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A STUDY ON WIND POWER GENERATION ACROSS THE TOP WIND GENERATING COUNTRIES IN THE WORLD – ITS FUTURE

M. Yendu Naidu, M.V.S. Karthik, Varun Kumar, M. Praveen
Yendunaidu9441@gmail.com

1.1 Introduction

Wind was traditionally employed topropel sailboats and sailing ships in the earlydays. Wind power has evolved over time, from the movement of ships to the operation ofirrigation pumps to the generation of electricity for common use. Wind power is one of therenewable energy sources available on the planet. The most common nonrenewable energysourcesin theworldareoil andcoal.They havealotof potential intermsof energyproduction efficiency. The fact that coal and oil are non-renewable energy sources is a majordisadvantage. Because it cannot be replaced in a short amount of time, they will eventuallyrun out and become exhausted. According to a survey published in May 2008 by the EnergyInformation Administration, non-renewable energy accounts for 93 percent of the energyconsumedin the United States. The remaining7% is made up of a variety of renewableenergysources,asindicatedinFigure1.EnergyBreakdownfortheUnitedStatesofAmerica, in 2007 [1]. Out of the 7% of renewable energy sources, only 5% of the original 7%is contributed by wind energy. There is plenty of room for improvement in this area for windenergy. Wind has always been here and it will always be here as long as the Sun shines. Itmakes sense to try to exploit this renewable energy source for use to preserve the world'senvironmentsandconserveournon-renewableenergysourcesfortimesofneed.Itisimportant to mention that all of the information in this paper is available from a multitude ofothersources. This paperprovides anoverviewofwindpower.

1.2 TYPESOFWINDTURBINES

There are two major classificationsfor wind turbines. The two are the vertical axisand the horizontal axis wind turbines. The end result of the two is the same as they bothprovide power from a mechanical means from the wind. The main difference is the cost ofbuildingandpowerefficiencyofeachsystemaswellasaestheticsandnoisefactors.

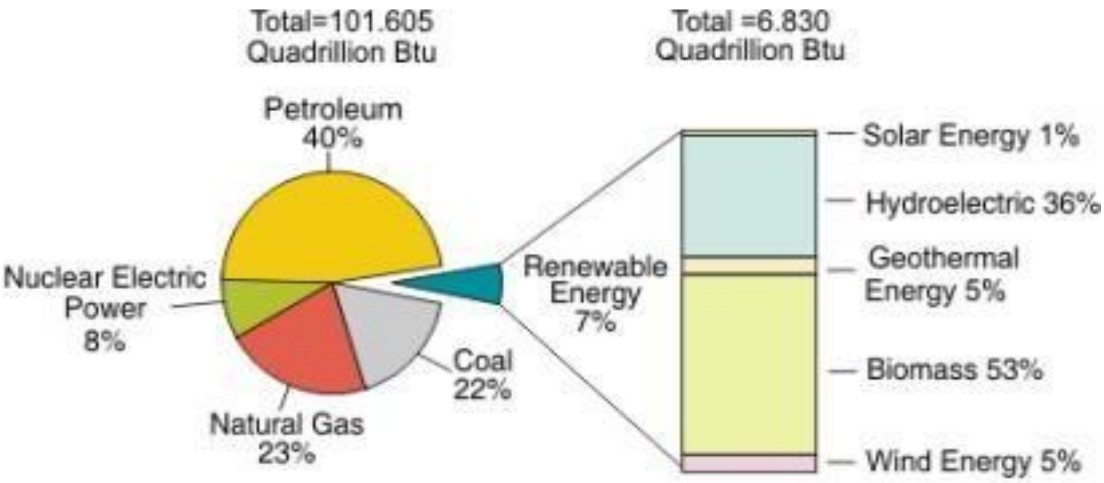

Fig. 1, Energy Breakdown for the United States of America, in 2007 [1].

1.2.1 VerticalAxis Wind Turbine

The first type of wind turbine is the VAWT. This turbine spins on a vertical axis asdepicted in Fig 2 there are many advantages and disadvantages to a VAWT. Typically, theadvantages are that the VAWT does not have to be mounted high in the sky to get a goodenough wind source to generate power. The VAWT can start to generate power at a lowerwind speed than the HAWT, therefore it can be mounted lower that other wind turbinesgenerally would be mounted. This defining feature makes it more residential friendly becauseit can be mounted onto the top of a building. Also, VAWTs do not have to change directionsto catch the wind. The VAWT will catch any wind no matter what direction it is blowing in.The VAWT alsospins quieter than the HAWT. This makes it ideal for applications that donot need much power but provides just enough to power the load. The disadvantages of theVAWT are also significant for the reason why it has not been adopted for commercial power.VAWTs usuallyprovide less power and have less efficiency than HAWTs. There blades havemore drag than the HAWTs so they provide less energy when they spin for the wind speeds itgets when compared to a HAWT. Another problem is that it uses guy wires to hold up thestructure. These guy wires cause a downward thrust onto the bearings of the blades causingincrease wearandtear.Anotherway tofixthisistohaveastructurebuiltabovetheVAWT to holdthe object up. This introduces a problem with upgrade and maintenance of theVAWT sincethebladeswouldbestuckinandwouldhavetobetakenapartformaintenance.

Fig. 2, VAWT, Darrieus wind turbine in Magdalen Islands [2].

1.2.2 Horizontal-axisWindTurbines

The second type of wind turbine is the HAWT. The HAWT has blades that spin on ahorizontal axis as shown in Fig 3. The HAWT is used more often than its counterpart, theVAWT. The HAWT is used by the commercial energy to provide power to customers. Theadvantages of the HAWT are that it has a variable blade pitch. This allows the turbine toadjust the blades for the time of day and direction of the winds. It increases the powerefficiency of the wind turbine for the seasons and situations. The HAWT also has the highestefficiency because it receives power from the entire blade rotation. The disadvantage of theHAWT is that it requires faster wind speeds to start producing sufficient power. These typesof wind speeds are generally acquired at higher altitudes where there is not much frictionslowing the velocity of the wind down. Therefore, the HAWTs have to be mounted on longand tall towers to maximize the power efficiency and allowing it to get the sufficient windrequirements to work correctly. Another disadvantage is that HAWTs are dependent on thedirection of the wind. It has to have a certain sensor to determine which direction the wind isblowingfromtomaximizeitspoweroutput.Thesesensorswillbediscussedinthenext

section. Generally, HAWTs are currently the more used version of thewind turbine due tothedifferencesbetweentheadvantagesanddisadvantages describedabove.

Fig. 3, HAWT, Horizontal-axis Wind Turbine Farm [3].

The abovefigure 3 describe about the Horizontal axis wind turbines which are placed onshore which generate a great amount of power by capturing the wind energy which wasgeneratedontheoceans.

1.3 CHALLENGESOFWINDPOWER

- **Wind power must still compete with conventional generation sources on a costbasis**. Even though the cost of wind power has decreased dramatically in the pastseveral decades, wind projects must be able to compete economically with the lowest-cost source of electricity, and some locations may not be windy enough to be costcompetitive.
- **Good land-based wind sites are often located in remote locations, far from citieswheretheelectricityisneeded**.Transmissionlinesmustbebuilttobringtheelectricity

from the wind farm to the city. However, building justa few already-proposed transmission lines could significantly reduce the costs of expanding windenergy.

- **Wind resource development might not be the most profitable use of the land**.Land suitable for wind-turbine installation must compete with alternative uses for theland,whichmightbe morehighlyvaluedthanelectricitygeneration.
- **Turbines might cause noise and aesthetic pollution**. Although wind power plantshave relatively little impact on the environment compared to conventional powerplants,concernexistsoverthenoiseproducedby theturbinebladesandvisualimpacts tothelandscape.
- **Windplantscanimpactlocalwildlife**.Birdshavebeenkilledbyflyingintospinningturbine blades.Mostoftheseproblemshavebeenresolvedorgreatlyreduced through technology development or by properly siting wind plants. Bats havealso been killed by turbine blades, and research is ongoing to develop and improvesolutions to reduce the impact of wind turbines on these species. Like all energysources, wind projects can alter thehabitaton which they arebuilt, which may alterthe suitabilityofthathabitatforcertainspecies.

2.LiteratureSurvey

2.1 LiteratureSurvey

Below table 2.1 gives a brief over view on different papers which discuss about the basicconstructionofthewindturbines,classificationofwindturbines,offshoreandonshorewindturbi nes, how the wind power generation take place in different countries and how thegenerationcanbeincreasedbyusingdifferentmethodsinfuture.

Table2.1:LiteratureSurvey

S.no	TitleofthePaper	Description
1.	Offshore wind energydevelopmentinChina:currentstatusandfutureperspective.Renewable andSustainable Energy	Thebasicconstructionoftheoffshorewindturbinesanditsworkingwasbrieflydiscussed.Differentcontrolmechanismswereintroducedintheoff shorewindturbines.

2.	GWEC. Global Wind Report, Annualmarketupdate2020.GlobalWindEnergyCouncil,Brussels,Belgium	Differentwindturbinemarketingtechnologiesandit‘sindustrialimplementationinvariouscountrieswas given inthispaper.
3.	ExploitationandutilizationofthewindpoweranditsperspectiveinChina.RenewableandSustainableEnergy	Thisgivesaboutthewindenergybecome a major contribution towards therenewablepowergenerationbyovercomingthenaturalresourceslike CoalandNuclearreserves
4.	Analysis of application situation andprospectofgeneratingelectricitytechnologybynewenergy.	Differentmotorsandconstructionalaspects for the wind turbines were giveninthepaper.
5.	Comparisonofpoliciesforwindpowerdevelopmentin Chinaandabroad	Differentpoliciesforwindpowerdevelopmentindifferentcountriesandthe major policies implemented in Chinaandhowitisperformingbetterfromthe other.
6.	Comparative assessment of performanceofforeignandlocalwind turbine manufacturers in China.RenewableEnergy	Howthebasicconstructionofthewind turbines varies from the place toplaceandwhetherconditionsindifferentlocalities.
7.	–WindTurbine‖Wikipedia[Online]	Thebasicdesignsofthewindturbinesanddifferentwindturbineconstructions ononshore andoff-shorewind turbines.

8.	JuanM.Carrasco,EduardoGalván,and Ramón Portillo, –Chapter 29 Wind Turbine Applications,‖ "PowerElectronicsHandbook‖,Edited by M.H.Rashid,ElsevierPublishing, (2006),	Thispapergivesthemainideaof theapplications of the windturbines otherthanthe windpowergeneration.

3:INSTALLATIONOFWINDTURBINESACROSSFEWCOUNTRIES

In the generation of wind power there are so many countries contributing their owncapacity Wind power sits at the heart of the energy transition for many countries. The race tobuild bigger, better wind turbines mirrors the efforts of global governments to increase theirrenewable power generation. The IRENA estimates that global wind generation exceeded732GW by the end of 2020. Across 2019, onshore and offshore wind generated 1,427TWh,withthe IEAexpecting100GW moreonshoregenerationbeforetheendof2021.

Acrosstheworldtopwindpower generationsare

- China is the top country with the installation capacity of 345Gw. China is the worldleaderinwind energy,withoverone-quarteroftheworld‘s wind powercapacity.
- US are 2nd country with the installation capacity of 139GW. The US has developed139GW of onshore wind generation capacity sofar, despite its heavy reliance onfossil fuels. Many of the world's largest onshore wind farms lie in the US. The world'ssecond-largestwindfarm,theAltaWindEnergyCentreinCalifornia,hasacapacityof 1,548MW. The state of Texas alone produces a quarter of US‘ wind power with24.9GW, providing more wind power than 25 other US states combined Recentlycoastal stateshavecommittedtomassiveoffshore winddevelopments,attractingmassive investment. The federal government has also committed to offshore winddevelopment,planning30GWofgenerationacrosstheAtlanticCoast.
- Germany is at 3rd place with the installation capacity of 64GW. In Europe, Germanyhas the highestinstalled wind capacity, with more than 60GW.Its largestoffshorewindfarmsaretheGodeWindfarms(phase1&2),whichhaveacombinedcapacityof 582MW. Germany isalso home to the Nordsee One Offshore Wind

farm,whichhas acapacityof382MWandprovidesenergyfor400,000homes.

- India is the 4th country with the installation capacity of 42GW. India's rapid economicdevelopment and population growth have seen it expand its renewable capacity. Thecountry aimed to install 175GW of unspecifiedrenewablegeneration by 2022, butthis now seems unachievable. Attime of writing,the country remains one of thelastto set a net zero target The country has the third and fourth largest onshore wind farmsin the world, the Muppandal wind farm in Tamil Nadu, SouthernIndia (1,500MW)and the JaywalkerWindParkinRajasthan,NorthernIndia (1,064MW).

- Spain is in 5th place with the installation capacity of the 29GWApproximately 20% ofSpanish electricity comes from wind power, with a generation capacity of 23GW. Thecountry has the fifth-most installed generation in the world, despite its relatively smalleconomy. Spain plays a large role in global wind manufacturing, hosting severaloperations of green giant Siemens Gamesa Renewable Energy. The company hasinstalled more than 100GW of onshore and offshore wind turbinesglobally. Thishelpsaccountforthethousandsemployedbythecountry'swindsector.Approximately 30,000people workin the Spanish windsector,accordingto thecountry'swindenergyassociation.Manufacturershavemorethan220locationsacrossal mostallofthecountry.
- United Kingdom is in the 6th place with the installation capacity of 26Gw. The UK isthe third European country on the list, relying more on offshore wind than othercountries. Six of the 10 highest-capacity offshore wind projects in the world lie in UKwaters, mostly on its North Sea coast The Hornsea One wind farm is currently theworld's largest wind farm, with a generation capacity of 1.2GW. The Hornsea Twosister project would add another 1.3GW of generation to the area upon completion. Inrecent years, the UK government has promised investment to develop the country'soffshorewindmanufacturingindustry.
- Brazil – installed wind capacity of 19.1GW. Brazil has the largest wind capacity inSouthAmericawithmorethan19GW.Thecountrygenerateshugeamountsofhydroelectri c power, with wind and biofuels vying for second place. In 2020, Braziladded approximately 1.8GW of wind generation, although solar grew faster in thesame period.
- France is at 8th place with the installed wind capacity of 18.7GW. France

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generatesmost of its electricity through a world-leading fleet of nuclear power stations.Inrecentyears,thecountryhasmovedtowardimprovingitsrenewablefleet,afterincreasing its renewable budget to €71bn for the period 2019-2028. This will allow itto triple its onshore wind capacity by 2030.France aims to have increase its windgeneration capacity to at least 21.8GW by the end of 2023. As part of this push, theFrenchgovernmenthasannouncedchangestoplanninglaws,makingwindconstructioneasier.

- Canada is at 9th place with the installed wind capacity of 14.4GW. Wind accounts forapproximately5%ofCanada‘srenewableenergysupply.Canada'smanymountains and rivers allow it to generation 67.5% of power from hydroelectric sources. Annualwind power additions peaked in 2014 and has significantly reduced since. The state ofOntario has the largest amount of wind energy, with over 5GW installed. On the otherhand, many states have little to no wind generation. The largest wind farm in CanadaistheRivière-du-MoulinprojectinQuebec,whichhasatotalcapacityof300MW.
- Italy is at 10th place across the world with the installed wind capacity of 12.7GW.Finally, Italy's installed wind generation capacity reached 12.7GW in 2021. Italianenergy giant Eni has played a big part in the oil and gas business for many years. Itnow aims to construct 60GW of renewable capacity by 2050, coming from just 1GWof installed capacity in 2020. Italy‘s wind industry is heavily concentrated in the southand on its islands. For example, all of Italian energy company ERG‘s onshore windcapacityisbasedsouth of Rome,withPugliaandCampaniabeingitsstrongestmarkets.

Table3.1:WORLDWIDEWINDPOWERINSTALLEDCAPACITY*Courtesy(WorldWindEnergyAssociation. Report2017)*

S.No	Country	Years						
		2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*
1	China	44,733	62,733	75,564	91,412	1,14,763	1,45,104	1,68,690
2	EuropeanUnion	84,278	93,957	1,06,454	1,17,384	1,28,752	1,41,579	1,53,730
3	UnitedStates	40,200	46,919	60,007	61,110	65,879	74,472	82,183
4	Germany	27,214	29,060	31,332	34,250	39,165	44,947	50,019
5	India	13,064	16,084	18,421	20,150	22,465	27,151	28,665
6	Spain	20,676	21,674	22,796	22,959	22,987	23,025	23,075
7	UnitedKingdom	5,203	6,540	8,445	10,711	12,440	13,603	14,542
8	France	5,660	6,800	7,196	8,243	9,285	10,358	12,065

9	Canada	4,008	5,265	6,200	7,823	9,694	11,205	11,898
10	Brazil	932	1,509	2,508	3,466	5,939	8,715	10,740
11	Italy	5,797	6,747	8,144	8,558	8,663	8,958	9,257
12	Sweden	2,163	2,970	3,745	4,382	5,425	6,025	6,519
13	Turkey	1,329	1,799	2,312	2,958	3,763	4,718	6,081
14	Poland	1,107	1,616	2,497	3,390	3,834	5,100	5,782
15	Portugal	3,702	4,083	4,525	4,730	4,914	5,079	5,316
16	Denmark	3,752	3,871	4,162	4,807	4,845	5,063	5,227
17	Others	17077	20081.4	29503.1	35794	41220	47504	47504
	Total	2,80,895	3,31,708	3,93,811	4,42,127	5,04,033	5,82,606	6,41,293

- The world is undergoing many changes in the field of energy sector due totheirimpact on climatic change. The challenge of the energy sector is to produce energyfromanenvironment-friendlyresourcewherewindenergyisoneamongtheenvironmentally friendly energy resources. At presentmore than 80 countries areinvolved in the global wind industry among them, 28 countries have 1 GW installedcapacity. The 28 countries include 17 countries from Europe, 4 countries from Asia-Pacific which includes China, India, Japan & Australia, 3 from North America whichincludes Canada, Mexico, US, 3 from Latin America which includes Brazil, Chile andUruguay, and South Africa from Africa. The world wind power installed capacity incountry wise is listed in table 1. There are totally eight countries with more than 10GWinstalledcapacityandtheyareChina,US,India,Spain,UK,CanadaandFrance.

4.WINDENERGYININDIA

India ‘s growth is in a rapid manner where energy is the solution to achieve growthgoals. India has taken enormous efforts in getting better access tomodern energy.Since2000, nearly 20% of the population or 240 million people are without access to electricity onthe other hand electrification rates in the rural area have been spiking. India has guaranteed atthe climate summit in mere future it will produce electricity by utilizing renewable energies.India has placed many goals in order to expand the utilization of renewable energy withadditional proficient technologies. The wind power industry is capable of meeting out theclimateandenergysecuritygoalsinIndia.AtpresentIndiaranks5thwiththetotalinstallation‘s

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capacity of 31 GW by the mid of 2017. The Indian wind industry will establishinstalled capacity of 60GW tomeetup the national objectiveby 2022.By the end of 2016,thetotal renewableenergy basedelectricpowergeneration capacity installedacrossthecountry has crossed 50 GW among which wind power contributes 57%. India‘s wind powerinstallations compared to the worlds overall installed capacity in 2016 is around 6.6%.Inhave discussed the development of wind energy-based power generation in India and its fivekeystates.Basedontheirstudy,theyhavesuggestedmanypredictionsonfuturedevelopment pattern of wind power in India, saying that 12875 MW of power generation maybe achieved by 2030. In have also discussed the prominence and advancement prediction ofwind power generation techniques in India. In have surveyed the progress of wind powertechnology in India like countries. The theory of diffusion of modernization for predicting thedistribution of wind power in certain states in India. have used GIS-based technology for theassess ability of the wind power generation potential in India. They approximated that windenergy potentialin Indiawasaround45–48.5 GW.Thetotal potential forWindpowergenerationinIndiaisestimatedaround 102,772MW basedon the reportpublishedbyMinistry of Statistics and Programme Implementation. On an average Wind power has aconsiderablecapacityfactorcomparedtosolarpowertechnologies.Thetheoreticallycomputed capacity factor ranges from 20% to 30% for wind power, which depends on thefactors like site and wind profile. The theoretical maximum annual generation, with 100%deployment of wind potential and 20% capacity factor, would be around 180,056 millionUnitsinIndiawindpowercontributesabout9%(32279.77MW)ofthetotalenergygenerated by it. When the Indian government announced 60GW target in 2015, wind industrytook it as a challenge to meet the goal. In 2016, the wind industry has installed new windturbinesof3.6GWcapacitiesandbrokeallprecedingpaperworkofannualinstallations.

During the period of 2016-17 annual installations has crossed 5.4 GW by the end of March2017, thereby bringing the bringing total installed capacity to over 31GW. The states withabundantwindpowerareGujarat,Karnataka,Maharashtra,andTamilNadu.

Table4.1:IndianWindpower–ABriefOutlook–GWEC.

S.No.	STATE	TOTAT INSTALLEDCAPACITYIN(MW)
1	AndhraPradesh	2,092.5
2	Gujarat	4,441.5
3	Karnataka	3,154.2
4	Kerala	43.5
5	MadhyaPradesh	2,288.6
6	Maharashtra	4,666.1
7	Rajasthan	4,216.6
8	TamilNadu	7,694.3
9	Telangana	98.7
10	Other	4.3
TotalinstalledcapacityinIndia		**28,700.4**

Till date, Indian wind sector is predominantly depending on private sector venture. Theeconomicandpolicy shoreupby the governmenthasmade theindustry toinvolveinessential commercial risks in order to progress and stimulate venture in this sector. The top-five winds power generation companies with respect to installing facility are Suzlon with35.4%, Wind world with 18%, Gamesa with 10.1%, Vestas with 7.6%, Regen with 7.3% andInox with 5.68%. Many winds power companies like LM Wind Power, Vestas, Senvion, aEuropean company, Gamesa, Acciona, Envision, and Sany Global have constructed theircompaniesinIndia[14].WindindustryindevelopingcountrieslikeIndiafacesmanychallenges, firstly the industry faces inadequate access to finance, and the industries have toinvest solemnly, which is a very high financial burden for wind industry. Lack of skilledlabour is another problem faced by them; the companies are not having adequate skilledlabour for erection and maintenance of wind turbines. India does not have sufficient physicalinfrastructure and logisticsfor transportation of the constructing and erection equipmenttothehighwindpotentialareas.Thegovernmentpoliciesarealsonotgoodenoughinencouragingandsupportingthe windindustries.

OFF-SHORE&ON-SHOREWINDS

Over the past decade, many countries have invested heavily in wind power, and currentenergy policies imply that there is a lotmore investment to come in. Most existing windfarms have been built on land (onshore) but some countries in north-west Europe have alsostarted to invest in offshore wind, and the UK (in particular) has aspirations for offshore windfarms to make up nearly one-third of its generating capacity in the 2020s. This is in thecontext of the EU 's demanding targets for renewable energy—20% of final energy demand isintended to come from renewables by 2020, and this could mean that one-sixth of Europe'selectricity comes from wind.1 Why would governments be interested in promoting offshorewind farms? Higher and steadier offshore winds make offshore wind farms more productive(UK figures suggest a capacity factor of about 36% compared to an average of 27% foronshore wind farms (Boyle, 2006)), which in turn implies a higher capacity credit, and thussmaller back-up costs (Millboron, 2009). Against this, the costs of building offshore are muchhigher, and there are bottlenecks in the supply chain, mostly due to the relatively limitednumber of installation vessels and the long queues in suppliers order books—due to the (sofar) limited production volumes of equipment and parts (Krohn et al., 2009). In the UKcontext, where many onshore wind farms have been delayed or blocked by difficulties ingetting planning permission, the lower visual and other impacts of offshore wind farms areimportant, and they can offer the flexibility to locate closer to (some) load centres, thushelping to reduce transmission losses and avoid congestion bottlenecks. Even if there were noproblems in getting planning permission, the physical space available for onshore turbines inthe UK is limited, and building offshore allows a significant increase in the total potentialcontribution (Mackay, 2008). This paper discusses the economic implications of the move tooffshore wind. Section 2 illustrates the dramatic increase in capacity and generation over thelast decade, and the even faster rise predicted for the next. This comes despite the higher costof building stations offshore than onshore, discussedin Section 3. Additional costs comefrom the need to use subsea cables to connect the stations to the transmission system, raisingissues which we cover in Section 4. The following section concentrates on the interactionbetween wholesale markets and the output from offshore wind farms, showing that

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they are atrisk of earning less than the time-weighted average price of power, should they depend onwholesale market revenues. Given this, and their high costs, government support is likely tobe needed for many years to come. Section 6 discusses the main ways of supporting offshorewindstations.Newinvestmentinoffshorewindgenerationcapacityhasshownaremarkable

increase, particularly in Europe, over the last two decades. Total offshore installed capacity inEuropehasincreasedfromunder50MWin2000

Country	2008capacity(GW)		2020nationalplan[a](GW)		2020EWEAhighcapacity(GW)		2020 nationalplan[a](GW)	
	Onshore	Offshore	Onshore	Offshore	Onshore	Offshore	2008(%)	2020high(%)
UK	2.7	0.59	14.9	13.0	14.0	20.0	2	25
Germany	23.9	0.01	35.8	10.0	42.0	10.0	7	17
France	3.4	–	19.0	6.0	20.0	6.0	2	11
Netherlands	2.0	0.25	6.0	5.18	5.4	6.0	4	22
Sweden	0.9	0.13	4.37	1.82	8.0	3.0	2	16
Denmark	2.8	0.41	2.62	1.34	4.0	2.5	20	46
Belgium	0.4	0.03	2.1	1.8	2.5	2.0	1	12
Spain	16.7	–	35.0	3.0	41.0	1.5	12	26
Finland	0.1	0.02	2.5	0.0[b]	2.0	1.0	0	8
Ireland	1.0	0.03	4.1	0.6	6.0	1.0	9	55
Italy	3.7	–	12.0	0.7	17.0	1.0	2	9
Poland	0.5	–	10.0	0.5	12.0	0.5	1	15
Greece	1.0	–	7.2	0.3	8.3	0.2	4	29
Estonia	0.1	–	0.5	0.0	0.5	0.1	2	11
Latvia	0.0	–	0.2	0.0	0.2	0.1	1	9
Lithuania	0.1	–	0.5	0.0	1.0	0.1	1	13
Others	4.3	–	11.3	1.0	26.1	–		
EU-27	63.5	1.47	168.1	45.2	210.0	55.0	4	17

[a]EntriesunderlinedwerefortheEWEA‘slowscenario,asNationalRenewableEnergyPlanswerenotavailableforthesec ountries.

[b] TheNationalPlanforFinlanddoesnotgiveseparatefiguresforonshoreandoffshorewind.

toabout1471 MW by the end of 2008 (EWEA,2009), translating toan average annual rateof growth of about 50% per year. Although currently the bulk of operating offshore systemsconcentrates within a small number of Northern European countries, the interest in offshorewind farms is widening rapidly around the world. Currently, most of the existing installedoffshore capacity concentrates within a handful of Northern European countries: the UK,Denmark and the Netherlands. As of 2008, these three countries accounted for 85% of theEU-27 offshore wind capacity (their corresponding combined share for onshore capacity wasjustover11%). In particular,the UK had thehighest total installed offshore capacity, with591 MW followed by Denmark (409 MW) and the Netherlands (247 MW). Although theseshares are likely todecrease over the comingyears, as investmentin offshore starts to catchup in the rest of Europe, the UK is expected to maintain its current leading position in thismarket. Indeed,theUK ‘sshare of totalEUoffshore capacityis predictedtobearound30%in

2020according to the National Allocation Plans submitted to theEuropean Commission bySeptember 2010. These imply a totaloffshore capacity of 43 GW, and 13 GW from the UK,while theavailable figures for onshore capacity add up to 155 GW.2Despite its spectaculargrowth, thecurrentshareof offshorecapacity remainsrelativelylowwhencomparedtooperatingonshore(andjustover2% of total windcapacityforEU-27).Thehighercostsassociated with offshore wind farms, as wellas supply chain bottlenecks (mainly attributed toyetsmallscaleproductionof turbines–implyingcapacitylimitations–andthelimitedavailability of suitable installation vessels, Musial and Butterfield, 2004) are often seen as themain drivers behind this gap. As interest in the market expands, both of these constraints arebecomingincreasingly less binding,and the supply chain isnow showingsigns of catchingup with demand. EWEA (2009) provides __conservative ‘‘(low) and __ambitious ‘‘(high)scenariosaboutthetotalnumberofwindsonshoreandoffshoreinstallationsby2020.According to these figures, the conservative scenario suggests an increase of total offshorewind installations in EU-27 to over 19% of total wind power capacity, thatis 40 GW ofoffshore and nearshore wind installations. According to this scenario, the UK is expected toincrease its share of capacity derived from offshore wind farms from 2.65 GW in 2008 to 13GWin 2020 (thus deriving 50% of its total wind capacity offshore). The__high‘‘scenariosuggests that the share of offshore wind will increase to 22.7% of total wind capacity in EU-27, with the UK‘ hare now assuming the value of 58.82% (20 GW). In both scenarios, the UKis expected to maintain its current leading position in offshore wind generation, followed byGermany with total offshore capacity of 8–10 GW. The details of the current shares andEWEA ‘s estimates for 2020 for EU-27 are summarized in Table 1. The value of investment inoffshore wind follows a similar pattern to the one described for installed capacity and isshowingFig.1.Assumingthecapacity pricessuggestedby theEWEA (1250h/kWforonshoreand2400h/kWforoffshore,in2005constantprices(EWEA,2009)andthe __conservative ‘‘(__lowscenario ‘‘)capacitytargetssummarizedinTable1,investmentinoffshore wind capacity isexpected to grow from its current value ofabout h2 billion per yearto just under h9 billion in 2020, reachingover h16 billion in 2030. EWEA expects the marketfor onshorecapacity in Europe to start showing signs of saturation after 2020 partly due to adeceleration in the demand for onshore turbines (e.g., due to utilisation of productive sites) andpartlyduetoashiftin interesttothemoreproductive (andbythattime morecostefficientcomparedtopresent)offshoregeneration.Asaresult,EWEAexpectsoffshoreinvestmenttoovertakeonshoreinabout 2023.

CONCLUSION

In this paper the offshore WF design with WTs of differentsizes has been considered.The results show, that for a given WF area, the optimization using larger WTs generallyresults in offshore WFs with a higher capacity factor, which is merely aresult of their higherhub height(thus a higher wind speed) and less wake effects (due to the larger spacingbetween WTs). Whether using multiple types of WTs in an offshore WF, i.e., a non-uniformdesign, depends strongly on the difference of mean capital costs of different types of WTs. Inthe scenario where the capital cost per MW of small WTs is cheaper than that of the largeWTs ata moderate degree (around 10% in our study), the design with multiple types of WTsoutperforms. Otherwise, the optimal offshore WF design will always be of a single type ofWTs. Thus, the advantage of non-uniform design is quite dependent on the cost, while itspossible disadvantages in terms of supply chain management, installation, and O & M areclearlypresented,duetothe inevitableincreasedlevelofcomplexityforthesefactors.

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