RENEWABLE ENERGY BENEFITS

LEVERAGING LOCAL CAPACITY FOR ONSHORE WIND

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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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DISCLAIMER

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INTRODUCTION

Developing a renewable energy sector brings immense opportunities to fuel economic growth, create new employment opportunities and enhance human health and welfare. Many countries increasingly consider the socio-economic benefits of renewable energy development as a key driver to support its deployment (IRENA, 2016a).

Analysis by the International Renewable Energy Agency (IRENA) shows that an accelerated deployment of renewable energy and energy efficiency, as needed to meet the goals laid out in the Paris Agreement, would increase global GDP by 0.8% in 2050 and support around 26 million jobs in the global renewable energy sector by 2050 (IRENA, 2017a). In recent years, job creation has been an important co-benefit of accelerated renewable energy deployment. IRENA estimates that the sector employed 9.8 million people in 2016 (IRENA, 2017b). Employment opportunities are created throughout the value chain for renewable energy deployment, from project planning to manufacturing, installing, operating and maintaining, as well as decommissioning.

This report assesses the types of jobs created along the value chain, in order to provide policy makers with an understanding of the human resources and skills required to produce, install and decommission renewable energy plants. It assesses the materials and equipment needed in each segment of the value chain to identify areas with the greatest potential for local value creation. The objective is to allow for an informed feasibility assessment of procuring the components and services domestically rather than from abroad. The study can help decision makers identify ways to maximise domestic value creation by leveraging existing industries if they want to do so. It is part of IRENA's extensive work on renewable energy benefits (see Box i.1).

Box i.1 ■ **IRENA's work on renewable energy benefits**

This study is part of a growing body of work by IRENA which began in 2011. It includes Renewable Energy and Jobs (2013), The Socio-Economic Benefits of Solar and Wind Energy (2014), Renewable Energy Benefits: Measuring the Economics (2016) and Renewable Energy and Jobs: Annual Review (2014, 2015, 2016 and 2017). This study is part of a series of reports analysing the opportunities for value creation through deployment of renewable energy technologies, including solar photovoltaics (IRENA, 2017c) as well as upcoming reports on solar water heaters and offshore wind.

The full report can be downloaded from **www.irena.org/Publications**

The data presented in the report were obtained through surveys and interviews with internationally recognised experts and from desktop research that gathered information published by leading companies and specialised institutions in the wind industry. Forty-nine stakeholders were interviewed or responded to questionnaires on the requirements to develop a wind industry. They included project developers, component manufacturers, service providers, energy authorities and national and global associations for wind and renewable energy. The study also draws on public reports of wind energy companies, including annual reports; technical specifications and equipment handbooks; and public price lists.[1] The scope of the study is global, covering Brazil, China, the European Union, India, Japan, Mexico, South Africa and the United States.

The first chapter of the report discusses the current and projected socio-economic benefits of wind energy deployment. The second chapter analyses the requirements (in terms of skills, materials and equipment) to develop wind projects along each segment of the value chain. The third chapter discusses the factors driving the development of a local wind industry in Denmark and Morocco. The last chapter presents recommendations on how to maximise value creation from the development of a domestic wind industry while leveraging existing industries.

[1] Public information comes from the following institutions: ABB, Acciona, ACWA Power, the African Wind Energy Association, the American Council on Renewable Energy, the Asociación de Productores de Energías Renovables (APPA), the Asociación Empresarial Eólica, the China Datang Corporation, the China Guodian Corporation, Clean Energy Resource Teams, the Danish Energy Agency, Delattre Levivier Maroc, Deutsche Energie Agentur, EDF, EDP Renovavéis, Enel Green Power, Enercon, EURO FORES, Fraunhofer, Gamesa, GE, Gestamp Wind, the Global Wind Energy Council, Goldwind, Iberdrola, the Inter-American Development Bank, the International Energy Agency, the International Monetary Fund, the Latin America Wind Energy Association, LM Wind Power, NextEra Energy, Nordex, North American Wind Power, REN21, Schneider, Senvion, Siemens, Sinovel Wind Group, Suzlon Energy, the UK Energy Agency, the UK Renewable Association, United Power, the US Department of Energy, Vestas, WindEurope and the World Bank.

1. VALUE CREATION IN THE WIND ENERGY SECTOR

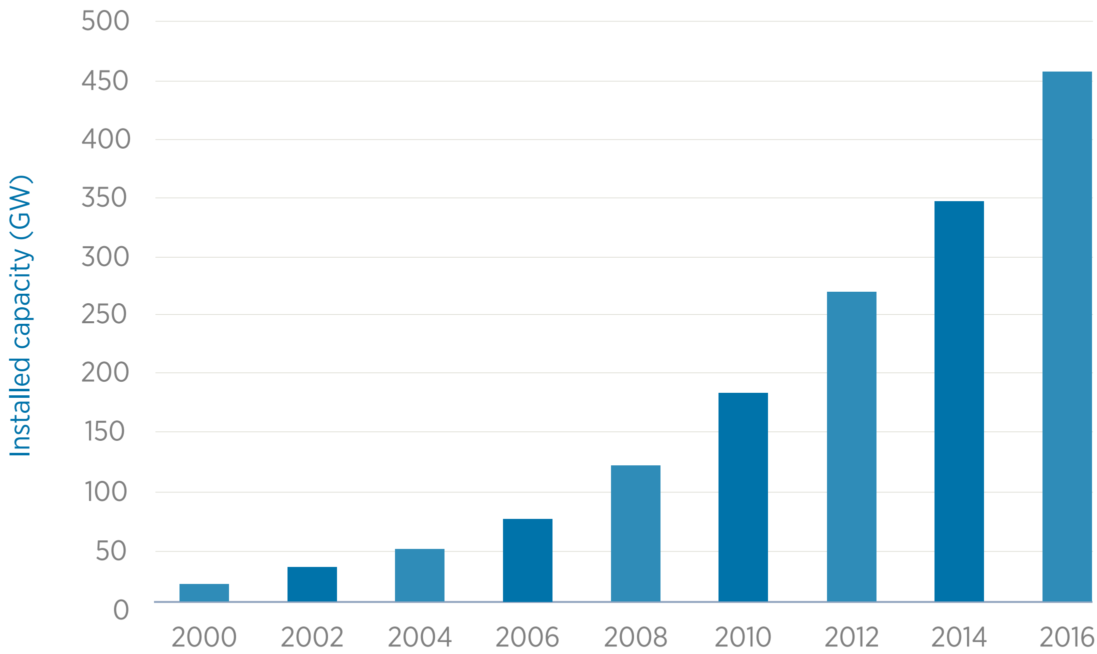
Among environmental concerns and with the growing demand for energy, the deployment of renewable energy is increasingly being driven by the potential it presents to develop a domestic renewable energy industry, offering opportunities for job creation and income generation. Analysing the potential for local value creation from wind energy deployment establishes whether economic benefits such as income generation and job creation can be realised in the country where the projects are located, and whether certain segments of the value chain should depend on the importation of products and/or services. The extent to which value can be created domestically will depend largely on the the size of its renewable energy market, stage of renewable energy and industrial development, establishment of other related sectors, dynamics of regional and global markets for components and services, the availability of skills and the general business environment of the country.

This chapter explore the potential opportunities for value creation from the development of onshore wind. It starts by an overview of the trends in the adoption of wind energy, followed by an estimate of the investments and jobs created in the sector, and a breakdown of the value chain into the different segments that present opportunities for value creation.

1.1 Trends and cost of onshore wind

The installed capacity of onshore wind energy has risen steadily for nearly two decades, increasing from about 17 gigawatts (GW) in 2007 to 450 GW in 2016 (IRENA, 2017d) (see Figure 1.1), resulting in ample socio-economic benefits.

Figure 1.1 **Wind global installed capacity (GW), per year**



Source: IRENA, 2017d

Worldwide employment (direct and indirect) in onshore and offshore wind energy grew at a steady pace reaching 1.2 million jobs in 2016 (see Box 1.1). Furthermore, wind power could support more than 3.8 million jobs in 2050 (IRENA, 2017b) (see Figure 1.2).

Box 1.1 ■ Overview of jobs in wind energy in 2016

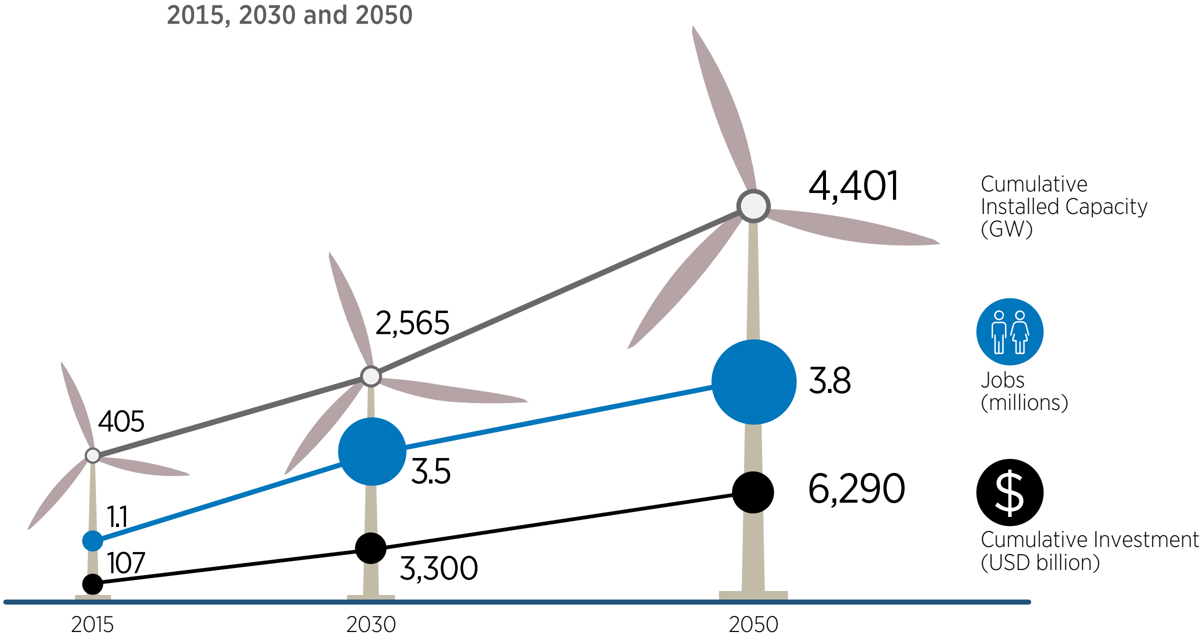
The wind energy sector employed an estimated 1.2 million in 2016, primarily fuelled by deployment in China, the United States, Germany, India and Brazil. More than half of these jobs were in Asia, where the share of global wind energy employment increased from 54 percent in 2014 to 56 percent in 2016. Over this period, employment in the sector rose by 35 percent in North America, 9 percent in Latin America, and 3 percent in the European Union.

China is the leading employer, and five out of the top ten wind companies in terms of new commissioned capacity in 2015 are Chinese (BNEF, 2016). That year, China accounted for 51% of global new additions, followed by the United States (13%), Germany (6%), Brazil (5%) and India (4%).

Sources: IRENA, 2016b; IRENA, 2017b

IRENA estimates that achieving the energy transition in the G20 countries would require cumulative investments in the wind energy sector of about USD 3.3 trillion by 2030 and USD 6.3 trillion by 2050 (IRENA, 2017a). Such investments can create value, and result in socioeconomic benefits including income generation and job creation (see Figure 1.2).

Figure 1.2 **Estimated cumulative capacity, investments and employment in wind, 2015, 2030 and 2050**



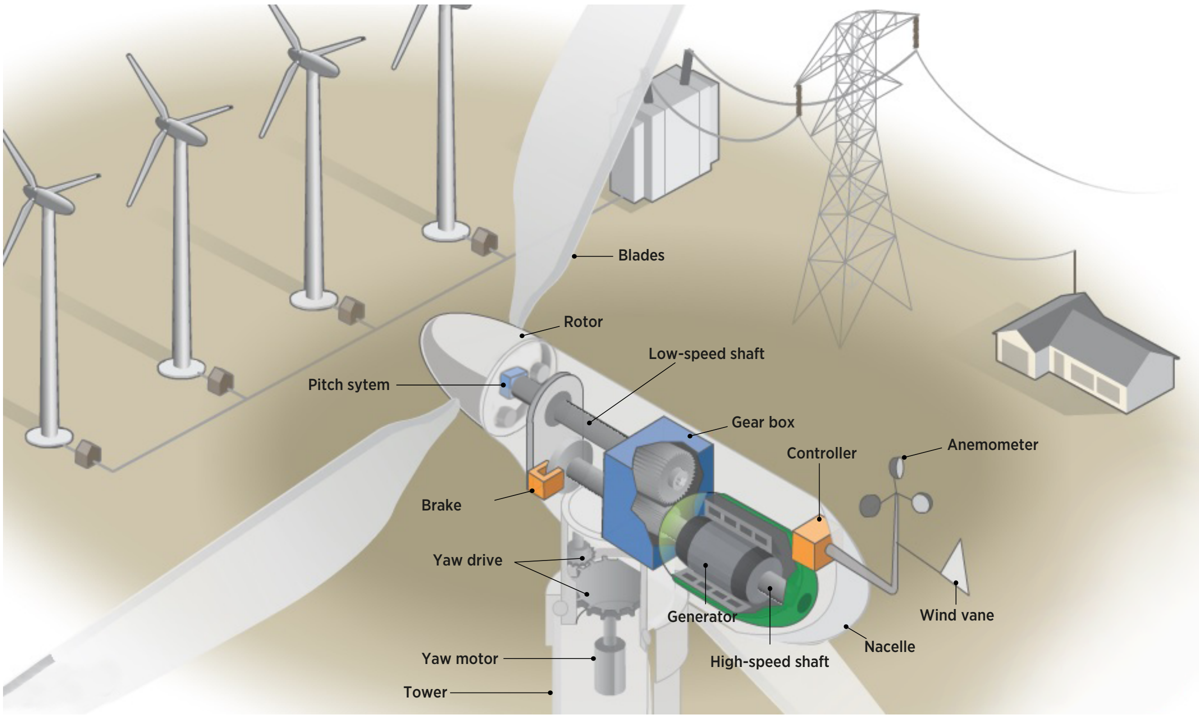
Note: Investment in 2015 is annual, not cumulative.
Sources: IRENA, 2016b; IRENA, 2017a

The wind industry has undergone considerable progress in technological maturity. Onshore wind power is now cost-competitive with other technologies such as new coal- or gas-fired plants in several countries. In Egypt and Morocco, recent wind auctions have resulted in bids as low as USD 40 and USD 30 per megawatt hour (MWh), and in Latin America, technology-neutral auctions have resulted in even lower prices for wind, demonstrating its competitiveness against conventional technologies (IRENA, 2017e). As a result, many countries are developing wind energy as the technology of choice in terms of cost competitiveness and opportunities for domestic value creation. However, an assessment of the main requirements to develop a wind industry is needed to assess the feasibility of sourcing equipment and services locally. Analysing the activities and requirements of a wind project requires an understanding of the different components of an onshore wind farm. Moreover, an understanding of the distribution of the total costs of the project can provide insights on the activities with the highest potential for value creation.

1.1.1 Components of a wind farm

Wind power technology transforms the kinetic energy of the wind into mechanical power: the wind turns the turbine blades that, via a drive shaft, provide the mechanical energy to power the generator in the turbine. The main components of a wind farm include the wind turbine (see Figure 1.3), the elements needed for the infrastructure (foundations) and the equipment for the connection to the grid (transformers, substation, cables and inverters) (ABDI, 2014).

Figure 1.3 **Wind turbine components**



Source: U.S. Office of Energy Efficiency and Renewable Energy, n.d.

The main components of a wind turbine include:

- **Nacelle:** the box located on the top of the tower, made of fiberglass, that contains approximately 8,000 subcomponents and connects them to the rotor. The size and weight of the nacelle vary depending on capacity (75 tonnes for a 2 megawatt (MW) turbine).
- **Rotor and blades:** the rotor is typically composed of three rotor blades, the rotor hub that holds the blades in position as they turn and a pitch mechanism that allows the blade to rotate in the direction of the wind, maximising its capacity to harness wind.
- **Tower:** the nacelle is mounted on the top of a high tower that allows using the best winds and avoiding obstacles. Towers for large wind turbines may be either tubular steel towers, concrete towers, or lattice towers.

In addition to the wind turbine, **other components** are needed to install and operate a wind farm, such as the following:

- Transformers to increase the voltage of the electricity generated. The system inverters generate power output at approximately 480 volts. Electricity grids operate usually in kilovolts.
- Capacitors to adjust the power factor and reduce the reactive energy generated.
- The electric installation requires cables to connect wind turbines to the inverters, transformers and grid. The installation includes contactors, circuit breakers and bypass contactors.
- Control equipment compromising microprocessor control, feeding source, heat resistors and coils.
- Electric protection equipment with relays and contactors of auxiliary or protection elements.
- Metering equipment to measure and control the quantity of electricity produced and supplied to the grid, and the reactive power.

1.1.2 Cost breakdown of a wind farm

The total installed capacity costs for wind energy have followed a decreasing trend, driven by growth in economies of scale as new yearly installations increased globally, from almost 7 GW in 2001 to 64 GW in 2015 (Figure 1.1). Another driver is the research and innovation that continue to make strides in the design of manufacturing processes and equipment. The technological areas with the most impact include the size of the wind turbine and rotors, given that the average size of wind turbines reached 2 MW in 2014 (*i.e.* longer and lighter blades with combined properties of carbon and glass fibre, higher tower height to reach stronger winds that impact power capacity); the ability to produce electricity with lower wind speeds, enabling the installation of turbines closer to consumption centres with normally lower speed areas; improvements in the reliability and efficiency of the technology; increasing competition among suppliers and improved logistical chains; and streamlined administrative procedures in many countries (IEA, 2013a) (Watson, n.d.). The decreasing cost of onshore wind is expected to continue, and it is anticipated that by 2025, the total installed cost of onshore wind farms will decline by almost 12% compared to 2015 (IRENA, 2016c).

Wind turbines, including towers and installation, are the main cost components in developing wind projects. The turbines can account for between 64% and 84% of an onshore wind project's total installed cost although, most commonly, it stands at between 64% and 74% of installed costs (IRENA, 2016c). The cost of the turbine fluctuates with economic cycles and the price of commodities, such as copper and steel, which constitute a significant portion of the turbine's materials (see Section 2.3). In 2009, the turbine price peaked in Europe and the United States (at USD 1,890/ kW and USD 1,728/kW respectively, for projects higher than 100 MW, up from USD 755/kW in 2002). This was driven by the rising costs of materials, labour and civil engineering; tight supply versus demand, allowing higher profit margins for manufacturers; and technological improvement, allowing the introduction of more expensive turbines with higher towers and more capital-intensive foundations. By 2014, prices had declined by more 30% (to as low as USD 931/kW in the United States) as a result of the declining cost of materials and increased supply versus demand. Manufacturers in emerging markets, such as China, have added to this downward trend with efforts to develop domestic manufacturing, with lower prices (USD 676/kW in 2014) and contribution to global overcapacity (IRENA, 2015).

The remaining costs can be broken down into the following: the cost of civil works varies between 8% and 17% of total project cost, including construction costs for site preparation and the foundations for the towers. The cost of connecting the wind farm to the grid, including transformers and sub-stations, and the connection to the local distribution or transmission network, ranges between 8% and 11% of total project cost. Finally, project planning may constitute between 9% and 11% of the total cost and may entail expenses and fees relating to development, licenses, financial closing, feasibility and development studies, legal processing, rights of way, owner insurance, among others (IRENA, 2015).

The breakdown of costs of a wind project gives an indication of the opportunities for value creation along the various segments of the value chain.

2. REQUIREMENTS FOR ONSHORE WIND ENERGY DEVELOPMENT

TThe different stages of the development of wind energy projects are commonly divided into several activities, based on their characteristics (*e.g.* economic evaluation, administrative activities, procurement process, engineering tasks, construction works). Table 2.1 provides a breakdown of the core activities carried out, from the selection of an appropriate project site at the planning stage to site clearance at the decommissioning stage.

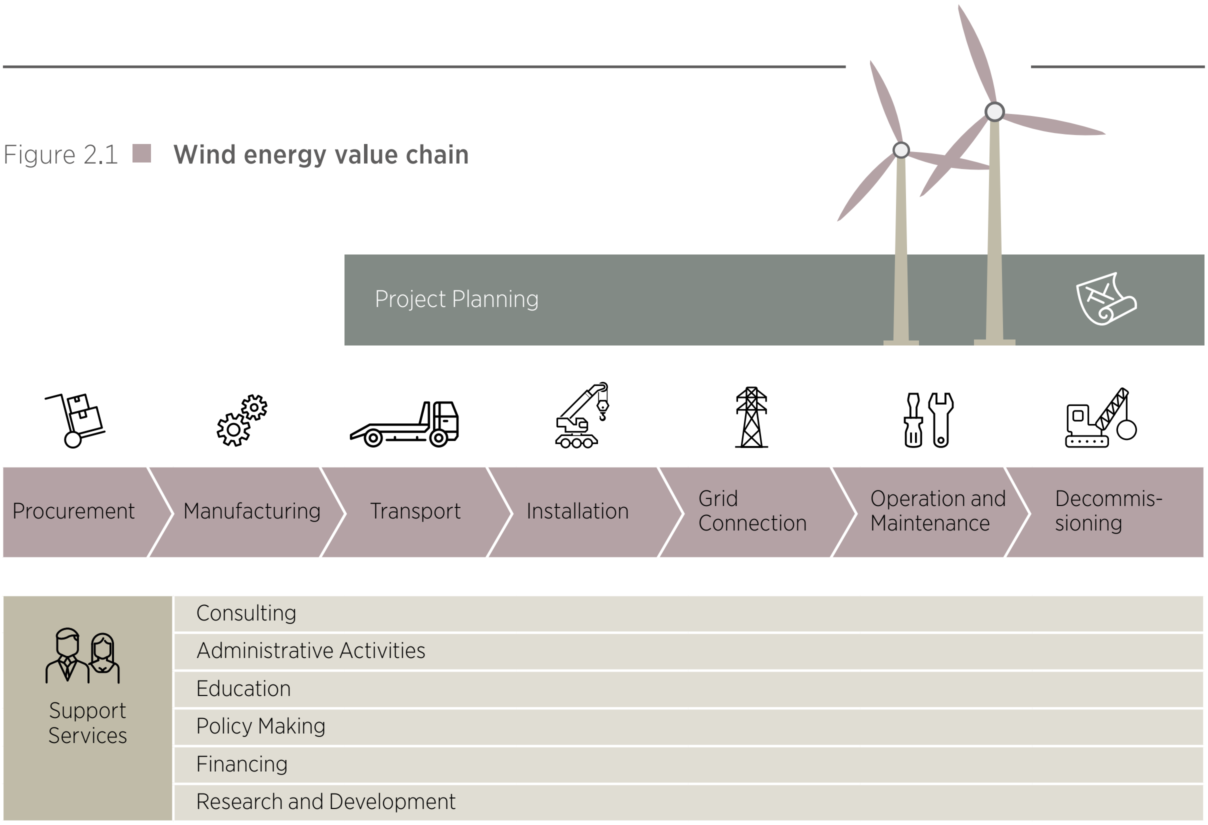
Table 2.1 **Activities in the onshore wind energy value chain**

SEGMENT OF THE VALUE CHAIN PHASE	ACTIVITIES
Project planning	1.1. Site selection
	1.2. Technical and financial feasibility studies
	1.3. Engineering design
	1.4. Project development
Procurement	2.1. Identification of specifications
	2.2. Assessment of the local availability of materials
Manufacturing	3.1. Nacelle manufacturing and assembly
	3.2. Blades manufacturing
	3.3. Tower manufacturing and assembly
	3.4. Monitor and control system manufacturing
Transport	4.1. Transport of equipment
Installation	5.1. Site preparation and civil works
	5.2. Assembling equipment
Grid connection and commissioning	6.1. Cabling and grid connection
	6.2. Commissioning
Operation and maintenance	7.1. Operation
	7.2. Maintenance
Decommissioning	8.1. Planning the decommissioning
	8.2. Dismantling the project
	8.3. Disposing/recycling the equipment
	8.4. Clearing the site

2.1. Value chain of onshore wind

The wind energy value chain is commonly divided into several segments/phases comprising related activities, pertaining to core and supporting activities. The core activities that are specific to renewable energy development include project planning, procurement of raw materials and intermediary products, manufacturing of components, transport of equipment, project installation, grid connection, operation and maintenance and decommissioning. Other activities from the various sectors that support deployment include consulting, financing, education, research and development, policy making and administrative activities[1] (see Figure 2.1).

Figure 2.1 ■ **Wind energy value chain**



The **project planning** phase entails the pre-development activities of the project, from inception to complete design. It includes the environmental and social impact assessment, site selection, pertinent feasibility studies, and administrative procedures required. This phase incorporates the engineering and designing of technical aspects of the project, including the operation, maintenance and decommissioning of the plant.

The **procurement** phase involves the acquisition of main components, intermediary products and raw materials. If these are not available locally, they are imported by the manufacturer or the developer in charge of project installation.

The **manufacturing** of components incorporates the processes needed for their production.

[1] An analysis of the support services is beyond the scope of this study

The **transport** phase encompasses the transport of components from the manufacturing warehouse to the project site, including the logistical arrangements that are required.

The **installation** phase entails the infrastructure works and construction of the facility itself, including site preparation, civil works, and on-site assembly and installation of the components.

The **grid connection** phase pertains to fulfilling all requirements of the grid operator so that the facility can begin to produce and sell electricity.

The **operation and maintenance** phase comprises the activities carried out throughout the operational lifetime of the project to ensure its uninterrupted functioning. It includes the commercial and technical control of the facility and its monitoring and maintenance activities.

The **decommissioning**[2] phase takes place at the end of the project's operational lifetime, when the components are essentially uninstalled, disposed of or recycled. It entails clearing the site and restoring it to its original state.

Cross cutting support services include consulting, education, financing, research and development and other administrative activities. These are important factors and key enablers for the achievement of local benefits; however, the analysis in this study focuses on core activities and, therefore, the detailed analysis of support services is beyond the scope of this study.

For a country deploying wind energy, the potential to generate income and create jobs will depend on the extent to which the local industry along the different segments of the value chain can leverage existing economic activities, and create new ones. The analysis in this study focuses on the core segments of the value chain: project planning, procurement, manufacturing, transport, installation and grid connection, operation and maintenance (O&M) and decommissioning. In designing policies to support value creation from the development of a domestic wind industry, a deeper understanding of the requirements in terms of labour, skills, materials and equipment is needed.

- Labour requirements: Analysing the person-days and skills required in each segment of the value chain is essential to estimate the potential for job creation and to assess the availability of skills needed to develop a domestic sector. This analysis can help make informed decisions regarding strategies to meet the skills requirements of developing a local industry as well as the import of labour in the meantime.
- Materials and equipment: Studying the raw and intermediary materials and equipment needed to manufacture components can support the decision on which segments of the value chain to localise. Depending on the availability of materials, domestic manufacturing of wind equipment would effectively support the industries that are relevant to wind energy. Some countries, for example, have a local steel or aeronautics industry that provides the basis for a wind industry.
- Information: Understanding the information that should be made available to attract the private investments in the sector is crucial for the development of a local industry. This includes policy information, grid access regulations, trade policies and other technical information such as resource assessments, institutions that offer attractive financing for renewables, among others.

[2] If projects are deemed fit for continuing operation, they are repowered

2.2 Project planning

The project planning phase comprises the initial activities of a wind project, including the identification of the investment opportunity, environmental impact assessment and technical and financial feasibility studies. At this stage, the project developer identifies a business opportunity as a result of a government policy (*e.g.* auction) and proceeds with the following activities: site selection, technical and financial feasibility studies, engineering design and project development. In the first two activities, the resource potential of a site is measured and the environmental and social impacts of the project are assessed. Engineering design covers the technical aspects of the mechanical and electrical systems; the civil engineering work and infrastructure; the construction plan; and the O&M model. Project development consists of administrative tasks, such as obtaining land rights, permits, licenses and approvals from different authorities; managing regulatory issues; negotiating and securing financing and insurance contracts; contracting engineering companies; negotiating the rent or purchase of the land; and managing the procurement processes.

Site selection

Feasibility studies

Engineering design

Project development

Planning a 50 MW wind farm with 2 MW turbines requires an estimated 2,580 person-days of labour. Project development activities account for about 70 percent of this labour (1,780 person-days), followed by engineering design (12%), site selection (11%) and feasibil ity analysis (8%). Table 2.2 presents a breakdown of the total **human resources** needed in project planning by activity.

As for the skills needed, almost 40 percent of the labour (1,020 person-days) falls in the 'legal, energy regulation, real estate and taxation experts' category, indicating the importance of knowledge of the local context. While some of these needs can be fulfilled by foreign experts, they offer considerable opportunities for domestic employment. About 16 percent of the total labour (420 person-days) requires specialised engineers, and environmental and geotechnical experts with knowledge of the wind sector (see Figure 2.2). These professionals can be hired from abroad on a temporary basis or skills can be developed domestically through education and training policies designed to meet future skills needs in the sector.

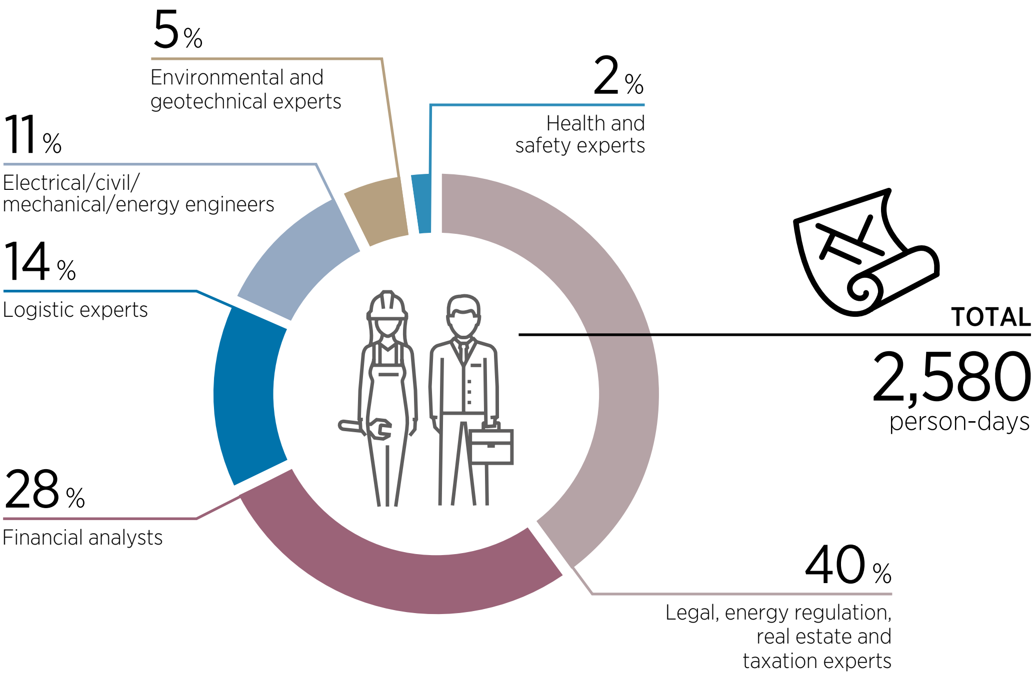
Project planning requires **equipment** to measure wind resources at the site selected, such as anemometers and wind vanes, along with wind energy simulators and programmes to measure wind speeds and direction and predict wind behaviour.[4] Computers and software to run simulations and produce feasibility analyses are also required.

Technical **information** is necessary to identify soil characteristics and climatic features at the site (such as snow or sand storms) that might affect a project's structural and operational requirements or place limitations on the wind turbines. Information about policies

Table 2.2 **Human resources required for the project planning of a 50 MW wind farm (person-days) and breakdown by activity**

TYPE OF HUMAN RESOURCES	Site selection	Feasibility analysis	Engineering design	Project development	Total by occupation
Legal, energy regulation, real estate and taxation experts	140	60	100	720	**1,020**
Financial analysts	–	30	–	700	**730**
Logistic experts	–	–	–	360	**360**
Electrical/civil/mechanical/energy engineers	50	90	150	–	**290**
Environmental experts	50	30	–	–	**80**
Health and safety experts	–	–	50	–	**50**
Geotechnical experts	50	–	–	–	**50**
Total (as %)	**290** (11%)	**210** (8%)	**300** (12%)	**1,780** (69%)	**2,580**

Figure 2.2 **Distribution of human resources required for the project planning of a 50 MW wind farm, by occupation**



and regulations related to support schemes for renewable energy, grid connection and land use is crucial for determining whether to proceed with the development of a wind farm.

In the project development stage, planners decide whether to procure domestically manufactured components (if available) or from foreign suppliers. The cost of technology and enabling conditions created by policies that support manufacturing, such as taxes on imports or local content requirements, affect this decision.

2.2.1 Site selection

The selection of an appropriate site for the wind farm can be the responsibility of the public sector or the project developer. In the latter case, location constraints can be imposed by government, and should the developer be selected by way of a competitive bid (*i.e.* auction), the characteristics of the site chosen can be a decisive criteria for the winner of the auction (IRENA and CEM, 2015).

The identification of the most suitable sites for large-scale renewable energy projects is not simply based on the economic valuation of high-quality renewable sources. Other criteria include environmental and social impacts, population density and potential conflict with other sectors such as agriculture, industrial sector, touristic sites and cultural heritage, grid operability (or the temporal correlation between generation and demand at a particular site), transmission costs, road infrastructure cost, overlap or proximity with environmentally sensitive areas, availability of land for purchasing or long-term leasing, suitability of local climate and landscape, among others[3]. Moreover, an evaluation is required of the climate factors (*e.g.* snow) which can reduce the efficiency of wind farms.

At this stage, the **human resources** that are essential are engineers who are specialised in wind energy and who can analyse local weather data and resource availability; geotechnical specialists to analyse land specifications; environmental specialists to evaluate impacts, possible risks and potential conflicts with other sectors; and lawyers and real estate experts to handle regulatory issues such as energy policy, land use or access to the grid (see Table 2.2). The level of effort required depends on the existing legal framework that relates to the site; regulatory framework of the energy sector; characteristics of the location and its accessibility; requirements for the connection to the grid; and size of the project. This activity can be performed using local resources, if available.

Equipment needed include those to estimate wind speeds. For example, anemometers and wind vanes can be used to measure the wind speeds and direction along a period of time. In addition, wind energy simulators are programs used to predict wind behaviour (*i.e.* direction, speed) in order to assess the feasibility of wind farms.

Information needed to undertake these activities include the policies and regulations on land use and the restrictions for the development of wind projects, in addition to that relating to resource availability. Other relevant information includes climatic and orographic features of site that may affect the operation of the wind turbines (*e.g.* snow, sand).

Once the study is performed and should a location be deemed suitable, an agreement is established with the landowner. This provides the developer the right to enter and evaluate, in detail, the site and, if suitable, develop the wind farm.

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[3] IRENA's Global Atlas for Renewable Energy provides high resolution maps that display suitability for projects according to resource intensity, distance to power grids, population density, land cover, topography, altitude and protected areas. See www.irena.org/globalatlas

2.2.2 Technical and financial feasibility studies

The next step is to conduct a more thorough analysis on the feasibility of developing a wind project in the designated site, especially with regard to its technical performance and financial profitability, as well as its bankability in order to secure financing. This activity involves an in-depth assessment of wind resources through the installation of a temporary meteorological mast on the site for a period of 12 to 24 months. In addition, a detailed assessment of the investment should be undertaken regarding the long-term demand for wind energy, taking into account the country's political stability, regulatory framework and legal security. Other issues that should be considered are the ease of access to the grid and to equipment providers, as well as existing and new infrastructure to reach the site location. Most importantly, the rate of return of the investment and the availability of financial resources should be assessed.

The study is typically carried out by the project developer, using expertise that is locally available and/or from abroad. **Human resources** include environmental experts; energy engineers specialised in wind; electrical and mechanical engineers; financial analysts; and experts in energy regulation, legal issues and taxation (see Table 2.2).

Equipment needed include those to estimate wind speeds, as well as computers and software to run simulations and feasibility analyses. Electricity grid simulators are needed to evaluate power system requirements to connect the wind farm to the grid.

2.2.3 Engineering design

Once the investment decision has been made — and in parallel with other administrative tasks from the project development activity — the multi-disciplinary engineering activity follows. This includes the mechanical and electrical systems design, civil engineering work and infrastructure, construction plan, operational model, maintenance strategy and decommissioning plan of the wind farm.

The engineering design can be performed by the project developer, when the necessary capabilities and skills are available in-house. In some cases, it is economically and technically more competitive to subcontract these tasks to third parties. **Human resources** needed include legal experts for the regulatory issues, mechanical engineers and computational fluid dynamics experts for designing the wind farm along with its maintenance plan, electrical and electronic engineers for the design of the electrical and telecommunication system; mechanical engineers for the operations; civil engineers for the design of the civil works/infrastructure, construction plan and decommissioning strategy; and health and safety experts (see Table 2.2).

Equipment needed includes computers and design software, such as CAD tools, for drawings and design.

Information required includes data on wind speeds, detailed cost of land, equipment and labour, availability and cost of financing and relevant information on regulation and policy.

2.2.4 Project development

Once the project is deemed feasible, the development stage is initiated with administrative procedures in place, using the results of the studies conducted in the previous stage: obtaining land rights, permits, licenses and approvals from the various authorities; managing regulatory issues with the authorities; negotiating and securing financing; negotiating and signing an insurance contract; contracting an engineering company; negotiating the rent or purchase of the land; and managing the procurement process. Project development is a labour-intensive activity that does not require high capital investment in equipment apart from operating expenses, such as offices and office equipment.

Human resources include financial analysts to perform the tasks that relate to financial closure and the negotiation of financing and insurance contracts, in addition to Engineering, Procurement and Construction contracts; and legal, energy regulation and taxation experts in charge of obtaining permits and the licenses that apply to grid access and electricity discharge to the grid. Also essential are lawyers and experts in land property, who can obtain the land rights and negotiate purchase/rent conditions. Logistics experts are needed to manage the procurement process (see Table 2.2). Most of the labour required is sourced domestically, as local knowledge of the laws and regulations.

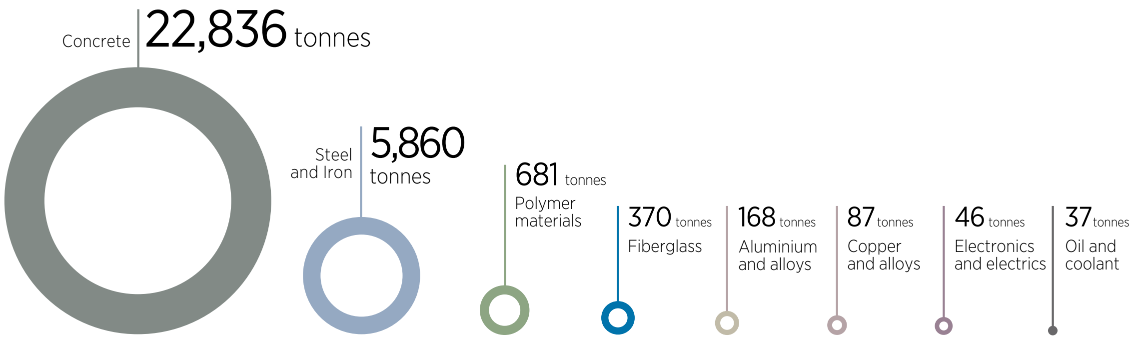
Equipment includes computers and software for administrative tasks.

Information includes relevant information on regulatory policy. Data to facilitate project development can be accessed on IRENA's online Project Navigator platform, which provides project developers the knowledge, tools, case studies and best practices to initiate, develop, fund and complete projects[4].

2.3 Procurement

Wind projects require equipment, intermediary products and raw material that could be procured domestically for maximum value creation. For example, the local procurement of steel or concrete to manufacture and install wind turbines benefits both industries. Figure 2.3 illustrates the quantities of materials needed to develop a 50 MW wind farm with 2 MW turbines.

Figure 2.3 ■ **Materials needed to develop a 50 MW wind farm (tonnes)**



Source: Vestas, 2015

[4] The IRENA Project Navigator can be accessed on www.irena.org/navigator

Table 2.3 shows the distribution of the materials needed along the main components of a wind farm. It covers the labour, materials, equipment and information required for each segment of the value chain. Almost 23,000 tonnes of concrete are needed for the foundations, and nearly 6,000 tonnes of steel and iron go into the turbines and the foundations, constituting the bulk of the material needed. More than 360 tonnes of fiberglass go into the turbines and almost 700 tonnes of polymers are needed for the turbines and cables. While not very significant in terms of weight (low density), these materials remain essential for the production of components locally. The procurement of intermediary products involves the identification of specifications of equipment required, assessment of the local availability of intermediary products and procurement of intermediary products. Some of these tasks overlap with other industries, as most materials are not specific to the wind industry. The human resources and equipment needed for these activities are accounted for in the equipment manufacturing and project installation phases.

Table 2.3 **Distribution of the materials needed to develop a 50 MW wind farm (tonnes), by component**

MATERIAL	Turbines	Foundations	Cables	Site switch-gears and transfomers
Concrete	–	22,836	–	–
Steel and iron	4,607	1,228	–	25
Fiberglass	368	–	1	1
Polymer materials	325	1	355	–
Electronics/electrics	46	–	–	–
Copper and alloys	32	1	41	13
Oil and coolant	18	–	–	19
Aluminium and alloys	9	–	159	–

Source: Vestas, 2015

2.3.1 Identification of specifications

Materials used for the manufacturing and installation of wind components are determined by taking into account such factors as resistance to corrosion, strength of material and weight and product specifications. At the same time, when importing products, transportation should be analysed according to site location and project lead time. This activity calls for industrial/mechanical/materials engineers to carry out assessments and ensure the timely delivery of products, as well as logistics experts to determine the supply process.

2.3.2 Assessment of local availability of materials

An evaluation of the domestic availability of products and raw materials, as well as one for goods to be imported, should be made. To select the most suitable suppliers of products and raw material will entail the services of engineers and procurement officers who are able to determine what can be found locally and what should be imported. Once the requirements and specifications have been identified, the potential procurement barriers should be identified, such as regulatory or logistical issues or possible restrictions to imports and local monopolies.

2.4. Manufacturing

At the project development stage, it is crucial to establish whether or not to procure components that can be manufactured domestically or to import them from foreign suppliers. Turbine manufacturers are mostly concentrated in China, Denmark, France, Germany, India, Japan, Spain and the United States, while components are available from many countries.

An increasing number of manufacturers of wind technology are located in Brazil, with South Korea emerging as a producer. Blade manufacturing has shifted from Europe to North America, South and East Asia, and, most recently, to Latin America to be closer to new markets (BNEF, 2016). Most European and American manufacturers have set up wind turbine factories in key markets such as Brazil, China, Europe and the United States. One example is Vestas of Denmark, which produces most turbine components, with the exception of the gearbox and the bearings that are manufactured by specialised suppliers. In some instances, the manufacturer will produce the generator or have a production line for blades, although in others these will be available from specialised suppliers, depending on location and volume demand. The towers are provided by third parties in most cases (*i.e.* a local specialist that supplies towers to different developers.

Chinese manufacturers mainly produce components within China and, in some cases, export them. In spite of the cost of transport, they remain competitive due to their low manufacturing costs. Nevertheless, some principal Chinese manufacturers are considering a shift of some activities overseas.

The main components of a wind turbine that decision makers may consider manufacturing domestically are the nacelle (along with its subcomponents), the blades, the tower and the monitoring and control system.

- From a project developer's viewpoint, the decision is mostly influenced by the cost of technology (*i.e.* local versus imported), the availability of maintenance services and warranties, and the presence of domestic policies, such as import taxes and local content requirements that support the development of local manufacturing. Such policies are established by governments that seek to maximise value creation specifically from the deployment of wind energy. In such cases, there may be a trade-off between achieving lower costs for electricity generation and the creation of jobs and income. The objective of the policy design, therefore, needs to be clear from the project's early stages.

- From the manufacturing company's perspective, the decision is made at the strategic level on whether to establish a facility in a particular country, or whether to limit the business to the assembly of parts that are imported from neighbouring countries. This depends on several factors, such as the potential demand for wind components (based on renewable energy policy), legal and regulatory framework, current market competition, availability of human capital and financing, incentives to install national equipment and components, access to intermediary products and raw materials and highly specialised main sub-components (*e.g.* gearboxes). Highly specialised parts that are easy to transport are usually produced in centralised facilities and the manufacturers partner with suppliers, based on specifications and standards to maintain quality control.

Decisions concerning the local manufacturing of wind components are mainly driven by the expected local/regional demand for wind energy and will depend on: 1) the existence of government policies incentivising local value creation; 2) the availability of raw materials and presence of related domestic industries; and 3) the high costs and logistical challenges related to transporting bulky equipment.

Incentivising local value creation. Wind turbines, including their installation, are the main cost components in developing wind projects. The turbines account for between 64% and 84% of an onshore wind project's total installed costs (IRENA, 2016c), offering considerable potential for local employment. In 2015, the total investment per MW installed was between USD 1 million and USD 1.3 million, of which USD 650,000 to USD 1,110,000 constituted the cost of the wind turbine. The variation depends on the market power of the project developer, brand of turbine and performance requirements that include resource availability and temperature of the location (*e.g.* whether or not de-icing systems should be installed). Many countries, therefore, see value in locally manufacturing components and equipment. Table 2.4 shows the cost breakdown of a wind turbine and it identifies the components with large potential for value creation (*e.g.* tower, rotor blades and gearbox). The cost, relating to transport, is another advantage of locally manufactured blades and towers.

Table 2.4 **Investment breakdown of wind turbine manufacturing and assembling**[5]

ONSHORE WIND TURBIN COST BREAKDOWN	
COMPONENT	% OF TOTAL INVESTMENT OF WIND FARM
Wind turbine	64 - 85
Tower	16 - 18
Rotor blades	13 - 15
Rotor hubs	0.8 - 0.9
Rotor bearings	0.7 - 0.8
Main shaft	1.2 - 1.3
Main frames	1.7 - 1.9
Gearbox	7.8 - 9.7
Generator	2.1 - 2.3
Yaw system	0.76 - 0.84
Pitch system	1.6 - 1.8
Power converter	3.0 - 3.4
Transformer	2.2 - 2.4
Break system	0.8 - 0.9
Nacelle housing	0.8 - 0.9
Others	7.7 - 8.5

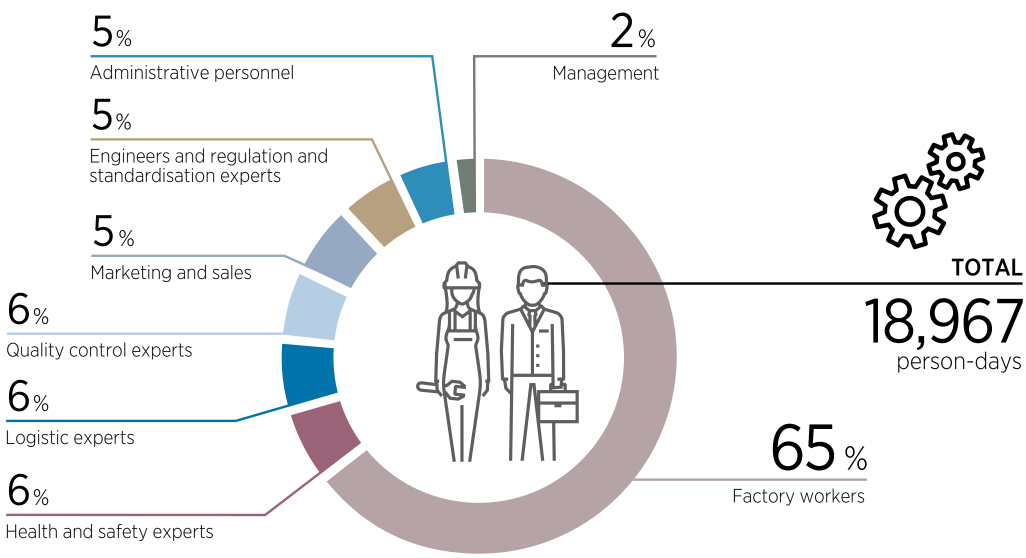
Manufacturing the main components of 50 MW wind farm requires 19,000 person-days. The nacelle, along with its subcomponents, is the part that needs the most work (almost half of the total). The blades and tower each require another 24 percent of the total person-day requirements (see Table 2.5). Much of the labour and skill requirements to produce the main components is low to medium skill jobs. Indeed, 66 percent of the labour required (12,500 person-days) to manufacture turbines is factory labour (see Figure 2.4), with medium to low skills related to wind energy. This may constitute a valuable proposition for governments to offer incentives for local manufacturing. The production of the technologically advanced subcomponents, such as the gearbox, the generator and the electronics requires highly specialised skills, which may not always be easy to source locally. (Figure 2.4) shows the distribution of human resources required to manufacture the main components of a 50 MW wind farm by occupation.

[5] Average of five wind turbine manufacturers selling prices for large scale projects (Germany, Spain, Denmark, the United States and China)

Table 2.5 **Human resources required to manufacture the main components of 50 MW wind farm (person-days) and breakdown by main component**

TYPE OF HUMAN RESOURCES	Nacelle	Blades	Tower	Monitor and control system	Total by occupation
Factory workers	5,890	3,400	2,850	300	**12,440**
Health and safety experts	620	125	300	30	**1,075**
Logistic experts	620	125	300	15	**1,060**
Quality control experts	620	125	300	15	**1,060**
Marketing and sales personnel	480	290	230	45	**1,045**
Industrial engineers	480	277	232	15	**1,004**
Administrative personnel	480	113	230	45	**868**
Management	185	110	90	–	**385**
Telecommunication and computer engineers	–	–	–	15	**15**
Regulation and standardisation experts	–	–	–	15	**15**
Total (as %)	**9,375** (49 %)	**4,565** (24 %)	**4,532** (24 %)	**495** (3 %)	**18,967**

Figure 2.4 **Distribution of human resources required to manufacture the main components of a 50 MW wind farm, by occupation**



Although building a domestic manufacturing capacity for wind turbines has the potential to create employment and income, this phase is very capital-intensive. Moreover, in some countries where wind energy growth was slower than anticipated, capacity may have exceeded demand. In 2014, for example, global demand for wind turbines was estimated at less than 47 GW while manufacturing capacity exceeded 71 GW (Navigant Research, 2014). Some manufacturers in China, the United States and Europe were running below capacity and struggling for survival, leading them to consider moving factories overseas where wind development was picking up at a faster rate (AEE, 2014). Value creation from domestic manufacturing therefore requires the existence of a long-term market with growing demand for wind energy, which relies on support for locally produced equipment, access to finance and skills, competitiveness in the regional and global market and access to subcomponents (some highly specialised) and raw materials.

Availability of raw materials and industries. Maximising value creation from the development of a domestic wind industry relies on leveraging existing capacities used in other industries, such as aeronautics and construction, that can provide expertise, raw materials and intermediary products such as steel, concrete, aluminum, copper, fiberglass and glass-reinforced plastic. Table 2.6 shows the quantities of materials needed to manufacture the main components of a 2 MW turbine.

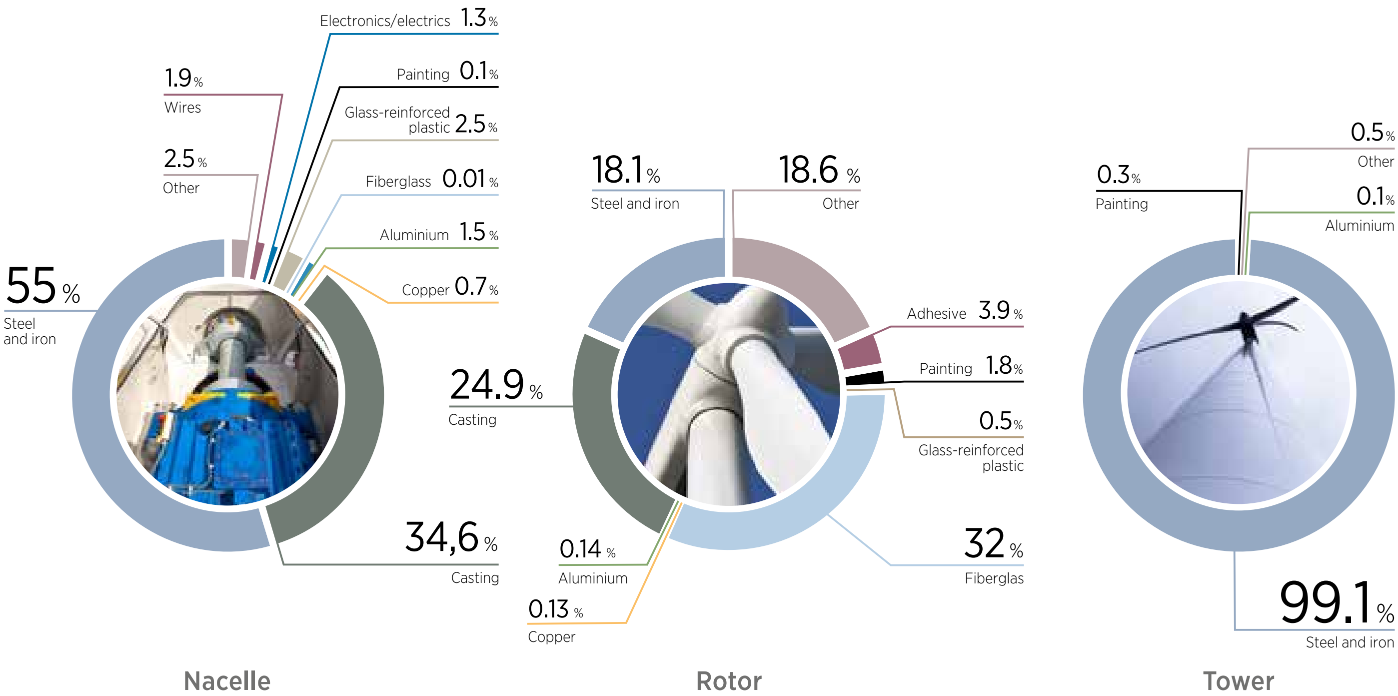
Table 2.6 **Materials needed to manufacture the main components of a 2 MW wind turbine (kilograms)**

Component	Nacelle			Rotor			Tower	Total
MATERIAL	Gearbox	Frame	Other	Blades	Hub	Other		
Steel and iron	8,159	2,963	26,221	898	–	5,992	188,179	**232,412**
Casting	8,008	10,900	4,730	–	8,360	1,086	–	**33,084**
Fiberglass	–	–	10	12,152	–	–	–	**12,162**
Glass-reinforced plastic	3	–	1,713	–	–	186	–	**1,902**
Painting	38	1	36	682	–	–	580	**1,336**
Aluminium	3	54	978	–	–	50	237	**1,322**
Wires	–	–	1,280	–	–	–	–	**1,280**
Electronics/ electrics	192	–	713	–	–	–	–	**905**
Copper	–	–	522	53	–	2	–	**577**
Adhesive	–	–	–	1,475	–	–	–	**1,475**

Source: Gamesa, 2013

In terms of weight composition of each of the main components, the nacelle, including the gearbox and frame, is mostly made of steel and iron and casting material (around 56% and 35% of total weight respectively). The rotor including the blades is mostly composed of fiberglass, casting material, and steel and iron (almost 40%, 30% and 22% of total weight respectively). As for the tower, it is mostly made of steel and iron (see Figure 2.5).

Figure 2.5 **Composition of the main components of a 2 MW turbine**



With regard to **equipment** and in addition to heavily specialised manufacturing hardware, manufacturing the main components of wind turbines requires specialised equipment (see Table 2.7). It also requires welding, lifting and painting machines that are used in other industries, such as construction or the aeronautics industry

Table 2.7 **Equipment needed to manufacture wind turbines**

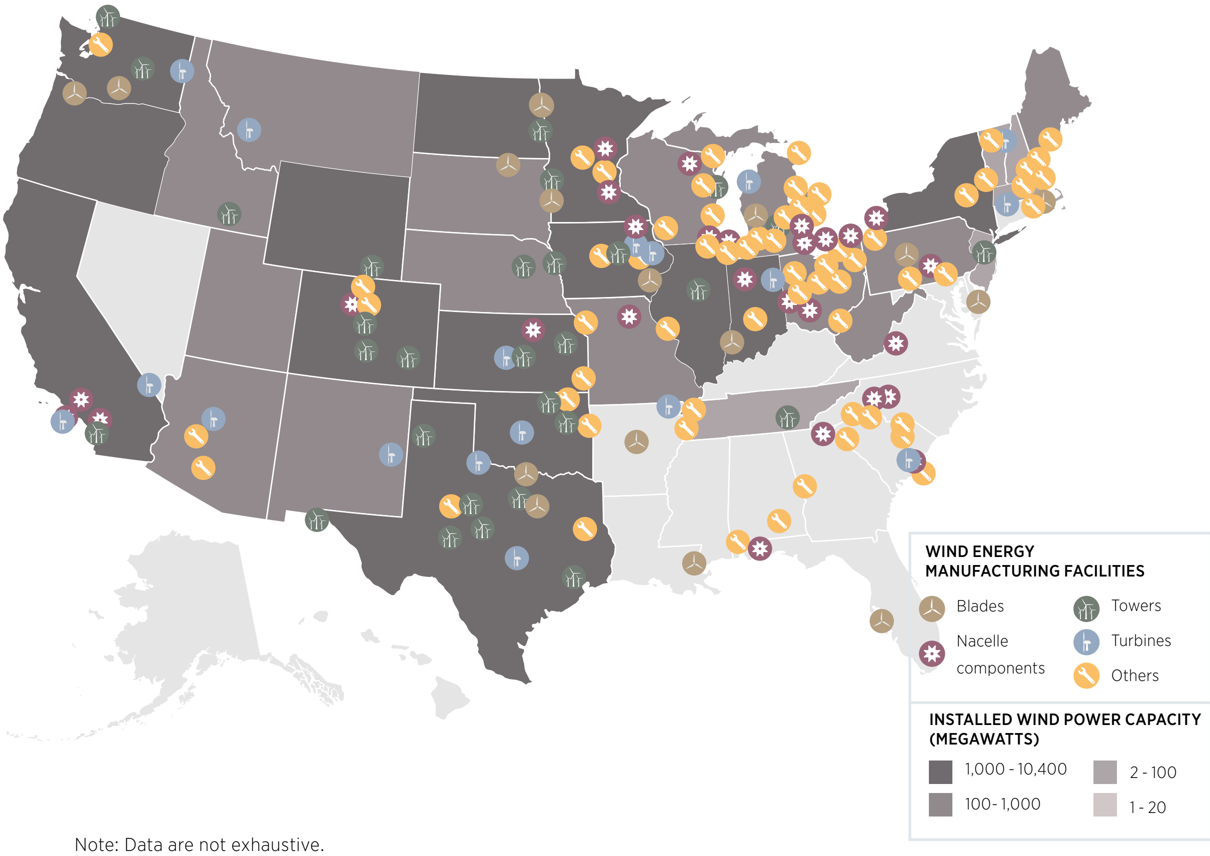
Nacelle	Blade	Tower
• Lifting equipment • Welding equipment • Shot peening machines • Polishing equipment • Automated Paint Machines • Testing dock	• Vacuum bag moulding machine • Resin transfer moulding – LITE machine • Vacuum infusion moulding machine • Open moulding (hand lay-up, spray-up) machine • Liquid moulding composite machine • In mould coating (IMC) • Bonding and assembly • Composite tooling manufacture • Robotic routing and water jet • Automated paint machines • Painted or gel-coated surface finishers	• Heavy cranes • Rolling machine • Welding machines (different technologies depending on process) • Shot peening machines • Material handling equipment • Automated Paint Machines • Inspection equipment (NDT)

Logistics. One of the biggest challenges facing the industry is transporting bulky parts, sometimes over long distances. Issues faced can include traffic congestion, road damage, the need for complex coordination and high costs. A single turbine can have blades 80 meters long weighing 33 tonnes each; it can require up to eight truckloads to transport it by land (one for the nacelle, one for the hub, three for the blades and three for the tower sections). For instance, one 150 MW wind farm in the United States required 689 truckloads, 140 railcars and 8 vessels (CN, 2009). Transport costs increase with the size of the turbines and the wind farm as well as with the distance travelled (see Section 2.5).

To reduce these costs, large turbine manufacturers are shifting parts of their supply chains to markets with high expected demand, such as Latin America. Domestic manufacturers in new markets produce bulky parts such as blades and towers (leveraging local steel and fiberglass industries if existent), following specifications and standards imposed by the main manufacturing company. The manufacturer generally produces the generator, gearbox and bearings, all of which require specialised knowledge.

Figure 2.6 illustrates the distribution of wind turbine components in the Unites States, and shows the installed wind capacity of each state. Clearly, the production of towers and blades goes hand in hand with installed capacity in order to minimise transport. Furthermore, the concentration of nacelle component production facilities demonstrates the clustering of companies that could be part of the same supply chain. Other parts and components are more dispersed in the country, including areas with no wind capacity, which would suggest that they may be parts that relate to other industries such as steel, cables or electronic components.

Figure 2.6 **Current location of wind energy equipment in the United States**



Note: Data are not exhaustive.
Source: U.S. Department of Energy , 2013

The domestic manufacturing of key wind components, including nacelles, blades, towers and monitoring and control systems requires specialised human resources, manufacturing equipment and raw materials. This section provides a description of the manufacturing process and requirements.

2.4.1 Nacelle manufacturing and assembly

The nacelle is the structure that is located on the top of the tower, connected to the rotor that contains the power generation unit. It can be over 15 meters long, and weigh up to 300 tonnes, depending on the manufacturer and power rating. The nacelle includes the gearbox, generator, transformer, brake, axes, hub, hydraulic system, platform, bearings and electric/electronic components (see Box 2.1).

Prior to production, the nacelle undergoes a product development cycle where the functional, aesthetic, and normative requirements of the system are captured so that it is designed accordingly. Parts and components are designed, prototyped, tested, validated, and certified, as necessary (Sharpley, 2015).

Box 2.1 ■ **Sub-components of a nacelle**

- The gear-box (when existent) connects the low-speed shaft to the high-speed shaft and increases the rotational speed from about 30-60 rotations per minute (rpm) to approximately 1,000–1,800 rpm, required by most generators to produce electricity. A gearbox should be robust to manage the frequent changes in torque generated by changes in the wind speed, and it should be well lubricated. It is a costly component. Some wind turbines do not have a gearbox, using a direct drive system connecting directly the rotor and the electromagnet. The electromagnet is moved, generating a changing magnetic field which generates an electric current by means of induction. A heat exchanger ensures that the generator temperature is not too high.
- The generator converts the mechanical energy into electrical energy, at alternating current.
- The yaw drive is the system that keeps the rotor facing the wind, adjusting the position of the nacelle to changes in the wind direction.
- The brake systems stop the rotor in case of emergency. It can be mechanically, electrically or hydraulically activated.
- The controller starts and shuts off the wind turbine. Wind turbines start operating at a set speed, which varies depending on many factors, and is automatically shut down at higher wind speeds due to risk of damage at the cut-out speed.
- The turbine includes a number of sensors which collect and transmit information about the speed and the direction of the wind, power generation, rotor speed, blades' pitch angle, vibration levels, temperature and pressure of the lubricants and other relevant variables. A computer analyses these variables, ensuring that the turbine works properly.
- There is a safety system, able to stop the turbine if it is working in dangerous conditions (*e.g.* high speed) and ensures that the electricity is generated at the proper frequency, voltage and current.
- A wind vane measures the direction of the wind, transmitting this information to the yaw to orient the turbine properly with respect to the wind.
- An anemometer measures the wind speed, and transmits wind speed data to the controller.

Manufacturing and assembling the components involve establishing the specifications for the different components, producing or procuring the sub-components, assembling the power unit (*e.g.* yaw motors, column, hydraulic group and rotational counter to the rear frame), assembling the transformer and the gearbox, integrating the generator, testing the power unit and, after verifying the operation of the nacelle, installing the upper frame. The ancillary elements (*e.g.* hub, anemometer, wind vane and pitch system) are also installed. Tables 2.5, 2.6 and 2.7 summarise, respectively, the human resources, materials and equipment that are needed to produce some of the nacelle's components.

2.4.2 Blades manufacturing

Wind blades are typically made of glass and carbon fibre materials, filled with epoxy resin. Manufacturing the blades includes procuring the material, placing the glass and carbon fibre in a mold for shaping, building the blade structure with a curing process and trimming and polishing the blade. Wind turbine manufacturers may purchase the blades from local partner manufacturers in lieu of importing blades from headquarters.

Materials used to produce blades are evolving, and experiments are being carried out to improve efficiency. The most used material is glass-reinforced plastic, or fiberglass, with a hollow core. Other less used materials are lightweight wood and aluminium. Wooden blades are solid, and have a skin that surrounds a hollow or a light substance, such as plastic foam, honeycomb or balsa wood. The length of blades is approximately 50 meters for a 3 MW power-rated turbine and the weight is approximately 7 tonnes. Transporting blades requires special logistical arrangements and an infrastructure that facilitates local manufacture, especially when there is a domestic steel or fiberglass industry. Tables 2.5, 2.6 and 2.7 summarise, respectively, the human resources, materials and equipment that are needed to produce wind blades (of a 50 MW wind farm in Table 2.5 and of a 2 MW turbine in Table 2.6).

2.4.3 Tower manufacturing and assembly

The nacelle is mounted on top of a high tower that harnesses high speed winds and avoids wind obstacles. Modern towers contain an inside lift, a ladder and several intermediate platforms. Towers convey the loads from the nacelle to the foundation (*i.e.* the transformer at the bottom), and they are typically about 80 to 100 meters tall. The amount of energy produced increases based on the height of the tower, whereby an increase of 20 meters (from the average height of 80 meters in Europe) can result in an extra 5% in energy production. Towers are made of several materials, including lattice, steel (tubular or segmented), concrete or hybrid, depending on factors such as cost, height of the turbine, ease of transportation, assembly and maintenance (Danish Wind Energy Association, 2016).

- Lattice towers, which in the past were the norm, had turbines of less than 1 MW capacity. They are rarely used today, mainly due to their visual impact and higher construction and maintenance costs. Nevertheless, they use approximately 50% less material than a standard steel tower with the same strength. Lattice towers, which can reach a height of above 100 meters, are commonly used on sites that are difficult to access and require simple logistics.
- Steel towers are the most commonly used today. They can rise to about 80 to 100 meters in height and contain from 100 tonnes to 200 tonnes of steel. They have a conical shape with a diameter varying from almost 4.5 meters at the base to 2 meters at the top. They are typically made of three or four tubular steel sections, coated with paints and sealants, and assembled at the wind farm (*i.e.* bolted together). The length of a section can vary from 20 meters to 30 meters, manufactured with steel sheets cut, rolled and welded to form the tower sections. New towers with a length above 100 meters require a base section diameter of over 5 meters, although in many countries, the maximum transportable size by road is less than 4.9 meters.
- Concrete towers are used in countries with a significantly high steel price, such as Brazil, where steel production is almost a monopoly. They are made of several smaller precast pieces,

assembled on site. Concrete towers are easier to transport as they are made of small components that are easier to handle.Concrete towers, however, can weigh more than the nacelle and can be more than 100 meters long.

- Hybrid towers are another solution — used by several manufacturers to reduce their exposure to steel price volatility — and they can be more than 100 meters in length. The bottom part (approximately 60 meters) is built of concrete and the upper part is made of steel. The two halves are coupled by a transition ring. The main drawback, however, is that they are rather complicated to assemble, thus increasing the cost to install.

Regardless of the materials used, towers are normally manufactured in sections that are transported to the site where they are assembled and installed. Towers are not high technology products, and due to the complications in transporting them, they are often outsourced to local manufacturers. In fact, towers have the highest percentage of local content among all major components in the United States, given that domestic content is the strongest for large, transportation-intensive components. Towers have local content of 70% to 80% in the United States, while blades and hubs have between 45% and 65% and generators have less than 15% local content. These numbers, however, do not account for imported manufacturing inputs such as foreign steel and oil that are used in domestic manufacturing (US Department of Energy, 2015). Tables 2.5, 2.6 and 2.7 summarise, respectively, the human resources, materials and equipment that are needed to produce tubular towers (of a 50 MW wind farm in Table 2.5 and of a 2 MW turbine in Table 2.6).

2.4.4 Monitoring and control system manufacturing

Wind blades are typically made of glass and carbon fibre materials, filled with epoxy resin. Manufacturing the blades includes procuring the material, placing the glass and carbon fibre in a mold for shaping, building the blade structure with a curing process and trimming and polishing the blade. Wind turbine manufacturers may purchase the blades from local partner manufacturers in lieu of importing blades from headquarters.

Materials used to produce blades are evolving, and experiments are being carried out to improve efficiency. The most used material is glass-reinforced plastic, or fiberglass, with a hollow core. Other less used materials are lightweight wood and aluminium. Wooden blades are solid, and have a skin that surrounds a hollow or a light substance, such as plastic foam, honeycomb or balsa wood. The length of blades is approximately 50 meters for a 3 MW power-rated turbine and the weight is approximately 7 tonnes. Transporting blades requires special logistical arrangements and an infrastructure that facilitates local manufacture, especially when there is a domestic steel or fiberglass industry. Tables 2.5, 2.6 and 2.7 summarise, respectively, the human resources, materials and equipment that are needed to produce wind blades (of a 50 MW wind farm in Table 2.5 and of a 2 MW turbine in Table 2.6).

2.5 Transport

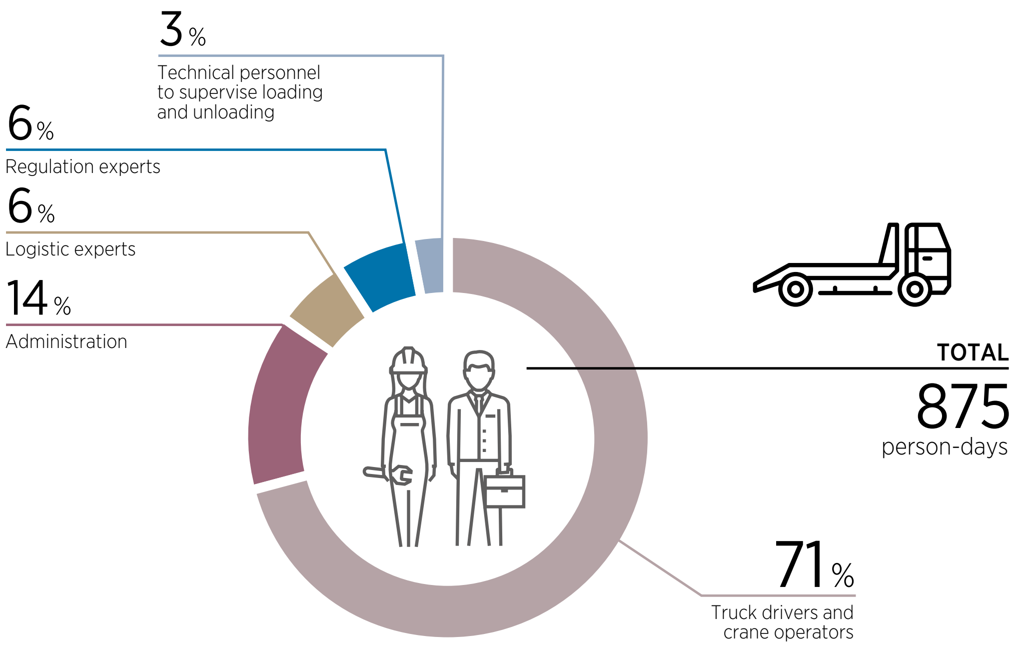
Developments in the material and design of wind turbines now enable the use of longer blades that can be deployed in low-wind sites, raising capacity factors and decreasing the cost of wind energy. Technologies that permit larger wind turbines to be placed on taller towers create opportunities for further cost reductions (NREL, 2014). Together with the increase of the turbine nameplate capacity — in the United States, up by 172% since 1998 to almost 1.9 MW in 2014 — the height of the hub and the rotor diameter have significantly increased by 48% and 108% since 1998 to 82.7 meters and 99.4 meters, respectively, in 2014 (US Department of Energy, 2015).

The transportation of blades that are 53 meters long or more, however, can form a construction bottleneck. Moreover, other components of the wind turbine are also very large, especially the towers and nacelles, which can be moved from the factories to the wind farm site by truck or railway, although due to their size and weight, long distance transport is complex and costly. of a 50 MW wind farm by truck over a distance of 300 miles (480 km) can reach up to USD 750,000. Moreover, special transport permits are required to ensure that traffic is safe and not affected by such cumbersome transport. There may be restrictions where bridges are unable to withstand such heavy weights, tunnels that are of lower height than required, or roads that have sharp bends. As such, existing infrastructures sometimes constrain the development of the wind energy sector by being unable to support the transportation of large-sized equipment.

The rationale for establishing manufacturing facilities at strategic locations near project sites is, therefore, an appealing alternative. Another option is rail transportation, especially in countries with open terrain and where the rail tracks run straight over long distances. It may be unsuitable, however, if there are many curves, tunnels and bridges. When the piece has to be transported by vessel, an important aspect to consider is the possibility to transfer the piece from the truck to the vessel. This can be difficult if the harbour has limited space, or if the piece is too heavy.

It takes about 875 person-days to transport the components of a 50 MW wind farm 300 miles by truck, most of which can be sourced domestically. The distribution of **human resources** needed is shown in Figure 2.7. Almost 70 percent of the labour needed consists of truck drivers and crane operators, who may require certified skills in some countries, but can generally be hired locally.

Figure 2.7 **Distribution of human resources required to transport the components of a 50 MW wind farm (25 x 2 MW turbines), by occupation**



Special **equipment** needed includes high-capacity trucks and trailers that are specifically designed for transporting blades. Freight rail can be used if the land is flat and tunnels, bridges and sharp curves can be avoided. Moreover, vessels can be used if the transport is carried out by sea, with cranes needed to lift the equipment onto the truck or the vessel. The installation phase can start in parallel with the transport of equipment.

2.6 Installation and grid connection

It takes approximately 12 to 20 months to install and connect a wind farm, including the construction of infrastructure to permit physical access to the site to facilitate the transport of equipment and components and wind farm construction. During this phase, the land is prepared, turbine foundations are built, key wind turbine components (*i.e.* nacelle, rotor, blades and tower) are assembled and turbines are mounted. In economic terms, the laying of the foundation is critical since it represents between 6% and 16% of total cost, depending on the soil characteristics and the weight of the wind turbine, among other aspects.

In some cases, the wind turbine manufacturer is able to offer complete installation within a turnkey project. In others, the project developer carries out these activities by subcontracting the different works, buying the equipment, and coordinating with the various contractors.

Installing and connecting a wind turbine takes about 34,500 person-days. The most labour-intensive activity is site preparation and civil works, which accounts for about half of the total (16,600 person-days). This activity is always sourced domestically, creating many opportunities for employment, especially for low- to medium-skilled workers. Assembling equipment account for 30% of the total labour needed, followed by cabling and grid connection (19% of the total) and commissioning (4%) (see Table 2.8). More than three-quarters of the person-days require construction workers and technical personnel, most of whom are available domestically. The second most prevalent occupations for the phase are crane operators and truck drivers, which account for about 10 percent of the total labour force (see Figure 2.8).

Site preparation and civil works

Assembling equipment

Cabling and grid connection

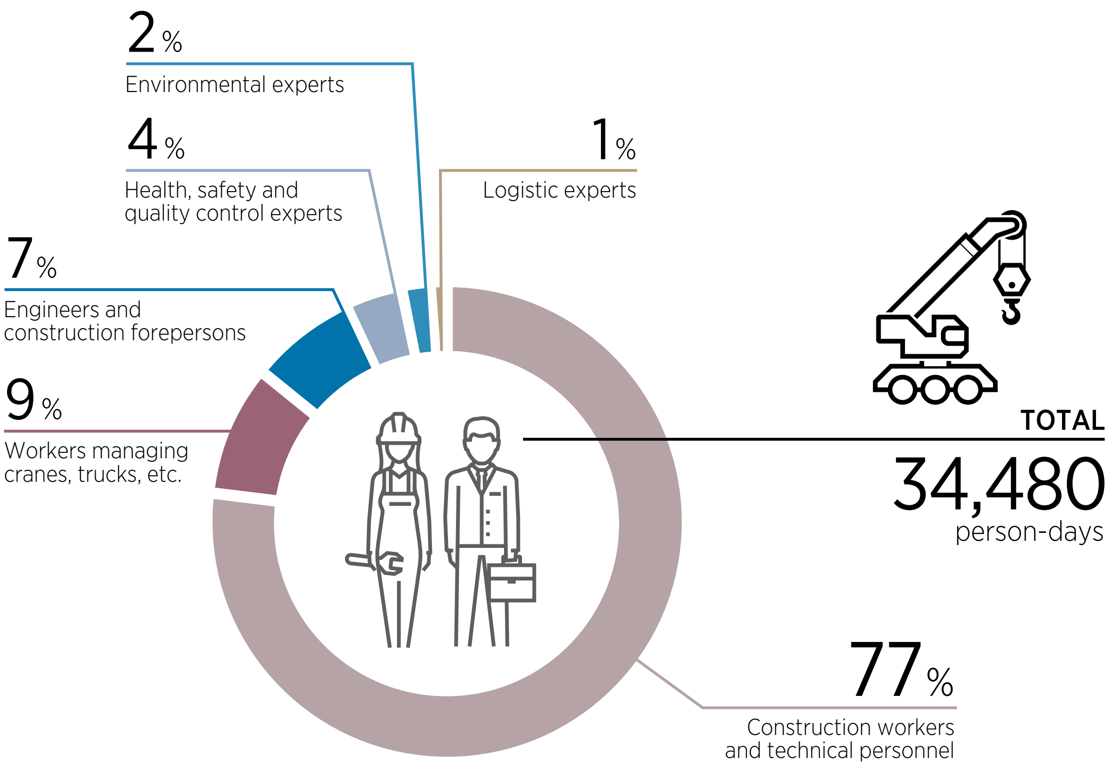
Commissioning

Table 2.8 **Human resources required to install and connect a 50 MW wind farm (person-days) and breakdown by activity**

TYPE OF HUMAN RESOURCES	Site preparation and civil works	Assembling equipment	Cabling and grid connection	Commissioning	Total by occupation
Construction workers and technical personnel	13,600	6,000	6,000	1,000	**26,600**
Professionals managing cranes, trucks, etc.	-	3,000	-	-	**3,000**
Engineers and construction foremen	1,320	600	-	-	**1,920**
Health and safety experts	720	600	100	100	**1,520**
Environmental experts	720	-	-	-	**720**
Electrical and mechanical engineers		-	180	200	**380**
Logistics experts	240	-			**240**
Quality control experts	–	-	100	-	**100**
Total (as %)	**16,600** (48 %)	**10,200** (30 %)	**6,380** (19 %)	**1,300** (4 %)	34,480

Materials and equipment needed for the installation phase are available in most countries. Materials include concrete (for the foundation), steel and iron, polymers, aluminium and alloys and copper (for cables). Highly porous soil requires a deeper foundation, which increases the amount of concrete needed. Equipment includes loaders, cranes, high-tonnage trucks and excavators as well as supervisory control and data acquisition (SCADA) equipment, electrical and electronic instrumentation and control systems used for grid connection

Figure 2.8 **Distribution of human resources required to install and connect a 50 MW wind farm, by occupation**



2.6.1 Site preparation and civil works

This activity relates to the removal of existing vegetation, clearing the land, flattening the surface in order to lay the foundation and install the turbines. Civil works include building the necessary infrastructure (*e.g.* roads and routes) to enable transportation of the equipment and components to the site; building of a logistics area to store equipment, components and materials during construction; building of warehouses for stocking components and materials for protection against weather conditions and theft, and workshops to carry out repairs; and restoring access roads, control of erosion and cleaning of the site to fulfil environmental requirements.

In particular, the preparation of the foundation should be according to soil characteristics. The foundation should be made deeper in soils that easily deform, such as vegetable soil and unconsolidated sand, unless the soil is resistant such as stone, gravel or consolidated soil. The concrete should be waterproof and be able to withstand thermal shock, as well as be mixed according to soil characteristics.

Since the installation activity is common for the construction of any site, a large percentage of the requirements are available in most countries.

An added factor is the potential to generate employment, skilled and unskilled. Table 2.8 shows the human resource requirements. Equipment includes heavy machinery (*e.g.* loaders, high-tonnage trucks, excavators) and personal protection equipment, available in all countries. Raw materials include quantities of asphalt and petrol, depending on the site, as well as approximately 600 tonnes of concrete per MW installed. Soil with high grades of porosity, in which density is lower or consistency requires a higher surface of foundation, will require more concrete.

2.6.2 Assembling equipment

Most of the wind turbine components are typically assembled in the factory at the manufacturing phase, with the exception of the rotor, blades and tower, which are assembled at the site during the installation phase. Assembly of the structure can take between 12 and 16 months and involves putting up the tower one section at a time with a crane; attaching the nacelle, rotor hub and blades; and testing the turbine for functionality. Cranes and trucks are part of the required equipment as are screws, adhesives, auxiliary toolboxes and personal protection apparatus. Table 2.8 shows the human resource requirements.

2.6.3 Cabling and grid connection

Various licences are required to connect to the grid and to enable the discharge of electricity, previously described in the project planning phase. Given that this process can be time consuming, the licence application process should begin before the facility has been developed. This is followed by developing the electrical and telecommunication infrastructure to connect the equipment and the wind farm to the high- or low-voltage grid and to commission the plant.

The cabling and grid connection activity involves installing electrical and electronic instrumentation and control systems; pulling cables to connect the wind turbines together and the wind farm to the grid; setting up the facilities and installing the equipment for the electrical substation and protection systems; and installing the telecommunication infrastructure. With regard to the cables, there are three types in the wind industry, namely those in the nacelle for signals and power, those for lightning protection and those from the transformer to the grid. The cables in the nacelle carry low-voltage control signals, data and communication signals. These should have flexibility at low temperatures and be oil resistant. Other cables transport electricity from the generator, inside the tower, down to the switch gear at the tower base. Those that connect to the grid should be of medium voltage (15 to 45 kilovolts) for underground distribution.

The cable industry is characterised by economies of scale in the procurement of raw materials (mostly copper and plastic) and in the manufacturing process. Moreover, as the transport costs are not very significant, the cabling industry is generally controlled by a low number of players: it is a global sector, with local distributions and installation agents. Therefore, although cabling and grid connection could benefit from the presence of a cabling industry, the bulk of value created is in connecting cables rather than producing them. This activity can benefit from the experience acquired locally in connecting power plants to the grid, including those that run on fossils and most human resources required can be found locally. Table 2.8 shows the human resource requirements.

The equipment that is essential for cable and grid connection includes control systems, such as the supervisory control and data acquisition (SCADA) and electrical and electronic instrumentation systems. Also essential are transport and personal safety equipment. Raw materials include copper for the cables, asphalt, concrete and petrol for building facilities.

2.6.4 Commissioning

Commissioning relates to putting into operation the wind turbines and the power station. This also involves mechanical testing to ensure compliance with manufacturer specifications, as well as electrical and communication systems checking. Once the necessary licences have been obtained and the facility has been approved by the grid operator, it can be connected to the grid for operation. Table 2.8 summarises the required human resources for this activity.

2.7 Operation and maintenance

The operation and maintenance (O&M) covers the expected lifetime of about 25 years. Modern wind farms are automated and controlled by SCADA. Their operation is normally monitored remotely, by operators who reset the systems after line or grid outages.

The O&M costs over the life of the wind farm depend mainly on the labour cost, design of the turbines, distance to the wind farm site and weather conditions. Preventive and corrective maintenance represents almost half of the total O&M costs of the companies surveyed for this report (see Table 2.9), followed by management and administration (about 20 percent of the total cost). It is usually undertaken by the turbine manufacturer as part of an O&M agreement tied to the sale of the turbine or subcontracted to engineering companies. Although O&M itself is generally not handled locally, a large share of O&M costs is spent domestically (such as insurance and land rental).

Table 2.9 **Annual operation and maintenance costs of a typical wind farm (USD/MW) and breakdown by cost component**

COST COMPONENT	Annual cost (USD/MW)	Percent of total
Turbine maintenance	20,100 – 24,500	**47.6 – 49.3**
Management and administration	8,100 – 9,900	**19.2 – 19.9**
Insurances	7,500 – 9,800	**18.9 – 18.4**
Land rental	4,000 – 6,000	**11.7 – 9.8**
Electrical installation maintenance	1,100 – 1,300	**2.6**
Total	**40,800 – 51,500**	**100**

Source: Based on data provided by European renewable energy project developers with wind energy installed capacity in China, Italy, Portugal, Spain and the United States.

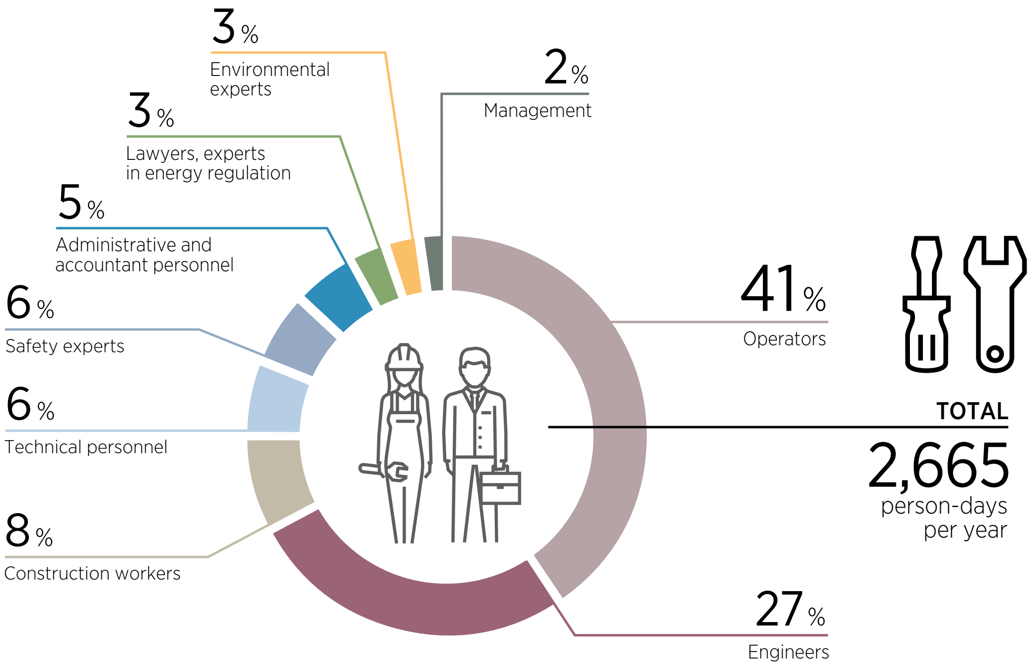
Operating and maintaining a 50 MW wind farm requires about 2,665 person-days per year. Of these, 66 percent are for operations (almost 1,800 person-days per year) and 34 percent for maintenance (almost 900 person-days per year) (see Table 2.10).

Table 2.10 **Human resources required to operate and maintain a 50 MW wind farm (person-days per year)**

TYPE OF HUMAN RESOURCES	Operation	Maintenance	Total by occupation
Operators	1,100	–	**1,100**
Telecommunication engineers	220	150	**370**
Industrial engineers	125	225	**350**
Construction workers	–	220	**220**
Technical personnel	–	150	**150**
Safety experts	–	150	**150**
Administrative and accountant personnel	125	–	**125**
Lawyers, experts in energy regulation	80	–	**80**
Environmental experts	80	–	**80**
Management	40	–	**40**
Total (as %)	**1,770** (66 %)	**895** (34 %)	**2,665**

A skilled workforce with solid knowledge of wind farm operations makes up the majority of the human resources needed. Out of the almost 1,800 person-days per year required for operation, more than 1,000 are high-skilled operators, equivalent to more than 40 percent of the total O&M labour force. Highly skilled industrial and telecommunication engineers together account for another 720 person-days per year, around 27% of total O&M labour requirements (see Figure 2.9).

Figure 2.9 **Distribution of human resources required to operate and maintain a 50 MW wind farm, by occupation**



2.7.1 Operation

The operation of a wind farm is normally undertaken by automated systems and remote operators who are responsible for resetting the systems in the event of line or grid outages. Modern wind farms are automatically controlled by a supervisory control and data acquisition (SCADA) system or telemetry, and they can reconfigure themselves to work at optimum efficiency. SCADA systems gather real time data from the wind farm in order to control the operation of equipment while telemetry is a complementary system that measures and analyses data. Both systems are able to measure variables such as wind direction, wind speed, vibrations, and temperature of components in the nacelle, providing the operator detailed information on the state of the wind turbine and the amount of electricity it is producing.

The technical personnel in charge of operating the wind farm are located in offices and they remotely monitor and control the wind farm and its equipment. The operation of a wind farm, however, can be subcontracted to a third party, with activities entailing the monitoring of real-time energy production to ensure that it is optimal; managing the procedures for selling the electricity produced and settling the sales (*i.e.* energy metering verification, calculation of revenue, issuance of invoices and follow up on payments); fulfilling legal and administrative tasks (*e.g.* licences, permits, taxes, other payments) and performing security surveillance to avoid theft. This activity is labour intensive and requires a specific set of skills. Table 2.10 summarises the human resources needed.

2.7.2 Maintenance

A wind project is normally maintained by the original equipment manufacturer during the warranty period, with the option for continued service. Maintenance activities include corrective actions as a result of abnormal operation of equipment and components, and preventive actions to ensure the proper working conditions and level of performance of the wind farm. These activities are usually carried out by the manufacturer or by subcontractors specialised in each component. Additionally, some periodic visual inspections are carried out by non-specialised local personnel.

The most common maintenance tasks include conducting on-site visual supervision of the wind turbine and auxiliary facilities; regular visits to the wind turbine to check its mechanical and electrical state; periodical oil changes and other mechanical activities, such as fluid level checks; greasing; bolt torque checks; filter changes; inspection of blades and brake pads; inspection of electrical components such as cable connections; fuse checks; voltage level checks; battery inspections; periodic in-depth revisions of the main wind turbine components; monitoring and controlling equipment and electrical and telecommunication infrastructure. Furthermore, it includes performing preventive activities in order to detect potential failures based on data recorded; performing corrective maintenance of wind turbines and other equipment or components if suboptimal behaviour or component failure is detected; and replacing components as necessary. Maintenance is typically one of the key aspects that must be done at the local level to reduce costs.

2.8 Decommissioning

Wind farms are decommissioned at the end of their operational life cycle. Wind turbines and other components are dismantled and recycled or disposed of, and foundations are taken apart. Once a wind farm is decommissioned, the site is restored to its original condition, according to commitments agreed with the landowner, municipality or government. It is best practice to draw up a decommission plan during the project planning phase, which also serves as a prerequisite to obtain the necessary licences.

The dismantled wind turbine can be sold to other project developers, if it has not reached the end of its useful life. The wind farm can also be repowered, taking advantage of good wind energy resource locations and benefitting from new technical advances. Repowering requires modifying or replacing the turbine to improve efficiency and capacity. While the process is yet to be substantially developed, some countries (*e.g.* Germany) are attempting to promote it through legislation. It is envisaged that many installations will be repowered in the future, given that current sites are a key asset.

Decommissioning a wind farm involves planning the activity, dismantling the project, recycling/disposing of the equipment and clearing the site. These activities can usually be handled locally, given that the necessary skills and equipment are usually available.

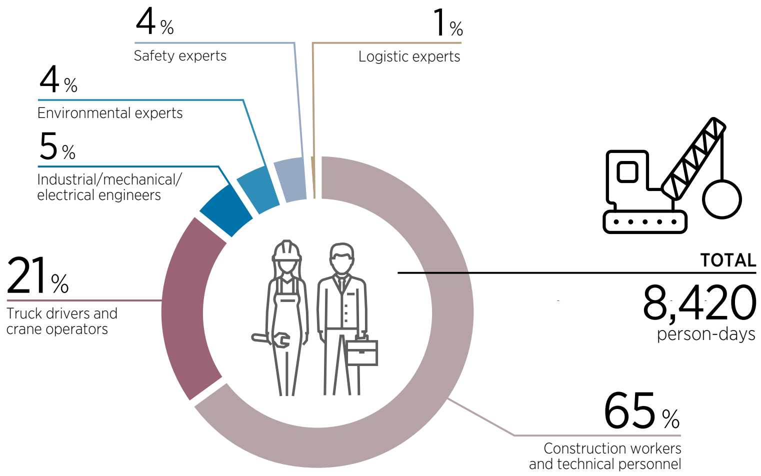
It takes about 8,420 person-days to decommission a 50 MW wind farm. The most labour-intensive activity is dismantling the equipment and it requires 6,220 person-days (77 percent of the total). Clearing the site and disposing of equipment requires 1,220 and 900 person-days respectively (see Table 2.11)

Table 2.11 **Human resources required to decommission a 50 MW wind farm (person-days) and breakdown by activity**

TYPE OF HUMAN RESOURCES	Planning	Dismantling	Disposing of equipment	Clearing the site	Total by occupation
Construction workers and technical personnel	-	3,700	800	1,000	**5,500**
Truck drivers and crane operators	-	1,800	-	-	**1,800**
Industrial/mechanical/ electrical engineers	30	360	-	40	**430**
Environmental experts	25	180	40	90	**335**
Safety experts		180	40	90	**310**
Logistic experts	25	-	20		**45**
Total (as %)	**80** (1%)	**6,220** (74%)	**900** (11%)	**1,220** (14%)	**8,420**

Technical and construction workers perform 65 percent of all decommissioning work. The second most-needed occupations in this phase are truck drivers and crane operators, who account for 20 percent of the total work (see Figure 2.10).

Figure 2.10 **Distribution of human resources required to decommission a 50 MW wind farm, by occupation**



The **equipment** needed is the same as that required for construction and installation – all of it commonly available in countries with functioning construction sectors.

Planning the decommissioning

Dismantling the project

Disposing/recycling the equipment

Clearing the site

2.8.1 Planning the decommissioning

During the project planning activity, the project developer should formulate a decommissioning plan, with an allocation of financial resources. Some regulatory frameworks require that a decommissioning plan is necessary to obtain an installation licence for a wind farm. Obligations that are relevant to this activity are established with the land lender and authorities.

2.8.2 Dismantling the plant

The elements of the wind farm are transported to be recycled or disposed of. Grid connection infrastructure and the substation can be re-used for other power units. The tasks to take apart a wind farm include dismantling the wind turbines (*i.e.* including the nacelle equipment), removing waste oil, dismounting the nacelle from the tower with cranes and disassembling the remaining components; bringing down the tower; dismantling the cabling system, including electronic components (*e.g.* buried cables require digging ditches after the metallic structure is demolished); transporting cables for disposal, recycling or reuse; and dismantling the warehouse and workshops.

Equipment and other resources needed are similar to those for the installation of the wind farm. These are heavy machinery, cranes, auxiliary tools and personal protection equipment for hazardous activities.

2.8.3 Disposing/recycling the equipment

Components with recycling potential are transported to specific sites. Recycling is only viable for metal components, and some of these are not economical to recycle due to the high cost of the process. Components not recycled should be disposed of in a landfill, including wasted lubricants and oil or electronic components that have been treated prior to disposal and transportation (*e.g.* blades, parts of the nacelle without residual value and power cables). This activity will require heavy machinery (*i.e.* loaders), personal protection gear and scrap cutter equipment

2.8.4 Clearing the site

Tasks that relate to site clearance include the restoration of the wind farm location, according to agreements with the landowner, municipality or government. The site should be left in its original state. Materials include plant seeds, wild plants for replanting and vegetable soil, while the relevant equipment includes heavy machinery (*e.g.* loaders, excavators) and personal protection equipment.

3. CASE STUDIES

The potential for value creation from the deployment of wind energy is country-specific and depends on factors that include the country's expected demand for the technology, availability of skills and resources and enabling environment (*e.g.* political stability, access to finance, growth forecasts and governance and transparency). This section analyses the framework of two countries, Denmark and Morocco, with varying characteristics that has enabled value creation from the deployment of wind energy. Both countries were selected based on their respective government's ambitious wind energy objectives that reflect a willingness to promote and develop this industry.

The case studies will provide an overview of the business environment and capacities, energy sector characteristics, renewable energy potential and human resource capabilities in each country. They will also assess the strengths of each country and the opportunities for local value creation along various segments of the wind energy value chain.

3.1 The Case of Denmark

Denmark, one of the world's leading countries in the wind energy sector, is an interesting case for analysing the key enabling factors that have paved the way for the development of its local wind industry along the various segments of the value chain. With 5,242 MW of installed capacity by the end of 2016 (including offshore) (IRENA, 2017d), Denmark has the highest share of wind in the electricity mix, globally. During some windy days, Denmark generates enough electricity to power the whole country's electricity demand. That was the case on the 22th of February 2017 when onshore wind generated 70 GWh of electricity, which is enough to power the equivalent of 7 million average European households (Clean Technica, 2017).

This large deployment is accompanied by the significant development of the Danish wind industry. In 2015, the turnover of the industry stood at USD 13.2 billion (EUR 11.9 billion[6]), with exports equalling USD 7.2 billion (EUR 6.5 billion) (Danish Wind Energy Association, 2016). This wind industry development has resulted in significant economic benefits, including the employment of 31,251 people in 2015 (in onshore and offshore). It has been a driver of competitiveness and technological progress, and in 2010, the sector surpassed 1% of Denmark´s total GDP.

The Danish wind energy sector has become a global leader in the industry with high technological capability and a significant competitive advantage. Some of the most reputable wind energy companies and wind turbine manufacturers are Danish, holding a prominent position on the international platform. Vestas ranks as the global leader of wind energy companies with a 13% market share. Other world-class companies, such as Germany's Siemens Wind Power, are also gaining a foothold in the Danish wind energy market.

This case study discusses the factors that have placed Denmark at the forefront of the wind sector. In particular, it analyses the enabling framework for the development of the sector and the domestic capacities that have been leveraged to establish a local industry.

3.1.1 Enabling policy framework for wind development in Denmark

Political support and the establishment of a stable regulatory framework have promoted the development of the wind industry in Denmark. The Danish government's commitment and support to wind energy, the adoption of policies to support private investment in the sector, funding for research and development, and measures to strengthen the capacities of local companies have been key characteristics that describe Denmark's success.

[6] 1 USD = 0.90 EUR on average in 2015.

Various administrations during the last 30 years have demonstrated a commitment to long-term and transparent plans for renewable energy deployment (IRENA and GWEC, 2013):

- The oil crisis of the 1970s drove Denmark towards the diversification of the energy mix, and wind power was selected as one of the sources. Taxes were imposed in the 1980s on electricity and used to support research and development (R&D) for renewable energy. Several manufacturing facilities were established for turbines with capacities larger than 55 kW. The local market for turbines was supported by a commitment to install 100 MW of wind while, at the same time, the international market began to develop as a result of growing demand in California. Tax incentives in Denmark drove local cooperatives to invest in community-owned wind turbines to meet energy needs with the option to sell excess electricity to the grid. In addition, capital grants as a percentage of the installation costs were provided, and utilities were required to interconnect and purchase power from wind projects at a fair price.
- In the 1990s, the fair price for wind power was set at 85% of the retail electricity rate until the introduction of a fixed feed-in tariff, set at 85% of the utility's production and distribution costs. The policy provided guaranteed interconnection, and municipalities were tasked to find suitable sites for wind farms following provisions for public hearings to ensure public acceptance. Moreover, wind projects received a partial refund on the energy tax and a refund from the Danish carbon tax, which doubled their remunerations during the first five years of operation. The Danish Energy Agency was later established for the implementation of renewable energy policies that supervised planning permissions. By the end of the 1990s, there were approximately 2,100 cooperatives in Denmark, creating the basis for continued popular support for wind and, by 2001, wind turbine cooperatives had installed 86% of turbines in the country.
- At the end of the 1990s, the feed-in tariff was abandoned and renewables were supported through a renewable portfolio standard mechanism with tradable green certificates and remuneration that consisted of the market price with a premium that was capped. Moreover, the new scheme no longer guaranteed interconnection.
- In 2004, Denmark's power supply sector was restructured with the privatisation of power companies, and distribution, transmission and production became independent sectors, each with different frameworks (*i.e.* not-for-profit cooperatives and municipalities for distribution, state-owned company Energinet for transmission and a mix of publicly and privately owned companies for generation).
- In 2009, the main policy support mechanism was a premium of USD 0.046 /kilowatt hour (kWh) (DKK 0.25/kWh[7]) for 22,000 full load hours added to the market price, with an additional USD 0.004/kWh (DKK 0.023/kWh) provided for balancing costs. For offshore wind, the costs of grid connection were financed by the electricity consumers, and special tariffs were defined based on auctions.
- The strong commitment of the government to wind energy was reaffirmed in 2012 when it set a target of fulfilling 60% of the Danish electricity demand with onshore and offshore wind by the end of 2021. Achieving this target requires the expansion of offshore farms, installation of additional onshore capacity and replacement of aging onshore wind turbines with new turbines that are larger and more effective than the old ones.

[7] 1 USD = 5.43 DKK on average in 2009.

- In 2014, onshore wind power received a feed-in premium for the first 24,000 full load hours, depending on the type of turbine, with a ceiling for the sum of the market price and premium. The offshore industry is driven by auctions, with innovative designs tailored to the country's specific context and requirements. The sophisticated designs limit transaction costs for the bidders in terms of permits and site selection while, at the same time, ensure project delivery through stringent compliance rules (IRENA, 2017e).

As for financing, Denmark has been at the forefront of innovative **mechanisms to channel investments from private investors.** For example, new onshore wind turbines are required to be co-financed by private, local investors with the return on investment over the lifetime of the wind farm considered a stable infrastructure investment. Community ownership is key, as local investors possess shares of the wind turbines in their community. Citizens living within 4.5 km of a new onshore wind farm are eligible to buy shares of the project which represents at least 20% of the project costs. Any shares not bought will be proposed to other permanent residents (Cave, 2014). As the sector developed, institutional investors became more prominent, particularly large-scale pension funds. Danish private and public investors are also partly financing new onshore and offshore wind farms on a global basis.

Another driver for the development of the industry is the development of local capabilities through **investment in R&D and supplier development programs.** Intensive innovation and R&D activities have resulted in technology leadership. Moreover, local capabilities have been supported by competitive parameters and supplier requirements focusing on the suppliers' capabilities, quality management, servicing, equipment manufacturing lead time, and optimisation of the supply chain. Denmark has also leveraged on its automotive and aerospace industries to build its wind industry and it has set the standards for structural change and new business models, such as systems solutions to strengthen its supply chains. As the industry develops, manufacturers require more integrated solutions and systems solutions, rather than single components. The industry is therefore supported by collaborative programmes, and suppliers are increasingly joining forces in collaborative networks. There are strong ties between the turbine manufacturers and the so-called "system suppliers" for continuous innovation.

3.1.2 Existing capabilities in wind energy in Denmark

The wind industry is an important growth engine for Denmark. With some of the best wind resources in the world, and supported by a steady enabling policy framework, Denmark has leveraged its capabilities to develop a unique value chain. Onshore wind power is now the cheapest form of electricity in the country. The Danish Energy Agency (Energistyrelsen) estimated that onshore wind power from plants coming online in 2016 cost around USD 0.05 per kWh, which is half the price of coal and natural gas plants. This is a result of extensive domestic experience from established businesses locally, building on the synergies with existing industries, and in the presence of the skills required.

Existing experience from established businesses

With almost 4,000 MW of installed and operational onshore wind projects, the Danish wind industry builds on established skills throughout the whole value chain. Denmark hosts over 500 companies that contribute to wind value chain, including some of the leading global manufacturing companies. The local industry comprises of component suppliers, turbine manufacturers, installation and service providers, energy companies, in addition to consultants and investors. In fact, companies from all segments of the value chain can be found within a radius of only 150 km, mainly in project planning, manufacturing, logistics and research.

- **Project planning.** Denmark has extensive experience in site selection, in wind resource assessments and environmental impact studies. The Technical University of Denmark (Danmarks Tekniske Universitet, DTU) is specialised in wind modelling, specifically creating mesoscale wind maps for use in resource assessment. The Section for Resource Assessment Modelling focuses on meteorological modelling of wind flows over terrain and ocean—for wind resources, site assessment, wind turbine loads, and wind farm operations (DTU Wind Energy, n.d.).
- **Procurement of raw materials and manufacturing.** Denmark only produces some of the raw materials required including cement and iron ore from the Greenland mines. The country imports iron and steel, among other materials. As for manufacturing components, Denmark has developed the world's largest wind turbine industry. Siemens and Vestas lead the production of blades and nacelles in the manufacturing of wind components. Several rotor blade manufacturing facilities have been established, building on the country's capacity for innovation, and the developed partnerships and technological cooperation with international companies and research centers. In addition, some foreign manufacturers have set up shop in Denmark for the production of steel and other wind energy components (see Box 3.1)

Box 3.1 **Global manufacturing companies based in Denmark**

- The NLMK DanSteel A/S, a Danish subsidiary of the largest steelmaker in Russia the NLMK group, started producing steel plates in 2012. With its own harbor and most advanced steel making equipment, DanSteel is one of the leading supplier of steel for wind energy in Northern Europe.
- Siemens Wind Power A/S manufactures wind turbines in Denmark and operates as a subsidiary of Siemens. Heavy investments of more than EUR 50 million have been made in the assembly plant in Brande and in the rotor blade manufacturing facility in Aalborg, employing approximately 7,000 people in Denmark.
- Titan Wind Energy, is a Chinese manufacturer of wind towers for Vestas, has set up a factory strategically located near to port of Esbjerb.

Source: NLMK, n.d.; Siemens AG, 2006; Titan Wind, n.d.

- **Shipping, logistics, and supply chain management** activities play a key role in the export of components. Denmark exported services and products equivalent to EUR 6.5 billion in 2013 (State of Green, 2016). Due to the favourable configuration of the country, Denmark has developed efficient harbors including state-of-the-art heavy duty harbors for manufacturing, assembly inspection and shipping of large wind turbine components. The exports infrastructure is supported by the Danish Wind Export Association (DWEA). It offers networking, market intelligence and assists Danish companies looking to expand to the global wind market. This association serves more than 300 companies in the Danish wind industry.

- **Installation and grid connection.** Denmark exchanges electricity via a network of transmission cables connected to Norway, Sweden and Germany, allowing Denmark to buy and sell electricity in a regional market, including wind power.
- **Research**, collaboration between universities and manufacturers, and state of the art testing sites have maintained Denmark as the world leader in wind technology. Strong networks have been established between manufacturers and research facilities and Danish universities. For instance, it is possible for the manufacturers to have their plants in proximity to the research and development facilities. The Technical University of Denmark (DTU) for example, is operating three test sites for wind turbines in the country, such as the Østerild National Test Center (See Box 3.2).

Box 3.2 **Østerild National Test Centre for Large Wind Turbines**

The Østerild National Test Center was established in October 2012 after the Danish Government passed a law in order to establish a national test centre for wind turbines in an effort to ensure that Denmark stays at the forefront of the industry.

The DTU Wind Energy research center is in charge of the installation and operation of the test center, enabling researchers from the university to benefit from the tight collaboration with the wind industry, and allowing Denmark to lead the development of new wind turbines technology.

Østerild is the only place in the world where turbines up to 250 meters can be tested, measured from the ground to the tip of the blade. Within the wind turbine value chain, the testing phase is a critical step to ensure the feasibility of a new prototype. Identifying and eliminating production errors in the early testing stages is crucial before worldwide implementation.

Research capabilities coupled with such state of the art testing sites have attracted manufacturers. Companies such as the Chinese wind turbine manufacturer Envision Energy, have established there global innovation center in Denmark to use Østerild testing facilities to carry wind turbines related research since 2010, employing 30 researchers.

Source: Østerild, DTU Wind Energy, n.d.; Stateofgreen, 2012

Moreover, the Danish Wind Industry Association (DWIA) supports the industry in terms of communications with authorities, research institutions, academia and international stakeholders. The association services more than 260 local wind companies and promotes members' interests on both the national and the international political stages.

Skills availability related to the wind industry

Skills needed are available as wind energy is embedded in the curricula of Danish universities. Technical universities such as The Technical University of Denmark (DTU), University of Aarhus, University of Aalborg, University of Aarhus, and University of Southern Denmark have programs offering wind power courses and specialized graduate programs. The high level of standards, especially in the field of engineering, helps to ensure a constant inflow of new competent employees to the industry (Invenstindk, 2017).

3.2 The Case of Morocco

Morocco experienced 4.5% gross domestic product growth in 2015, with expectations of average annual growth to exceed 3.1% between 2016 and 2020. This is accompanied by rapidly increasing electricity demand (*i.e.* annual average of 6% increase since 1990), expected to quadruple by 2030. As such, challenges relating to energy security, as well as youth unemployment, make renewables an attractive proposition for the country. These drivers for renewable energy adoption are further supported by rich wind resources. Morocco's coastline extends to about 3,500 km, with average wind speeds of up to 11 meters/second, which is among the highest in the world. The wind power potential is estimated at approximately 25,000 MW with potential to provide electricity for more than 6 million houses. This case study discusses the factors that have driven the development of a wind sector in Morocco. These include the enabling framework for the development of the sector and the existing capabilities that have been leveraged for the development of a local industry.

3.3.1 Enabling policy framework for wind development in Morocco

Morocco has set the target of a 14% share of wind in the electricity mix, equivalent to 2,000 MW installed capacity by 2020. Morocco aims to fulfil those targets through the implementation of deployment policies; establishment of institutional capacity to manage, supervise and promote projects; and implementation of financial investments and projects to build the required facilities (World Future Council, 2015).

- While the national utility, Office National de l'Électricité et de l'Eau Potable (ONEE) is developing approximately 50% of the planned wind projects, deployment policies are supporting private investments in the sector. Such policies consist mainly of laws that allow private producers to sell renewables-based electricity, and large industrial facilities to self-generate electricity for up to 50 MW, and auctions that require public institutions to award projects on the basis of competitive public bidding. The auction initially adopted an Engineering, Procurement and Construction model, whereby the projects were owned by the ONEE with no Power Purchase Agreements (PPA) limiting the liabilities of bidders, but then moved to the Public Private Partnership model where the developer designs, builds and manages the wind farm following a PPA. The latest wind auction in Morocco of 850 MW was awarded in January of 2016 at a record low average price of USD 30/megawatt hour (IRENA, 2017e). The local wind industry was further supported by local content requirements, estimated to reach 55% of total project costs in 2016 (EIB and IRENA, 2016).
- The renewable energy sector is also supported through the establishment of public agencies and institutions responsible for promoting renewable energy and implementing the targets. These include the National Agency for the Development of Renewable Energy and Energy Efficiency (Agence Marocaine pour l'Efficacité Energetiques, or ADEREE), responsible for the implementation of plans for renewable energy and energy efficiency; The SIE (Société d'Investissements Energetiques), an investment fund that promotes renewable energy and energy efficiency; along with other institutions for research, training and innovation such as the Research Institute for Solar Energy and New Energy (Institut de Recherche en Energie Solaire et Energies Nouvelles, or IRESEN) and the Renewable Energy University Network (REUNET).

- Moreover, the government has been involved in facilitating public, private and international investments in the sector through a system that allows an optimal distribution of risks. The Moroccan Integrated Wind Energy project was launched in 2010 to deliver 2,000 MW of wind farms across five different sites in Morocco. The investment is estimated at USD 3.5 billion.

The enabling framework established by the government is complemented by existing industries and capabilities. The availability of domestic resources can be leveraged to develop a local industry for wind.

3.3.2 Existing capabilities in wind energy in Morocco

Approximately 797 MW of installed wind capacity is now in operation in Morocco (*i.e.* Tarfaya — among the largest wind farms in Africa with 300 MW capacity —Tanger and Abdelkhalek Torres) with five wind farms, totalling 850 MW, awarded in 2016. The consortium responsible for the Tarfaya project aims to reach 35% of local content, and the 850 MW —with a total investment estimated at USD 1 billion — aims to reach 55% local content, with the development of a significant and stable local market.

The Moroccon wind industry has gained maturity, with an established experience with wind projects involving several suppliers, and synergies with the existing aircraft and automobile industries. The high transport costs encourage the local manufacture of large components. Moreover, the industry benefits from a stable policy framework that guaratees a market for the products on the long term and favours local production for value creation. Nevertheless, some limitations include the limited production capacity to supply the whole market, in addition to the lack of some technological capacities needed to develop high-capacity towers and the limited financial capabilities that hinders investments in new production lines. The development of a Moroccan wind industry can face some challenges when it comes to developing wind turbine manufacturing facilities. On the one hand, existing manufacturing capacities are insufficient to cover the high demand in the years up to 2020 when all the projects are planned to be built, and on the other hand, investing in large manufacturing facilities might not be profitable in the long term, given the limited local market. Other challenges include the limitedness of financial resources needed to invest in production lines and the increasing regional competition from neighbouring countries such as Egypt and Europe (EIB and IRENA, 2016).

The African continent, however, has a large potential of untapped wind resources that can offer a market for the equipment. In addition, private investments in the sector can be driven by stable policy frameworks for wind deployment, supported by preference for projects with high local content in ongoing auctions. Siemens, for example — part of the consortium that won the bid for the development of the 850 MW wind farms with Enel Green Power (EGP) and Nareva Holding — is planning a rotor blade manufacturing facility in Tanger Automotive City, creating 600 jobs (Windpowermonthly, 2016). Moreover, other factors driving the development of local industry include existing experience and established businesses, availability of resources, existing skills, and synergies with other industries.

Existing experience, established businesses and resource availability

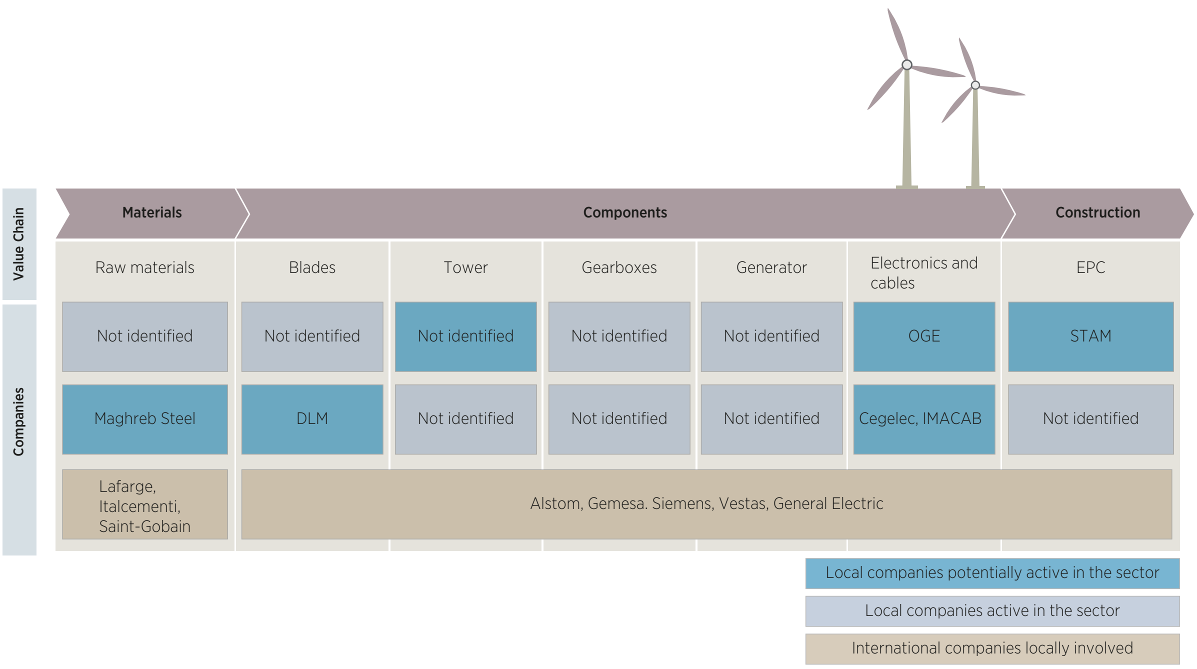
With almost 800 MW of installed and operational wind projects, many activities in the value chain have been localised in Morocco, mainly in project planning, manufacturing and construction.

- **Project planning.** The country has developed experience in site selection, wind resource assessments and environmental impact studies. Specific studies evaluating the environmental impact of the wind farm of Tarfaya (300 MW), commissioned in 2014, are available on the website of the ONEE.

  ADEREE provides expertise in wind resource assessment with a wind atlas published in 1986, 1995 and updated in 2007. More than 50 anemometers were installed between 1991 and 2009, assessing a total exploitable potential of 25,000 MW. These were developed as part of the wind resource evaluation program by the Centre for the Development of Renewable Energies. Moreover, studies on the soil and climate features of the country are publicly available. This is based on their relevance to the agriculture sector.

- **Procurement of raw materials and manufacturing.** Morocco has estabished some manufacturing facilities, supported by the availability of raw materials needed. Figure 3.1 shows the existing local businesses along the segments of the value chain.

Figure 3.1 ■ **Existing local businesses along the segments of the Moroccan wind value chain**



Note: OGE = Offgrid Electric; STAM = Société de Travaux Agricoles Marocaine; DLM = Delattre Levivier Maroc.
Source: EIB and IRENA, 2016

Morocco produces some of the raw materials required, limiting imports and maximising local value creation. These include cement, steel, copper, iron ore, and pig iron, as shown in Table 3.1.

Table 3.1 **Production of raw materials in morocco**

MATERIAL	PRODUCTION OF RAW MATERIALS IN MOROCCO (THOUSAND METRIC TONNES)				
	2008	2009	2010	2011	2012
Cement	14,047	14,519	14,700	16,300	16,500
Steel	478	479	455	460	475
Copper	21	42	43	43	43
Iron ore	23	31	45	79	79
Pig Iron	15	15	15	12	12

Nevertheless, the country continues to import iron and steel, among other materials, with a mature experience in the import sector (see Table 3.2). An increase in the demand from manufacturing industries, such as wind, automotive, aeronautics and electronics will increase import requirements.

Table 3.2 **Moroccan imports of some raw materials**

MATERIAL	IMPORTED VALUE (THOUSAND USD)		
	2012	2013	2014
Iron and steel	1,413	1,537	1,440
Salt, sulphur, earth, stone, plaster, lime and cement	910	594	770
Copper and copper-made articles	448	459	474
Aluminium and aluminium-made articles	390	423	463
Stone, plaster, cement, asbestos, mica articles	170	174	185

Source: International Trade Statistics

As for manufacturing components, Morocco has developed integrated programmes to improve renewable energy manufacturing capabilities. ONEE supports local manufacturing through auctions on two levels: in the pre-qualification phase, preference is given to regional and national companies; in the evaluation phase, local content requirements are among the criteria assessed.

Morocco has a strong potential for local manufacturing of wind turbine components. Some companies are now producing towers locally, thus fulfilling auction requirements of local production. Delattre Levivier Maroc (DLM), for example, can produce up to 300 towers a year at its new facility located in Casablanca.

The local production of blades is considered as the next step in the manufacturing of wind components, with Siemens planning a rotor blade manufacturing facility, building on the country's capacity for innovation in addition to the developed partnerships and technological cooperation with international companies.

In addition, companies involved in the development of projects in the past decade — especially in the local assembly of steel towers — have developed know-how in this sector. Moreover, companies from the automotive and aircraft industries can produce main electrical components, cables and parts of the generator.

- **Transport.** The availability of cargo ports in the country enables sea transport and the import of wind turbine components, such as nacelle parts, that are usually manufactured abroad. It also enables the future export of equipment produced locally, such as blades. Port of Casablanca is considered one of the largest artificial ports in the world and the port of Tangiers is the largest port on the Mediterranean and in Africa in terms of capacity.

  Morocco possesses the specific equipment and capabilities for the transport of wind components, given the size of the cranes needed and the features of high-capacity trucks, as well as professional truck driver capabilities. Some expertise exists in this area, after the installation of almost 800 MW of wind capacity by the end of 2015.

- **Installation and grid connection.** The local content requirements in the auctions have encouraged developers to source the installation of their projects locally. For example, the 150 MW Taza project was awarded in 2011 to a consortium led by France's EDF Energies Nouvelles (EDF EN), with a local subsidiary company (EDF EN Maroc) and other companies, including Japan's Mitsui and the turbine manufacturer, Alstom. The consortium subcontracted almost a third of the project's construction works to local companies. As for grid connection, ONEE is the entity responsible for expanding the Moroccan power transmission grid. The grid covers the entire country, with interconnections with Algeria and Europe through the Moroccan-Spanish network. The large penetration of renewables expected requires reinforcement of the transmission and distribution grid, and technical and infrastructural improvements are necessary to integrate intermittent wind energy. In this line, the country is planning efforts to standardise grid codes. As for the cable industry, Morocco is a producer of copper, with 43,000 metric tonnes produced in 2012. Although cables still need to be imported to date, one of the world's largest cable manufacturers, Nexans, has opened a facility in Morocco for the aeronautical industry. Synergies can be exploited, taking advantage of the local knowledge developed.

- **Operation and maintenance.** Wind turbine manufacturers —usually in charge of designing maintenance practices, according to technical requirements for components — and wind farm operators are currently present and undertake O&M activities in Morocco. They are leveraging on synergies with existing industries such as the automotive and aeronautics.

Synergies with related industries.

Synergies with similar industries can provide a wide range of resources and know-how. These can vary from qualified professionals and established training structures in the country to a wide variety of suppliers and import relationships.

The Moroccan industrial sector is well developed and it contributed to 28.8% of the country's GDP in 2015 (Economic Intelligence Unit, n.d.). There are different industries in Morocco, the most relevant being the automotive, aeronautics and electronics industries. The manufacturing sector has heavy industry (*e.g.* automobile and tractor assembly, foundry work), as well as metals processing and cement production. The existence of these industries entails a greater ease of access to skills, equipment and raw materials needed in the wind value chain.

Skill availability related to the wind industry.

The development of the wind industry requires different skills, from highly technical capabilities to personnel with a low level of specialisation. Morocco has established institutions for higher education and universities that offer specialised programmes in renewable energy, in addition to centres that offer training in the field (Box 3.3).

The Moroccan education sector has the resources to provide the industry with the required skills and the specialised and technical professionals needed in the different activities of the wind value chain. Qualified professionals, such as lawyers, administrative personnel, electrical or civil engineers and economists, are also widely available. Finally, specific profiles, such as safety experts, are present in the main industries that are currently operating in Morocco (*e.g.* automotive, aeronautics, electronics).

Box 3.3 ■ **Renewable energy education and training programs in Morocco**

Examples of universities include the Al Akhawayn University in Ifrane (Master of Science in Sustainable Energy Management) and others that offer common engineering degrees relevant to renewable energy. These include the Université Abdelmalek Essaadi, Université Mohammed Premier, Université Mohammed V in Agdal and the Euro-Mediterranean University. In addition, the Renewable Energy University Network (REUNET) was established in 2012 to promote research and innovation in renewable energy technologies and to spread knowledge in the sector through research activities and dedicated seminars.

Moreover, a Centre of Excellence has been established in Oujda for promoting manufacturing of wind components (*e.g.* blades, towers, turbines). Additional programmes focused on training professionals are also promoted within the country:

- Since 2012, several training events for professors from scientific institutions have been developed in the fields of renewable energy, based on the national conferences organised by the Moroccan-European network and attended by the institutions. These were focused on various technologies, providing professors with knowledge and helping institutions establish strong research networks and competence centres.
- The German Climate Technology Initiative has established vocational training centres specialised in the field of renewable energy.

4. CONCLUSIONS AND RECOMMENDATIONS

The socio-economic benefits of renewable energy have become a key consideration in building the case for its wide deployment. Increasingly, governments see the potential to fuel economic growth, create employment opportunities and enhance welfare by investing in renewable energy.

Opportunities for domestic value creation can be created at each segment of the value chain, in the form of jobs and income generation for enterprises operating in the country.

To assess the case for domestic industry participation in onshore wind farm development, policy makers need to analyse the labour, materials and equipment requirements of each segment of the value chain. Based on such an analysis, opportunities for leveraging local labour markets and existing industries can be identified to maximise domestic value. Regional and global market dynamics also strongly influence the decision to pursue domestic industry development.

To realise the full range of socio-economic benefits from the development of renewable energy, a conducive environment needs to be established. Should countries choose to support the development of a local industry, a broad mix of policies are required, including those related to deployment and to other sectors of the economy:

- Setting clear targets for renewable energy development provides a long-term view of the market's development trajectory. These are effective when accompanied by suitable deployment policies which provide a stable and predictable environment for attracting investments into the sector.
- To meet the human resource requirements associated with deployment targets, education and training policies would need to consider the skills needs of the wind energy sector which would increase opportunities for local employment.
- To strengthen the industrial capability of domestic firms, policy measures and interventions are needed that contribute to increased competitiveness. Measures include industrial upgrading programmes, supplier development programmes, promotion of joint ventures, development of industrial clusters and investment promotion schemes.
- To ensure the full-fledged development of a nascent industry, policy support should be time-bound and include broader aspects beyond deployment, human resources and industrial development.

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