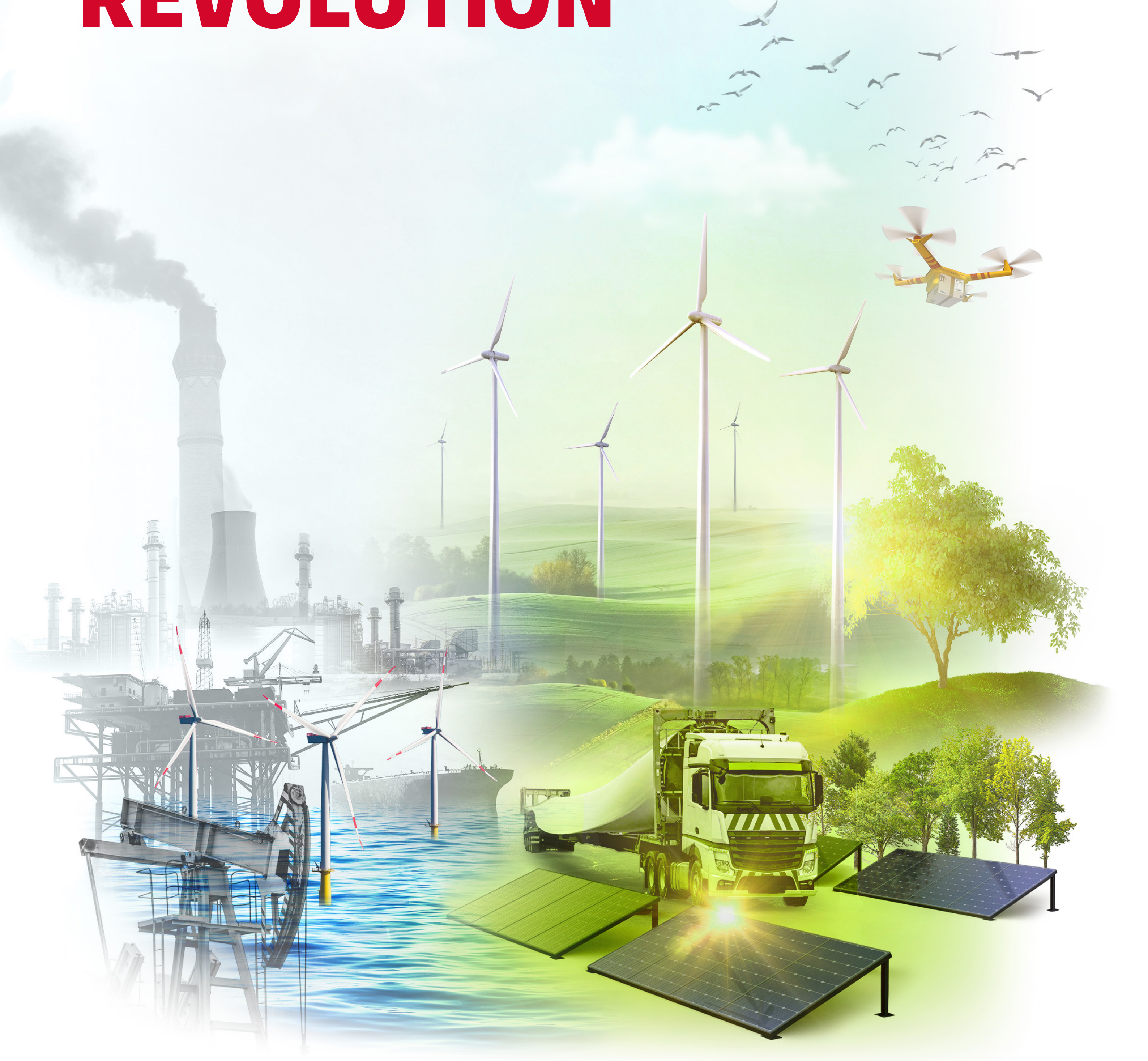
DHL WHITE PAPER

LOGISTICS OF THE ENERGY REVOLUTION



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CONTENTS

PREFACE

Being one of the world's largest logistics service providers, DHL is a significant energy consumer. In 2020, our transportation activities generated 33 million tons of global greenhouse gas emissions, representing 0.4% of the world's transportation sector emissions. In parallel, the energy sector itself is a significant contributor to greenhouse gas emissions and faces transformational challenges across the entire industry.

As a consequence, DHL has established close, long-term relationships with energy companies around the globe and we understand and accept the responsibilities of our energy consumption. Along with a firm commitment to greening all our own operations, we act as a catalyst for decarbonization across our industry, and we are helping to accelerate the energy transition through leadership in integrated energy logistics.

In this white paper exploring the transformation of the entire energy industry, you'll recognize that the logistics challenges are dynamic and often unique to the energy industry. Take, for example, the extraordinary tasks of moving ever-larger wind turbine blades around the globe and of enabling more sustainable operations in some of the most remote locations imaginable. This requires agility, innovation, and a willingness to continuously evolve in order to solve tomorrow's energy challenges today.

One thing's for sure. The energy transition is bringing us closer together – the energy industry requires tighter integration of services and a closer partnership with logistics service providers.

Mutual dependence of expertise will maximize value creation at the intersection of both industries. Signs of current collaboration in support of the energy transition include initial use of sustainable biofuels, piloting hydrogen technology in transportation assets, and applying vehicle-to-grid (V2G) smart charging technology to send battery power back to the grid as well as cloud-based virtual power plants (VPPs) for decentralized power generation and a new era of power trading.

We are excited to travel this path together, evidenced by this new report on logistics as a critical enabler of the energy revolution.

Let both our industries join forces, Powering our World, Together.

Katja Busch
CCO and Head of CSI
DHL Customer Solutions and Innovation

Michael Wiedemann
President Energy Sector and Head of CSI EMEA
DHL Customer Solutions and Innovation

Amadou Diallo
CEO Middle East & Africa
DHL Global Forwarding

Bastian Thöle
Vice President
Enterprise Model & Strategy
Capgemini Invent

EXECUTIVE SUMMARY

The energy transition is happening. As the effects of climate change become more obvious, governments and businesses are accelerating their efforts to reduce greenhouse gas emissions. At the center of these efforts is a significant transformation of the global energy system, with a shift in primary energy supply from fossil fuels to renewable energy sources such as wind and solar power.

This shift has far-reaching implications for energy companies' strategies. It will also require dramatic changes to their supply chains. As this report shows, logistics will be a critical enabler of the energy revolution.

THE EMERGING CHALLENGE OF RENEWABLE ENERGY SUPPLY CHAINS

More decentralized and distributed power generation boosts logistics demand
Renewable energy technology requires a dramatic increase in the volume and variety of logistics services required to deliver each unit of generating capacity. Today's large, centralized power plants are being replaced by networks of smaller, widely distributed renewables generating equipment with hundreds of thousands of wind turbines along with millions of solar panels installed on rooftops and in dedicated solar parks.

Limited availability of logistics assets and services increases costs
The availability of logistics services, facilities, and assets to deploy renewable energy systems is already constrained, with shortages of specialized assets for the transportation of large components, as well as ongoing shortages of ocean and air freight capacity following the COVID-19 crisis. In addition, the equipment needed to handle future generations of very large wind turbines does not yet exist.

Rising supply chain complexity requires better visibility and control
The smooth operation of complex, decentralized, and often global renewable energy supply chains will require companies to manage the manufacture, storage, and transportation of thousands of critical components. This necessitates full visibility of the end-to-end supply chain, which the industry has yet to achieve.

Net-zero energy technology needs low-carbon logistics
The increasing demand for logistics services coincides with industry-wide pressure to reduce the environmental impact of business operations. This makes emissions reduction in the supply chain a priority for the energy sector.

CALL TO ACTION

We have identified five key areas of focus for any organization involved in the energy revolution:

1. Collaboration is key
Robust, resilient logistics systems for renewables will require intelligent coordination and collaborative innovation among multiple stakeholders, including energy companies, equipment manufacturers, and logistics service providers. We are there to power the world together!

2. Work end-to-end
Companies need an end-to-end perspective on their logistics systems, especially as they plan their entry into new areas of technology, new markets, and new regions. This perspective should address the whole supply chain and the full lifecycle of energy infrastructure, including logistics requirements for service, maintenance, upgrades and asset end-of-life

3. Focus on visibility and digitization
To help them manage logistics execution and optimize supply chain design, energy companies can make use of smart digital platforms and tools. Future energy supply chains will rely on a suite of advanced technologies, including smart connected sensors, drones, and digital twins.

4. Identify transferrable skills from adjacent industries
As renewable networks expand, standardization and industrialization will be important for rapid, cost effective development. The energy sector could replicate and adapt successful logistics approaches from other sectors, such as the automotive industry, just as it has already done in the transfer of offshore skills and technologies from oil and gas to wind energy.

5. Pursue sustainable logistics solutions
In the medium term, energy companies should partner with logistics service providers to develop early use cases for key emerging technologies, from synthetic fuels to electric aviation. In the immediate term, logistics providers can help the energy industry reduce both costs and supply chain emissions through operational changes such as route optimization and improved utilization of transportation assets.

CHAPTER 1

INTRODUCTION

TIME TO ACT

In early summer 2021, a dome of warm air settled over North America, leading to record high temperatures. On 29th June, a weather station in the village of Lytton, British Columbia, Canada recorded a peak temperature of 49.6°C, the highest ever recorded in the country. The next day, Lytton was engulfed by a wildfire that destroyed 90% of its buildings and killed two people.

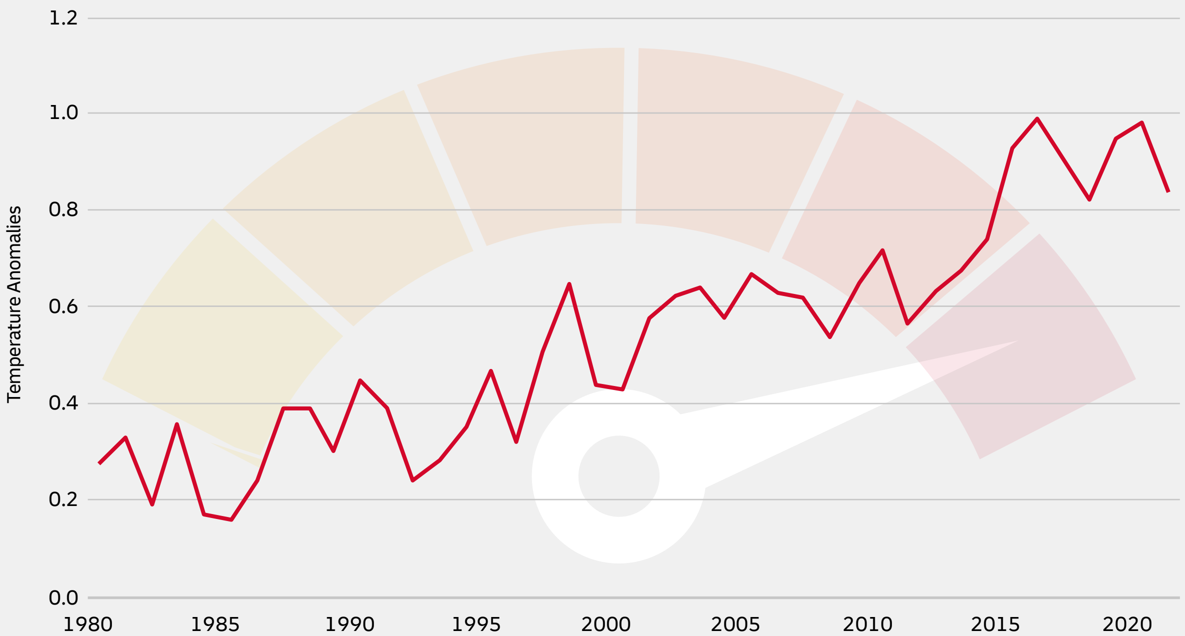
Two weeks later, several countries in Western Europe saw prolonged heavy rainfall, with some regions experiencing a month's worth of precipitation in a single day. In Germany, the resulting floods killed at least 184 people, the country's deadliest natural disaster for almost 60 years. In December 2021, an unusual late-season outbreak of tornadoes destroyed buildings and caused more than 100 fatalities across five US states.

According to the World Meteorological Organization, 62 of 77 extreme and deadly weather events reported between 2015 and 2017 revealed significant human influence.[1] **To limit anthropogenic climate change, the world needs to dramatically reduce the emission of CO_2 and other greenhouse gasses** (see Figure 1 for global temperature anomalies). The United Nations (UN) estimates that, if significant action is not taken during this decade, the damage done by global warming may become irreversible[2].

That action will involve nothing less than a **transformation in the global energy system, with a significant shift away from the combustion of fossil fuels and a dramatic increase in the deployment of low and zero-carbon energy sources such as wind and solar power**. Achieving that transformation will have an impact on both energy users and energy producers, but it will bring significant opportunities too. New technologies, new skills, and new large-scale supply chains will be required to build, support, and maintain tomorrow's energy infrastructure.

FIGURE 1: GLOBAL TEMPERATURE ANOMALIES SINCE 1980

Source: Climate at a Glance: Global Time Series, 2022, NOAA National Centers for Environmental information



Anomalies refer to the 20th century average

[1] Climate and weather-related disasters surge five-fold over 50 years, but early warnings save lives – WMO report, 2021, United Nations

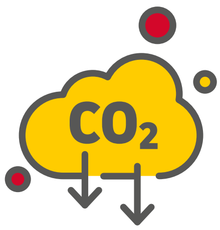
[2] Only 11 Years Left to Prevent Irreversible Damage from Climate Change, Speakers Warn during General Assembly High-Level Meeting, 2019, United Nations

Government institutions are aware of the need for action. 193 parties signed the 2015 Paris Agreement, aiming to implement policies to limit the temperature increase to well below 2°C, preferably to 1.5°C above pre-industrial levels.[3] Today, many countries have pledged to reach net zero (see below: Net zero explained).[4] With its Green Deal, for example, the European Union (EU) has set up a climate program to achieve this goal by 2050.[5] In the US, the Biden administration plans to set up a climate program to create a net-zero emissions economy by 2050.[6] However, even though there has been progress, efforts are currently insufficient as only a few countries have made their ambitions to reach net zero legally binding.

For these ambitions to become a reality, it is time to act now: net-zero targets need to be widely enshrined in law and legislation must be backed by tangible measures. Today, overall CO_2 emissions continue to rise with energy-related CO_2 emissions being the main driver for climate change – reaching around 34 billion tons (Gt) in 2021 (see Figure 2).

62 of 77

EXTREME AND DEADLY WEATHER EVENTS REVEALED SIGNIFICANT HUMAN INFLUENCE



TO REACH NET ZERO BY

2050

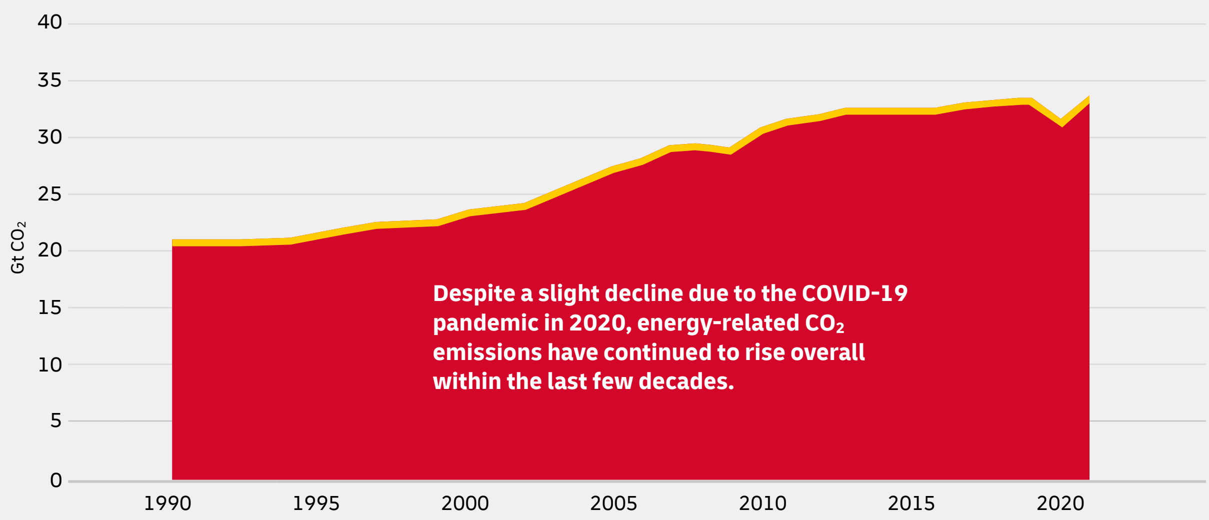
OVERALL CO_2 EMISSIONS NEED TO START TO DECREASE WELL BEFORE 2030[7]

NET ZERO EXPLAINED

The emissions reduction approach pursued by most governments and organizations does not aim to eliminate CO_2 emissions altogether. Instead, the goal is to prevent further accumulation of CO_2 in the atmosphere. This would be achieved primarily by shifting to more sustainable energy sources. Carbon removal technologies such as carbon capture, utilization, and storage (CCUS) and direct air capture (DAC) also play a role here, but to a significantly lesser extent.

FIGURE 2: GLOBAL ENERGY-RELATED CO_2 EMISSIONS FROM 1990-2020

Source: Global Energy Review: CO_2 Emissions in 2021, 2022, IEA



[3] Paris Agreement, 2015, United Nations

[4] Carbon Neutrality - The Road to Net Zero, 2021, Statista

[5] The European Green Deal, 2019, European Commission

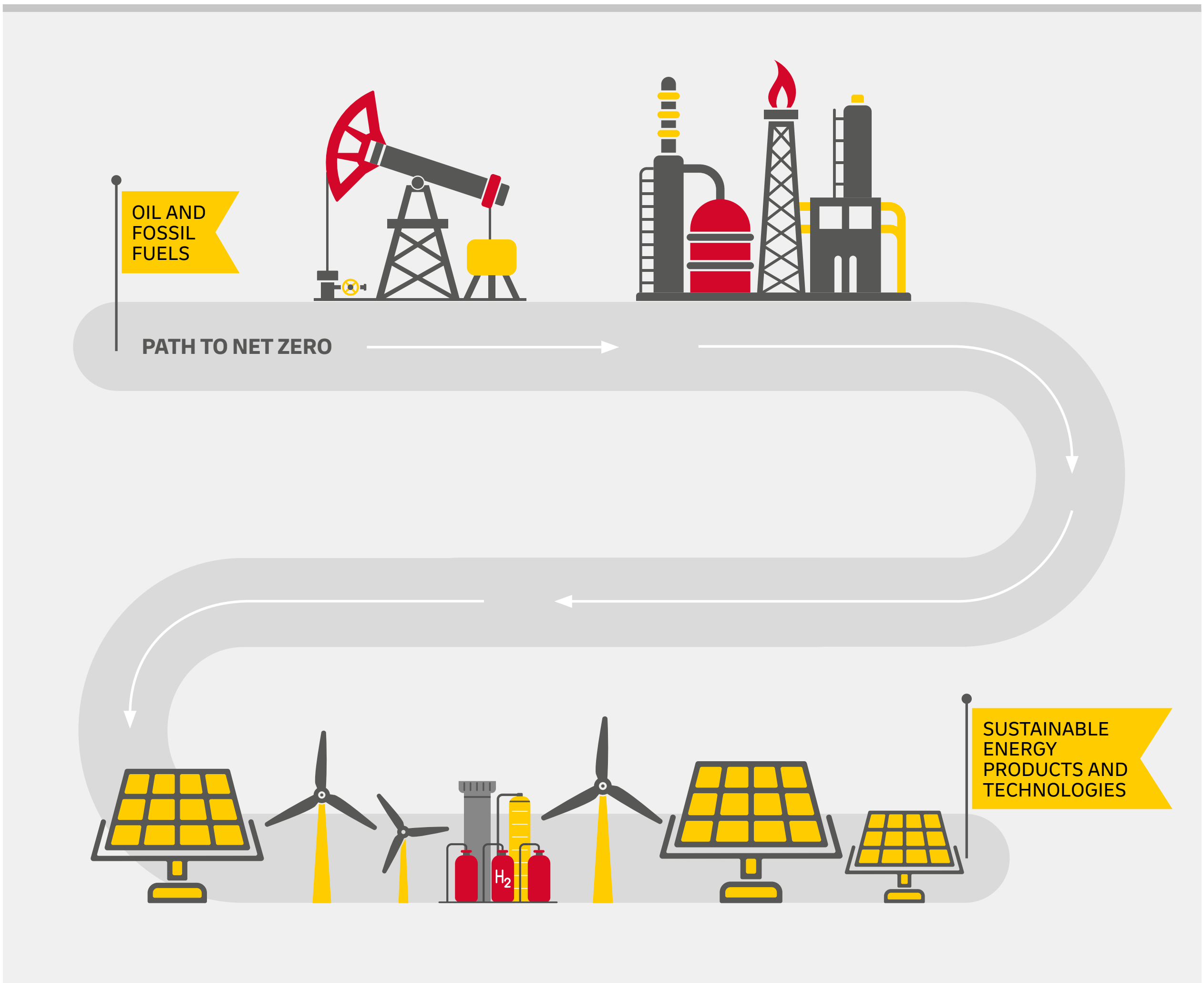
[6] Fact sheet: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies, 2021, The White House

[7] Summary for Policy Makers, 2018, IPCC

THE ENERGY REVOLUTION

A significant change in the way we produce and consume energy will be an essential part of the path to net-zero emissions. This path will be characterized by a shift to lower-emission fossil fuels, such as switching from coal to natural gas, along with the development of more sustainable, and ultimately emission-free, energy products and technologies. It will include increased electrification, the growing use of hydrogen and bio-based synthetic fuels, and dramatic expansion in the generation of electricity from renewable sources.

THE SHIFT OF ENERGY SOURCES



For the energy sector, this transition will be nothing less than a revolution. As global energy production shifts away from fossil fuels and towards alternative energy sources such as solar and wind power, there will be a role to play both for oil and gas companies and for renewable energy specialists. Oil and gas companies need to focus on reshaping their business portfolio and increasing their investments in renewable energy and sustainable technologies (e.g., CCUS). This change will also be driven by societal pressure for more climate-friendly energy production, while incorporation of climate protection into law may increase the business risk faced by companies with too much exposure to high-emissions businesses. In contrast, as wind and solar photovoltaic (PV) technologies take on greater significance, renewable energy companies will be challenged to meet the increasing demand for alternative energy and to provide the associated infrastructure.

MAPPING OUT THE NEW ENERGY LANDSCAPE

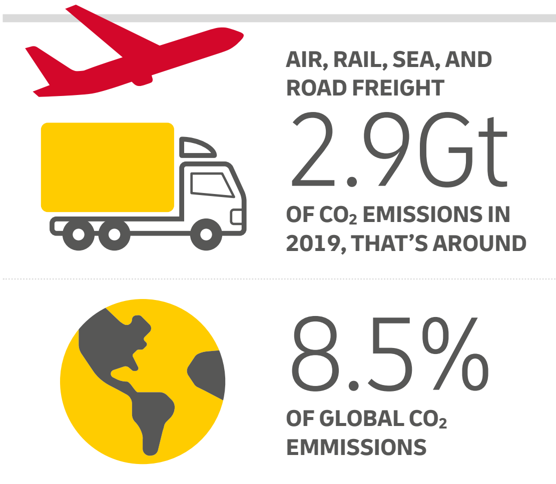
The shift to new energy sources and technologies will have far-reaching consequences for energy companies. Energy generation will tend to become more fragmented, decentralized, and remote as, for example, large power stations are replaced or supplemented by small-scale plants in rural areas, solar farms, and onshore or offshore wind installations.

The logistics industry will become a key enabler in the energy revolution. The energy density of renewables is much lower than that of fossil fuels, and availability is often intermittent. The world will therefore need more energy infrastructure, and a greater diversity of infrastructure, to meet its energy needs from renewable sources, with a correspondingly greater requirement for logistics and supply chain capabilities.

To deliver these capabilities, the logistics sector needs to adapt to the changing requirements of its customers. Those requirements will be increasingly diverse, ranging from the installation and support of small-scale off-grid solar installations to handling the giant components used in ever-larger offshore wind turbines.

In addition, the logistics industry itself is a contributor to CO_2 emissions. According to the International Transport Forum, air, rail, sea, and road freight accounted for roughly 2.9 Gt of CO_2 emissions in 2019.[8] That's around 8.5% of global emissions. Pressure to reduce those emissions will require the logistics sector to consider how its operations can become more sustainable and streamlined, for example through the adoption of new environment-friendly fuels and through digitization to improve asset utilization and efficiency.

Due of the lack of alternatives and the ultimacy of achieving net zero, **companies will have to find new ways of doing business and will need to transform their business models and corporate strategies. New thinking, capabilities, and solutions are needed**. However, accessing new markets, adjusting business models, and implementing new technologies will require time and commitment from every participant in the value chain. That's why it is essential that governmental bodies, companies in the energy sector, logistics providers, and other stakeholders work together to shape a more sustainable future.



[8] ITF Transport Outlook 2019, International Transport Forum

CHAPTER 2

THE FUTURE OF ENERGY SUPPLY

The Paris Agreement set an objective to limit global warming to well below 2°C, preferably to 1.5 °C. To achieve that objective, carbon emissions need to decline rapidly in the coming years, ideally reaching net zero by the middle of this century.

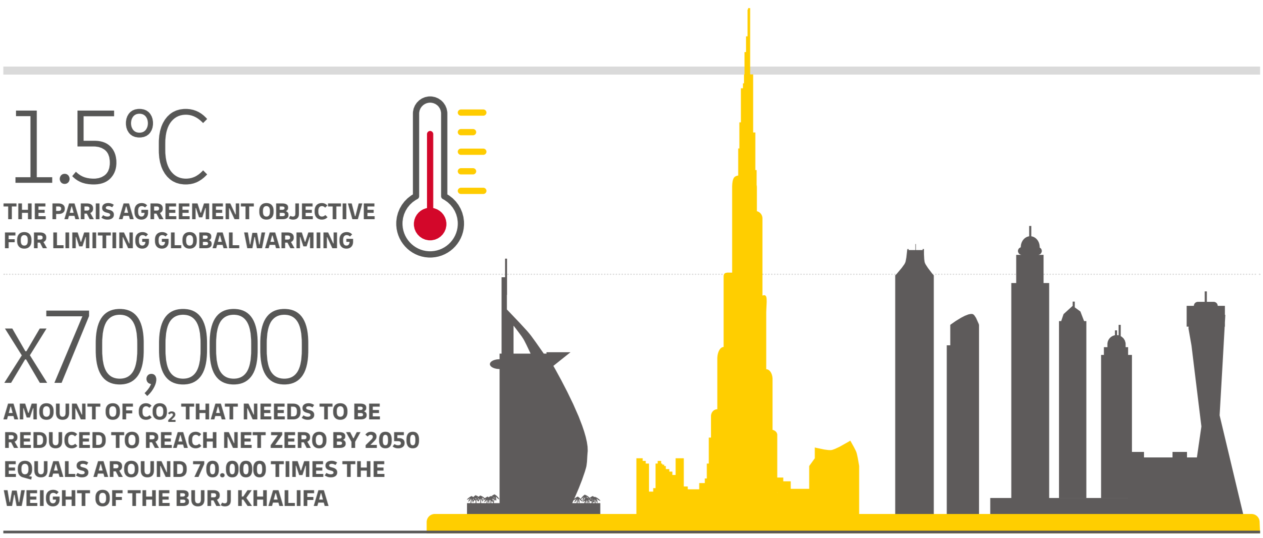
In this chapter, we will examine the implications of net zero for the global energy sector. Our outlook is based on mitigation scenarios developed by international organizations including the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA).[9, 10]

THE CO_2 EMISSION REDUCTION PATHWAY

The transition to net zero calls for steep cuts in the emission of CO_2 over the next three decades, starting today. Under IRENA and IEA scenarios, achieving the net-zero target or even slight negative emissions by 2050 will require emissions to drop around 40% from current levels by 2030, and halve again by 2040, respectively dropping to one third (see Figure 3). Reaching net zero by 2050 ultimately means that an amount of CO_2 equivalent to around 70,000 times the weight of the highest building in the world, the Burj Khalifa, needs to be reduced.

These reductions represent a formidable challenge, especially set against a background of decades of gradually rising emissions. It will require significant changes across many aspects of society, from the way individuals travel and how we keep our homes at a comfortable temperature to the technologies used by industry to manufacture and deliver materials, products, and services.

For the energy sector, the required changes are particularly significant. That's because the production of electricity and heat from fossil fuels is the largest generator of carbon emissions today. Additionally, the sector can offer a range of proven technological solutions to the carbon reduction challenge. As an example, under the IEA Net Zero Emissions by 2050 Scenario (NZE), the energy sector would become slightly net negative by 2040 ten years before the rest of the economy approaches net zero (see Figure 4).



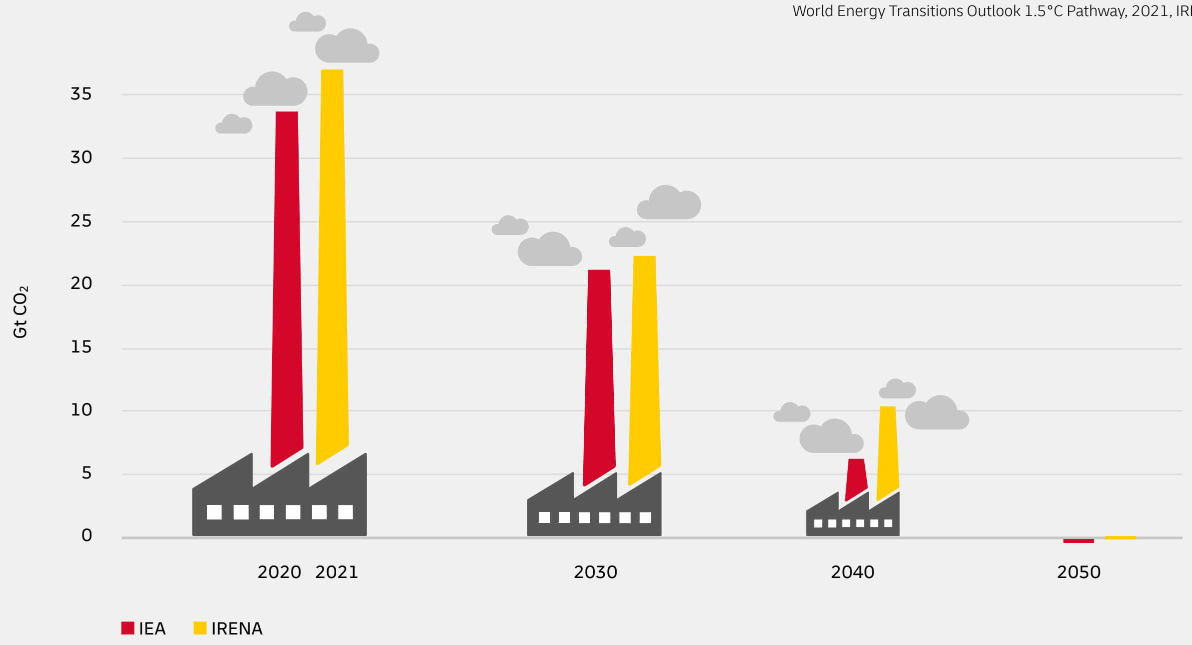
Weight of Burj Khalifa in tonnes: 500.000

[9] IEA: The International Energy Agency is an intergovernmental organization that was founded in 1974 as an autonomous unit of the Organisation for Economic Co-operation and Development (OECD). While its original mission was to ensure oil security, the organization now also promotes the sustainable energy transition at global level.

[10] IRENA: The International Renewable Energy Agency was founded in 2009 as an intergovernmental organization. With its current 167 members it promotes the transformation to a sustainable energy future and fosters the use of renewable energies worldwide.

FIGURE 3: GLOBAL NET CO_2 EMISSIONS IN NET ZERO EMISSIONS BY 2050 SCENARIO (NZE) AND 1.5°C SCENARIOS

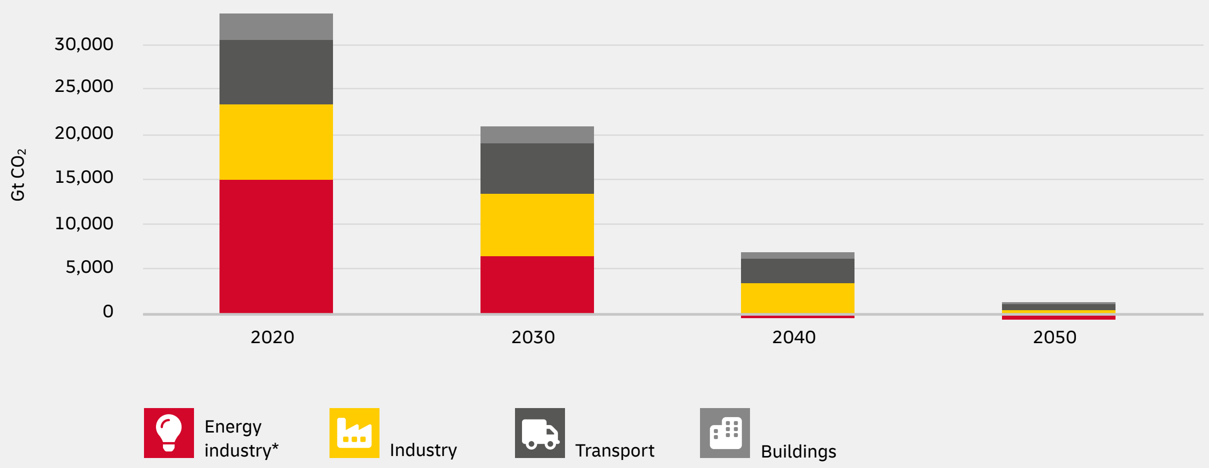
Source: Net Zero by 2050 – A Roadmap for the Global Energy Sector, 2021, IEA
World Energy Transitions Outlook 1.5°C Pathway, 2021, IRENA



For the energy sector, the required changes are especially significant as the production of electricity and heat from fossil fuels is the largest generator of carbon emissions today

FIGURE 4: CO_2 EMISSIONS BY SECTOR IN THE NZE

Source: Net Zero by 2050 – A Roadmap for the Global Energy Sector, 2021, IEA



*Electrical and heat sectors and other energy sectors

Direct air capture not taken into account

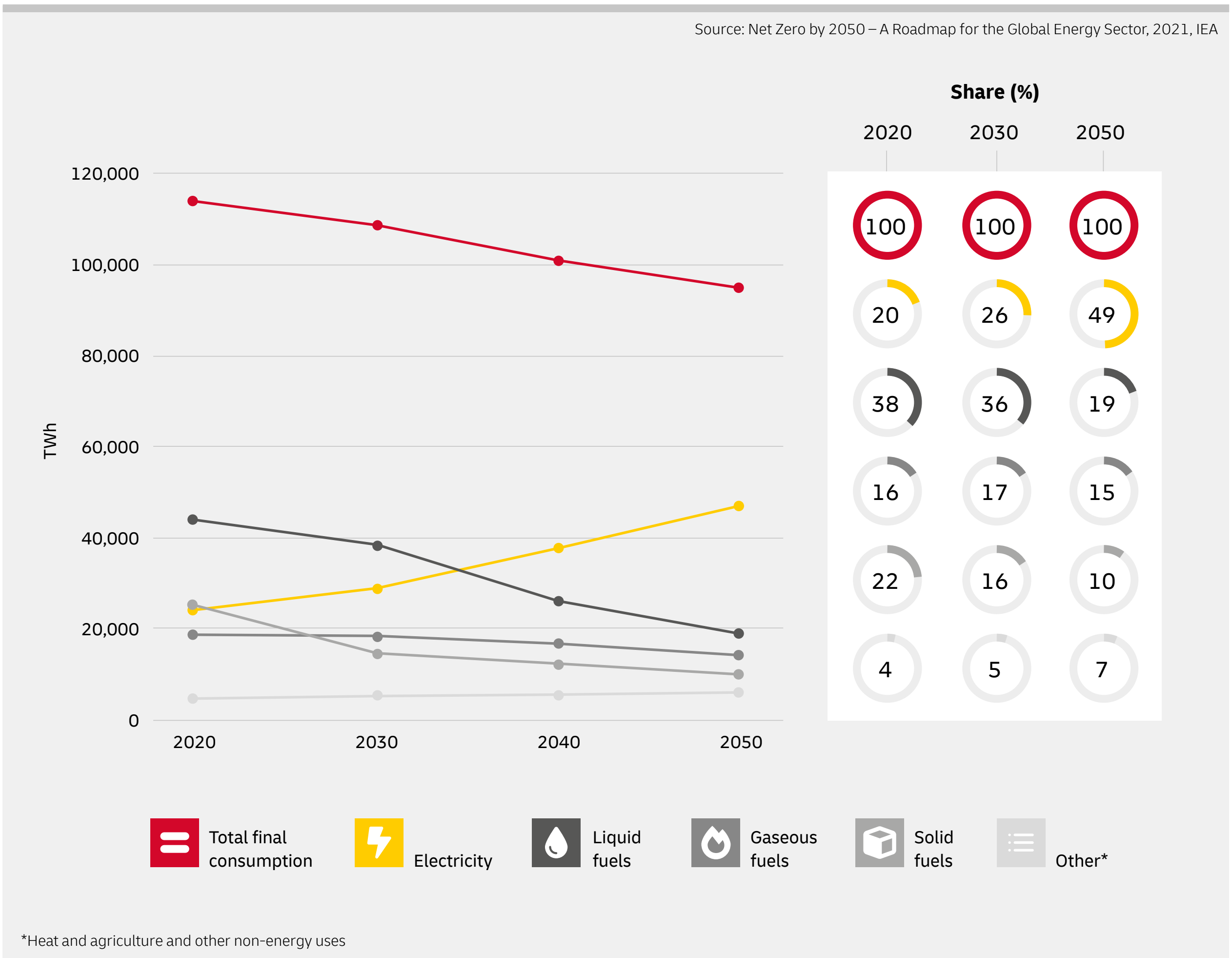
DEMAND: STILL HIGH, BUT DIFFERENT

The transition to a net-zero energy supply has two main components: reducing energy demand and reducing the quantity of greenhouse gasses emitted to meet that demand. Reduction in energy demand can come from changes in consumption behavior and from improvements in the efficiency of end-use applications. That might involve changes in travel behavior, for example, the introduction of more efficient homes, motors and machines, and the use of less energy-intensive materials and supply chains.

Demand reduction efforts are a vital part of the pathway to net zero, and they will change where and how energy is consumed around the world. They are expected to have only a relatively small impact on overall consumption, however. That's because a growing and increasingly affluent global population will continue to put upward pressure on demand. IRENA's 1.5°C Scenario outlines an energy demand of around 96,000 terawatt-hours (TWh) in 2050. Similarly, under the IEA NZE total energy demand in 2050 will be around 95,000 TWh, only 17% lower than the 2020 level.

While demand for energy is expected to remain high, the way that energy is delivered to the end user is set to undergo a profound shift. In 2020, electricity accounted for 20% of total global energy consumption. By 2050, it will make up 49% of the energy mix, becoming dominant thereafter. This transition 'from atoms to electrons' will be driven by multiple factors, including the higher overall energy efficiency of electric machines compared to their liquid-, solid-, and gaseous-fueled counterparts, and the growing role of electricity generated by renewable energy technologies and other low-carbon energy sources.

FIGURE 5: ENERGY DEMAND IN THE NZE



THE ROLE OF RENEWABLES

Today, fossil fuels are still the largest primary energy source for electricity generation, accounting for around 55% of total electricity generation capacity in 2020, according to IEA. Under different scenarios in line with net zero by 2050, this share is expected to fall to only around 2 to 7% by 2050.

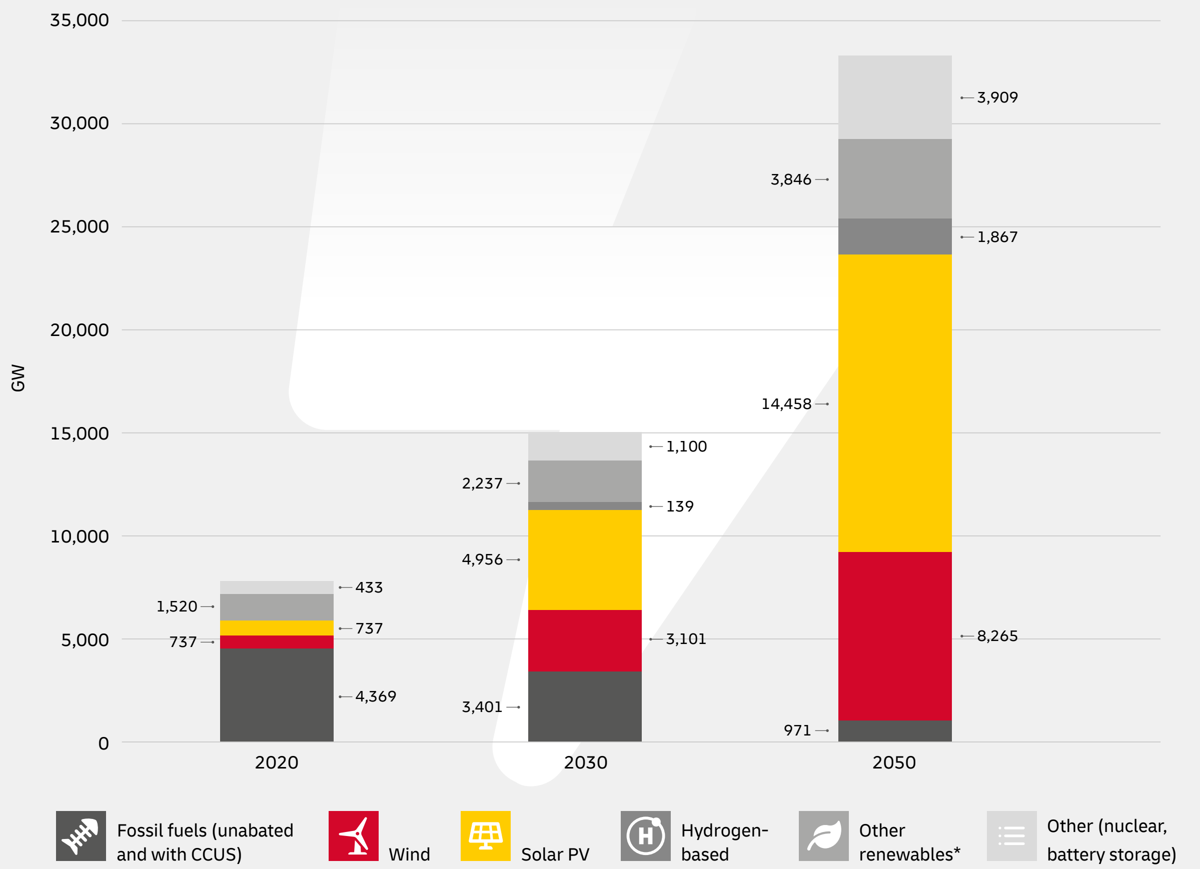
Most of the gap will be filled by renewable energy sources such as wind or solar and the remainder is made up by other fossil free sources such as nuclear energy. The recent surge in renewables investment has already seen these sources reach about 38% of total electricity generation capacity in 2020.

Under the IEA NZE the world would need to increase the share of renewables to 70% of electricity generation capacity by 2030 and to about 80% to 90% by 2050 (according to IEA and IRENA). However, things are made even more difficult as overall electrical capacity will need to double by 2030 and again more than double between 2030 and 2050.

This means the investments in wind and solar will have to significantly increase for the world to have any chance to achieve net zero by 2050. To be precise, **installed solar capacity will have to 7-fold by 2030 and 20-fold by 2050** (compared to 2020 levels) according to IEA's NZE. Similarly, **wind will have to quadruple by 2030 and 10-fold by 2050** (compared to 2020 levels). Achieving these levels of growth will require the renewables industry to more than double the installation rate for new generation assets, from a recent average of just over 193 GW per year to 548 GW per year.[11]

FIGURE 6: DEVELOPMENTS IN ELECTRICAL CAPACITY IN THE NZE

Source: Net Zero by 2050 – A Roadmap for the Global Energy Sector, 2021, IEA



*i.a. hydro, bioenergy, geothermal

[11] Fuels and Technologies – Electricity, 2022, IEA

THE NEW ENERGY LANDSCAPE

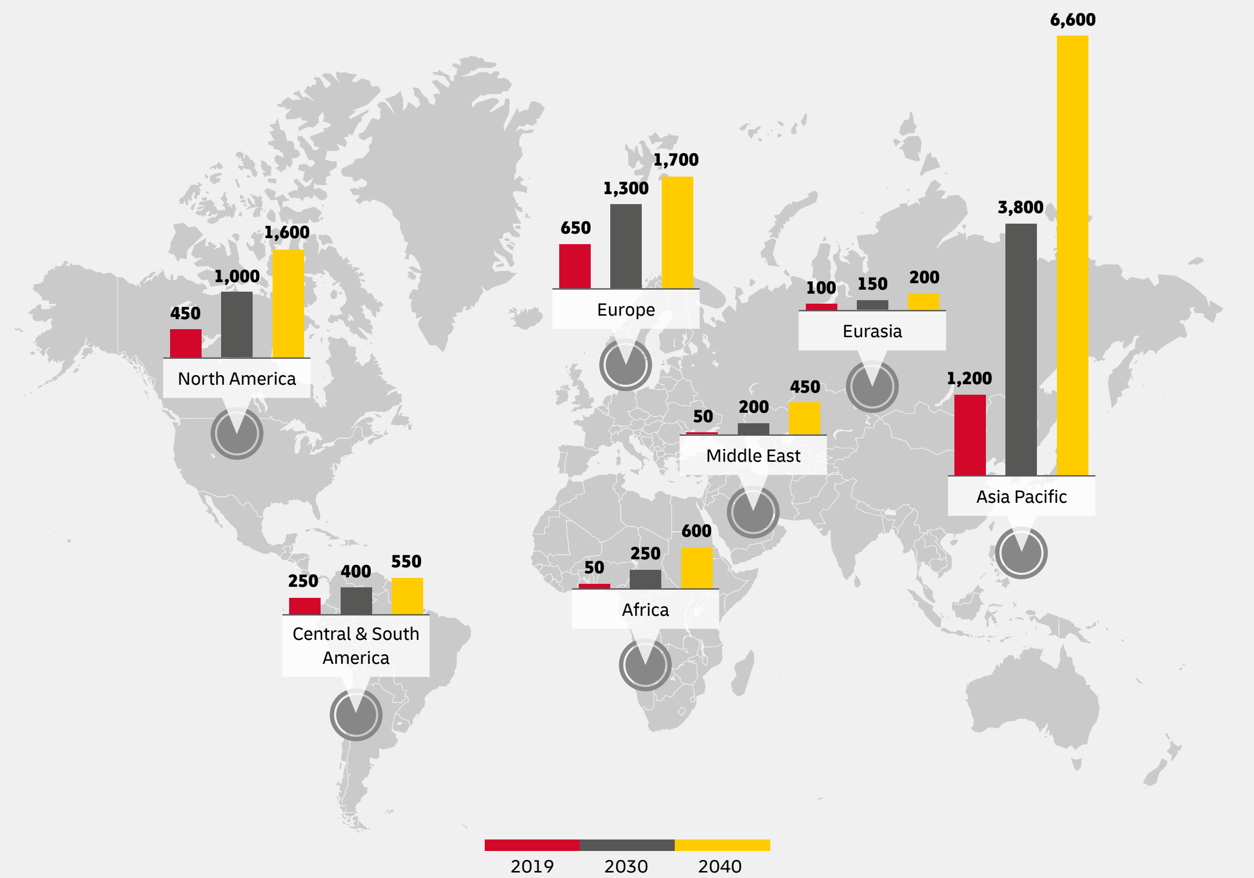
A net-zero energy system will be structured very differently from today's fossil fuel-based approach, and those changes will be evident at regional and local levels. As has been the case in the past, energy demand is still expected rise most steeply in places where economic growth is fastest. **That means Asia and the Pacific will have the largest absolute requirement for new renewables capacity** (see Figure 7). Under its Sustainable Development Scenario (SDS) the IEA expects China alone to account for about 30% of all new capacity in 2030 and 2040, for instance. **Europe and North America will share the number two position** for new infrastructure investments, with a smaller but still significant share of new infrastructure built in other regions.

Within regions, decisions about where renewables capacity is deployed will be driven by multiple factors, including the quality of local renewables resources, the availability of suitable sites, and the proximity of demand. Wind and solar infrastructure require significantly more space than traditional thermal power stations, which will be easier to find in sparsely populated or unpopulated areas, including offshore locations. Those sites create their own challenges, however, including the need for suitable infrastructure for electricity transmission and access for construction and maintenance.

Another key trend will be an increase in the quantity of distributed generation capacity. In areas with mature electricity infrastructure, this involves a wind, solar, or other renewables generation plant embedded in local electricity distribution networks. In remote regions, networks based on local renewables generation and storage may be the primary source of electricity. In either case, successful implementation requires sophisticated control technology to keep demand and supply in balance, and to integrate the combined use of centralized and decentralized resources. Analyst Frost & Sullivan expects the installed capacity of distributed generation to double by 2030 with overall investments of approximately USD $850 billion within the current decade.

FIGURE 7: ELECTRICAL CAPACITY (GW) BY REGION IN THE IEA SUSTAINABLE DEVELOPMENT SCENARIO

Source: World Energy Outlook 2020, 2020, IEA

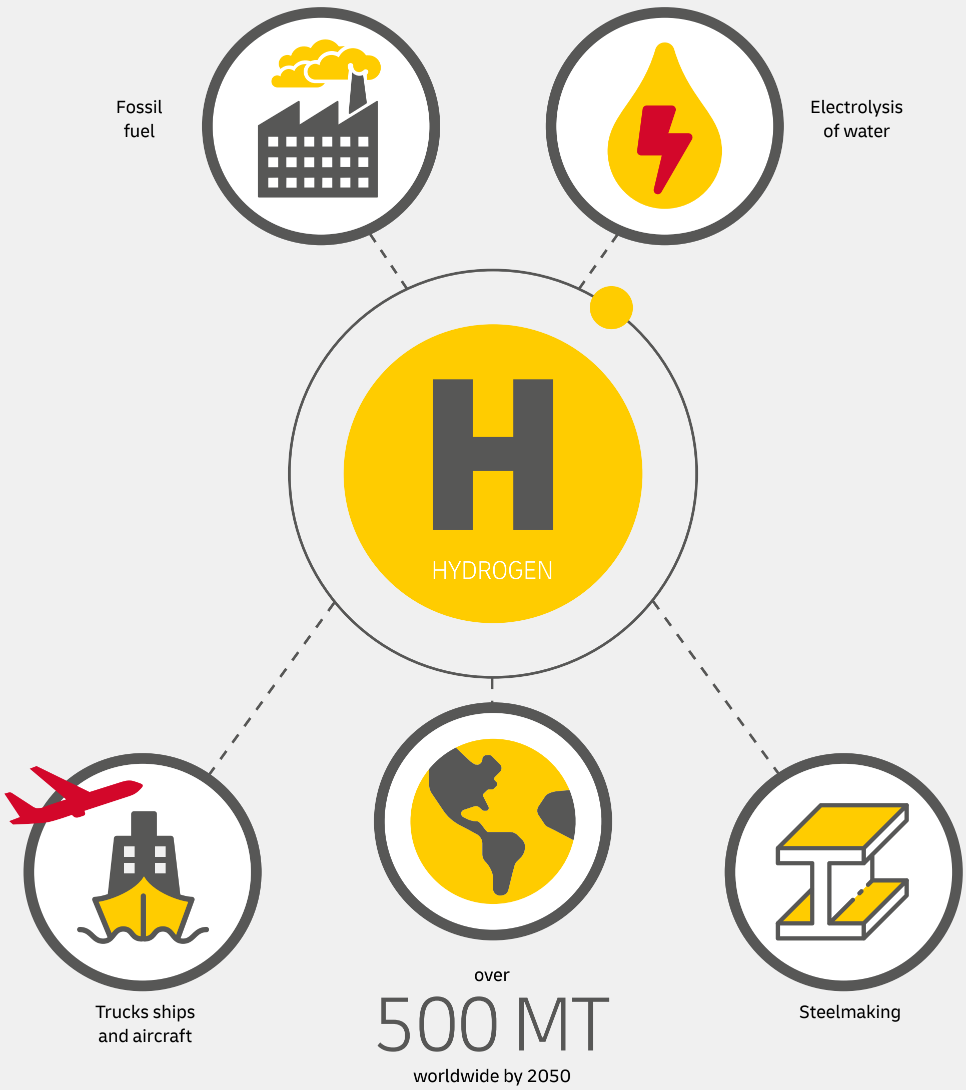


Rounded values

THE HYDROGEN ECONOMY

Renewables won't just play a dominant role in tomorrow's electricity networks. They are also likely to be critical elsewhere in the energy system. Under many net-zero scenarios, hydrogen and products derived from it are expected to carve out important niches in a range of applications. These include the use of hydrogen to power high-temperature industrial processes such as steelmaking and in the production of synthetic fuels for trucks, ships, and aircraft. In its NZE, the IEA expects hydrogen production worldwide to rise from just under 100 megatons (Mt) in 2020 to somewhat over 200 Mt by 2030 and over 500 Mt by 2050.

Hydrogen can be produced from fossil fuels, a process with net-zero potential if the associated stream of CO_2 is captured and stored. Or it can be generated through the electrolysis of water. The use of renewable electricity in the latter process could pave the way for significant energy developments in places that are rich in wind, solar, or hydropower resources but remote from major electricity customers. Over time a significant global trade in hydrogen or hydrogen-based products is expected to develop, "with large volumes exported from gas and renewables-rich areas in Australia, Central and South America, and the Middle East to demand centers in Asia and Europe."[12]



[12] Net Zero by 2050 – A Roadmap for the Global Energy Sector, 2021, IEA

CHAPTER 3

NEW BUSINESS STRATEGIES FOR CHANGE AND THE IMPLICATIONS FOR LOGISTICS

FROM FOSSIL FUELS TO RENEWABLES

In the previous chapter, we saw how the transition to net zero will dramatically increase the demand for renewable energy generation capacity, especially wind and solar power. Now we will look at how the energy industry is changing, and the different strategies being pursued by established oil and gas companies and other energy sector players to meet this demand. The energy transition presents significant new challenges to companies that install and operate renewable energy systems, and to manufacturers of renewables generation equipment, especially in their logistics and supply chains.

One key characteristic of renewable energy infrastructure is the structural shift it requires. It means moving from large, centralized fossil fuel power stations to a much greater number of smaller, decentralized renewable energy systems producing energy within a more fragmented and distributed market. In this context, the role of logistics and supply chains is also changing fundamentally. This chapter will illustrate how the supply chain will evolve from a supporting function for the oil and gas industry to a key enabler for the growth of renewables.

The increasing importance of logistics is largely driven by the fact it takes much more logistics effort to provide the same generation capacity with renewables than with oil and gas. It isn't just the volume of logistics support required that makes renewables different from fossil fuel energy, however. The nature of this support will be very different too. Emerging challenges include the need for new solutions to transport the very large blades used by future generations of wind turbines and for new transportation assets to support offshore wind developments. In the solar sector, distribution networks will need to adapt to support new locations and installations of widely differing scales. Incumbent energy players will need to establish collaborative supply chain relationships with new partners too, especially the manufacturers of renewable power generation equipment.

In this chapter, we will look in more detail at the supply chain implications for large-scale renewable energy deployment. We will focus on the wind and solar power sectors, which are expected to make up the bulk of renewable energy investments in the coming years.

EVOLVING BUSINESS STRATEGIES

Many of today's energy players expect to participate in the renewables revolution. Some are already extremely active in the sector, while others are still developing their strategies. Let's look at the approaches adopted by three important groups of organizations: international energy companies (IECs), national oil companies (NOCs), and major utility companies.

International energy companies

IECs are shifting their focus as they diversify from fossil fuels to new energies and as new players enter the market. The change is illustrated by the strategies of four of the largest IECs: BP, ExxonMobil, Shell, and TotalEnergies.

The **European oil and gas majors** BP, Shell, and TotalEnergies have clear climate change mitigation goals, reflecting new market dynamics, social dynamics, and an intention to diversify their business activities given the projected end of the fossil fuel era. They are transforming themselves more into utility companies, are in the race to become renewable energy majors, and have made clear statements about their energy transition investments (see Figure 8) particularly in wind and solar. However, the focus of these plans differs:[13]

- BP and TotalEnergies are focusing on solar development – BP has 8 GW of solar investments and TotalEnergies has 14 GW in the pipeline
- Shell is more focused on wind development (6 GW in its portfolio or in development) and in green hydrogen production, where it aims to become the global leader

The business model of these IECs is slowly transforming from extracting, refining, and selling oil and gas to operating wind and solar assets, and distributing renewable energy.

The **American IEC** ExxonMobil is more focused on transforming its core business to achieve net-zero greenhouse gas emissions for operated assets by 2050, through investments in carbon capture and storage, hydrogen, and biofuels.

FIGURE 8: ENERGY TRANSITION STRATEGIES OF SELECTED OIL AND GAS MAJORS

Source: World Energy Market Observatory 2021, Capgemini & companies communication

	BP	Shell	ExxonMobil	TotalEnergies
GHG EMISSIONS (ACTUALS – Gt/Y)	1.2	1.7	0.12 (Scope 1 & 2 only, no reporting Scope 3 so far)	0.45
ENERGY TRANSITION COMMITMENTS/ ROADMAP	**2025:** -20% emissions **2030:** -30-35% emissions Net zero across entire operations on an absolute basis by **2050** or sooner	**2023:** -6 to 8% emissions **2030:** -20% emissions **2035:** -45% emissions **2050:** -100% emissions	**2025:** -15 to 20% GHG (compared to 2016) **2030:** -20-30% corporate-wide GHG intensity & -70-80% in corporate-wide methane intensity Net-zero emissions (Scope 1 & 2) from operated assets by **2050**	**2025:** >-15% Scope 1 +2 emissions from operated assets (compared to 2015) **2030:** >-40% Net Scope 1+2 emissions on operated activities & >-20% in average carbon intensity of energy products (scope 1+2+3) **2050:** Net-zero emissions worldwide on operated activities (scope 1+2) and for indirect emissions (scope 3)
ENERGY TRANSITION INVESTMENTS	US$ 5bn/y in low carbon electricity and energy	US$ 3 bn/y in Renewables and Energy Solutions	$15 bn in greenhouse gas emission-reduction projects **2021-2027**	US$ 3-3.5 bn in Electricity & Renewables
ENERGY TRANSITION PILLARS	Natural Gas/ Rebewables/ City colutions/ Mobility/Reduction on Oil Productions/ Carbon Pricing/ Energy Management	Natural Gas/ Renewables/ Heping Customers Decarbonate/Mobility Hydrogen Market/ Utilities	Scope 1 & 2 emissions, methane flaring reduction + Hydrogen and CCS	Natural Gas/ Renewables/Energy Efficiency/Sparing use of oil/Helping customers decarbonate/Carbon Sinks/Carbon Price

[13] World Energy Market Observatory 2021, Capgemini

ØRSTED BECAME THE WORLD'S MOST SUSTAINABLE ENERGY COMPANY IN JUST

10 YEARS

SAUDI ARAMCO, WHICH IS ONE OF THE THE WORLD'S LARGEST ENERGY COMPANIES, HAS SET ITS AMBITION TO ACHIEVE

NET-ZERO

GREENHOUSE GAS EMISSIONS ACROSS ITS OPERATIONS BY 2050

National oil companies
Some currently or formerly state-owned energy businesses are already ahead of the European IECs in their transformation. Notably, the Nordic **national energy companies** Equinor (formerly Statoil) and Ørsted (formerly DONG Energy) have significantly transformed their operations and business models:

- Equinor has become a global offshore wind major and the world's leading floating offshore wind developer[14]
- Ørsted has changed from one of the most coal-intensive energy companies in Europe to the world's most sustainable energy company (Global 100 Index) in just ten years – with investments made exclusively in green energy[15]

Change has been slower at many **non-European NOCs**, for example those in Latin America and in the Middle East. Committed investments in the wider energy value chain have been small and concentrated on technologies such as CCUS that support demand for fossil fuel. Many NOCs are shifting their exploration and production efforts from oil to gas, which is expected to see continued high demand during the energy transition. These companies are also diversifying downstream, with plans to expand investments in refining and petrochemicals to create additional outlets for their crude oil and new revenue streams.

Saudi Aramco, the world's largest energy company, has set an ambition to achieve net-zero greenhouse gas emissions across its operations by 2050 and announced plans to expand its focus on emerging sectors such as green hydrogen, sustainable technology solutions, advanced nonmetallic building materials, and digitization.[16]

Major utility companies
The energy transition has been a core focus for utility companies for several years. Leading international utilities such as Enel, ENGIE, Iberdrola, NextEra Energy, and RWE have already invested in renewables with plans to extensively develop power generation capacity from wind and solar. Their goals are similar in scope and ambition to IECs (see Figure 9). Their individual choices differ in relation to other areas of the energy transition such as storage, biomass, hydrogen, and CCUS.

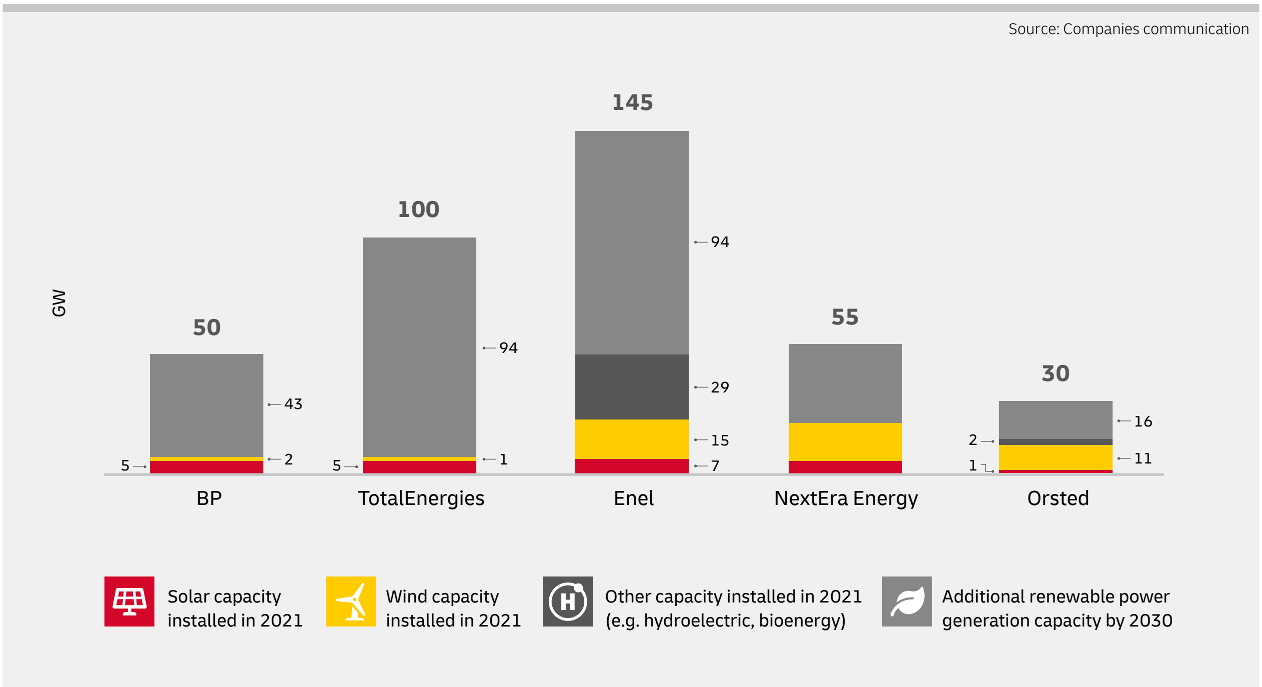
[14] Industrialising floating offshore wind, 2022, Equinor
[15] Our green business transformation, 2021, Ørsted
[16] Aramco expands focus on emerging sectors at Future Investment Initiative, 2021, Aramco

EV charging
As the world prepares for the electric vehicle (EV) boom, IECs and utility companies have both turned their focus to the market for EV charging infrastructure. All these companies are involved in the EV charging value chain – as charging equipment manufacturers, EV charging point operators, or e-mobility service providers.

One key outcome from all these different investments is a **blurring of the boundaries between the energy and utilities sector and the oil and gas sector**. It is likely that new renewables majors will emerge from former IECs and utility companies soon.

Figure 9 shows selected examples of the renewable power generation capacity targets of IECs (BP and TotalEnergies), utility companies (Enel and NextEra Energy) and a former NOC (Ørsted). By far the largest share of planned new capacity will come from wind and solar. If these targets are to be realized, however, manufacturers of wind turbines and solar panels will need to scale up their production and delivery capacity significantly. Logistics will play a central enabling role.

FIGURE 9: ADDITIONAL RENEWABLE POWER GENERATION CAPACITY TO BE INSTALLED BY 2030; SELECTED ENERGY PLAYERS



"At TotalEnergies, we do not see ourselves as an equipment producer. Our core business is to produce energy, and to distribute and sell it to customers. This was true for oil and gas and is true for our renewables businesses, be it biofuels, low-carbon natural gas, biogas, green electricity, or hydrogen. In terms of electricity, we have the ambition to be among the world's top 5 renewable power producers by the end of the decade. We are becoming a big player in that domain, now in competition with major utility companies."

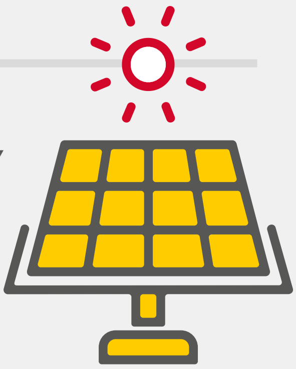
Mathieu Soulas, SVP Strategy & Supply - Marketing & Services, TotalEnergies

EXCURSUS: OIL AND GAS COMPANIES FOCUS ON OFFSHORE WIND AND SOLAR

For the traditional oil and gas companies, investments in offshore wind energy hold appeal, due to the transferability of experience gained in the construction and operation of offshore oil and gas assets. According to consultancy Wood Mackenzie, oil and gas majors are involved in only 5% of today's offshore wind installations, but they accounted for 30% of the planned installations that reached the final investment decision point in 2020. By 2030, total offshore wind capacity is expected to reach 200 GW, a sevenfold increase on today's levels.[17]

Oil industry experience may become even more relevant over time, as offshore wind farms move to ever deeper waters, driven by the desire to exploit more consistent wind resources and by growing resistance in local communities to near-shore sites. Deep water sites will also rely on a new generation of floating turbine designs, an area of technology to which the oil and gas sector can bring knowledge and experience from the design and operation of floating offshore production platforms.

LIGHTSOURCE BP, IS DEVELOPING AND MANAGING SOLAR ENERGY PROJECTS WITH



3.8GW

SOLAR PROJECTS DEVELOPED TO DATE AND

20GW+

IN ITS GLOBAL PROJECT DEVELOPMENT PIPELINE

The development of deep-water offshore wind resources is also likely to proceed hand in hand with the development of the **green hydrogen** sector.[18] Producing hydrogen offshore is one way that these sites can overcome the challenges of limited electrical grid connections, for example. Also, in the offshore environment, wind has a higher capacity factor than other renewables, which means that an electrolyzer (a system that uses electricity to break water into hydrogen and oxygen) can operate a greater proportion of the time, improving project economics. Moreover, many of the potential end uses of hydrogen, such as in refineries, the metals industry, maritime transport, and export/import facilities, are located on the coast, near offshore wind farm sites.

One example of ongoing collaboration between IECs, NOCs, and utility companies is the NorthH2 project, where a consortium of companies – including Equinor, Gasunie, Groningen Seaports, RWE, and Shell – has set out to build major wind farms in the European North Sea, investigating the feasibility of large-scale production, storage, and transmission of green hydrogen, with ambition to produce 4 GW of green hydrogen by 2030.[19]

The market for **solar energy** is also becoming more interesting for oil and gas companies. BP has its own subsidiary, Lightsource BP, developing and managing solar energy projects with 3.8 GW solar projects developed to date and 20 GW+ in its global project development pipeline.[20] Oil and gas companies are increasingly partnering with solar panel manufacturers, too. One example of this is the multi-year agreement between BP/ Lightsource BP and First Solar for up to 5.4 GW of solar modules with scheduled deliveries from 2023 to 2025.[21] A similar approach can be observed at TotalEnergies, which is expanding its solar activities, producing and distributing solar energy with focus on three countries: India (5 GW installed and planned), Spain (5.3 GW in 2025), and the US (4 GW installed and planned).[22] In the US, TotalEnergies' affiliate SunPower is one of the leading distributed generation companies, both in the commercial and residential segments.

[17] How Big Oil is set to transform the offshore wind sector, 2021, Wood Mackenzie
[18] Offshore Wind to Green Hydrogen, 2021, Clean Energy States Alliance
[19] NorthH2, 2022
[20] Lightsource BP, 2022
[21] Lightsource BP and BP sign multi-year agreement for up to 5.4 GW of First Solar modules, 2021, Lightsource BP
[22] Solar Power at TotalEnergies: https://totalenergies.com/media/video/solar-power-at-totalenergies-key-facts-in-pictures

STRUCTURAL SHIFTS IN THE ENERGY SYSTEM

The location of generating capacity for fossil fuel power is mostly demand driven. Power stations are typically built close to where electricity is needed (i.e., near cities). For renewable energy, the situation is often different. Wind parks and solar farms are often supply driven – they are built where space is available and solar or wind conditions are good. In addition, for social reasons, these are often further away from regions with high populations, as communities can be reluctant to have a wind turbine "in their backyard." As a result, renewable energy infrastructure is often far more decentralized and remote than traditional energy infrastructure.

One source of renewable energy that is relatively centralized is **offshore wind**, where huge offshore wind farms could replace traditional power plants in the future. Today, these are mainly located in the European North Sea and the Baltic Sea. So far in the US, there is only one fully installed wind farm in the Atlantic Ocean off the coast of Rhode Island. However, many more projects are currently being developed and executed with commissioning in the coming years.

The development of offshore wind is limited by water depth. Currently, the offshore industry uses fixed-bottom wind turbines installed on the seabed in shallow waters off the coast. In the future, however, countries without shallow waters off the coast will also be able to develop offshore wind through floating turbine technology.

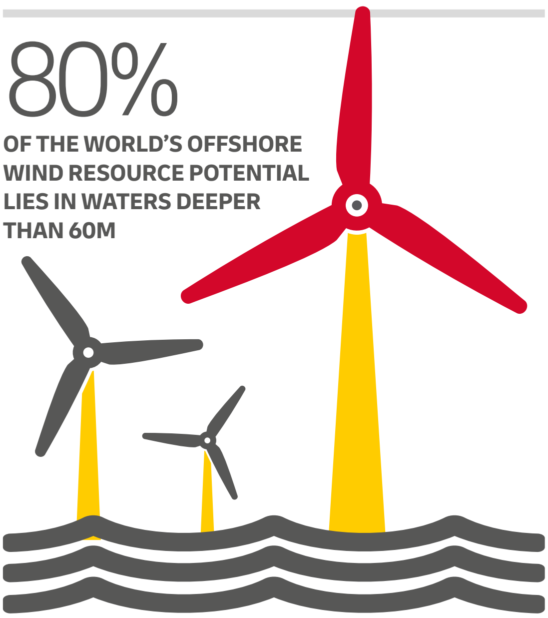
Offshore floating wind has the advantage of being able go wherever the best wind resources are. According to the Global Wind Energy Council (GWEC), 80% of the world's offshore wind resource potential lies in waters deeper than 197 ft (60 m). The best locations for floating wind are Argentina, Australia, Chile, China (south coast), Europe, Japan, South Africa, South Korea, Taiwan, and the US (west coast).

In 2017, the offshore industry connected the world's first commercial floating offshore wind project, Hywind Scotland in the United Kingdom by Equinor, and in summer 2021 commissioned the world's largest floating offshore wind turbine, the Vestas V164-9.5 megawatt (MW) model, at the 50 MW Kincardine project in Scotland.[23]

Today, floating turbine technology remains expensive and relatively immature. It will need to be commercialized very quickly to fully exploit global offshore wind potential and accelerate the energy transition. Over the past decade, floating technologies in the MW range have been tested in demonstration and pilot projects in both Asia and Europe. According to GWEC Market Intelligence's global database, floating wind turbines are likely to become operational from the second half of this decade, and are expected to reach the milestone of 1 GW of floating wind turbines per year in 2026. Full commercialization is expected to be achieved towards the end of this decade.[24]

80%

OF THE WORLD'S OFFSHORE WIND RESOURCE POTENTIAL LIES IN WATERS DEEPER THAN 60M



"Scaling is the key to reducing costs and expanding floating offshore wind. Between the pilot and Hywind Scotland, CAPEX/MW dropped by 70%. Technological advances through larger generators increase margins but are also accompanied by increased costs for logistics."

Gjert Anders Gjertsen, Product Owner Supply Chain Logistics, Equinor

[23] Global Offshore Wind Report, 2021, GWEC
[24] Global Offshore Wind Report, 2021, GWEC

"We will go where the turbines need to go, regardless of the geography and the complexity of the terrain, to get the components to the site. In order to do this, we must take into account the challenges from a logistical point of view and all other associated risks to make sure we can overcome them. For example, we are currently transporting 84-meter long blades across difficult roads and long distances in Brazil, and we have also installed turbines in the northernmost part of Norway."

Michael Peffermann, Onshore BU Head of Construction & Logistics, Siemens Gamesa

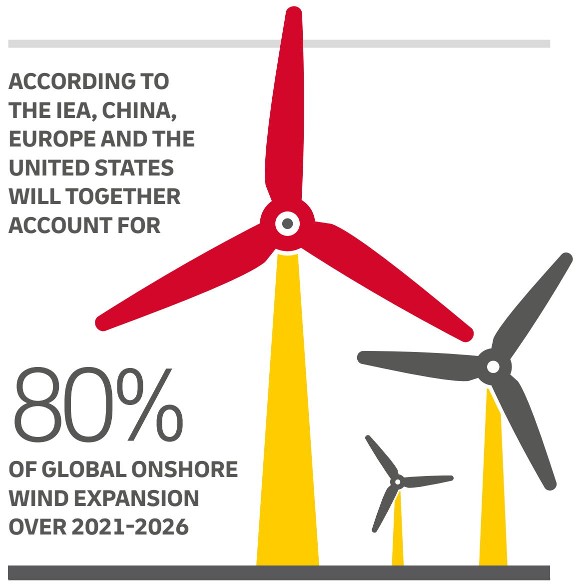
Onshore wind turbines can be operated economically in a decentralized way, with single turbines or small wind farms connecting directly to local power distribution networks. While it is likely that very large onshore wind parks will continue to be built in future, there is a trend towards smaller-scale onshore wind farms, often owned and funded by private investors. Onshore turbines are smaller than their giant offshore counterparts, and turbine technology has developed rapidly in recent years, dramatically reducing the cost of wind power generation.

According to the IEA, China, Europe, and the United States will together account for 80% of global onshore wind expansion from 2021 to 2026.[25] However, growth in Europe has been hampered by a lack of social acceptance and political guidelines, among other things. Despite the logistics difficulties involved in developing onshore wind, which are described in the following section, there are no real limits to site selection for onshore wind turbines, as is described by Siemens Gamesa's Michael Peffermann.

Solar energy installations can be divided into two types: large-scale photovoltaic (PV), often in the form of solar parks, and residential and commercial PV, with panels mostly installed on building rooftops. Solar energy can generally be considered the most widespread form of renewable energy, as there are virtually no locations where solar cannot be installed. Due to robust increases in panel efficiency in recent years, it has also become worthwhile to install solar in regions with relatively less sunshine. Solar energy has become so accessible that new installations are being commissioned in unexpected places – even in the depths of winter in Alaska.[26]

Although solar energy resources are highly distributed, it's like that large-scale solar capacity will develop in clusters with larger solar farms and collections of farms close together to optimize the cost of installation, grid connection, and maintenance. In countries such as Portugal and Spain, where a lot of solar capacity has been built in recent years, space for further expansion is already limited due the size of the local population and other demands on available land. Today, the growth potential is highest in countries like Brazil and India.

Recent developments in battery technology are also boosting the growth potential of solar, making it possible to store energy for use at night. According to the IEA, large-scale solar power is currently the most cost-effective option for adding new electricity capacity. It continues to account for more than 60% of global PV additions, while policy initiatives in China, the European Union and India promote the deployment of commercial and residential PV projects.



[25] Renewables 2021, IEA
[26] The world's most unlikely solar farms, 2020, BBC

"First Solar is a global company – our thin film PV modules power solar projects in over 40 countries around the world. We have invested heavily in our technology and it continues to evolve at a rapid pace. And while the performance of PV modules is dependent on the environment in which they operate, the fact is that you can make an economic case to install solar PV in just about any operating environment where the sun shines."

Bart Verbeke, Head of Global Logistics, First Solar

SUPPLY CHAIN IMPLICATIONS

Distributed power generation boosts logistics demand

An energy system based on renewables technologies will be significantly more diverse and geographically distributed than today's fossil fuel-based system. Instead of being concentrated in a relatively small number of large plants, future power generation capacity will come from hundreds of thousands of wind turbines, both onshore and offshore, and millions of solar panels installed on rooftops and in dedicated solar parks.

To build these new power systems, the energy sector will need to upgrade its supply chains and transform its logistics capabilities. With a larger number of freight movements and a greater number and variety of destinations, the energy sector will need more logistics capacity and more sophisticated logistics management. Thus, the energy paradigm shift from fossil fuels to renewables and from centralized to distributed generation is accompanied by a fundamental **shift in logistics, from a supporting function for oil and gas to a key enabler for the growth of renewables**.

There is a considerable task ahead. In 2021 Germany had 13 oil refineries[27] and around 100 natural gas power plants with a nominal total capacity of 32 GW.[28] The country's 2021 onshore wind energy capacity comprised 28,230 wind turbines, with a nominal capacity of 55 GW. At the most basic level, a gigawatt of electricity generation capacity requires three or four gas power plants, or between 200 and 300 onshore wind turbines of the latest models. Real-world calculations are not so simple, however, as there are intermittent winds and the challenges of matching renewables output to demand.

Logistics complexities extend well beyond the sheer number of assets that must be built and maintained. Wind energy, for example, involves a large proportion of out-of-gauge (OOG) items such as turbine blades that require special equipment, handling capabilities, route planning, and permits. Meanwhile, the manufacture of solar cells is currently concentrated in Asia. To support rapid deployment, the sector will need to invest in new networks of regional distribution centers close to end customers. And the shift in energy delivery from tankers and pipelines to cables will also require extensive upgrades to electricity transmission and distribution systems.

Green **hydrogen** produced using renewable energy will also require new production, distribution, and storage infrastructure. Hydrogen is expensive to store and ship, due to its low volumetric energy density, and the ease with which small hydrogen molecules can escape from containers and pipelines. Offshore hydrogen production would require specialized pipeline infrastructure to bring the fuel onshore. In addition to transportation via pipelines, there are other hydrogen carrier technologies such as liquefied hydrogen, ammonia, and liquid organic hydrogen carriers (LOHC). Each of these approaches has different technical and commercial benefits and limitations, and each has its own specialized equipment requirements.

"The current grid is not set up for distributed energy supply in a net-zero scenario. Transforming the grid is as much of a challenge as transforming energy generation."

Guido Wendt, Executive Vice President – Energy & Utilities, Capgemini Invent

[27] Number of oil refineries in Germany from 2009 to 2020, 2021, Statista

[28] Bundesnetzagentur 2022: Kraftwerksliste

Multiplication of logistics needs

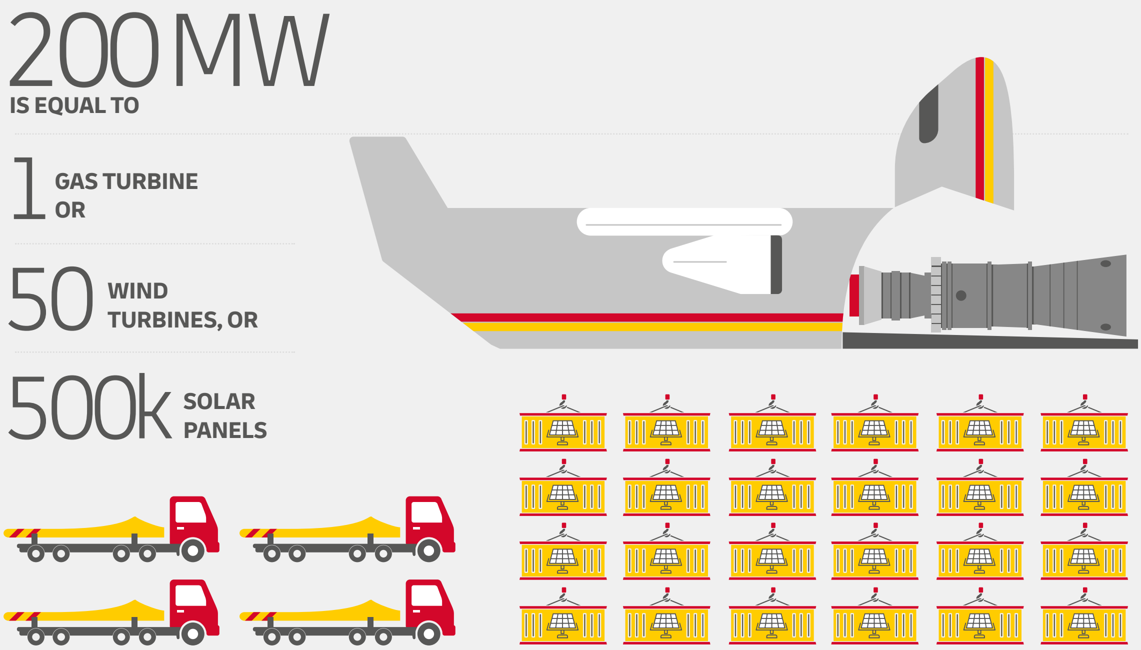
The simplified example below shows how logistics needs change for different power generation solutions. It compares the shipments required to install a 200 MW gas turbine with those needed to deliver the same generation capacity using either onshore wind or solar PV.

As this example shows, replacing fossil-fuel generation equipment with renewables equipment of the same capacity can lead to a 1,000x increase in logistics volumes, together with a significant increase in logistics complexity. And that simplified example is highly conservative. The real increase in energy sector logistics requirements is likely to be two, three, or even four times higher than that. As discussed in Chapter 2, overall generation capacity will need to double between 2030 and 2050 in the NZE, to meet rising demand and compensate for the lower capacity factor of most renewable energy technologies.

Logistics costs

The recent COVID-related supply chain disruptions have led to shortages in both ocean and air freight capacity, pushing up shipping costs globally. Those freight costs are not expected to ease before 2023.[32] And even before the COVID-19 crisis, the renewables sector had reported challenges associated with the rising cost and limited

FIGURE 10: INFOGRAPHIC: LOGISTICS FOR A 200 MW GAS TURBINE COMPARED WITH WIND AND SOLAR



	200 MW		
	Gas	**Wind (onshore)**	**Solar**
	1 Turbine	**50** Turbines	**500,000** panels
Vessel charters	-	16	-
Special transport*	1	500	-
Containers		100	1,400
FTL		100	

*special transport: #of 'Out of Guage' components

ASSUMPTIONS:

200 MW[29]
Capacity average gas turbine German gas-fired power plant

4 MW[30]
Capacity average German onshore wind turbine

0,0004 MW[31]
Capacity average solar panel

[29] Levelized Cost of Electricity Renewable Energy Technologies, 2018, Fraunhofer ISE
[30] Status of Onshore Wind Energy Development in Germany, 2021, Deutsche Wind Guard
[31] Maxeon 3, 2019, SunPower

availability of logistics assets and services. While rapid expansion of the wind energy industry encouraged more logistics specialists to enter the market, for example, the development of larger turbine designs, with longer blade lengths and heavier nacelles, meant the cost of shipping each turbine carried on rising. Those challenges are set to continue, especially as the solutions needed to transport the wind turbines of the future do not yet exist. Vestas, a major wind turbine manufacturer, reported that rising transportation costs would strongly affect its profitability in 2021.[33]

In the solar industry, prices for modules have fallen rapidly over the last few decades. The challenging market conditions of the last two years have begun to push those prices back up, however, due to the rising costs of materials and transportation (Figure 11). According to consultancy Rystad Energy, these increases could threaten the viability of 50 GW of utility PV developments planned for 2022, more than half the global total for the year.[34]

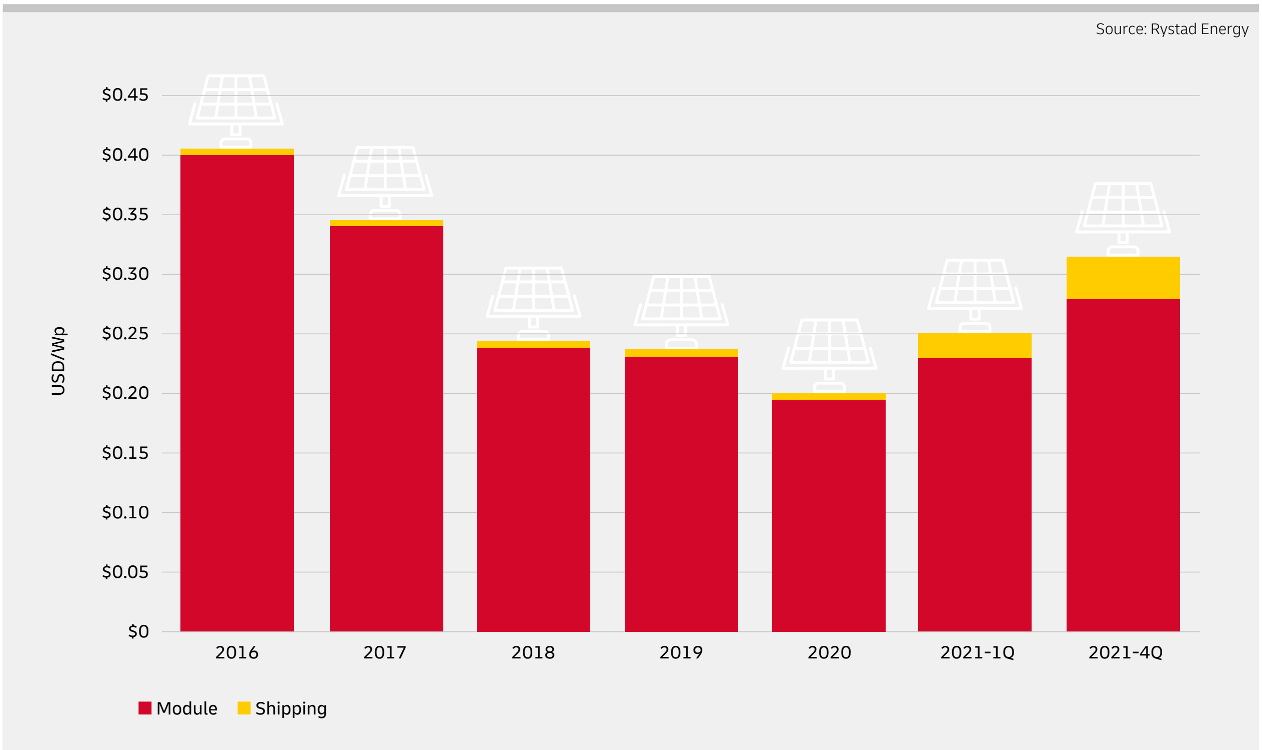
Today, the energy sector faces a significant challenge. To meet net-zero targets, it must dramatically increase the availability of logistics services and assets which are already in short supply. And that challenge won't stop when thousands of new renewables assets are installed and

"Logistics is more and more recognized as a driver of wind power projects. It is increasingly involved in decision making, and it can therefore no longer be assumed that it 'just works' in the background."

Stefan Bernotat, Unit Lead CoC for Digitalization in Supply Chain & Logistics, Siemens Gamesa

operational. With operating lives of several decades, renewable energy equipment will require regular maintenance. Particularly in the wind energy sector, the management of spare parts has a significant impact on overall operating costs, a topic that we will discuss in Chapter 4.

FIGURE 11: SOLAR PV MODULE SHIPPING COST OVER TIME



[32] DHL expects freight rates to stay high in 2022, 2022, Reuters
[33] Interim financial report, third quarter 2021, Vestas
[34] Most of 2022's solar PV projects risk delay or cancelation due to soaring material and shipping costs, 2021, Rystad Energy

EXCURSUS: SUPPLY CHAIN CHALLENGES IN ONSHORE AND OFFSHORE WIND

Size has been a major driver of performance improvement in the wind energy sector, since bigger turbines produce more energy at lower cost. Over the past 30 years, blade lengths and tower diameters have increased by a factor of around four. The average capacity of onshore turbines in 2025 is expected to be more than double those used in 2018. Offshore, capacity is expected to quadruple over the same period.

To unlock the potential of the technologically enhanced **onshore wind** turbines with larger capacity and improved energy yields, new manufacturing and installation techniques are needed. And it will be essential to overcome the challenges associated with transportation and logistics.

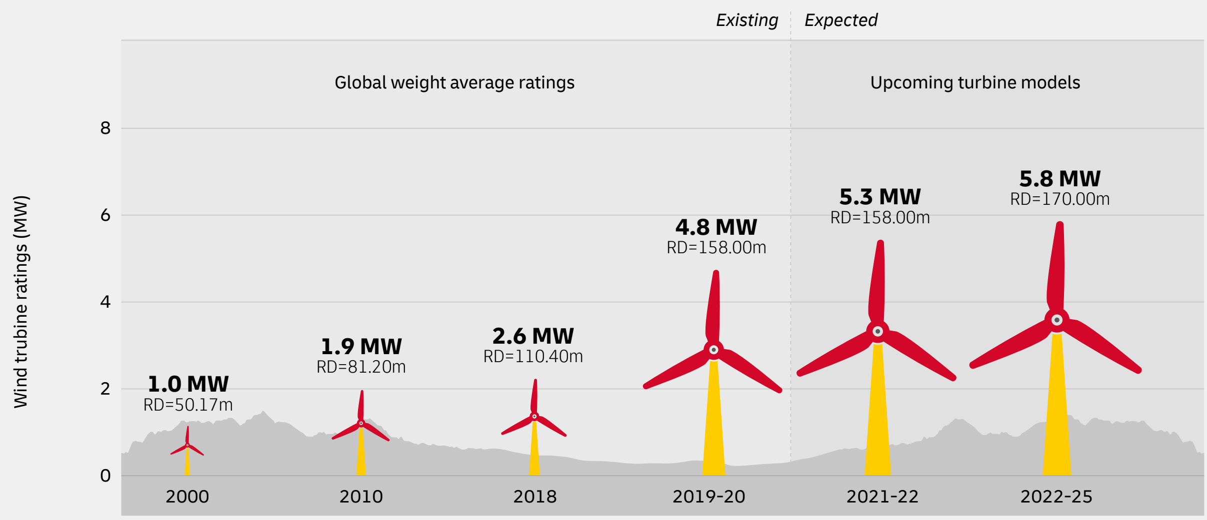
Significant logistics effort is required to transport items with the size and complexity of turbine blades, towers, and nacelles from manufacturing locations to where they are needed, using road, rail, and ocean. It takes extensive planning and requires special vehicles, equipment, and technicians. The tower usually has to be transported in three parts, on a double or single Schnabel trailer. Each of the rotor blades is transported separately on a specially designed trailer and so too is the nacelle. The remaining components are usually transported on flatbed trucks.

In traditional logistics route planning, the fastest and most cost-effective route is chosen. However, when transporting wind turbines, the route must be adapted to accommodate numerous constraints:

- **Road:** Large, long components put limits on the route a truck can take and the radius of the turns it can make.
- **Rail:** Railway curves may be too narrow for long components (e.g., blades) and tunnels too narrow for nacelles and tower parts, so that complete routes may not be feasible.
- **Ocean:** Under-deck volume capacities are too restrictive to accommodate certain components due to their volume or weight, and vessels with large carrying capacities are a limited resource.

FIGURE 12: TURBINE DEVELOPMENTS FOR ONSHORE WIND ENERGY PRODUCTION

Source: Future of Wind – A Global Transformation Paper, 2019, IRENA



For **offshore wind**, synergies with existing industries can be found in the supply chain. Most importantly, the oil and gas industry's experience with offshore logistics is likely to influence evolving supply chain strategies. There are also many similarities with maritime logistics – as factories are usually located near ports, which simplifies the transportation of components. These can be shipped directly from the port to the construction site of the offshore wind turbine. However, compared to the industry's ambitions for offshore wind development, the port infrastructure of markets outside Europe is generally insufficient to support the construction of offshore wind farms.

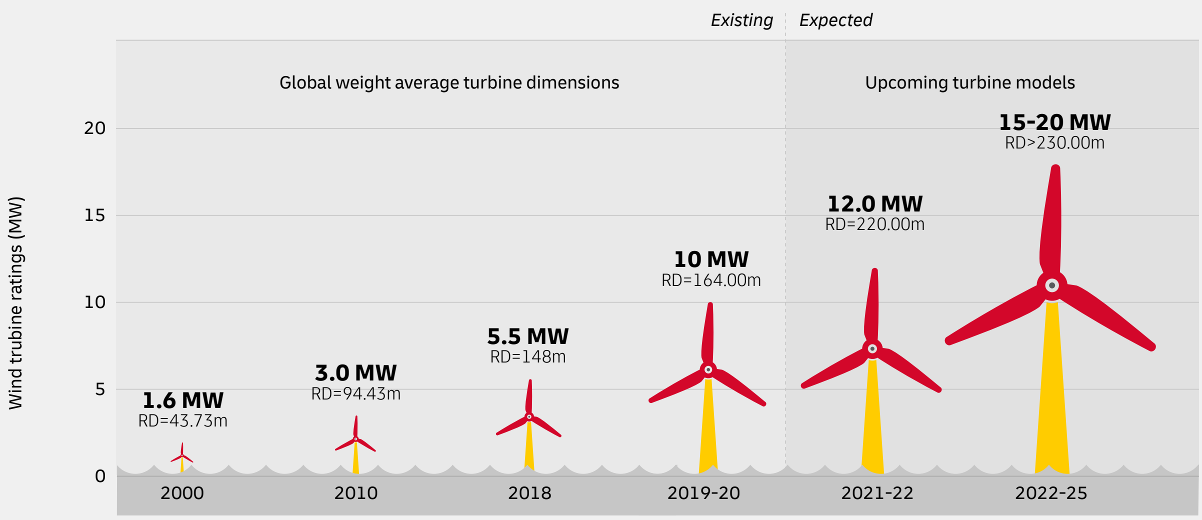
Weather is a critical factor in offshore development. Storms on the high seas can lead to delays in transportation and the assembly of the turbines. In addition, servicing and spare parts logistics offshore become much more complicated.

Further challenges are associated with the availability of specialized turbine installation vessels. The size of turbines has increased faster than the investment-intensive shipbuilding industry has been able to keep up. Vessel suppliers have responded by upgrading existing vessels, including crane capacity. This approach is likely to reach its limits, however, especially as the offshore market expands beyond Europe. The number of jack-up and heavy-lift vessels capable of installing monopiles for the current largest turbine size is in the low two-digit range nowadays. This bottleneck is expected to worsen in the coming years.

Ultimately, today's logistics solutions are inadequate to transport future wind turbine models. There is an urgent need for supply chain innovations and a necessity for manufacturers, developers, and logistics service providers to collaborate for joint solutions.

FIGURE 13: TURBINE DEVELOPMENTS FOR OFFSHORE WIND ENERGY PRODUCTION

Source: Future of Wind – A Global Transformation Paper, 2019, IRENA



Logistics footprint considerations
Today's energy industry supply chains have evolved around key oil and gas production locations, so there is a significant concentration of technical and logistics capabilities in the Middle East. As the energy system shifts to renewables, such concentrations will be less common. Instead energy generation will take place across the world, and locations will be chosen by proximity to consumers and the availability of renewable energy resources. For today's energy players, that change will require adaptation of the supply chain footprint.

Some parts of the existing energy supply chain may be repurposed to support new renewables investments. The Middle East, for example, has considerable potential as a location for large-scale solar infrastructure. Several major projects are under development, especially in the Gulf region. The area has favorable solar conditions with cheap and sunny desert land and large projects benefiting from economies of scale, as well as well-designed bidding structures.

In general, renewable energies, especially onshore wind and residential solar, can be set up in less remote areas than oil and gas development, allowing them to benefit from existing logistics infrastructure. This is the case in the most attractive markets such as China, Germany, and the US. For onshore wind, again, the primary logistics challenges are due to the technical difficulties and the special transportation solutions that are needed.

Drivers for local content and shortened supply chains
Unlike their fossil-fuel counterparts, renewable energy supply chains may evolve along regional, rather than global lines. In the wind energy sector, the industry is asking itself how to transport more with less (less time, fewer ships etc.) and how to improve the reliability and predictability of construction projects. Manufacturing closer to the areas where wind turbines will be installed supports all these objectives, and may be a key factor in the spread of turbine production beyond China to new manufacturing hubs in Europe and the US.

In the case of offshore wind, growing demand for onshore facilities already provides a new lease on life for ports and dockyards that were previously underutilized following declines in fishing and other maritime industries. Ports – especially those with sufficient space for production halls, storage, assembly, and loading areas – are well positioned to meet the requirements of companies in the offshore wind industry and can serve as a base. To this end, they must be equipped with suitable infrastructure facilities such as loading cranes and equipment for the loading and delivery of wind turbine components or raw materials. This development can already be observed in the European North Sea and especially in the United Kingdom. Ports along the UK's eastern coast have witnessed massive investments related to wind energy development in the past decade. Here smaller communities that suffered job losses as maritime and industrial industries declined now benefit from job creation in the growing energy sector.

For companies like First Solar, sustainability also plays an important role in the desire for more localized supply chains. Manufacturing solar equipment closer to the point of use reduces the energy consumed in transportation, for example, and setting up production in areas where clean energy is available reduces the environmental footprint of production. Today, the company is encouraging key suppliers such as glass manufacturers to set up operations close to its production sites, pursuing the campus concept widely adopted by the automotive industry.

Need for service logistics to support installed wind farms
The biggest challenges in the operation of wind farms are sudden and unexpected failures as well as downtime. As installations age, maintenance becomes a key issue. Important and expensive components reach end of service life and need to be overhauled or replaced. The blades suffer from significant erosion due to constant wind exposure, which reduces their efficiency.

Inspection and maintenance of wind turbines is particularly time consuming and costly, exacerbated by high failure rates and expensive spare parts. It is also challenging to work at wind farms as a defective component can be more than 325 feet (100 m) above the ground. In the case of offshore wind farms, access to turbines is an even greater challenge, as the maintenance of these wind farms is both technically and logistically more complex, especially when it involves large-scale maintenance.

The optimal maintenance strategy maximizes availability at the lowest cost by ensuring best access to each wind farm and carrying out planned maintenance as efficiently as possible. New, innovative solutions for wind turbine maintenance, including the use of drones, will be discussed in more detail in Chapter 4.

CHAPTER 4

INNOVATIVE LOGISTICS FOR THE ENERGY REVOLUTION

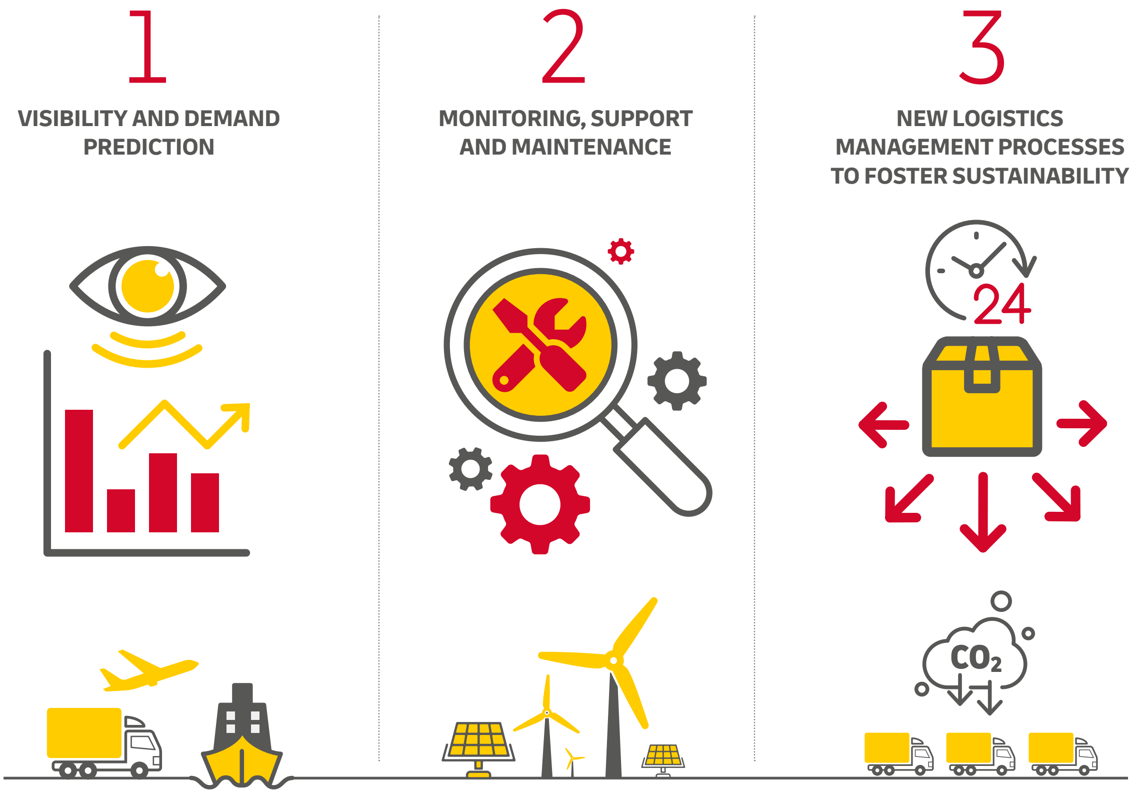
In the previous chapter, we highlighted the dramatic increase in demand for logistics services that will accompany the energy revolution. The shift from fossil fuels to renewables will require significantly more logistics effort for each unit of generation capacity. That's because wind and solar equipment produces less power per installation, and because renewables installations will be less centralized than their fossil fuel counterparts. Moreover, the transition to net zero will require more electricity generation capacity overall, as electrical power takes over from oil and gas in applications such as transportation and space heating, and as networks adapt to meet this demand using renewable energy assets with lower capacity factors.

Logistics is already a real challenge for the renewables sector. Projects must cope with capacity constraints on critical equipment such as specialized vessels for the transportation and installation of large wind turbine components, for example. And the logistics equipment required by future generations of giant turbines does not yet exist. As the industry increases its scale and expands into new markets, these challenges will be compounded by the need to operate big, complex supply chains across multiple regions and locations, many with limited existing infrastructure.

Some of these issues will be addressed by investment in new logistics assets, from specialized transportation equipment to new warehouses and dockside facilities. But **to manage the rapid increase in scale demanded by the net-zero transition, logistics in the renewables sector will also need to innovate**. We see three main areas where technology and ingenuity could help the energy industry obtain the logistics capabilities it needs while keeping costs under control. Firstly, advances in visibility and demand prediction, enabled by digital technologies and smart analytics capabilities, will help the sector plan and operate increasingly complex and distributed logistics networks. Secondly, technology-driven approaches to the monitoring, support, and maintenance of renewable energy assets will help to improve reliability and availability while cutting long-term operating costs. Thirdly, new logistics management processes and new technologies will be essential as the energy sector seeks to reduce – and ultimately eliminate – the carbon emissions generated in its own supply chain.

TECHNOLOGY AND INGENUITY

3 Areas of application for innovations to meet the challenges in renewable energy logistics



VISIBILITY AND DIGITIZATION IN LOGISTICS

The smooth operation of complex, decentralized, and often global renewable energy supply chains will require companies to manage the manufacture, storage, and transportation of thousands of critical components. To do that well, they need to know the status and location of those items.

Full visibility of the end-to-end supply chain has multiple benefits. It allows companies to optimize the utilization of logistics assets, especially specialized transportation equipment and other highly constrained assets. It improves the accuracy of predicted arrival times, a critical issue in complex construction projects with multiple interdependencies. It allows companies to spot delays and other potential problems earlier, when there is more time to intervene and adapt their plans. And it helps them optimize supply chain operations – this could mean picking the most reliable routes and most appropriate transportation assets for each shipment.

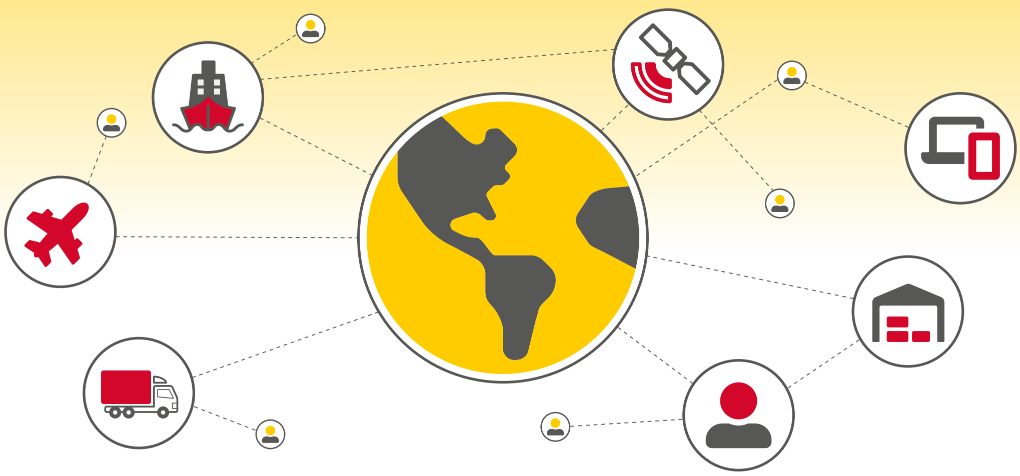
The foundation of supply chain visibility is digitization. Accurate, timely, and detailed data on the location of items and assets within the supply chain provides the basis for more effective decision making, improved supply chain performance, and greater efficiency.

Michael Peffermann, Onshore BU Head of Construction & Logistics at Siemens Gamesa says that digitization is "a necessity, especially in the onshore and also offshore sector. Logistics needs this know-how to manage volumes and movements. But not only in logistics, also in manufacturing and design – digital solutions need to be used in all lines of production."

Digital supply chain technologies have evolved extremely rapidly in recent years. The **Internet of Things (IoT)** has made it possible to connect almost everything on earth. Half the world's population can already access the Internet through smartphones, and IoT technologies have extended connectivity to billions of objects too.[35] New wireless communication technologies are making IoT devices cheaper, more energy efficient, and more reliable in even the most remote locations, paving the way for fully connected global supply chains.[36]

THE INTERNET OF THINGS

The Internet of Things (IoT) has potential to connect virtually anything to the internet and accelerate data-driven logistics. Everyday objects can now send, receive, process, and store information, and thus actively participate in self-steering, event-driven logistics processes. IoT promises far-reaching payoffs for logistics providers, generating actionable insights that drive change and new solutions.



[35] DHL Trend Radar, 5th Edition, 2020
[36] DHL Trend Radar, 5th Edition, 2020

IoT technology provides the connectivity needed for supply chain visibility, but it is smart sensors that increasingly supply the data. Robust, low-cost sensors can store and transmit a wide range of critical logistics information, including the real-time location of shipments, the completion of actions (such as loading and unloading), and the physical conditions experienced during transportation and storage (such as shocks, water ingress, and extreme temperatures). Smart sensors are playing a central role in the logistics processes of many industries today.[37]

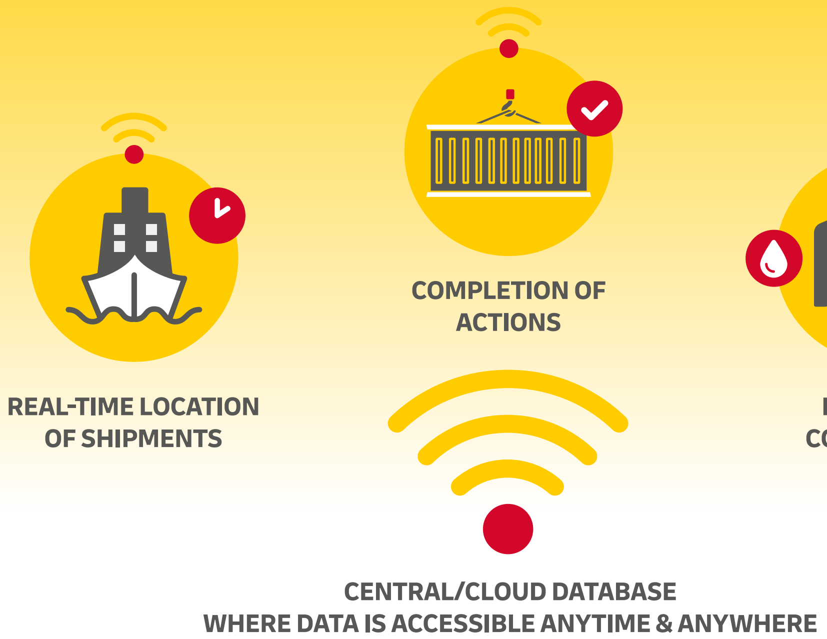
So far, the renewables sector has been slow to adopt these technologies in its supply chains. For companies in the industry, implementing approaches that are already mature and widely used in other sectors, such as shipment tracking with IoT sensors, could deliver significant benefits.

To capture the full potential of digitization, however, renewable energy players will need digital approaches that are tailored to the unique needs of their sector. That may require further incremental innovation in technology, such as the development and deployment of low-cost sensors optimized for the condition monitoring requirements of sensitive wind and solar energy components. **It will also require supply chain actors to invest in the right infrastructure and capabilities to collect, analyze, and act upon digital supply chain information. For example, it will be essential to integrate data from different hardware vendors into a single IoT-based platform and not only capture the data but also convert it into actionable insights.** Furthermore, the global shortage of semiconductors must be considered in this context. The current and coming years are crucial for the energy transition. Hence, it is important that all the basic requirements to expand digitization, such as a sufficient stock of semiconductors, are in place.

It will also require supply chain actors to invest in the right infrastructure and capabilities to collect, analyze and act upon digital supply chain information

SMART SENSORS

Smart sensors are devices with built-in electronics for GPS tracking that provide real-time visibility, as well as condition monitoring to protect against variations in temperature, humidity, vibration, light and even air pressure.



[37] DHL Trend Radar, 5th Edition, 2020

INNOVATION IN SERVICE AND SUPPORT

For complex, high-value equipment like wind turbines, the need for effective, efficient supply chains extends well beyond the production phase. Modern renewable energy assets are designed to operate with a high degree of autonomy. Many are installed in remote locations with no day-to-day human supervision. To keep such assets operating over a service lifetime that can extend to decades, operators need smart, cost-efficient approaches to asset monitoring and maintenance. Once again, digitization and IoT technologies are likely to be key parts of the solution to this challenge, with networked sensors allowing the continuous, online remote monitoring of renewables equipment.

Fixing that equipment when it goes wrong also relies on the timely availability of tools and spare parts, and this will become more challenging as renewables networks expand across the world. Here the sector can follow the example of other industries, such as aerospace, which use sophisticated analytics approaches to categorize parts based on criticality and frequency of failure. This helps determine the optimum size and composition of spare parts inventories.

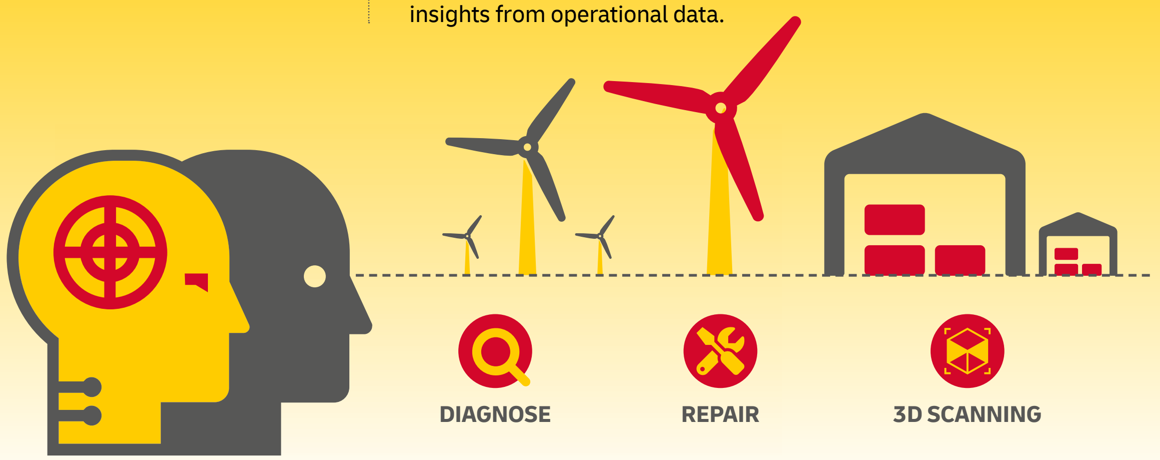
Increasingly, companies are looking for ways to further automate all these activities, and to streamline maintenance and support to the greatest possible degree. Digital twin technology provides one way to do this. This approach connects the digital and physical worlds, using sophisticated computer models of renewable energy assets that are continually updated with data collected from their physical counterparts. Digital twins give operators additional insights into the condition of their equipment, helping them do things such as diagnose problems. They even allow potential solutions to be tested in a virtual environment before being applied in the real world.

To optimize in-service support, the digital twin of an asset can even be connected to the logistics and supply chain systems that manage the manufacture and distribution of replacement parts. If the digital twin identifies a problem in a wind turbine, it can automatically place an order for the relevant replacement parts, so these can be delivered to the maintenance team that executes the repair. In the aerospace industry, some companies are strengthening the link between digital twins and physical products even further, using additive manufacturing technologies (3D printing) to produce service parts on demand directly from digital models, anytime and anywhere, removing the need to transport service parts through the supply chain.

Digital twins have many other potential applications in the renewable energy supply chain. They can be used during manufacture and construction to track progress and create a highly detailed 'living record' of an installation, such as a wind farm. The detailed information on a component's performance and operating conditions stored in a digital twin can inform decisions about repairing and remanufacturing parts for future reuse. Digital twins of warehouses or port operations can help companies manage and improve their logistics planning and fulfillment processes.

DIGITAL TWINS

As unique, virtual representations of potential or actual physical objects and processes, digital twins enable companies to design, visualize, monitor, manage, and maintain their assets more effectively. These simulated replicas help unlock new service-based business models built on valuable insights from operational data.



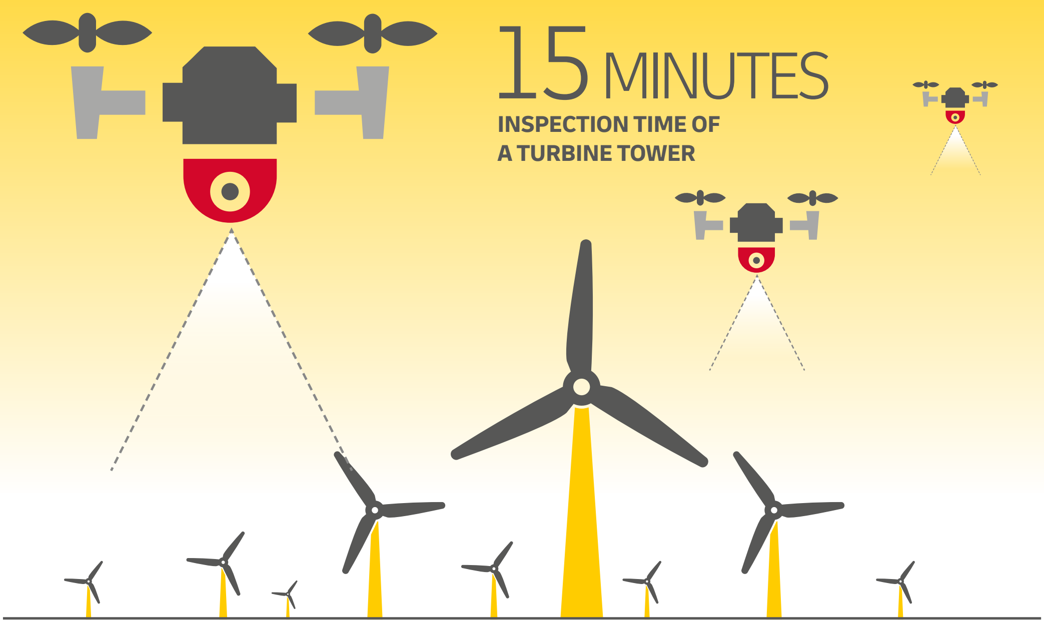
Drone technology is another area with the potential to improve speed, efficiency, and safety across the renewable energy supply chain. Drones may be relatively expensive so far, but their usage may pay off in targeted scenarios. An example of this could be drones equipped with sophisticated control algorithms and appropriate sensors conducting inspection operations on wind turbines and solar installations. This reduces the need for human technicians to spend time in remote and sometimes dangerous locations. It saves time too, since a drone can inspect a turbine tower within 15 minutes.[38] Drones can also be used to deliver tools and small parts to technicians during maintenance operations. This can speed up unplanned maintenance tasks and improve operational safety, especially in offshore installations where the alternative is the descent of a 325 ft (100 m) ladder to reach the support vessel.[39]

The full development of drone technology for renewable energy applications requires maturation of inspection technology, together with the development of operating practices that ensure safety on production sites. Within this framework, it also makes sense to combine progressive technologies – many of which are developing in parallel and often intersecting.

Gjert Anders Gjertsen, Product Owner Supply Chain Logistics at Equinor, says his organization is exploring the use of both drone delivery and 3D printing to improve offshore service and support operations. “Equinor is looking into drones and 3D printing combined for emergency deliveries to offshore installations; but we are still in the early days,” he says. “3D printing can be a solution for spare parts for old equipment or where a vendor has gone out of production. It will also enable express delivery and improve inventory cost.”

DRONE TECHNOLOGY

Drones can be used to deliver goods in the first and last mile, as well as for intralogistics and surveillance operations. However, they will not replace traditional ground-based transport, rather they will augment delivery with point-to-point and automated operations.



3D printing can be a solution for spare parts for old equipment or where a vendor has gone out of production. It will also enable express delivery and improve inventory cost

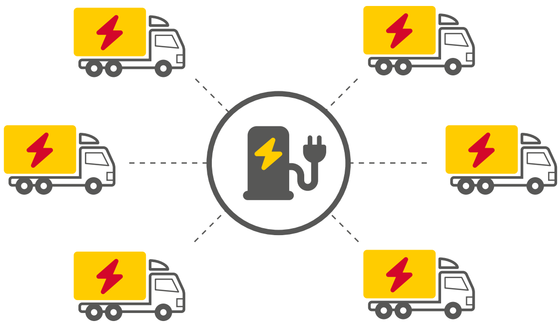
[38] How Drones Help Workers Inspect Wind Turbines, 2021, Bloomberg

[39] Siemens, Orsted partner on drone-based offshore turbine parts delivery, 2020, Smart Energy International

SUSTAINABLE LOGISTICS

Logistics is an energy-intensive business. The increased demand for logistics services to support renewable energy development will inevitably lead to increased focus on the carbon footprint of those services. "Sustainability is a clear target for us. The less we need to transport, the better – and sustainability is an important driver," says Michael Peffermann at Siemens Gamesa. "For example, if vessels consume high energy, this is not only a cost driver. CO_2 emissions are also a driver and come into the equation. Hence, it's costs, sustainability, safety, and executability. Can business be done with a vessel that spends and consumes less?"

CHARGING INFRASTRUCTURE



Furthermore, as companies in all industries seek to reduce the environmental impact of their operations, sustainable logistics is also becoming a priority for the wider energy sector, including oil and gas companies. Providers of logistics services are now expected to report the environmental footprint of their activities to their customers, and to reduce that footprint wherever feasible. "Today, everybody is struggling to get full transparency about their supply chain's end-to-end carbon footprint," says Florent Andrillon, Global Head of Climate & Sustainability at Capgemini. "Access to data will be critical to achieve the next step in transparency."

Sharing data on the carbon footprint of logistics activities allows supply chain participants to find collaborative ways of reducing their impact. That might include optimizing route choices for road transportation, maximizing the utilization of logistics assets through changes to load planning, and switching to less carbon-intensive transportation modes, such as from air to rail for long-distance shipments.

Sustainability in transportation and logistics is not limited to reducing the carbon footprint though. Throughout the whole supply chain, circularity should be considered – beginning from the design and type of input material (e.g., steel made with green hydrogen) and the transportation process (e.g., with green fuels) right the way through to the afterlife management of components and their return to materials recycling. The extensive topic of circularity and the circular economy require more attention. You may wish to read these articles from DHL 'Delivering on Circularity'[40] and Capgemini Invent 'Loops of Life'.[41]

Collaboration will also be necessary as companies seek to go beyond the optimization of existing approaches in logistics. As an example, DHL and TotalEnergies act collaboratively in some markets, with DHL operating a fleet of electrically powered trucks and TotalEnergies providing the necessary charging infrastructure.

According to Siemens Gamesa's Michael Peffermann, this kind of collaboration provides a template for further progress. He emphasizes the importance of beginning conversations with logistics providers as early as possible about designing new supply chains and business models. "Two types of collaboration are crucial for the future," he says. "Early involvement of logistics, and different types of involvement, such as agreements, development workshops, implementation, and mutual transfer of knowledge."

Some low-carbon logistics challenges are not yet solved. There are no commercially available alternatives to fossil fuels for heavy trucks, long-distance ships, or air transportation, for example. Alternative fuels such as green hydrogen may provide solutions here in time but will also require a new low-carbon distribution infrastructure of their own, and they are not yet competitive in terms of price.

While collaboration between logistics providers in support of energy sector companies can make significant progress along the pathway to net zero, the full journey will require collaboration on a bigger scale, involving technological innovation and a cross-society effort to implement new approaches to logistics and transportation. As Capgemini's Florent Andrillon puts it, "Three quarters of the technology required to become net zero globally needs support from governments, corporations, and citizens to reach economic viability and achieve greater scale as quickly as possible."

[40] Delivering on Circularity, 2022, DHL
[41] Loops of Life, 2019, Capgemini Invent

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

A net-zero energy system will be structured very differently from today's fossil-fuel based approach. Demand for energy is expected to remain high, but it is set to undergo a profound shift towards electrification. Power generation will move away from coal, oil, and gas to renewable energy sources such as wind and solar. Rising demand and the lower capacity factors of renewables mean that installed wind power capacity will need to increase by a factor of four, and solar PV by a factor of seven, between 2020 and 2030.

Logistics will be subject to the energy transition, but it **will also be a means to drive the energy revolution**. Yet today's logistics approaches offer too little capacity – and generate too much CO_2 – to fully meet the needs of the global transition to zero emissions.

The shift from large, centralized fossil-fuel power plants to networks of smaller, widely distributed renewables generating equipment will result in a dramatic increase in the volume and variety of logistics services required to deliver each unit of generating capacity. And pressure on logistics will be further exacerbated by the need to accelerate the introduction of new renewables capacity over the coming years.

For energy companies, this means logistics is becoming more important and will make up a much greater proportion of their overall costs. And constraints on the availability of logistics capacity will become a critical factor in the deployment of new energy projects. The energy sector is already feeling the pinch of logistics capacity constraints, due to shortages of specialized assets for the transportation of large components, as well as ongoing shortages of ocean and air freight capacity following the COVID-19 crisis.

Future renewable energy development will also present entirely new logistics challenges. **Wind turbine** components have increased in size by a factor of four over the past thirty years. While existing transportation assets have been upgraded to cope with today's largest turbines, the equipment needed to handle future generations of very large turbines does not yet exist.

The rapid expansion of **offshore wind** presents additional challenges in both construction and operation. There are only a handful of vessels worldwide capable of installing the largest offshore turbines, for example. And the development of new wind farms further offshore is greatly increasing the cost and complexity of maintenance and service parts logistics, with longer transportation times and a greater risk of disruption due to bad weather and sea conditions.

These issues are set to become more pressing with the introduction of floating turbines capable of operating in deep water locations. Comparing the installation logistics for floating offshore turbines with those required for fixed offshore wind farms, much more material is required and, although more processes take place on land (in the shipyard) than at sea, this requires changes to the supply chain.

The **solar** sector, meanwhile, will face a different set of challenges. Solar power is set to become the largest and most widely used renewable energy power source, with development of both utility-scale solar parks and smaller distributed rooftop installations. Building this capacity will require the shipment of large volumes of fragile freight, often to places with limited road infrastructure. And with panel manufacture currently concentrated in Asia, efficient, time-critical last-mile transportation solutions will need the backup of streamlined global supply chains and distribution networks.

Furthermore, the logistics challenges of the energy revolution extend well beyond the installation and support of renewables generation capacity. Electricity transmission and distribution networks will need to be upgraded to handle the new decentralized power infrastructure. And new energy technologies such as green hydrogen will need their own dedicated large-scale storage and transportation systems.

The transportation intensity of renewable energy development is already creating problems for the energy sector, which is operating at the limit of available cargo capacity. In an environment still affected by COVID-related challenges, rising transportation costs and transportation asset shortages are contributing to project delays.

OUR RECOMMENDATIONS

Addressing logistics challenges will be critical to the success of the net-zero transition. From now forward, energy companies need to consider logistics as vitally important to business viability and profitability. Here are five key areas of focus for any organization involved in the energy revolution:

1. Collaboration is key

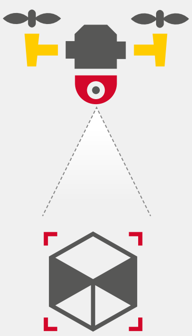
Robust, resilient logistics systems for renewables will require intelligent coordination between multiple stakeholders, including energy companies, equipment manufacturers, and logistics service providers. To deliver the best solutions, these collaborative relationships should begin early. Including logistics engineers during the initial design of future wind turbine models will be essential to address the logistics requirements associated with transporting and maintaining them, for example. Design decisions that can significantly impact logistics costs include setting the maximum dimensions of major components, so they fit through tunnels and under bridges, and designing modules suitable for containerized transportation.

2. Work end-to-end

Logistics for renewable energy development presents companies with a series of discrete – and difficult – problems. But solving these problems one by one will lead to sub-optimal solutions. Instead, companies need to take an end-to-end perspective on their logistics systems, especially as they plan their entry into new areas of technology, new markets, and new regions. Such thinking should address the full lifecycle of energy infrastructure, including logistics requirements for service and maintenance right the way through to handling end-of-life assets.

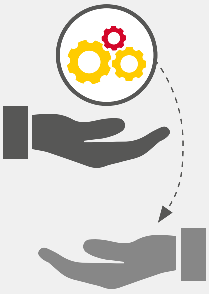
The best way to ensure such a perspective is to make one organization responsible for central coordination of supply chain and logistics activities, and to limit handover points between contractors. The responsible organization needs to take a highly proactive approach, given the long lead times required to establish supply chains in new markets, and the need to secure licensing and access to ports, yards, and other logistics infrastructure.

Thinking in an end-to-end way will also help companies evaluate the case for the regionalization of production, which can be an enabler of faster, more flexible, and lower-cost supply chains.



3. Focus on visibility and digitization

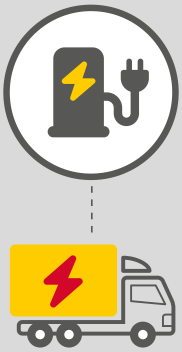
High-performing supply chains can't afford blind spots. Energy companies need to invest in smart digital platforms, capabilities, and tools to help them manage logistics execution and optimize supply chain design. Full supply chain visibility is a critical enabler for many of the approaches that can have the biggest impact on end-to-end costs. As an example, in service and maintenance logistics it allows companies to move non-critical and rarely used items away from frontline locations and hold them within the upstream network. That can lead to significantly lower inventory carrying costs, since the same parts can be ready to support multiple wind or solar installations.



4. Identify transferrable skills from adjacent industries

With so much to do and so little time to get it right, the energy sector can't afford to spend time finding solutions to problems that have already been solved elsewhere. Instead, the industry should be willing to seek out, replicate, and adapt successful existing approaches wherever they can be found.

Energy companies are doing some of that already, especially in the transfer of offshore skills and technologies from oil and gas to wind energy, but there are opportunities to go much further. The automotive industry's approach to industrialization provides a template for project design and execution, for example. Instead of treating each factory build or new model introduction as a standalone effort, car companies attempt to standardize wherever they can, making changes only where there is a clear business case to do so.



5. Pursue sustainable logistics solutions

Energy companies have both an opportunity and an imperative to support the development of sustainable logistics solutions. That transition will take time. While the logistics industry is critical to the success of the energy revolution, the sector also depends on that revolution to power its own net-zero journey.

In the medium term, energy companies can partner with logistics service providers to develop early use cases for key emerging technologies, from synthetic fuels to electric aviation. In the immediate term, however, logistics service providers can help the energy industry reduce both costs and supply chain emissions through operational changes such as route optimization and improved utilization of transportation assets. New service offerings such as managed transportation solutions can improve emissions, end-to-end visibility, and cost control while also giving energy companies the ability to manage their supply chain networks in an agile and proactive way.

The net-zero transition will drive fundamental change in the way energy networks are designed, built, run, and maintained. As this report has shown, advanced logistics capabilities will be a key element of that change, and they will be required at a scale previously unseen in the energy sector. That's why energy companies and their logistics partners must start collaborating today to develop innovative solutions to emerging logistics challenges. We look forward to working with you to enable and support the energy revolution.

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LIST OF ACRONYMS

CCUS ....Carbon capture, utilization, and storage
DAC ....Direct air capture
EV ....Electric vehicle
GW............Gigawatt
GWEC ......Global Wind Energy Council
IEA............International Energy Agency
IECs..........International energy companies
IoT ....Internet of Things
IRENA......International Renewable Energy Agency
LOHC ....Liquid organic hydrogen carriers
MW...........Megawatt
NOCs........National oil companies
NZE ....IEA Net Zero Emissions by 2050 Scenario
OoG ....Out of gauge
PV ....Photovoltaic
RD.............Rotor diameter
SDS ....IEA Sustainable Development Scenario
TWh ....Terawatt-hour

FURTHER INFORMATION

Michael Wiedemann
President Energy Sector and Head of CSI EMEA
DHL Customer Solutions and Innovation
e-mail: michael.wiedemann@dhl.com

Gert Van Dijck
Business Development Renewable Energy
DHL Customer Solutions and Innovation
e-mail: gert.van.dijck@dhl.com

André Hartig
Senior Analyst, Global Sector Development Energy
DHL Customer Solutions and Innovation
e-mail: andre.hartig@dhl.com

Bastian Thöle
Vice President, Enterprise Model & Strategy
Capgemini Invent
e-mail: bastian.thoele@capgemini.com

Jonathan Kahe
Senior Manager, Supply Chain Transformation
Capgemini Invent
e-mail: jonathan.kahe@capgemini.com

PUBLISHER
DHL Customer Solutions & Innovation
Represented by Katja Busch

PROJECT MANAGEMENT AND EDITORIAL OFFICE
André Hartig, Allinson Ziolkowski
DHL Customer Solutions & Innovation

AUTHORS
Clemens Pudewill
Levin Dumm
André Hartig
Dr. Kristina von Gehlen
Gert van Dijck
Jonathan Ward

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Deutsche Post DHL Group is the world's leading logistics company. The Group connects people and markets and is an enabler of global trade. It aspires to be the first choice for customers, employees and investors worldwide. To this end, Deutsche Post DHL Group is focusing on growth in its profitable core logistics businesses and accelerating the digital transformation in all business divisions. The Group contributes to the world through sustainable business practices, corporate citizenship and environmental activities. By the year 2050, Deutsche Post DHL Group aims to achieve zero emissions logistics.

The Group is home to two strong brands: DHL offers a comprehensive range of parcel and international express service, freight transport, and supply chain management services, as well as e-commerce logistics solutions. Deutsche Post is Europe's leading postal and parcel service provider.

Deutsche Post DHL Group employs approximately 570,000 people in over 220 countries and territories worldwide.

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DHL Research and Innovation GmbH
Kurt-Schumacher-Str. 12-14
53113 Bonn
dhl.com
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