provide *inertial response* as they have large rotating mass that resists instantaneous imbalances in supply and demand – the spinning masses prevent abrupt changes in frequency on the grid. These two properties have made thermal power plants the main sources of system flexibility in most power systems today. Other sources of power generation can also provide system flexibility, but to a more limited extent.

As renewables increasingly dominate power systems, the physical sources of system flexibility are becoming more diversified. With improved technologies and increased decentralization and digitalization, various types of energy storage and demand response can provide large amounts of system flexibility at an affordable cost. Grid infrastructure, interconnectors, and power generation could all provide some forms of system flexibility. The optimal way to provide system flexibility will include a

[2] The speed at which power plants could ramp up and down output affect their flexibility. Open cycle gas turbines (OCGT) have a ‘hot start-up time’ of about 5-11 minutes, while combined cycle gas turbines(CCGT) and coal-fired power plants are about 1-1.5 hours and 2.5-6 hours respectively.

diverse mix of these resources as they have unique properties and can complement each other. Table 1 provides a list of different types of flexible power system resources.

Table 1 Physical sources of system flexibility

Physical source	How it provides flexibility	Examples
Generation	Ramping power output up/down to meet system requirements	• Dispatchable thermal power plants • Renewable power
Energy storage	Storing energy when it is relatively abundant, and releasing the stored energy back to the system when it is scarce	• Batteries (e.g., lithium-ion, flow batteries) • Thermal storage (e.g., liquid air, molten salt) • Electro-mechanical (e.g., flywheels) • Pumped hydro storage • Hydrogen ('power-to-gas')
Demand response	Using electricity when it is relatively abundant, and reducing usage when energy is scarce	• All kinds of residential, commercial, industrial power demand, e.g., electricity used for heating/ charging electric vehicles
Network infrastructure	Allowing for greater power flows to balance system requirements across space	• Transmission grid • Distribution grid • Interconnections

System flexibility already plays a crucial role in power systems with high solar and wind penetration. In Denmark and Ireland, where variable renewable energy (VRE) as a share of total power generation has already exceeded 60% and 30%, respectively, system flexibility mainly comes from interconnection with the European power grid, alongside a significant rollout of smart grid technologies. In Southern Australia, registered capacity for battery storage already reached 205MW in 2020, which is over 6% of the peak load. Meanwhile, California is expecting battery storage to reach 3GW by the end of this year, which is also around 6% of its peak load.(1)

1.2. Future role and deployment potential

System flexibility is increasingly important to integrate more solar and wind in power systems. Although solar PV and onshore wind are already cheaper than fossil fuel power in areas covering two-thirds of the world population, they are inherently *variable* and *unpredictable* both within days and across seasons.(2) Increased variability of power supply means the net load on the grid will ramp up and down more rapidly. More unpredictable power supply, meanwhile, implies that supply forecast errors will increase, making it more challenging to reliably meet energy demand and maintain stable grid operations. These are exacerbated by additional changes in the power system: the closure of thermal power plants that provided flexibility, growth in peak demand as heat and transport electrify at scale, and the prevalence of distributed energy resources that require more active management in distribution networks.

Amongst 1.5°C scenarios, global electricity demand more than doubles by 2050, while the share of electricity generated by VRE grows from 9% today to 64-74% in 2050.[3] Growth in electricity demand is driven both by population and economic growth, as well as widespread electrification of all end-use sectors, including industry, buildings, and transport.

This will dramatically increase the need for power system flexibility. For example, the capacity factor for wind farms over a large area could fall to near-zero for sustained periods, effectively removing large

---

[3] BP Statistical Review for 2020 electricity generation mix; NGFS net zero scenarios for 2050

amounts of power generation capacity from the grid, as it happened in Britain for nine consecutive days in 2018.(3) To avoid the severe consequences for grid stability and energy prices, power systems that rely on solar and wind power will also have to invest more in dispatchable power (e.g., gas CCS), bulk energy storage, and interconnections. Meanwhile, on the demand side, widespread electrification will require greater ramping capabilities in the system. For instance, the energy demand from electric heat pumps in the evening peak hours could be three or four times greater than the rest of the day.(4)

Significant growth in energy storage and demand response is needed to provide such flexibility as the share of dispatchable thermal power in the generation mix declines. Table 2 below showcases the large increases in energy storage among scenarios consistent with 1.5°C warming. Battery storage is projected to grow rapidly between now and 2030, with capacity growing by 15x to 30x in IEA and IRENA scenarios. Other sources of system flexibility, such as demand response and interconnection, are not explicitly quantified in global scenarios.[4] However, recent studies in the literature indicate that they need to increase in similar proportions under cost-effective pathways.[5]

Table 2 Growth in energy storage in different energy transition scenarios

Storage type	Current size	2030	2050	Scenario
Stationary battery	11 GWh	180-420 GWh	NA	IRENA REmap Doubling
Electricity storage	NA	1340 GW	5030 GW	MESSAGEix-GLOBIOM 1.1 Net Zero 2050
Battery storage	18 GW	585 GW	3100 GW	IEA Net Zero Emissions
Battery in EVs	0.16 TWh	6.6 TWh	14 TWh	

Source: Vivid Economics

This report covers selected innovations in system flexibility which help to make either power demand or supply more responsive to system needs. System flexibility is a broad topic area that intersects many other technologies covered by separate GINA's reports, such as electric vehicles, heat pumps, hydrogen electrolysis, and synthetic fuels. As such, this report focuses on innovations that *specifically* improve power system flexibility, rather than generic improvements in costs or performance of system resources. For example, in power-to-gas, this report discusses how electrolysers could be made more flexible, rather than general improvements in electrolysers. Where benefits and spending requirements are quantified, they do not overlap with estimates discussed in other reports.

---

[4] Most energy system scenarios do not provide much granularity in the power system. While the capacity of dispatchable power is an output of such scenarios, it is difficult to determine how much of it serves to provide flexibility (e.g., peaking power rather than baseload power). Meanwhile, power system models provide greater granularity but are often performed on a regional basis rather than at a global scale.
[5] For example, see the scenarios published by UK's National Grid ESO

2. Innovation opportunities

2.1. Costs and deployment barriers

The technologies and services required to improve system flexibility are well understood. As the world moves away from fossil fuel power generation and towards solar and wind power, system flexibility will increasingly come from energy storage and demand response, including vehicle-to-grid and various forms of power-to-X. Many studies have already validated the potential of such flexibility options.

However, most of these applications are only in early stages of adoption due to various deployment barriers:

- **Cost barriers:** For immature flexibility options, a key barrier against adoption has been technology cost and performance, and the related financing costs for capital-intensive projects. For example, the lithium-ion battery was not commercially viable for utility-scale energy storage several years ago – but is now a leading option due to dramatic cost reductions in recent years and the increased value of storage.
- **Infrastructure barriers:** Another common bottleneck for system flexibility innovations lies in the scale of required hardware and software infrastructure. This is often true for demand response applications, as appliances need to be fitted with smart controls and given the option to respond to time-varying price signals. Advanced metering infrastructure is a prerequisite to many demand-side flexibility options, but rollout is slow due to the inconvenience of replacing legacy infrastructure in buildings.
- **Market barriers:** Most forms of system flexibility are currently not well-integrated in electricity markets. Many wholesale markets were designed primarily for power plants as the main suppliers, making it difficult for small generators (e.g., rooftop solar), demand response, and energy storage to participate. Even in markets where these restrictions are lifted, the lack of scarcity pricing means that flexible resources do not receive adequate remuneration for the energy or ancillary services they provide.

Innovations can address some of these barriers and accelerate the integration of flexible resources in the power system.[6] More than any other technology areas covered in the GINAs, innovation in system flexibility consists of not only hardware, but also the software and business models that integrate physical resources within the power system.

---

[6] Policy-induced barriers are significant for flexible resources, such as rules that undermine market access for emerging sources of flexibility. These issues cannot be addressed by technical innovations alone and require a change in policy and regulations.

2.2. Key innovations

This report focuses on selected innovations in system flexibility: battery storage, demand response, power-to-X, and the physical integration and market platforms for flexible resources. As described in the introduction of this report, power system flexibility can come from many different sources. Within the scope of this report, notable innovations and emerging sources of system flexibility include:

- **Battery storage performance and costs.** The primary innovations with the greatest potential to reduce both storage costs and deployment barriers in the next two decades are expected to be in Li-ion technologies. This is primarily because Li-ion chemistries are expected to dominate the storage market relative to other intra-day energy storage options. While battery innovations from the EV industry could benefit stationary battery applications, some other aspects of batteries could be enhanced for the purpose of stationary energy storage, including optimized usage patterns, smart inverters, cooling efficiency, and improvements in electrode materials.
- **Demand response innovations and aggregation.** In residential and commercial settings, the key opportunities for demand side flexibility are concentrated in smart appliances (e.g., heat pumps, air conditioners) and vehicle-to-grid (V2G) charging. Meanwhile, energy-intensive industries can also provide substantial flexibility by shaping their loads over time. Innovative ICT interfaces will be valuable to coordinate the various DSR applications across residential, commercial, and industrial contexts – not only in power demand control, but also their interaction with market trading platforms. Smart metering, charging, and communication standards are key enablers to this. To help integrate demand response sources, aggregators (also known as virtual power plants, or VPP) also need to innovate and better understand customer behavior.
- **Power-to-X innovations.** Power-to-X is a broad term that refers to various ways of converting surplus electric power to other forms of energy, some of which are also commonly regarded as examples of energy storage or demand response (e.g., power-to-gas could involve electrolysers with flexible demand and hydrogen storage). Most notably, innovations aimed at increasing the scale and flexibility of power-to-gas projects could provide more seasonal flexibility to power systems. Key innovations include improving electrolyser flexibility with designs that enable rapid response and minimize cell degradation.
- **Network management of distribution grids**. Distribution grids play a key role in integrating distributed generation (e.g., rooftop solar) and other distributed energy resources (DER) such as electric vehicles, behind-the-meter batteries, and heat pumps. At this level, key innovations include the collection of data on electricity consumption, local grid loads, and generation. Without this, smart grid operation is unlikely to develop. Furthermore, innovations can automate the analysis of real-time data and help optimize grid operations.
- **Markets and platforms to integrate flexible and decentralized supply and demand:** Electricity markets process supply and demand signals from generators, consumers, and storage to optimize the dispatch of energy. Smarter markets can reflect the whole system value in price formation, allowing more efficient market operation, thereby improving system flexibility. While the precise structure of electricity markets will depend on regulations, innovations in trading platforms and IT architecture can improve markets by allowing the trading of energy or ancillary services at high spatial and temporal resolutions at both local and national levels.

3. Benefits of innovation

3.1. Low-cost decarbonized energy

Box 2 System benefits and low-cost decarbonized energy

Lower energy costs are unlocked by the system benefits of innovation. System benefits of innovation refer to the net reduction in costs across the entire energy system as a result of stronger RD&D *and* commercialization of technologies. In the context of this report, system benefits are calculated as the difference in total system costs between a high-innovation scenario and a low-innovation scenario, where:

- System costs: all capital, operating and fuel costs within the global energy system.[7]
- Low-innovation scenario: market-driven progress under a lack of government support
- High-innovation scenario: optimistic progress where governments help drive cost reductions by supporting RD&D and deployment (i.e., commercialization)

This metric provides an aggregate estimate of how innovations in selected technologies can reduce system costs after least-cost optimization of all energy carriers and technologies from both the supply and demand sides.

Strong innovation in system flexibility could reduce annual system costs by $190 billion per year (1.6% of total) on average between now and 2050.[8] In both the low- and high-innovation scenarios, global energy system costs start at around $10 trillion a year in 2021, then begin to diverge noticeably after 2030. By 2035, the annual system costs in the high-innovation scenario are $100 billion lower than those in the low-innovation scenario. This widening gap reaches around $490 billion by 2050, similar to the scale of benefits from stronger innovation in wind power (covered in a separate GINAs report). Table 3 reports the system benefits for 2021/50 in the high-innovation scenario, measured as the cost savings against that of the low-innovation scenario.

Table 3 System benefits of innovation

System benefits ($b)	2021-50, cumulative, undiscounted	2021-50, cumulative, discounted 5%	2021-50, annual average, undiscounted
High innovation	5,900	1,900	190

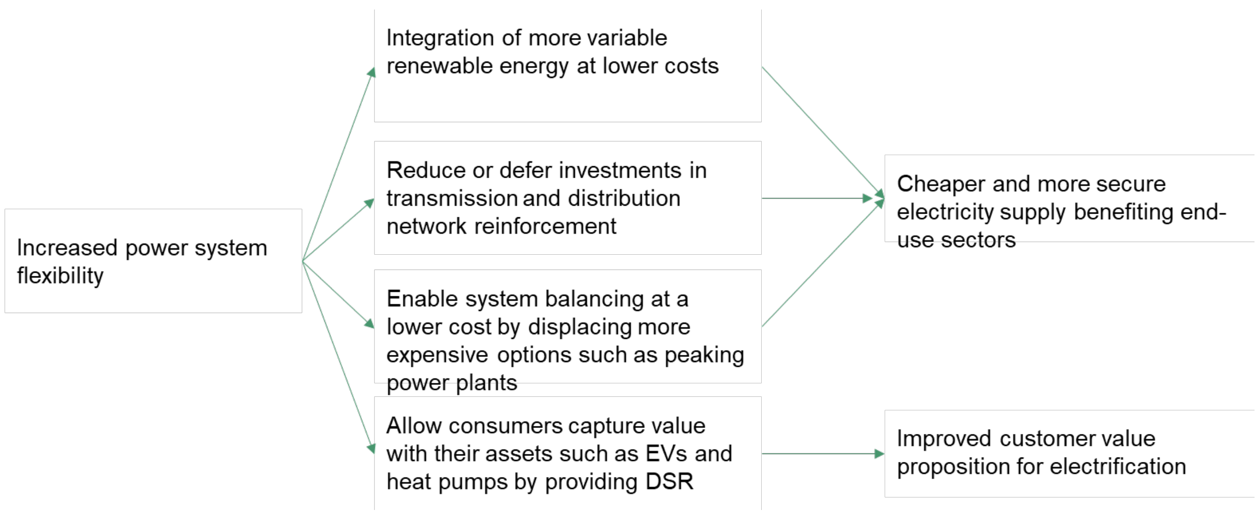
[7] System benefits may be calculated on an annual basis, or cumulatively between 2020 and 2050 (with or without discounting).
[8] The modelling of system benefits of improved system flexibility is represented by cheaper energy storage and expanded potential for demand response. Some other forms of system flexibility and their benefits are not explicitly quantified, e.g., retrofit to increase flexibility of power plants, or better management of distributed energy resources on the grid.

Source: Vivid Economics

Strong innovation in system flexibility benefits the energy system through four main channels:

- They reduce the capacity of low-carbon generation needed to achieve carbon reduction targets by improving the utilization of cheap but intermittent low-carbon power, i.e., solar and wind power. The share of electricity generated from solar and wind by 2050 increases from 70% in the low-innovation scenario to 80% in the high-innovation scenario.
- They enable system balancing at a lower cost by displacing more expensive flexibility options such as peaking power plants, with substantial savings in fuel costs for the power system. Dispatchable thermal power plant generation capacity required by 2050 is 31% lower in the high-innovation scenario.
- They defer expensive investments in transmission and distribution network reinforcement.
- They enable greater consumer participation in the energy market, with two related benefits. First, this reduces the investment needs on the supply side, e.g., storage and peak generation. Second, this improves the customer experience of managing their power consumption and empowers consumers to capture value associated with their assets (such as EVs).

Figure 1 Impact of innovation on the energy system

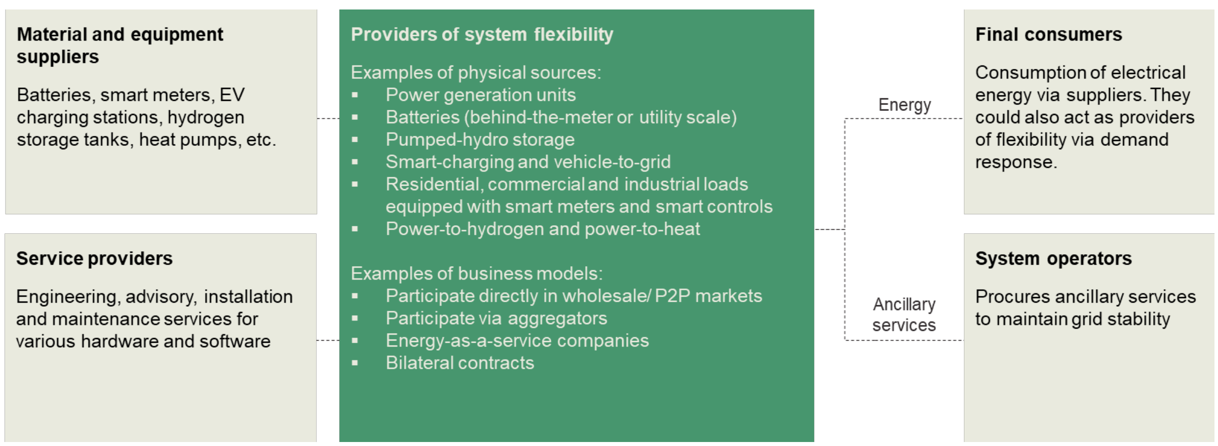


Source: Vivid Economics

3.2. Jobs and Growth

The rapidly increasing demand for system flexibility will create business opportunities for innovative companies in the value chain. The value chain covers a multitude of industries, ranging from battery manufacturers to energy companies that aggregate distributed energy resources. Figure 2 illustrates the value chain for system flexibility, identifying the different physical sources of flexibility (in green), whose owners and operators have different routes to market. Ultimately, the market value of system flexibility is realized in two ways: (a) by providing energy to meet consumer demand, and (b) by providing ancillary services to help system operators maintain grid stability. Different remuneration mechanisms exist depending on local market designs and regulations. Upstream in this value chain lie in the many different manufacturers and service providers that supply the owners and operators of flexible resources – some of which, such as manufacturers of batteries and smart appliances, will have to scale up rapidly to meet the substantial demand for their products.

Figure 2 Simplified value chain for system flexibility



Source: Vivid Economics

For emerging sources of system flexibility, the market size could increase by over 20 times by 2050 to reach $260 billion per year. Industries within the value chain depicted above are extremely diverse, some of which overlap with other GINA reports (e.g., heat pumps, electrolysers and EVs). This section covers three other distinct markets that will be increasingly important: aggregation services (i.e., virtual power plants), utility scale batteries, and EV chargers (that enable V2G). By 2050, these three markets combined would generate up to $82 billion in GVA, $260 billion in turnover, and directly support over 760,000 jobs per year, as shown in Figure 3. Major omissions from this scope include flexibility from power generation, other forms of energy storage (expected to be 30-50% smaller than battery storage globally), and demand response not provided through aggregators.

Aggregators of demand response and distributed energy resources (e.g., rooftop solar, behind-the-meter batteries) could support $36 billion in GVA and 86,000 jobs per year by 2050. The global market size for aggregators, as measured by revenues, currently stands at roughly $1 billion. Aggregators are becoming increasingly popular in many countries as they help pool resources to provide valuable demand response solutions, some of which have already reached a capacity of multiple gigawatts.(5) Innovations in IT infrastructure and data processing will further help aggregators play a major role in a future where widely distributed energy resources are ubiquitous. In a high-innovation scenario where aggregators become the major channel through which half of all demand response and distributed energy resources provide flexibility to the power system, this market size could reach $15 billion by 2035 and over $100 billion by 2050. The direct jobs that aggregators could support will be mostly related to technology and engineering and will grow moderately relative to the amount of energy resources they manage. Nevertheless, aggregators potentially have large indirect effects in supporting the deployment of distributed energy resources.

Utility-scale batteries could support $34 billion in GVA and 500,000 jobs per year by 2050. Currently, installed capacity of utility-scale batteries is estimated at 4 GW by the IEA (less than 0.1% of total power capacity)[9], with annual investments of just around $4 billion.(6) In a high-innovation scenario where installation costs fall by nearly a half by 2050, installed capacity could reach 1,700GW by 2050. This will imply annual investments increasing dramatically to $42 billion per year in 2030 and approaching $70 billion per year in 2050. The utility-scale battery industry alone would directly employ over 500,000 manufacturing and installation jobs in 2050, with the number of jobs depending on the rate at which new battery capacities are added to the system. Related industries for energy storage – including behind-the-meter batteries, thermal storage, hydrogen storage, etc., could combine to provide economic benefits of a similar scale. Importantly, innovative companies could benefit from a sizable export opportunity on the global market.

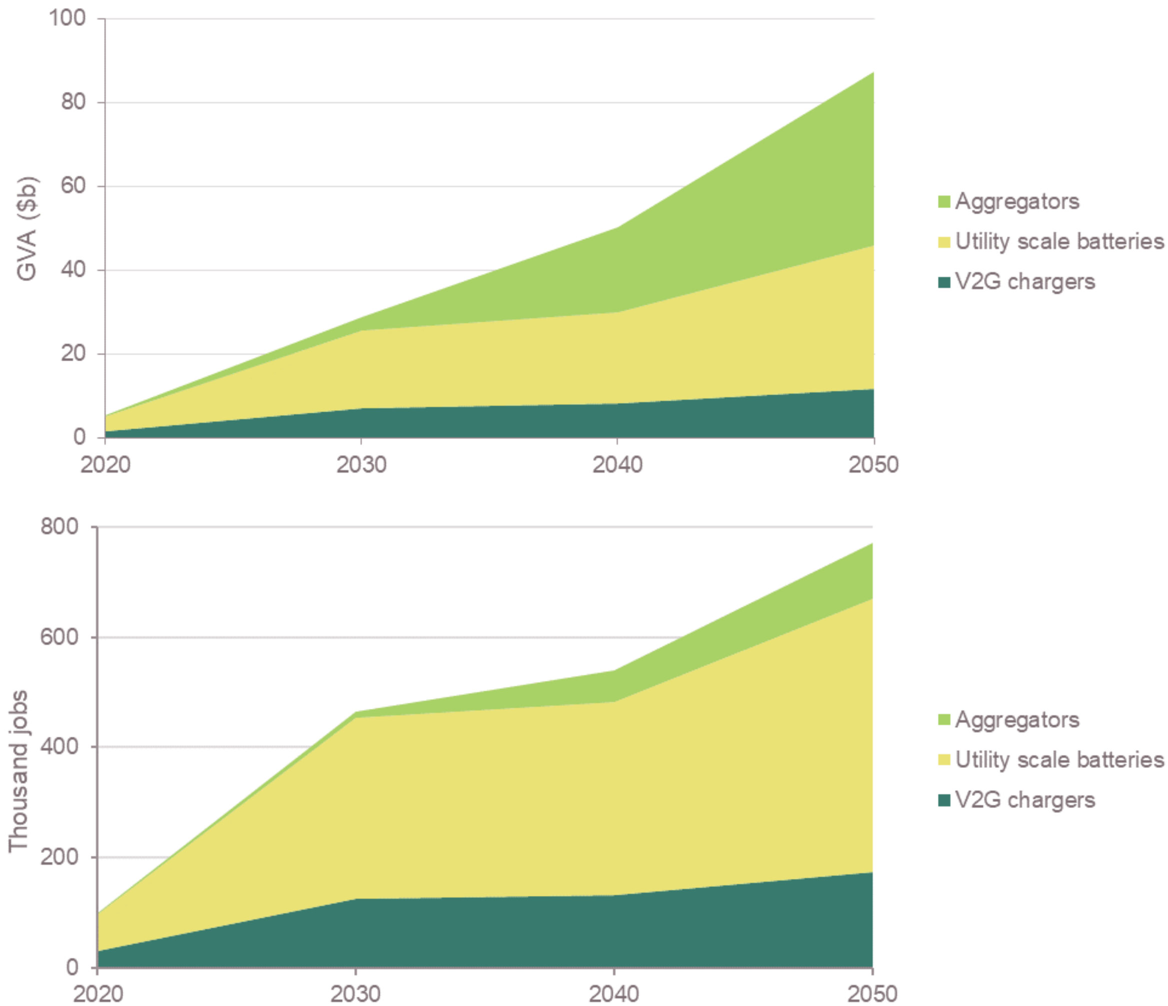
The deployment of EV chargers could support another $12 billion in GVA and 170,000 jobs per year by 2050. In any deep decarbonization trajectory, the EV rollout is expected to bring about significant business opportunities for manufacturers and installers of EV charging points – both in public and private parking spaces.[10] Most of these EV charging stations could be designed with smart charging features and hence help provide power system flexibility. In a high-innovation scenario, EV charging capacity could increase by 30 times by 2050, creating a large number of direct jobs for the manufacturing and installation of chargers.

---

[9] For comparison, most of the energy storage capacity currently are in the form of pumped hydro storage systems, with a global total of 153GW.

[10] In terms of quantity of units, the deployment of private charging stations is expected to outweigh public charging stations. However, public charging stations typically have higher rated powers (three to ten times greater) and have four times the unit costs.

Figure 3 GVA and jobs directly supported by global deployment selected system flexibility technologies



Source: Vivid Economics

4. The case for supporting innovation

To unlock the substantial benefits from innovation system flexibility, global public RD&D and commercialization spending needs to increase to $4.3 billion per year and $5.6 billion per year, respectively. For RD&D spending, this represents more than tripling the current global public RD&D budget of $1.1 billion per year for energy storage, power transmission, distribution, and grid control systems.[11] An increase in the RD&D budget could accelerate progress in a wide range of technologies. For instance, there are various types of battery storage that are currently less developed than lithium-ion batteries but offer better chemistries for long-term energy storage (e.g., flow batteries). Thermal energy storage and hydrogen storage represent two other types of energy storage that offer significant potential for deployment in the medium term. As for commercialization spending, the focus falls on technologies that are already available but not yet cost competitive. A notable example is utility-scale battery storage, for which $1 billion commercialization spending would be comparable to building dozens of 100MW storage facilities.[12]

Despite the substantial spending requirements, innovation in system flexibility delivers far greater benefits. As described in the previous sections, stronger innovation in system flexibility results in energy system cost savings worth $190 billion per year on average between now and 2050, far exceeding proposed levels of innovation spending in this report. Governments play an important role in strengthening incentives for innovation as businesses along the value chain do not internalize the societal benefits they create when developing products and services that improve system flexibility. In particular, commercialization spending is vital for accelerating deployment of capital-intensive options such as utility-scale energy storage and HVDC transmission infrastructure, helping to establish key supply chains.

Critically, public spending on RD&D and commercialization needs to be accompanied by electricity market reforms that support business models for flexible resources. Innovation spending is valuable in providing financial incentives to develop and deploy technologies when they are still relatively immature, helping them scale into commercially-viable options on the market. However, there are other market barriers that cannot be easily addressed by innovation spending and require other kinds of policy action – collectively referred to as 'pull policies' that stimulate demand for cheaper and better forms of system flexibility. Energy and ancillary service markets should encourage participation from all possible system resources, including power generation, storage, interconnections, and demand response, including those via aggregators. Furthermore, markets should provide granular price signals and hence reward flexible resources that can provide energy and ancillary services at times and locations where they are scarce. Finally, system operators could consider new market products such as fast-ramping products that cater to the physical properties of batteries and other emerging sources of system flexibility.

---

[11] Current RD&D budget on the selected technologies derived using 2019 data from the IEA RD&D database and adjusting for non-IEA countries such as China.

[12] As reference, the 100MW Hornsdale Power Reserve in Australia was the largest utility scale battery storage facility when it was built in 2017. Currently, a 100MW storage facility would cost about $100 million to manufacture and install. The size of storage capacity that could be supported by commercialization spending depends on the mix of public and private financing.

References

1. California ISO. California ISO Peak Load History 1998 through 2020. 2020.

2. Bloomberg New Energy Finance. New Energy Outlook 2021. 2021.

3. Energy Voice. Britain has gone nine days without wind power. 2018;

4. National Grid. Future Energy Scenarios 2021. 2021.

5. IRENA. Innovation landscape for a renewable power future. 2019.

6. IEA. Battery storage is (almost) ready to play the flexibility game. 2019.