SECTOR COUPLING

A KEY CONCEPT FOR ACCELERATING THE ENERGY TRANSFORMATION

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About the Coalition

The IRENA Coalition for Action brings together leading renewable energy players from around the world with the common goal of advancing the uptake of renewable energy. The Coalition facilitates global dialogues between public and private sectors to develop actions to increase the share of renewables in the global energy mix and accelerate the energy transition.

About this paper

This white paper has been developed jointly by members of the Coalition's Working Group on Towards 100% Renewable Energy. Building on a selection of sector coupling case studies based on information from and first-hand interviews with company and country representative, the paper provides an overview of sector coupling as a strategy to increase energy system flexibility and reliability through direct or indirect use of electricity across end-use sectors. The white paper specifically aims to support governments and companies in the decision-making and implementation process of using sector coupling as a powerful tool towards 100% renewable energy and a net-zero emissions future.

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01 INTRODUCTION

The successful achievement of the objectives set out in the United Nations 2030 Agenda for Sustainable Development and the 2015 Paris Agreement requires a rapid transformation of energy systems across the globe towards high shares and eventually 100% renewable energy. As a growing number of countries announce ambitious pledges and actions to phase out fossil fuels and enact policies in line with achieving net-zero emissions by 2050 or earlier, renewable energy will need to play a dominant role across all sectors.

Renewable energy has demonstrated consistent resilience during the COVID-19 pandemic and will continue to lead decarbonisation across sectors. The International Renewable Energy Agency's (IRENA's) findings suggest that in 2018 the share of renewables within end-use sectors was as follows: 26% electricity, 14% industry, 3% transport and 34% buildings (IRENA, 2022a).[1] The penetration of renewable energy in the power sector has advanced significantly in comparison to other sectors. Increasing the share of renewables in, and across, sectors and technologies will require the rapid and significant scaling up of efforts in areas such as end-use electrification, direct use of renewable energy, energy efficiency and infrastructure development.

Sector coupling strategies and technologies have the potential to enhance the flexibility of energy systems and thereby integrate higher shares of renewables. Coupling different sectors has many advantages: it increases the share of renewable energy across sectors and thus mitigates energy-related emissions, including greenhouse gases, for instance by replacing petrol and diesel in transport, or replacing natural (fossil) gas, coal and oil for heating in buildings (IRENA, 2021a).

Sector coupling can also provide increased grid flexibility by broadening the options for dispatching electricity from variable renewable energy sources – if the coupled sector can be inter-operated in an intelligent and smart way. These dispatching options effectively increase the share of renewable energy across sectors, resulting in lower energy-related emissions. For instance, batteries in electric vehicles (EVs) can be used to reinject power into the grid at times when the vehicle is not used (vehicle-to-grid) if smart charging systems are put in place and clear economic incentives provided.

Ongoing advancements in digitalisation, electrification and decentralisation are contributing to significant advancements in the power sector while also enabling smooth and smart system integration of low-cost variable renewable energy (IRENA, 2019). The objective of electrifying end-use sectors – either directly or indirectly – presents strong economic and environmental benefits. Renewable electricity

[1] *The Global Status Review 2022 indicates that renewable energy accounted for a share of 29% within the power sector in 2020 (REN21, 2022).*

(often from wind and solar power, thanks to their improved cost-competitiveness over fossil fuel-based electricity) provides a range of opportunities for direct and indirect electrification,[2] allowing conventionally non-power end users to benefit from it while at the same time reducing their carbon footprint. To capitalise on these opportunities, it is crucial to make sure the integrated system can be inter-operational in an intelligent and smart manner, thus being highly flexible. This includes both physical systems and market designs (IRENA, 2022a). Technologies such as private or commercial battery storage, EVs, green hydrogen, and power-to-gas can be used to couple different sectors with the power sector to achieve a highly interconnected, flexible and integrated energy system.

This white paper provides an overview of sector coupling as a strategy to increase energy system flexibility and reliability through direct or indirect use of electricity across applications in end-use sectors, with the aim of accelerating the transformation towards 100% renewable energy. The white paper specifically aims to support governments and companies in the decision-making and implementation process of using sector coupling as a powerful tool towards 100% renewable energy and a net-zero emissions future.

There is no universally agreed-upon definition of sector coupling. IRENA defines sector coupling as the process of interlinking the power sector with the broader energy sector (*e.g.* heating, cooling, mobility, industrial processes) and thereby facilitating the integration of higher shares of variable renewable energy sources into the power mix through enhanced grid flexibility (IRENA, 2021a). In this white paper, the IRENA Coalition for Action has developed a more holistic definition of sector coupling that extends beyond providing flexibility for the power system and towards facilitating a 100% renewables-based energy supply and demand across all sectors (see Box 1).

Box 1 **The IRENA Coalition for Action has agreed on the following definition for sector coupling:**

To become a strong and supportive driver of the transformation towards 100% renewable energy in all end uses, the concept of sector coupling needs to be extended beyond providing flexibility for the power system towards facilitating an integrated transformation towards fully renewables-based reliable energy supply and demand across all sectors.

Sector coupling focuses on combining at least two of the different sectors of energy demand and production (*i.e.* electricity, heating, cooling, transport and industrial processes).

Enabling technologies including smart grids, district heating and cooling, short-term and seasonal storage in pumped hydro, batteries, green hydrogen and other innovative or readily available solutions are applied to balance resource availability and energy demand. This results in significantly higher levels of direct or indirect electrification of end uses and system integration. Adapting energy market designs can effectively support the transformation towards a more electrified and renewables-based energy system.

*Companies featured in the case studies may apply different definitions when referring to sector coupling.

[2] *Direct electrification refers to the replacement of technologies that rely on fossil fuels with technologies that directly use electricity such as heat pumps, EVs and electric furnaces. Indirect electrification refers to producing hydrogen or its derivatives for industry, residential use and transport.*

The IRENA Coalition for Action Towards 100% Renewable Energy Working Group has over the years produced a series of white papers that analyse case studies and best practices for achieving 100% renewable energy across major sectors and key actors. The white papers put forward concrete recommendations for both policy makers and companies on how to support an accelerated energy transformation towards 100% renewables (see Box 2).

Following this introduction, this white paper is organised as follows: Chapter 2 provides an overview of the current status of sector coupling and includes a mapping of regional and national sector coupling trends; Chapter 3 examines sector coupling progress across specific end uses (*i.e.* heating, cooling, transport and industry) and proposes key dimensions (technical, economic and regulatory) by which the opportunities and challenges of sector coupling can be identified and addressed; Chapter 4 summarises key takeaways on how governments and companies can each support advancements in sector coupling in relation to the aforementioned key dimensions; and finally, Chapter 5 showcases a selection of sector coupling case studies based on information from, and first-hand interviews with, company and country representatives.

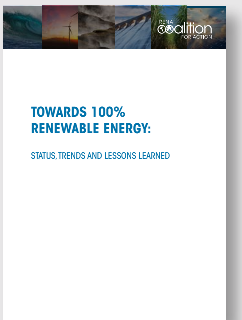
Box 2 **IRENA Coalition for Action Towards 100% Renewable Energy Working Group**

Established in 2018, the IRENA Coalition for Action Towards 100% Renewable Energy Working Group has produced a series of white papers and analyses that document case studies and best practices for achieving 100% renewable energy. These analytical outputs include a comprehensive mapping of 100% renewable energy targets at national and subnational levels, as well as key messages to policy makers on how to support an accelerated energy transformation.

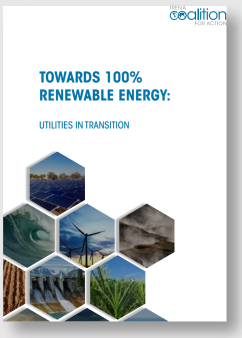
The Working Group's first white paper analysed the transformation to a 100% renewable energy system from the point of view of national and subnational governments (IRENA Coalition for Action, 2019). A second white paper followed, focusing on utilities in transition towards 100% renewable energy and addressing energy generation, transmission and distribution in the electricity sector (IRENA Coalition for Action, 2020). The Working Group's last white paper showcased the opportunities and challenges faced by companies in the industrial sector with targets/activities to increase the share of renewable energy in their heating and cooling operations towards 100% (IRENA Coalition for Action, 2021).

This fourth white paper offers a logical follow-up to the previous three by exploring the potential of sector coupling to advance a fully renewables-based energy supply and demand across all sectors.

Coalition for Action white paper series – Towards 100% renewable energy



2019



2020

2021

2022

SECTOR COUPLING: STATUS AND TRENDS

02

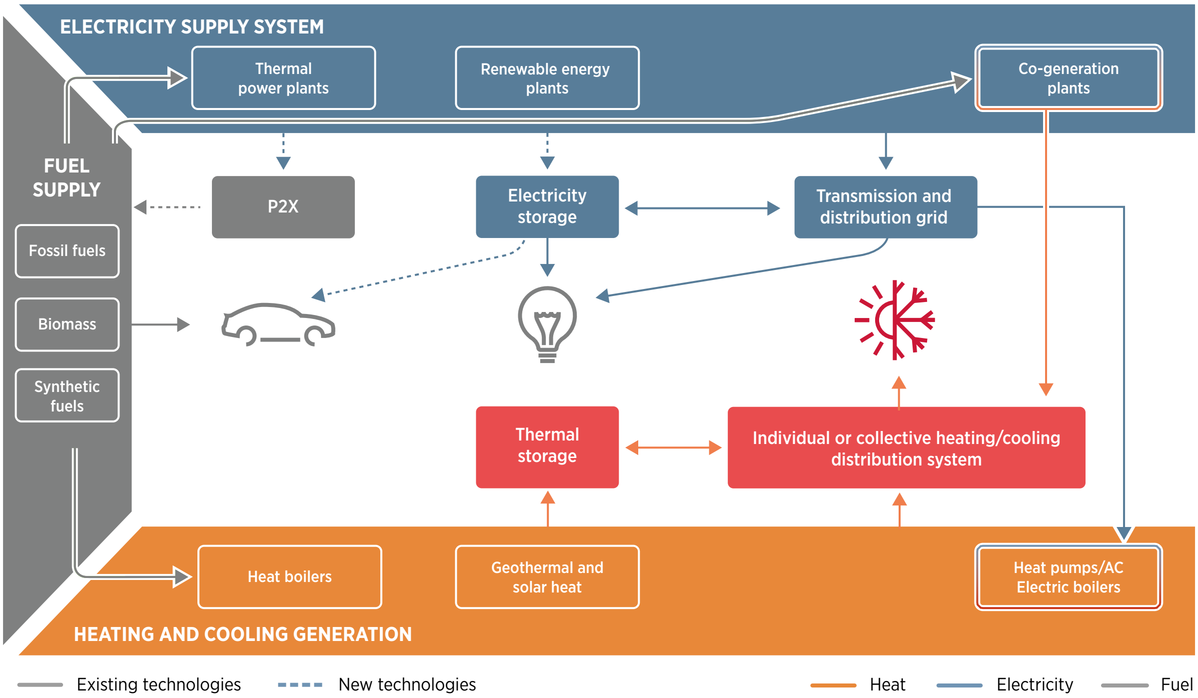
2.1 Sector coupling: An overview

Sector coupling broadly describes an important strategy to optimise the energy system by increasing its flexibility and reliability through direct or indirect use of electricity across applications in end-use sectors, with the aim of accelerating the transformation towards 100% renewable energy. This concept of combining different energy supply and demand options has been applied to energy systems for many years.

Figure 1 illustrates the overall structure and steps for coupling different sectors. One strategy consists of linking an energy source to a type of service such as heat or transport. A second strategy can include the development of new links between energy carriers to allow for indirect electrification of processes that cannot be electrified directly, such as in industrial operations. For example, electricity can be used to electrify the heat and transport sectors and can also create a synthetic fuel that is then used to provide an additional energy service (IRENA, IEA and REN21, 2018). The electricity from renewable energy sources can provide heating services through various sector coupling technologies, such as heat pumps and electric resistance boilers, and to power EVs in substitution for petroleum-based transport fuels or fossil fuel-based electricity. Electrolysis and methanation are indirect means for applying electricity to produce green hydrogen or methane for industry, residential use and transport.

A variety of energy services can be provided at different times using various applications. For the system to be fully renewables-based, electricity from fossil sources cannot be used for sector coupling in any step of the value chain. With growing applications of sector-coupled technologies, the demand for renewable electricity would increase. With the support of digitalised intelligent and smart energy management systems enhancing flexibility, the reliability of system operation can be maintained; in turn, this would facilitate the penetration of renewable electricity in the energy mix (IRENA, 2021a).

Figure 1 Sector coupling

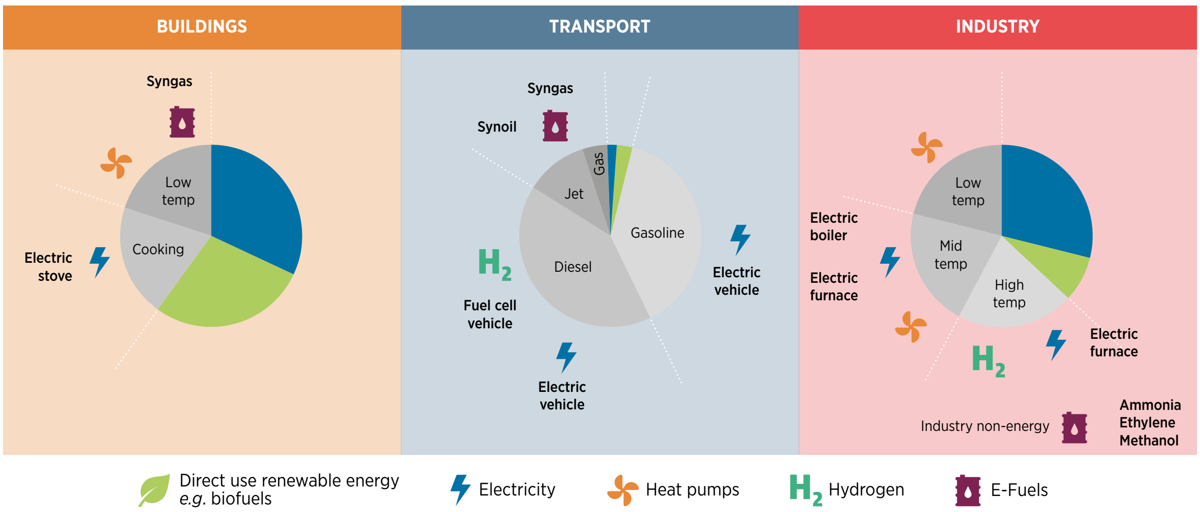


Source: IRENA, IEA and REN21 (2018).
Note: A/C = alternating current.

2.2 Technology applications in sector coupling

A broad variety of technologies and applications have been developed to implement the coupling of different sectors – most of them based on direct or indirect electrification of processes which, up to now, have used other forms of energy (Clean Energy Wire, 2018; Virtual Power Plant, 2020). Figure 2 shows which sector coupling technologies are currently applied across end-use sectors (IRENA, 2021a). These include the direct use of renewable electricity for cooking, heat pumps or water boilers, as well as indirect use via green gas such as hydrogen, biofuels and e-fuels.

Figure 2 Schematic summary of potential electrification technology applications



Source: IRENA (2021).

Buildings

The use of direct electrification is increasing in buildings, not only for electric appliances but also more and more for heating and cooking. Heat pumps are becoming an increasingly important and efficient technology to decarbonise heating and cooling operations. IRENA estimates that the total number of heat pumps is expected to increase by close to threefold, exceeding 142 million by 2030 compared to 53 million in 2022 (IRENA, 2022).[3] A major share of this growth can be attributed to countries such as Japan, the United States and European Union members increasingly adopting financial incentives for heat pumps such as tax incentives, grants and rebates.

Electric appliances, such as induction cook-top stoves and convection ovens using renewable electricity, are expected to gradually complement other renewable solutions and replace the traditional use of biomass, which would reduce indoor air pollution, and natural gas or liquified petroleum gas (LPG) for cooking. This transformation will occur not only in developing countries, where traditional use of biomass for cooking has led to increased indoor air pollution with detrimental effects on people's health (European Heat Pump Association, 2021a), but also in places where cooking with fossil natural gas will be replaced by induction stoves and convection ovens. These cooking technologies will also be integrated in smart home applications[4] and thus benefit from further digitalisation (European Heat Pump Association, 2021b).

At a centralised level, solutions for the electrification of heating and cooling systems are available. Electrification can be achieved by integrating existing electricity infrastructure with the district heat systems, accompanied by centralised heat storage facilities, existing combined heat-and-power plants, and green hydrogen, if sufficiently available. Centralised approaches can also result in higher investment costs, especially in countries without developed district heating networks (Münster *et al.*, 2020; Ramsebner *et al.*, 2021; Van Nuffel *et al.*, 2018).

Larger-scale electrification solutions, however, may lead to increased peak electricity demands if price and energy signals are not shared with the consumers, and if smart operation systems are not in place. This would require additional investments in enhancing the existing electricity distribution network, creating an opportunity to stimulate regionally-tailored[5] cost-efficient solutions (Munster *et al.*, 2020).

Most of these solutions are at commercial or near-commercial stages of application in various regions of the world. At the decentralised level, heat pumps and electric boilers can be combined with a rooftop photovoltaic (PV) system or with battery storage. Such combinations could not only provide heating or cooling, but also enhance system stability by providing balancing services (Ramsebner *et al.*, 2021).

Solar thermal systems, such as solar thermal hot water systems, will continue to be used in buildings in many regions around the world. These systems provide a reliable and cost-effective source of renewable heat, especially in areas with high solar irradiance. Other renewable sources, such as modern bioenergy and geothermal heat, will also play a critical role in heating buildings. Large-scale biomass boilers or even district heating systems can ensure the efficient use of biomass at more competitive heating costs compared to fossil fuels, and they also lessen air pollution (IRENA, 2022a).

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3 *This increase may be even greater if global ambitions to diversify energy supply and phase out natural (fossil) gas are implemented.*

4 *Smart home appliances refer to the use of automation processes to convert houses into smart homes. This addresses demand-side flexibility by increasing demand response to price signals (IRENA, 2019).*

5 *For example, in the case of Europe, Nordic countries' heating demand is in line with levels of wind power production in the winter months, whereas cooling demand in southern Europe coincides with solar power peaks during daytime.*

As global temperatures rise, significant increases in demand for cooling are expected in developing as well as industrialised countries. A major source of electricity consumption in buildings is associated with building cooling in hot and warm climate zones, which is accomplished primarily through central and room air conditioning systems running on electricity. In a warming climate, building cooling demands will likely represent an increasingly important source of peak loads on electricity grids around the world, particularly during periods of intense heatwaves.

One technology that can help mitigate this demand is the mini-split heat pump, which provides both heating and cooling in a building space, often at much higher overall efficiencies than traditional heating and cooling systems. However, over the past decades important research and development (R&D) on other cooling technologies that rely on solar thermal energy rather than electrical power has been undertaken. Much of this work has been reported through the International Energy Agency's Solar Heating and Cooling Technology Co-operation Agreement.[6] In these systems, thermal energy derived from concentrating or flat plate solar collectors is used to run various cooling systems based on technologies such as adsorption or absorption chillers, desiccant coolers and heat ejectors. In addition to replacing electricity to provide building cooling, many of these systems have the added advantage of also providing building heat and domestic hot water when needed. In some cases, the thermal energy source could be supplied by other non-carbon-emitting technologies, such as geothermal heat, waste heat or modern bioenergy. Because space cooling will have growing importance in future energy demand, solar thermal cooling technologies should also be considered along with electricity-driven cooling solutions when developing sector coupling strategies.

Transport

The dominant technology to decarbonise road transport will be EVs powered entirely by batteries, and to a much lesser extent plug-in hybrid electric vehicles (PHEVs) and perhaps even fuel cell vehicles. Alongside increasingly electrified public railways, buses, metros and trams, millions of individuals, companies, and public organisations have replaced their fossil fuel-based internal combustion engine (ICE) vehicles with electrified ones. While EV sales have been increasing in major markets such as China, the European Union, and the United States, one of the main barriers to the further expansion of EVs is the lack of adequate infrastructure and battery technologies, as well as financial or fiscal policies to incentivise the uptake of EVs and disincentivise ICEs (IRENA, 2022a).

Several technical solutions could stimulate the growth of EV penetration. These solutions, also referred to as smart charging, include bidirectional charging and other vehicle-to-grid models, transformer capacity upgrades and improved forecasts of charging demand. In addition, standardising charging plugs would remove complexities currently in place due to different charging plug configurations across different EV brands and within different regions. Standardisation would increase the number of public charging points for all EVs. Strategic planning of public chargers that includes renewable energy generation infrastructure and development of public electric fleets (*e.g.* buses) could lead to substantial technology cost reductions. EV adoption could be further improved if EVs offered ancillary grid services, such as frequency regulation or balancing out loads, as more and more EV batteries are connected to the grid (Van Nuffel *et al.,* 2018).

EVs have huge potential for sector coupling through three scenarios: smart charging (V1G), which can reduce peak demand and improve system flexibility; vehicle-to-grid (V2G), which can provide more benefits to the power system, such as peak shaving, reduced network outages, support for mini grids and accommodation of more variable renewables; and vehicle to building (V2B), which can provide supplemental power for buildings. As these technologies continue to advance, along with the development of charging infrastructure and battery technology, the rate at which EVs are integrated into the transport sector will greatly accelerate.

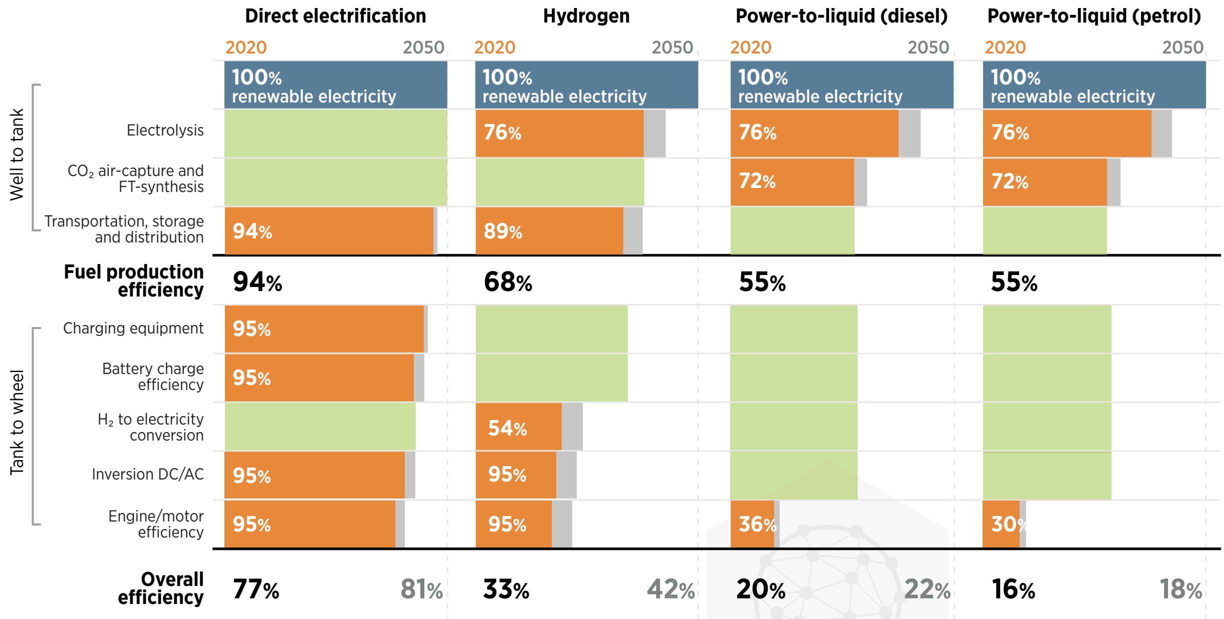
[6] *See www.iea-shc.org.*

Heavy-duty long-haul road freight, ocean and aviation transport remain more difficult to electrify. These transport systems would require much higher battery capacities, leading to more weight and higher energy consumption, making these battery-powered vehicles currently less efficient than other possible options (Ramsebner *et al*., 2021). The bulk of road transport (including trucks) is expected to be suitable for direct electrification, but the specific share that ultimately ends up being directly electrified also depends on innovation around battery chemistry and costs, and battery technology development.

Indirect electrification that involves green hydrogen and liquid fuels is another option to further decarbonise trucks, aviation and shipping (Ramsebner *et al.,* 2021). Hydrogen use for transport may be relevant for heavier loads or where longer ranges are needed and will depend on technology evolution. This option could be attractive for a niche set of conditions. Wind-assisted ocean freight is another option for decarbonisation. In aviation and maritime transport, technologies based on direct electrification are already available, although so far only for shorter ranges and lighter vehicles. These sectors are relatively hard to electrify and are therefore likely to see a larger use of hydrogen derivatives (ammonia and synthetic fuels) or modern biofuels (IRENA, 2015).

When electricity-based alternatives exist, it is possible to use efficiency estimates to assess the amount of additional electricity required from the use of hydrogen in comparison with direct electrification. This provides policy makers with the estimated additional power capacity required for a certain sector to be powered with green hydrogen (see Figure 3).

Figure 3 Efficiency of direct electrification for EVs



Source: CleanTechnica (2021).

Industry

Most industrial processes require some form of heat source, and sometimes multiple heat sources, each of which has a different temperature. In most cases these heat sources are currently generated by fossil fuels. Decarbonising these heat sources can be among the most challenging of all end-use sectors. This section discusses decarbonisation options for high-, mid- and low-temperature industrial processes.[7]

[7] *High-temperature industrial process heat is considered to be above 400°C (degrees Celsius), while low- and mid-temperatures are considered to be below 400°C. Low-temperature industrial process heat is generally considered to be that which can be supplied by heat pumps (IRENA, IEA and REN21, 2020).*

Sector coupling has to the potential to contribute to the decarbonisation of the industrial sector. Direct electrification based on onsite renewable energy generation, in addition to the renewable power coming from the utilities that serve these facilities, is one way to provide carbon-free power for manufacturing processes. Several industrial processes, such as production of iron and steel and chemicals, typically require high- and mid-temperature process heat and are commonly listed among the hard-to-decarbonise, or "hard-to-abate", sectors (IRENA, 2022a). The major abatement challenge for these industries is to find ways to produce high- and medium-temperature process heat using carbon-free energy technologies other than direct electrification such as via concentrating solar thermal, geothermal, and modern biogas or biofuels. Some energy-intensive heavy industries – like fertiliser, steel, cement, or plastics and chemical production – cannot be electrified either directly or indirectly. As an abatement strategy these sectors will require development and implementation of power-to-gas (green hydrogen) and power-to-liquid fuel (*e.g.* ammonia, methanol, ethanol) technologies (Munster *et al*., 2020; Ramsebner *et al*., 2021).

Although the direct use of electricity for producing heat (such as resistance, infrared, induction, microwave and plasma heating technologies) is a viable option, other considerations (such as cost, energy density, technology maturity and existing infrastructure) could preclude using direct electrification to achieve the required temperatures.

Several approaches using alternative energy sources other than electricity are possible, and there are promising developments. For example, concentrating solar thermal systems can provide carbon-free medium- to high-temperature heat. Costs for these technologies continue to come down. In some markets, geothermal heat and heat generated from modern biomass or biogas also offer promising solutions.

Another approach is to use green hydrogen generated from electrolysers powered by renewable electricity. Green hydrogen has emerged as a shared decarbonisation solution for some hard-to-abate processes. As green hydrogen production becomes cheaper, with promises of further cost reductions (IRENA, 2020c), it can be used as a feedstock and as a fuel for high-grade heat.

Low-temperature and some mid-temperature processes can be effectively decarbonised using heat pumps powered by direct electrification. Non-electrification approaches such as concentrating solar thermal, geothermal and bioenergy are also low-cost abatement strategies for these temperature ranges. Waste heat is another viable source of low- to mid-temperature heat, particularly for those cases where the direct use of solar thermal, geothermal, biomass or biogas is not an efficient option.

Digitalisation and smart systems can take technologies another step forward through sector coupling by combining two or more energy sectors. For example, electricity produced by the industry itself or purchased from the grid can be used to charge EVs, such as delivery trucks or industrial EVs. Excess electricity can also produce green hydrogen for use as process heat (IRENA, 2022e). By combining these applications with demand response and/or flexible energy pricing, such as through load shifting and peak shaving, they can significantly contribute to more efficient energy use.

Economic factors may preclude the shutting down of certain production processes required to convert from fossil fuel-based production technology. However, electrification of production processes that do not need to run continuously (such as chlorine production) can be used as an industrial demand flexibility option to balance the electricity system (Van Nuffel *et al*., 2018). A shift to a greater use of clean and innovative industrial processes and tools will also trigger new investments, jobs and growth.

SECTOR COUPLING ACROSS END USES

03

This chapter takes a closer look at the general opportunities and challenges related to sector coupling in the context of achieving 100% renewable energy. It also sheds light on more specific opportunities and challenges in the concrete end-use sectors. As stated in the introduction, sector coupling will lead to a substantial expansion of the electricity consumers in end-use sectors, and this will, in turn, facilitate the scale-up of renewable electricity from variable energy sources.

This growing share of electricity supplied from renewable sources requires a more flexible energy system for the grid operator to operate the electricity system safely and reliably. In this context, sector coupling presents opportunities if coupled technologies can be managed in an intelligent and smart way to make the overall system more flexible, thereby not only achieving the objective of reliable grid operation but also improving overall energy system efficiency.

3.1 Key drivers and barriers for sector coupling

This subsection lists some of the challenges and opportunities of sector coupling related to the general energy system's features, elements and processes – such as decarbonisation and digitalisation. These conceptual components allow for a better understanding of the rationale for sector coupling (Di Silvestre *et al.*, 2018).

Deep decarbonisation of energy supply combined with energy efficiency measures

Delivering carbon neutrality in line with the Paris Agreement can be enabled by a 100% renewables-based integrated energy system. Direct electrification is a key enabling measure because of the maturity of renewable energy technology options available on the market. Furthermore, energy efficiency measures will lower the required energy supply in the system as well as the primary energy demand. However, some of the applications will still require thermal energy (*e.g.* hydrogen, solar thermal, waste heat). Indirect electrification, in which electricity is used to produce gas, liquids or heat sources of energy, can result in larger efficiency losses (see Box 3) than with direct electrification (Ilo *et al.*, 2021). These efficiency differences must be considered when assessing whether direct or indirect electrification is the preferred option. Therefore, as a rule, indirect electrification should be applied only in hard-to-decarbonise sectors (*e.g.* heavy industry, long haul transport, shipping and aviation).

Box 3 Indirect electrification and efficiency losses

As a result of conversion losses, the production of synthetic fuels, serving as a means of indirect electrification, requires large volumes of electricity. Consequently, indirect electrification is more expensive, and the massive application of power-to-gas and power-to-liquid technological processes would require much more installed renewable generation capacity. The graphs below present the efficiency values for different vehicle drive technologies (transport sector) and different heating systems (buildings sector). According to the numbers, EVs and electric heat pumps represent the highest overall efficiency rating that decreases with each additional conversion step.

Figure 4a Overall efficiencies of different vehicle technologies

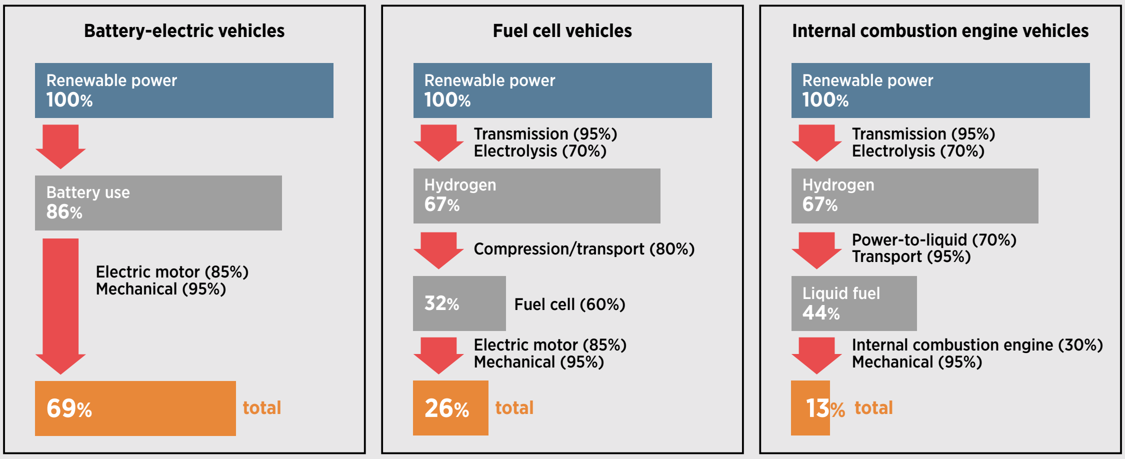
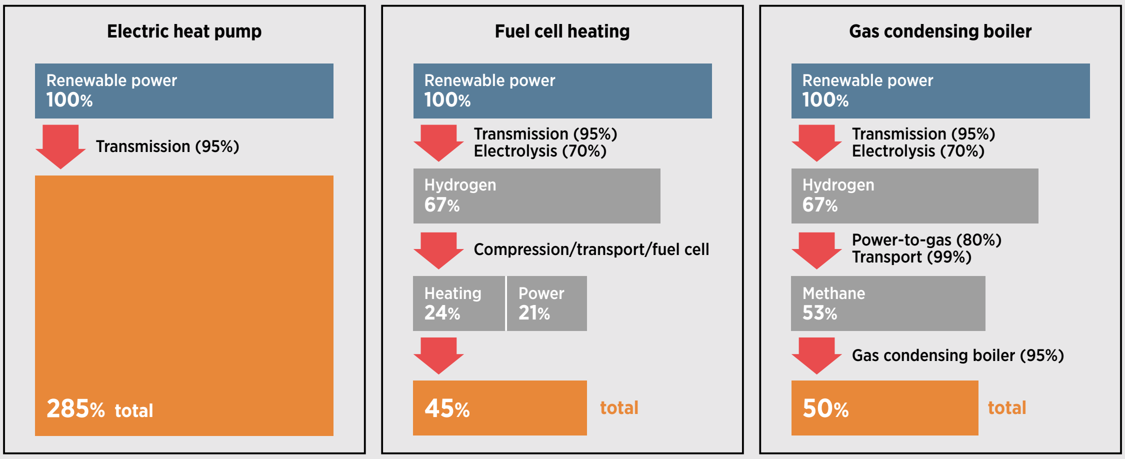


Figure 4b Overall efficiencies of different vehicle technologies



Source: Perner, Unteutsch and Lövenich (2018).

Flexibility potential and energy system optimisation

Energy sector coupling and smart integration will require further digitalisation. In addition, the electricity system needs smart energy management. Progressive digitalisation allows for better observation, forecasting, monitoring and control of the increasing number of renewables-based, distributed generation resources. Furthermore, digitalisation contributes to reducing connection and activation costs and enables small prosumers to participate in the energy transformation democratically, making the energy system more just and inclusive. More digitalised energy infrastructure that encompasses the deployment of smart grids not only improves operating efficiency, but also integrates new demand-side flexibility resources (Ilo *et al.*, 2021).

A full exploitation of different flexibility options, such as demand response or electricity storage options (not limited to batteries), requires a proper regulatory framework that can ensure the development of flexibility services alongside market participation, remuneration and related business cases. Developing a business case for an individual flexibility option (*e.g.* in buildings) can be an important pointer to reward increased flexibility of the system and raise awareness about related benefits and opportunities. This concerns differentiated capabilities of various technologies, different country contexts and different sectors. For example, the industrial sector still requires market and regulatory conditions that would allow the purchase of renewable electricity. From a governance point of view, the activation of different flexibility options should be backed by co-ordinated actions of responsible actors operating at multiple levels (local, regional, national, and international). This is showcased, for example, by adding flexibility to the grid at different voltage levels by the transmission and distribution network operators (Fridgen *et al.*, 2020; IRENA, 2022d; Renewables Grid Initiative, 2020).

Infrastructure optimisation

Electrification of non-power end-use sectors would allow more players to participate in demand response programmes, providing the right regulatory framework is put in place and intelligent energy management is installed. Smart system integration can contribute to optimisation and utilisation of the existing infrastructure and reduce the need for isolated infrastructure investments, which can be costly and space demanding. Optimising the energy infrastructure can additionally improve system security and resilience and reduce the impacts on nature and local communities. In turn, energy infrastructure optimisation creates an opportunity to save resources, lower operational costs, and reduce environmental and societal impacts (Bazzana, Zaitchik and Gilioli, 2020).

Promoting the additional benefits of sector coupling

While sector coupling has generally been identified as an integral part of the energy transformation, applications are still few and for the most part concentrated in developed countries. Therefore, increasing the understanding of the concept among policy makers and businesses is crucial to increase real world applications globally. This could be done through dedicated training and knowledge exchange, as well as sharing best practices among businesses and policy makers on the one hand. On the other hand, awareness of sector coupling strategies could be strengthened by including approaches within energy access projects.

Decentralisation and integrated approaches for improving energy access and reliability

Delivering energy access to remote areas is an ongoing challenge in many countries and can be overcome by scaling up decentralised renewable energy approaches, focusing on micro- and mini-grid approaches. By integrating decentralised energy access measures, offered by renewable energy sources, with broader sector coupling opportunities, many countries in the Global South would avoid being locked into volatile fossil fuel markets and could consume energy more efficiently and reduce overall energy demand. Some examples of basic sector coupling technologies gaining momentum are e-cooking stoves, electric water boilers, water desalination and improving cold storage for food produce.

3.2 Key dimensions of sector coupling

As the previous sections have shown, sector coupling can be a substantial enabler of the energy system transformation to high shares of renewables (up to 100%). While different end-use sectors require varying, and sometimes very specific, technologies to transform to direct and indirect electrification, all potential technologies should be considered in a co-ordinated way to maximise the optimal use of resources and strengthen the synergies between them. The previous sections have also presented the multiple challenges and opportunities of sector coupling, combined with corresponding solutions and measures. These challenges and opportunities can be grouped into three main dimensions: technology, financial, and institutional and regulatory. Of course, all three dimensions are interrelated and influence each other.

Technology considerations for sector coupling are primarily linked to technology advances and developments, as well as the maturity of sector coupling solutions across multiple scales – from individual components and units to the integration of the entire system. In particular, power-to-X technologies should be improved so they can be deployed on a large scale. Moreover, an increasing amount of new renewable generation assets – both mature and emerging renewables technologies – is needed to achieve full decarbonisation. These increased amounts will have a direct impact on accompanying infrastructure, both new and retrofitted, including transmission, distribution, and storage assets.

Financial considerations for advancing sector coupling are related to the high costs of technologies along the power-to-X chain and additional investments into accompanying infrastructure. Measures for advancing sector coupling currently lack financial incentives, as flexibility is not always adequately rewarded. Without additional incentives, there might be no motivation for change (for example, the share of energy costs is low in industry, and some technologies such as heat pumps do not provide a comparative advantage to users). In this regard, many of these technologies as well as ancillary services need tailored and relevant market designs answering to the different needs and financial capacities of developing, emerging and industrialised markets. These designs include the development of viable business models tailored to specific regions. If implemented properly, such market structures can deliver a cost-efficient system enabling an optimised use of resources and storage opportunities along with cost-efficient utilisation and investments in infrastructure.

Institutional and regulatory considerations include legal and governance actions. Sector coupling requires the implementation of clear definitions of specific power-to-X technologies, integrated system planning, and legal or institutional arrangements that unambiguously specify and regulate the responsibilities of the energy system actors. Understanding the ownership of various assets and their operation and maintenance is key, just as it is with electricity and gas transmission and distribution system operators. Institutional and regulatory frameworks also encompass activities that address and foster co-ordination and collaboration among different stakeholders at multiple levels. These frameworks also need to stipulate go-to institutions responsible for system planning to identify opportunities for sector coupling. This can be accomplished by co-operation among prosumers, distribution system operators (DSOs) and transmission system operators (TSOs) at local and regional levels as well as international arrangements and trade agreements with supportive incentives and pricing mechanisms (Renewables Grid Initiative, 2020; Van de Graaf *et al.*, 2020).

KEY TAKEAWAYS AND LESSONS LEARNT

04

The transformation of global energy supply and demand towards a system based on renewable energy has successfully been implemented in the power sector in a growing number of cities and businesses. Costs for new renewable energy installations are rapidly decreasing and outcompeting existing and new coal and gas and nuclear power plants in most markets (IRENA, 2022b). Cheap and readily available renewable electricity supported by rapidly advancing digitalisation is facilitating the direct and indirect electrification of other end uses. Technologies for decarbonising harder-to-abate sectors are now or soon to be available. Sector coupling is becoming a strong strategic tool to decarbonise end uses whose energy services are met by non-electricity forms of energy carriers and at the same time to increase energy system reliability and flexibility based on high shares of variable renewable energies. This is true around the globe, but due to different local and regional conditions, a variety of policies, frameworks and capacity-building measures will be needed to trigger and facilitate implementation at a global scale.

Ultimately, all energy carriers should be based on renewable energy sources. This will help prevent the lock-in of unsustainable sources that would hinder and delay the decarbonisation of the energy system, resulting in continued dependence on fossil fuel imports for most countries. The global shift towards 100% renewable energy needs to go hand in hand with significantly increased energy efficiency, maximising the use of heat or chemical energy to decarbonise hard-to-abate processes that cannot be directly electrified (either because of technical or market-related reasons).

Based on these considerations and underpinned by our research and analysis of case studies and expert literature, we provide the following **recommendations for how to successfully implement sector coupling** as a strategic means towards faster and deeper decarbonisation and a stable and affordable energy supply based on 100% renewable energy.

- **Assess the current and future energy demand of sector coupling initiatives, particularly renewable energy capacities.** Include existing and additional capacities across all end uses, and account for ambitious – but realistic – energy efficiency increases. It is also important to consider local availability and costs of renewable electricity.

- **Evaluate renewable energy potentials and needed infrastructure investments to harness resources in line with valid forecasts of higher demand through increased electrification of end uses**. Assess the capacity and flexibility of existing and required infrastructure, including thermal and electricity storage as well as liquid or gaseous resources. Include investment needs and finance availability and the existing and required level of digitalisation and energy management systems. Evaluate potential flexibility gains achievable by different pathways, including through optimisation of demand and supply.

- **Strengthen key stakeholders' and citizens' awareness of and participation in sector coupling initiatives. Capacity building, experience sharing, case studies and broad-based communications should be used to include local communities as active agents in sector coupling initiatives and the broader energy transition.** Structural challenges to sector coupling strategies may be overcome through policy frameworks and regulations that encourage higher levels of decentralisation, self-production, and self-consumption. Through high levels of private and industrial self-consumption, existing infrastructure can be enhanced and optimised. An example of a more optimised energy infrastructure is a reduced need for new transmission and distribution capacity. Further, higher self-production and consumption would add local economic value as well as benefits such as job creation, improved air quality and broader engagement by local populations.

- **Re-assess existing and future distributed energy access projects in many developing countries with the aim of identifying the potential for continued and new sector coupling initiatives.** To support sector coupling uptake in developing countries, sector coupling strategies should be part of energy access efforts. Current energy access measures undertaken are often solely focused on increasing energy access via expansion of a central grid or using off-grid solutions (mini-grids, solar home systems, etc.). Expanding such measures with considerations about battery storage for surplus production or charging of e-vehicles could improve livelihoods while sensitising the population to the benefits of sector coupling.

- **Develop localised business models for storage and prosumers.** To find the right balance, set up a process based on co-operation between operators of different electricity voltage levels and other actors to achieve effective data exchange and real-time communication between them. Such co-operation allows consumers across all sectors to participate in flexible dynamic markets and thus be an active part of a system that connects them to different suppliers using different energy sources and flexibility options, which can contribute to increasing the efficiency of the whole system.

- **Establish a large-scale, cross-sectoral collaborative infrastructure planning approach that can facilitate the achievement of multiple objectives, such as effective climate protection as well as environmental and social sustainability.** Countries with ambitious policies and limited resources can move faster in the energy transformation by importing renewable energy. Similarly, for countries with high renewable energy potential, exporting energy can support investments in building local infrastructure – including plants, transportation, storage, etc. – which have the potential to significantly speed up local energy transformations once favourable policies are set in place.

  Note: In many cases, an assessment about the **availability or realistic growth potential of local or regional resources** needs to be made and discussed against a **potential inclusion of international energy trade and imports of green electricity or molecules.** While green electricity or derivates like green hydrogen or synfuels may have lower direct costs in some sunnier or windier parts of the world, exporting these commodities to other countries may delay the transformation of the energy system within the energy exporting countries. This may negatively impact local and regional system change towards renewable energy within these countries and slow down global decarbonisation.

- **Develop a sector coupling strategy that addresses the level of direct electrification of end uses in relation to the use of green hydrogen.** Where direct use of locally or nearby produced renewable electricity is not possible, using hydrogen or synfuels produced from renewable power may be more efficient, cheaper, and environmentally friendlier than long-distance transmission lines. Furthermore, the direct use of renewable energy is more effective and efficient in most cases than using power-to-gas or power-to-liquid (including hydrogen) technologies. Green hydrogen may be prioritised in certain sectors and for applications where direct electrification or other renewable options are not currently feasible.

- **Calculate local availability of renewable electricity and storage capacities compared with conversion processes for hydrogen production and applications, including hard-to-abate processes.** Large-scale use of hydrogen – to be consumed directly as a gas or further converted into synthetic liquid fuels – requires strong regulation that clearly aims at renewable gas or green hydrogen exclusively from renewable energy sources. Regulatory frameworks based on consistent definitions and reliable data need to be implemented across different markets. In addition, as power-to-gas and power-to-liquid technologies are not yet cost competitive, more R&D, legislative support and appropriate regulatory frameworks need to be established to foster and enhance innovation and project development to scale up capacities.

- **Consider steps such as residential heating and cooling, water heating, and cooking, within relevant sector coupling strategies in the building sector.** This must include optimising building envelopes, adopting specific measures for retrofitting and advancing existing low-energy building standards. Such considerations are important steps towards net-zero and plus-energy buildings.

  Note: For new buildings, **net-zero and net-zero-plus standards** should become mandatory, including the optimal use and installation of on-site renewables for power, heating and cooling.

- **Support and subsidise EV charging stations for at-home installations, heat pumps for heating and cooling, and energy efficiency improvements** to strengthen sector coupling approaches in the residential sector and make these more affordable while also strengthening the resilience of the distributed energy system.

Fundamentally, prior to and during the stages of project development, it is necessary to agree on prioritising areas and sectors. Can progress in electromobility be reaped first? Where are hard-to-abate sectors – such as some industrial processes – that need special attention but could still be bolstered to accelerate decarbonisation and sector integration? Building on these deliberations, **enabling policy frameworks and regulations should be set up to incentivise and accelerate successful sector coupling projects.**

05 CASE STUDIES

EFARM GP JOULE

GP Joule is geared entirely towards 100% renewable energy. The company recognises that renewable energy projects can contribute to a 100% renewable energy system and increasingly includes power-to-X[8] and sector coupling projects as important cornerstones of its business model. To achieve its goal of connecting different sectors to eventually decarbonise all industries, GP Joule has expanded to countries like Canada and the United States and has increased the number of its employees to more than 500.

GP Joule's eFarm project is located in Nordfriesland, Schleswig-Holstein, northern Germany. With 20 shareholders, 5 electrolysers (at production sites in Reußenköge, Bosbüll, Langenhorn and Dörpum) and hydrogen refuelling stations in Husum and Niebüll, eFarm is Germany's biggest green hydrogen ecosystem to date.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

8 *Power-to-X (also P2X) means the use of electricity as the basis for the production of intermediate products for further use in the provision of energy and materials.*

Hydrogen is mainly used in the mobility sector, for instance for fuel cell buses and cars. After electrolysis, the hydrogen is compressed, filled into trailer tanks and transported to refuelling stations, where it is further compressed to a higher pressure to refuel vehicles. The overall energy consumption for all five electrolysers (225 kilowatts [kW] each) this year is 1.7 gigawatt hours (GWh). When the project reaches full utilisation (currently envisioned for 2028), the overall energy consumption will be 28.7 GWh per year, consisting of 100% renewable energy. The main source is currently nearby wind turbines, but solar power will be added in the future. What makes the eFarm project special is that the electrolysis takes place close to the power generation plants, on-site. The power demand by the electrolysers only constitutes a small part of the power generated by the wind turbines. Most of it is fed into the grid.

eFarm is about more than just generating hydrogen via power-to-X; it also involves additional elements of applied sector coupling. For example, the waste heat from the two electrolysers (amounting to 450 kW or 30% of consumed energy) in Bosbüll that is generated from green power during the production of hydrogen is fed into the district heating network. Within the context of sector coupling, GP Joule intends to further implement functions that support electricity grid management, such as a system that allows for the optimisation of electrolysers' use according to times of surplus renewable energy production.

Moreover, the electrolysers installed for the eFarm project produce hydrogen, oxygen and heat. The hydrogen is used in the mobility market; this will continue in the short- and mid-term future. The hydrogen is transported via truck and trailer. In the long run, GP Joule will evaluate how to supply green hydrogen to other sectors, such as steel, cement and the chemical industry, and thereby to increasingly contribute to the decarbonisation of the industrial sector.

Currently, existing technology in the mobility market is advanced, having reached a level that allows for the economically viable use of green hydrogen. However, green hydrogen utilisation for industrial processes like green steel or aviation is not yet ready for the market. For this reason, mobility is a suitable market in which to ramp up sales of green hydrogen. Thus, GP Joule partners with a regional bus operator with plans to increase the use of hydrogen buses by a factor of eight in coming years. Moreover, the company's focus is on companies within the logistics sector to integrate trucks because heavy-duty transport has high potential for the deployment of hydrogen propulsion vehicles.

The eFarm electrolysers are highly adjustable and can ensure steep growth gradients. Therefore, the electrolysers not only produce hydrogen to fuel the renewable mobility transition but also to serve as electricity storage to reduce bottlenecks in public power grids by increasing or reducing their load.

Interview with Ove Peterson, CEO, GP Joule

1. ***What are your most relevant motivations/drivers and expected benefits for advancing from growing the share of renewable energy separately in one or more end uses towards sector coupling and increasing the share of renewables in an integrated way across two or more end-use sectors? How have these advancements impacted costs and competitiveness in a way that you consider relevant for your business/policy development? How do you expect this impact to develop in the near future?***

   The eFarm project has been planned and built by GP Joule. GP Joule's vision is an energy system that runs on 100% renewables. Every project we set up is intended to support this vision. The eFarm project uses 100% renewable electricity to produce mostly H_2 [hydrogen] and – as a by-product – heat. By feeding the nearby district heating grid with the electrolyser's process heat, nearly no energy is wasted. Furthermore, we can offer heat energy at a very low price because we use a waste product of the electrolysis. In the mobility sector, green H_2 produced by eFarm is at the same level as the price for diesel, if you compare the price per kilometre. We expect to increase our competitiveness with fossil fuels in the future, in particular due to the rising pricing of carbon.

Our main strategy was, and still is, to supply the mobility sector with green hydrogen, in particular road vehicles and more specifically commercial vehicles such as vans, buses and trucks since the advantages of hydrogen are especially present for these in comparison to alternatives such as BEVs [battery electric vehicles]. in the future, we will also supply trains, ferries, ships and even airplanes with green hydrogen.

The eFarm project was planned and is designed for a daily production capacity of up to 600 kilogrammes of H_2. According to our business plan we will make full use of our production capacity due to existing demand by 2028. We will then be capable of fuelling approximately 20 buses or 120 cars per day.

2. ***What has been and what is your main strategy for achieving sector coupling – overall and in specific end-use sectors? Please give examples of successful implementation strategies and concrete applications already implemented or planned to be implemented and by when.***

   We realised in 2016 that the technology for green hydrogen mobility – the production and the usability of fuel cell cars – had been developed, but there was still no showcase. So, we decided to go ahead and set it up ourselves: eFarm was born. The electrolysers were built, as well as the filling stations. To be as energy efficient as possible, we fed the district heating grid we established in Bosbüll, North Frisia, northern Germany with the process heat from the electrolysers.

3. ***How would you describe the main rationale behind your sector coupling strategy? To what extent do you rely on direct (e.g. electric vehicles, heat pumps) and indirect electrification (e.g. hydrogen, power-to-X) of specific end uses? Does your sector coupling strategy have a specific focus, e.g. on green hydrogen, battery storage, or demand- and supply-side flexibilities?***

   Our main rationale is energy efficiency. In the eFarm project, we focus on green hydrogen, but in terms of district heating we use heat pumps as well as the heat from the electrolyser. The electrolyser not only provides heat, feeds a hydrogen storage system, and supplies hydrogen for mobility, but it also provides flexibility for the power grid. With respect to efficiency, we are not seeking to focus solely on the efficiency of one conversion step, *e.g.* the "loss" of energy in the production of hydrogen. Our aim is to look at energy efficiency from the perspective of the energy system as a whole. Crucial to system efficiency is when and where the hydrogen is produced. From a system perspective, it is highly efficient to produce hydrogen (as long as the heat is used) when there is a high level of renewable energy production or when the electrolyser can be run as a helping response to the power grid. This way decentralised production of hydrogen can take pressure off of the power grid. The costs for the congestion management – today more than EUR 1 billion [billion euros] per year in Germany – can be reduced by at least 20%. So generating, transporting and using hydrogen can relieve the burden on the power grid, therefore resulting in quicker and more effective use of 100% renewables.

4. ***How are you measuring progress towards sector coupling and an integrated renewable energy supply and demand? Please describe your progress so far in achieving sector coupling. Where appropriate, please describe what measures (policies, regulations, business plans, investment decisions …) have been of support in this progress.***

   We were pioneers: we had to get suppliers developing new products for and with us. We had to define standards with others. The funding by the federal government was important for building up this groundwork, but just as important was the willingness of the local district, Nordfriesland, to let two fuel cell buses run in the local transport system. So, we had and have a steady customer for our green hydrogen.

Beside the funding, regulation has in fact been of little support for the eFarm project to date. The project has been successful in spite of regulation.

Today we have achieved nearly 100% use of renewable energy sources. As mentioned, we use electricity from renewable sources to produce green hydrogen for H_2 mobility and use the waste heat of this process in a district heating system. Almost no energy is wasted.

5. ***What are the main barriers you are facing in achieving sector coupling? Which end-use sectors do you find are most challenging in terms of including in sector coupling, and why? How have you or are you planning to overcome these barriers?***

   In the area of mobility, the most interesting vehicles are not on the market yet. While we are already seeing very good hydrogen-powered passenger cars, buses are at an early stage of development. They are still too expensive. Heavy-duty trucks are not available yet. And we will have to wait years before we can purchase hydrogen-powered planes and ships.

6. ***Are there particular policy barriers that you are facing when attempting to achieve sector coupling? Please list key policy barriers and elaborate.***

   The main barriers are the grid fees in Germany. They do not support flexible use of electricity. Quite the contrary: only high demand that is not flexible benefits from reduced grid fees. Low grid fees for flexible consumers such as electrolysers would make the whole system more efficient and allow electrolysers to take electrical energy from the grid. Therefore, it is important that the green energy is produced at the same time as the electrolysers produce green hydrogen and that this concurrency is closely monitored. This way grid congestions can be avoided.

7. ***What response/engagement have you had with citizens, communities, energy producers, energy traders, consumers, and investors in relation to sector coupling advancements?***

   Very positive. They are excited and want to get involved in numerous ways. Twenty shareholders from northern Germany are part of the eFarm project. Dozens of households are connected to the district heating system.

8. ***Based on your experiences in advancing towards sector coupling, what can policy makers do to drive progress and encourage more cities/regions/companies like yours to set ambitions and take action towards sector coupling? Please elaborate on which policy or regulatory or legislative support you would consider useful or necessary.***

   Most importantly we need a new system of grid fees that encourages flexible use of electricity. In order to strengthen the market for hydrogen systems, regions should pay subsidies for buying and running hydrogen buses. This would make sector coupling systems like that of eFarm economically more feasible.

9. ***Has COVID-19 impacted your progress towards increasing the share of renewables, particularly in regard to achieving sector coupling? If so, please explain how.***

   The pandemic has no impact in this regard.

NOVA INNOVATION


Photo: Nova Innovation (2022)

Photo: Nova Innovation (2022)

Nova Innovation is a global tidal energy company focused on designing, building, and operating tidal turbines to transform the power of the sea into clean, predictable electricity. Founded in 2010, the company is headquartered in Edinburgh (United Kingdom), with projects across Europe, North America and Asia.

Nova Innovation installed its first offshore tidal array in Bluemull Sound in Shetland, Scotland in 2016. The electricity produced by the array has been powering homes, businesses and the grid in Shetland for the past five years. Each of the four turbines in the Shetland Tidal Array has a rated capacity of 100 kW. On average, over the course of a day (based on a 720 kilowatt hour [kWh] output over 24 hours) one turbine can supply electricity for 72 homes, boil a kettle 4 320 times, keep a television on for 9 360 hours and power a 60 kWh battery electric car for 2 400 miles.

Following the success of the first four 100 kW turbines in the array and the positive impact they have had on Shetland's carbon emissions, Nova plans to install a further two 100 kW turbines in 2022. Furthermore, the European Union has provided EUR 20.2 million in funding for a five-year flagship tidal energy project, "Enabling Future Arrays in Tidal" (EnFAIT) based at the Shetland Tidal Array. EnFAIT will work to establish a cost-reduction pathway for tidal energy that is cost-competitive with other forms of renewable energy by surveying the offshore tidal array's development, operation and decommissioning of six turbines. As part of EnFAIT, Nova will demonstrate that tidal energy costs can be cut by at least 40% by the end of the project in 2022.

Following the addition of energy storage capacities in 2018, the Shetland Tidal Array became the world's first baseload tidal power plant. The array provides uninterrupted access to electricity and helps to balance supply and demand. The changing tides create four predictable periods of electricity generation per day, as the tide repeats every six hours. When it changes direction – known as "slack tide" – there is a 20- to 30-minute gap between generation cycles. To ensure an uninterrupted energy supply, a Tesla battery stores electricity generated during peak periods and exports it to the grid during slack periods. The station can therefore deliver baseload and dispatchable electricity to meet consumer demand at any time.

In 2021, Nova Innovation developed the world's first EV charging point powered entirely through tidal energy in Cullivoe, Shetland. The EV charge point is suitable for the use of all EVs. In total, the complete array of six turbines could provide the equivalent of 30 000 vehicle charges per year. The local community has been welcoming and enthusiastic about this tidal-powered EV project. Nova is now looking at opportunities to replicate tidal-powered EV charging points in other locations.

The predictable nature of tidal energy – regulated by the constant cycles of the moon, sun and earth – adds much-needed reliability within the grid from a purely renewable energy source and enables a higher penetration of variable renewables. Moreover, tidal energy is an abundant source of renewable energy, and there are vast opportunities across the world to tap into this global market – across Europe to North America and Southeast Asia, where projects are being developed.

Interview with John Meagher, Director of Business Development, Nova Innovation

1. ***What are your most relevant motivations/drivers and expected benefits for advancing from growing the share of renewable energy separately in one or more end uses towards sector coupling and increasing the share of renewables in an integrated way across two or more end-use sectors? How have these advancements impacted costs and competitiveness in a way that you consider relevant for your business/policy development? And how do you expect this impact to develop in the near future?***

   Nova Innovation is on a mission to provide its clients with clean, predictable electricity from tides, estuaries, and large river flows. We are providing a renewable source of energy in an innovative, environmentally friendly way, motivated by our desire to be part of the solution to the climate emergency. Sector coupling provides new market opportunities for Nova Innovation. The EV charge point that we developed in Shetland is an excellent example of sector coupling and one which we would like to replicate elsewhere. Next to the transport sector, we are also looking to work with the whisky industry. Within our tidal energy project, "Òran na Mara",[9] we will have a tidal turbine array in the Sound of Islay that could power local whisky distilleries on Islay and Jura.

2. ***What has been and what is your main strategy for achieving sector coupling – overall and in specific end-use sectors? Please give examples of successful implementation strategies and concrete applications already implemented or planned to be implemented and by when.***

   Sector coupling helps to create opportunities for tidal energy to benefit the lives of people across different sectors and industries. We are enthusiastic about unlocking the opportunities in other industries and building on the sectors we have already coupled with, such as transport. There are immediate opportunities around island communities, and this is where we have focused efforts initially. Within these areas, where the grid infrastructure can be limited, we can create solutions that do not always correspond to a traditional grid model and where more sectors can be involved.

   Before powering an EV charging point, Nova's turbines have powered an icehouse in Shetland to increase white fish fleet and aquaculture productivity. Nova plans to replicate both examples in other projects, demonstrating the tangible economic benefits that tidal energy is already providing to coastal communities. Providing electricity to industries in remote locations, such as the whisky industry in Islay, is important as we seek to decarbonise from oil and gas. Next to powering industry, opportunities for hydrogen production and desalination are being explored.

3. ***How would you describe the main rationale behind your sector coupling strategy? To what extent do you rely on direct (e.g. electric vehicles, heat pumps) and indirect electrification (e.g. hydrogen, power-to-X) of specific end uses? Does your sector coupling strategy have a specific focus, e.g. on green hydrogen or on battery storage or demand- and supply-side flexibilities?***

   As mentioned above, we welcome opportunities for sector coupling as we seek to use renewable energy for our everyday needs. For example, we would be open to working with green hydrogen to decarbonise Scotland's whisky industry.

   In addition to producing baseload tidal power that can displace traditional fuels such as coal and nuclear, Nova's tidal technology with energy storage can respond instantly to client demand. This gives tidal power a unique ability to displace diesel generation in coastal areas around the world and unlock opportunities for sector coupling.

[9] *For more information, see www.novainnovation.com/news/news_/i/creating-water-of-life-from-the-power-of-the-sea/.*

4. ***Are there particular policy barriers that you are facing when attempting to achieve sector coupling? What can policy makers do to drive progress and encourage more cities/regions/companies like yours to set ambitions and take action towards sector coupling? Please elaborate on which policy or regulatory or legislative support you would consider useful or necessary. Please list key policy barriers and elaborate.***

   Market mechanisms need to work to support tidal energy, in the way that they were used to promote wind and solar technologies in the past. This is needed so that we can increase capacity and bring down costs. Appropriate support is needed to foster development of the tidal sector, *e.g*. through revenue support mechanisms such as the UK government's Contracts for Difference (CfD) scheme.

   Another idea would be to allocate a proper price to carbon and to publicly disclose details on the amount of carbon that industries use. This would work across the economy to increase the use and development of renewable energy, and tidal energy, in particular, as it is completely predictable.

5. ***What response/engagement have you had with citizens, communities, energy producers, energy traders, consumers, and investors in relation to sector coupling advancements?***

   The EV charge point in Shetland, as an example of sector coupling with transport, has had huge interest and enthusiasm from the local community in Shetland and the wider world. This is something that people are really interested in as they can clearly see how the generation of tidal energy benefits their lives, and we would like to replicate this globally.

6. ***Has COVID-19 impacted your progress towards increasing the share of renewables, particularly in regard to achieving sector coupling? If so, please explain how.***

   COVID-19 presented significant challenges across the world. Like other companies, we faced delays, but we continued to make progress. Significant offshore operations went ahead, such as the installation of a fourth tidal turbine into the Shetland Tidal Array, which was successfully delivered in October 2020. Nova was also able to deliver the world's first EV charge point powered by tidal power during the pandemic – powering vehicles for the first time in March 2021.

COSTA RICA

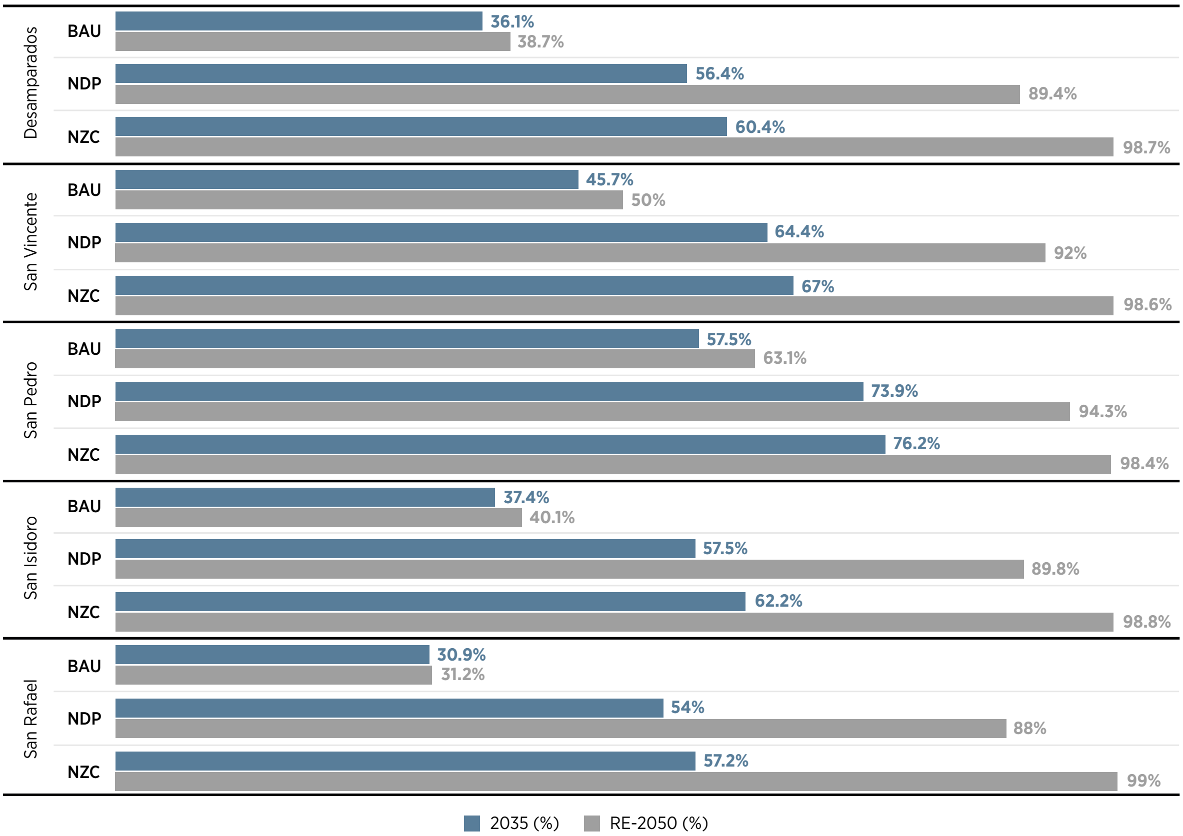
Photo: Gianfranco Vivi/Shutterstock.com

Costa Rica's electricity sector has successfully reached close to a 100% share of renewable energy, primarily sourced from hydropower, geothermal and wind energy. Beyond the power sector, the country relies on oil for over 65% of its total energy consumption. Costa Rica's transport sector accounts for 83% of this, followed by industry, which accounts for 12.4% of total energy consumption (IRENA, 2022a). The transport sector also accounted for three-quarters of the country's energy-related carbon dioxide (CO_2) emissions in 2018.

In the face of its high vulnerability to the adverse impacts of climate change, Costa Rica has developed a national target and strategy to decarbonise its energy system to net-zero emissions by 2050 (IRENA, 2022c). The transport sector encompasses a significant portion of the country's energy consumption and energy-related CO_2 emissions, so Costa Rica has prioritised the electrification and sustainability of its transport sector as a means of accelerating progress towards its decarbonisation objectives. Furthermore, Costa Rica is also making efforts to diversify its electricity mix and move towards more variable renewable energy technologies, as well as reducing the share of hydropower in its energy mix, which over the past years has accounted for over 70% of electricity generation (Government of Costa Rica, 2019; World Future Council, 2020).

IRENA's analysis suggests that under the net-zero carbon emissions scenario, the share of renewables in Costa Rica's total final energy consumption can increase considerably across urban cities, as outlined in Figure 5 (IRENA, 2022c). Such advancements would require sector coupling strategies to be effectively implemented in end-use sectors, particularly the transport sector. In accordance with Costa Rica's National Decarbonisation Plan, renewable electricity will supply 70% of public transport by 2035 and 80% by 2050 (World Future Council, 2020). Appropriate strategies to achieve this may include increasing the share of electricity in the transport sector through locally generated renewable energy such as rooftop solar PV, storage systems consisting of lithium batteries, and hydrogen. The country's grid infrastructure will also need to be upgraded to cope with higher variable loads (IRENA, 2021a).

Figure 5 Share of renewable energy in total final energy consumption by district across Costa Rica: Business as usual (BAU) and low-carbon (NDP and NZC) scenarios



Note: NDP = National Development Plan; NZC = net-zero carbon emissions.

IRENA's findings suggest that Costa Rica's target of reaching net-zero emissions by 2050 is indeed possible. A combination of technologies and applications, including solar PV, energy storage, heat pump technologies and electro-mobility will allow the country to reduce at least 90% of its emissions from cities (IRENA, 2021a).

VANCOUVER, CANADA

Photo: Evgeny Pylayev/Shutterstock.com

The city of Vancouver has been at the forefront of prioritising sustainability in recent decades. British Columbia, the province in which Vancouver is located, already benefits from an electricity supply in which over 97% of its electricity came from renewables in 2018 – 91% from primarily large hydropower and 6% from biomass and geothermal (Canada Energy Regulator, 2021). However, 68% of Vancouver's final energy supply across the different sectors was still sourced from fossil fuels in 2015, with the remaining met with biofuels and electricity (City of Vancouver, 2015). Because its production of electricity is mostly renewable, Vancouver's strategies emphasise efficiency and emissions-reduction targets for buildings, while also encouraging the electrification of transport and low-carbon heating/cooling.

The city adopted the Greenest City 2020 Action Plan (GCAP) in 2011. At the plan's halfway point, Vancouver set two ambitious targets in its Renewable City Strategy, aiming to reduce its GHG emissions by 80% compared to 2007 emissions and reaching 100% renewable energy consumption by 2050 (City of Vancouver, 2015). Its current Climate Emergency Action Plan (CEAP), adopted in 2020, aims to reduce its carbon pollution by 50% in 2030 compared to 2007 emissions, with a special emphasis on two carbon emitting sectors it has jurisdiction over - transportation and buildings (City of Vancouver, 2020).

The city identified the greening of its building sector as key – Vancouver possesses considerable regulatory power over its land-use and building standards, which enables it to act decisively on its building sector. The Zero Emissions Building Plan (ZEBP) was released in 2016, with a focus on high efficiency building envelopes and ventilation systems, and district (neighbourhood) systems to provide energy for heating and cooling (City of Vancouver, 2016).

Vancouver has encouraged the shift away from fossil fuels and towards renewables through the use of heat pumps, biogas and district energy systems. Rebates, incentives supporting policies (*e.g.* the Building Bylaw and the Rezoning Policy for Green Building) and other supports for certain types of buildings are offered in partnership with concerned organisations, such as utilities, in addition to informational assistance (City of Vancouver, 2020). The ZEBP sets phased targets for a number of indicators, such as greenhouse gas (GHG) intensity, energy use intensity and thermal energy demand intensity, while leaving the approach somewhat flexible for developers. GHG intensity is slated to be zero for all new buildings by 2030 (City of Vancouver, 2016). Such moves are also encouraged through "catalyst" policies, *i.e.* bonuses such as additional floor space for buildings that meet such standards (City of Vancouver, 2018).

Vancouver's strategy for its transportation sector includes encouraging the use of zero-emissions vehicles, especially through greater electrification, in addition to tackling emissions by encouraging active transportation and transit (City of Vancouver, 2020). The city has supported the expansion of public charging infrastructure, mandating that certain new buildings have EV charging plots and instituting policies to support retrofitting, collaborating with the private sector to integrate charging infrastructure in their properties (City of Vancouver, 2012; City of Vancouver, 2020).

The scope for hydrogen uses in Vancouver was seen as being limited to heavy transport (City of Vancouver, 2015). However, British Columbia recently laid out a hydrogen strategy that foresees the use of power-to-gas in sector coupling and better integration of variable renewable energy. British Columbia has encouraged the production of hydrogen through discounted electricity, facilitating the creation of hubs to concentrated demand and supply, financial support for fuel cell vehicles and infrastructure, and by supporting innovation (Government of British Columbia, 2021).

KIGALI, RWANDA

The city of Kigali and the district of Muhanga in Rwanda recently demonstrated the use of solar thermal technologies to couple renewables and heating in the area of health care on a small scale. This approach, *i.e.* targeting critical development sectors such as health care for the deployment of renewable energy, can be promising, particularly in areas where access to electricity is an issue. By meeting energy end uses through renewable energies, their impact can be amplified through avoided emissions, as well as providing a tangible benefit to local communities and increasing resilience.

Rwanda's overall final energy consumption features a large share of renewables already (85.7% in 2018) owing to the reliance on traditional biomass (IRENA, 2021b). Its renewable energy consumption was made up of bioenergy (98%) and electricity (2%). However, in general, electrification rates in Rwanda remain low, accounting for around 3% of final energy consumption in 2018, and energy demand has been growing steadily (UNSD, 2022). Households are primary consumers of electricity (51%) for use in lighting, cooling, ironing, cooking and water heating (Rwanda Ministry of Environment, 2019).

Rwanda has set a target of 100% electricity access by 2024, of which 60% is to be met through renewable sources; this share was already 54% in 2019 owing to significant hydropower resources (48% of total generation) and a small share of solar PV (6% of total generation) (IRENA, 2021b). Of the 110 megawatts (MW) of installed hydropower capacity, the largest project is a run-of-river dam, which accounts for 28 MW. Micro hydropower plants account for around 11 MW, with some pico hydropower plants (1-10 kW) also present (Rwanda Ministry of Infrastructure, 2022). Substantial progress has already been made in expanding access to electricity, although a large discrepancy between urban and rural areas remained as of 2016 (80% for urban areas and 17.8% for rural areas) (SEforAll, 2022). In 2019, households accounted for the majority of energy consumption (72%), followed by transport (16%) and manufacturing (8%) (UNSD, 2022).

Rwanda has also placed health care at the forefront of its development agenda, pushing for a decentralised health care system and greater access to finance for health centres to allow for universal access to health care for its citizens. Its strategy to adopt a low-carbon development pathway, which began implementation in 2011, has emphasised the use of renewable energy in the grid, as well as for small-scale applications (Republic of Rwanda, 2011). While sector coupling has not received explicit policy support at a national or local level yet, its application can be seen on a smaller scale. Health care centres can, for the moment, see their need for water heating and electricity being met through renewable energy. Local and regional governments in Rwanda are also looking for alternative development pathways that can guarantee improved socio-economic outcomes, while mitigating their overall impact on climate change (Mason, 2020; WHO, 2017).

Kigali and Muhanga have been at the forefront of this effort. Through the Urban-LEDS II project, funded by the European Commission and jointly implemented by ICLEI and UN-Habitat, they have demonstrated the potential of renewable energy – primarily solar PV and thermal – to meet the energy needs of buildings and complexes, specifically in the health care sector. This includes lighting as well as heating. In 2021, the Gitarama and Gahanga health centres – in Kigali and Muhanga, respectively, and supported by ICLEI Africa – were able to install efficient lighting solutions indoors and outdoors, including solar-powered streetlights, which brought down costs associated with electricity.

Access to clean water is also a pressing concern, especially in urban health care centres in the face of a rapidly growing population and increasing urbanisation. The project installed rainwater harvesting systems and solar-powered water pumps to address this. The need for water heating was met through solar water heaters that were also installed at the two centres. These high-pressure geysers provide hot water for daily use, such as cooking, cleaning, and sterilisation. A number of local officials from Kigali and Muhanga have commended this decentralised approach, which allowed for more reliable electricity, lower energy costs and improved service provision (ICLEI Africa, 2021).

The need for space heating is minimal, given Rwanda's climate; however, there is growing demand for space cooling and a robust cold chain. The deployment of renewable energy off-grid has also enabled the use of cooling solutions such as cold storage, which is a boon to the country's agriculture and horticultural sector (USAID, 2019).

Renewable energy technologies can enable off-grid applications, insulating consumers from the effects of unreliable grid electricity. The projects in Kigali and Muhanga also demonstrate the importance of pilot projects in creating stakeholder buy-in for local renewable energy projects, and in increasing the potential to upscale such local solutions (ICLEI Africa, 2021). Moving forward with sector coupling can see such local solutions upscaled to meet energy needs such as heating and cooling through renewable energy.

REFERENCES

Bazzana, D., B. Zaitchik and G. Gilioli (2020), "Impact of water and energy infrastructure on local well-being: An agent-based analysis of the water-energy-food nexus", *Structural Change and Economic Dynamics*, Vol. 55, pp. 165-176, https://doi.org/10.1016/j.strueco.2020.08.003.

Canada Energy Regulator (2021), *Provincial and territorial energy profiles – British Columbia*, www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-british-columbia.html (accessed February 2022).

City of Vancouver (2021), *Climate Emergency Annual Report*, City of Vancouver, Vancouver.

City of Vancouver (2020), *Climate Emergency Action Plan*, City of Vancouver, Vancouver.

City of Vancouver (2018), *Zero Emissions Building Catalyst Policy, City of Vancouver*, Vancouver.

City of Vancouver (2016), Z*ero Emissions Building Plan, City of Vancouver*, Vancouver.

City of Vancouver (2015), *Renewable City Strategy 2015-2050*, City of Vancouver, Vancouver.

City of Vancouver (2012), *Transportation 2040*, City of Vancouver, Vancouver.

CleanTechnica (2021), *Why battery electric vehicles beat hydrogen electric vehicles without breaking a sweat*, https://cleantechnica.com/2021/02/01/chart-why-battery-electric-vehicles-beat-hydrogen-electric-vehicles-without-breaking-a-sweat/ (accessed March 2022).

Clean Energy Wire (2018), *Sector coupling – Shaping an integrated renewable energy system*, www.cleanenergywire.org/factsheets/sector-coupling-shaping-integrated-renewable-power-system (accessed December 2021).

Di Silvestre, M.L. et al. (2018), "How decarbonization, digitalization and decentralization are changing key power infrastructures", *Renewable and Sustainable Energy Reviews*, Vol. 93, pp. 483-498, https://doi.org/10.1016/j.rser.2018.05.068.

European Heat Pump Association (2021a), S*trategic research and innovation agenda for heat pumps: Making the technology ready for mass deployment*, Renewable Heating and Cooling Platform, Brussels.

European Heat Pump Association (2021b), *A digital revolution for the built environment? Flexibility, comfort and new business models for heat pumps*, European Heat Pump Association, Brussels.

Fridgen, G. et al. (2020), "A holistic view on sector coupling", *Energy Policy*, Vol. 147, https://doi.org/10.1016/j.enpol.2020.111913.

Government of British Columbia (2021), *B.C. hydrogen strategy*, Government of British Columbia, Victoria.

Government of Costa Rica (2019), *Decarbonization Plan 2018 – 2050*, Government of Costa Rica.

ICLEI Africa (2021), *Making urban healthcare resilient for a green economic recovery*, ICLEI Africa, Cape Town.

Ilo, A. et al. (2021), *Smart sector integration, towards an EU system of systems. Building blocks, enablers, architectures, regulatory barriers, economic assessment*, European Technology and Innovation Platform.

IRENA (2022a), *World energy transitions outlook: 1.5°C pathway*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2022b), *Renewable power generation costs in 2021*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2022c), *Urban energy transition for the greater metropolitan area of the central valley of Costa Rica*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2022d), RE-organising power systems for the transition, International Renewable Energy Agency, Abu Dhabi.

IRENA (2022e), *Green hydrogen for industry: A guide to policy making*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2021a), *Sector coupling in facilitating integration of variable renewable energy in cities*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2021b), *Rwanda: Energy profile*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/IRENADocuments/Statistical_Profiles/Africa/Rwanda_Africa_RE_SP.pdf, (accessed February 2022).

IRENA (2019), *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2015), *Renewable energy options for shipping*, International Renewable Energy Agency, Abu Dhabi.

IRENA Coalition for Action (2021), *Companies in transition to 100% renewables: Focus on heating and cooling*, International Renewable Energy Agency, Abu Dhabi.

IRENA Coalition for Action (2020), T*owards 100% renewable energy: Utilities in transition*, International Renewable Energy Agency, Abu Dhabi.

IRENA Coalition for Action (2019), *Towards 100% renewable energy: Status, trends and lessons learned*, International Renewable Energy Agency, Abu Dhabi.

IRENA, IEA and REN21 (2020), *Renewable energy policies in a time of transition: Heating and cooling*, IRENA, OECD/IEA and REN21.

IRENA, IEA and REN21 (2018), *Renewable energy policies in a time of transition*, IRENA, OECD/IEA and REN21.

Mason, E. (2020), "Universal health coverage: How Rwanda is moving forward with healthcare for all", *Innovations in Healthcare*, 13 November, www.innovationsinhealthcare.org/universal-health-coverage-how-rwanda-is-moving-forward-with-healthcare-for-all/ (accessed February 2022).

Münster, M. et al. (2020), *Sector coupling: Concepts, state-of-the-art and perspectives*, European Technology and Innovation Platform, Smart Networks for Energy Transition.

Perner, J., M. Unteutsch and A. Lövenich (2018), *The future cost of electricity-based synthetic fuels*, Agora Verkehrswende, Agora Energiewende and Frontier Economics.

Ramsebner, J. et al. (2021), "The sector coupling concept: A critical review", *WIREs Energy and Environment*, Vol. 10/4, https://doi.org/10.1002/wene.396.

REN21 (2022), *Global status report 2022*, REN21 Secretariat, Paris.

Renewables Grid Initiative (2020), *Flexibility: The need for flexibility in a climate-neutral energy system*, Renewables Grid Initiative, https://renewables-grid.eu/fileadmin/user_upload/2020_RGI_Flexibility_Discussion_Paper.pdf.

Republic of Rwanda (2011), *Green growth and climate resilience*, Republic of Rwanda, Kigali.

Rwanda Ministry of Environment (2019), *Rwanda National Cooling Strategy*, Rwanda Ministry of Environment, Kigali.

Rwanda Ministry of Infrastructure (2022), *Energy Division*, www.mininfra.gov.rw/digital-transformation-1-1 (accessed February 2022).

SEforAll (2022), *Rwanda, Sustainable Energy for All*, www.se4all-africa.org/seforall-in-africa/country-data/rwanda/ (accessed February 2022).

UNSD (2022), *Energy balance visualization (Rwanda)*, United Nations Statistics Division, https://unstats.un.org/unsd/energystats/dataPortal/ (accessed February 2022).

USAID (2019), *Off-grid solar energy market Rwanda*, United States Agency for International Development, www.usaid.gov/sites/default/files/documents/1860/PAOP-Market-Assessment-Brief-Rwanda-English.pdf (accessed February 2022).

Van de Graaf, T. et al. (2020), "The new oil? The geopolitics and international governance of hydrogen", *Energy Research & Social Science*, Vol. 70, https://doi.org/10.1016/j.erss.2020.101667.

Van Nuffel, L. et al. (2018), *Sector coupling: How can it be enhanced in the EU to foster grid stability and decarbonise?*, European Parliament, Brussels.

Virtual Power Plant (2020), *What is sector coupling?*, www.next-kraftwerke.com/knowledge/sector-coupling (accessed December 2021).

WHO (2017), *Primary health care systems (PRIMASYS): Case study from Rwanda*, World Health Organization, Geneva.

World Future Council (2020), *Policy roadmap for 100% renewable energy in Costa Rica – Achieving a fully decarbonised energy system*, World Future Council, Hamburg.

ANNEX A:

MORE EXAMPLES OF SECTOR COUPLING PROJECTS

COMPANY COUNTRY SECTORS	TECHNOLOGY	DESCRIPTION
BANULA **Germany** **Electricity, transport**	Solar PV	BANULA is a transformation project of the electric mobility ecosystem. Electric mobility is holistically integrated as part of the energy system. EVs are balanced according to their actual load behaviour and, in the future, for the supply in case of bi-directional load management by the electric mobility service provider, enabling customer-centric services. Charge point operators (CPOs) on private properties, such as retailers, are enabled to separate the energy used by the charging point from the energy for the property and the actual business. Consumers are enabled to freely choose their supplier at any charging point, with the same comfort and trust as in home charging, but independent of their location (*e.g.* employer, retail site, parking garage). The new ecosystem reduces the barrier to providing flexibility. The BANULA-IT-network transcripts and energy transactions are rendered tamper-proof by blockchain technology.
Vulcan Energy Zero Carbon Lithium **Germany** **Electricity, heating, mining**	Co-generation of geothermal energy from production wells coupled with lithium extraction	The Vulcan Zero Carbon Lithium Project's objective is to pioneer the first zero-carbon lithium project – the production of lithium hydroxide – by 2024. Located 60 kilometres from Stuttgart and near the seat of Europe's auto and lithium-ion battery manufacturing industry, Vulcan's vision is to deliver a project with a net-zero CO_2 footprint as part of its environmental, social and governance (ESG).
Liquid Wind **Sweden** **Electricity, shipping**	Hydrogen and biomass	Liquid Wind plans to use low-cost electricity to produce hydrogen. Hydrogen and CO_2 from a biomass-fuelled co-generation plant will be used to produce methanol as a liquid fuel for the shipping sector. The company has built a strong consortium of suppliers, some of whom are also co-owners of Liquid Wind. They have selected a site for the first plant and have a committed customer for the fuel produced.
First Grid Integration with Solar Irrigation Pump System **Bangladesh** **Electricity, heat, agriculture**	Solar PV irrigation pumps (24.5 kW capacity installed so far)	First Grid Integration uses solar PV to irrigate farmland for six to seven months per year. In the remaining months, it aims to feed unused electricity generated by the pumps back into the grid. In the long term, this will reduce energy imports and allow the additional energy to be used for other end uses.

Marine energy-cooled data centres **Finland** **Industry, cooling, data centres**	Marine energy	Google is building a second data centre cooled by the sea using the Seawater Air Conditioning (SWAC) technique. SWAC uses deep cold water from oceans, rivers, and lakes as a substitute for conventional air-conditioning systems.
Marine energy integrated in coastal protection infrastructure **The Netherlands** **Industry, electricity**	Marine energy	Using the difference in salt levels, blue energy can generate electricity. By reversing the method of blue energy, sea water can be turned into potable water. This form of desalination has already been tested successfully and this process will now be scaled up at the REDstack test site on the Afsluitdijk.
Marine energy desalination **United States** **Industry, electricity, desalination**	Electricity and marine energy	The Waves to Water competition by the US Department of Energy aims to harness the power of ocean waves to make potable water using modular desalination systems. These systems use power from ocean waves to make clean drinking water, which can be used in disaster recovery and for coastal and remote communities.
Energy Superhub Oxford (ESO) **United Kingdom** **Transport, heat**	Energy storage and ground-source heat pumps	Oxford City Council has facilitated what is expected to be the world's largest hybrid energy storage system, the Energy Superhub Oxford (ESO). The system will assist in decarbonising energy in two major sources of carbon emissions in Oxford: transport and heat systems. The project will help reduce 44 000 tonnes of CO_2 annually by 2032 and reduce emissions by 40%. The superhub comprises a 50-megawatt (MW) grid-scale battery supporting a 10 kilometre network of EV charging points and ground-source heat pumps servicing about 300 households. Currently, the ESO can integrate multiple sources of energy – including renewables – to manage energy demand. However, because Oxford is part of the UK100 network (local government leaders who develop and execute clean energy transition plans), the ESO will run entirely on renewable energy by 2050.
Holzkirchen Geothermal combined heat and power plant **Germany** **Electricity, district heat**	Geothermal	Holzkirchen's 3.2 MW geothermal combined heat and power plant uses binary-cycle technology to generate electricity from geothermal fluid of around 150°C. It supplies the local district heat network with the residual energy from the plant.

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