FIMOI version 2

Cost estimates for the first offshore wind farms in India

April 2022

Centre of Excellence
for Offshore Wind and Renewable Energy

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This draft report was jointly prepared by DEA and COWI after consultations with MNRE, IREDA and NIWE. The assumptions and opinions expressed in this report do not necessarily reflect the view of the Government of India and its related agencies on offshore wind development and/or policies. The report is intended to be used as a research study for providing insight on the first cost estimates for offshore wind farms in India. Therefore, the results and findings presented in the report should be treated as indicative.

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Credits

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Introduction and key findings

Financial Modelling of Offshore wind in India (FIMOI) is an initiative launched within the Centre of Excellence for Offshore Wind and Renewable Energy, established as part of the India-Denmark Energy Partnership programme. The partnership is centred on a government-to-government cooperation between the Indian Ministry of New and Renewable Energy (MNRE), the National Institute of Wind Energy (NIWE) and the Danish Energy Agency (DEA) under the Ministry of Climate, Energy and Utilities

The first FIMOI report was successfully disseminated in February 2021. This first version of the report provided LCoE estimates for the first offshore wind farm in India and the related risks. Since then the offshore wind industry has gained even more momentum and the cost for offshore wind has been significantly lowered internationally. For the Indian market there is a stronger interest for offshore wind. The FIMOI project is an iterative process by nature in order to get the newest insights for the offshore wind market and come with the most relevant estimation Therefore an updated Version 2 of the FIMOI report has been initiated.

Since the dissemination workshop, a market dialogue and further assessments have been undertaken to strengthen the foundation for the input parameters to provide an improved basis for decision-making. Since offshore wind projects have not yet been constructed in India, there is an inherent challenge in estimating costs. At the same time, extensive investor dialogue with Indian and international stakeholders has provided a good foundation for India-specific LCoE estimations. One of the primary changes to the last report in terms of input parameters is the increase in the anticipated turbine size, which reflects the rapid technological development seen within the offshore wind sector. The hypothesis of larger turbines was also tested in an investor dialogue, confirming with the industry that these larger future state of art turbines will be the primary choice of turbine for projects with a Final Investment Decision (FID) around 2025. The latest line of offshore wind turbines expected to go into mass production by early 2024 has a rated power of up to 15 MW. As a consequence, the production estimates in this report have been based on a 15 MW turbine. In the case of Gujarat, sensitivity analysis indicates that a lower rated turbine with longer blades will perform better, but such a turbine does not yet appear to be on the market or in the test phase.

Larger turbines lead to improvements in expected capacity factors and Annual Energy Production (AEP), as well as reductions in projected operational expenditures (OPEX), which point towards a reduction in LCoE. To verify the reliability of the FIMOI cost data, comparisons have been made to several internationally recognised benchmark reports, such as the World Energy Outlook, the Danish and British Technology Catalogues for offshore wind, and cost projections made in the Dutch market.

The data provided in this report are estimates for FID in 2020, 2025, and 2030. As we are now moving into 2022, the 2020 estimates have remained the same as in the previous report, while the expectations for 2025 and 2030 have changed in line with the new inputs. If a potential project would have a FID date between 2020 and 2025, an interpolation between the data points provided in this report could be used as an approximation.

The basic findings of this report is based on a full-scope offshore wind project, i.e. a project that includes offshore substation, export cable and onshore electrical infrastructure. Various countries have adopted different approaches to the split of risk between the private project developer and the government in relation to the provision of infrastructure. It is recognised that the Indian Government is in a process of deciding on the scope around offshore wind projects in India, and the interface between the developer and Transmission System owner. This scope split is briefly touched upon in the last chapters.

The overall LCoE estimation in this FIMOI report and subsequent calculation of subsidy levels is based on the most basic LCoE calculation, which does not include considerations of VAT, duties, PPA design or other economic incentives. The numbers show a rapid decreasing trend for both Tamil Nadu and Gujarat with a 28% and 22% reduction in LCoE respectively from 2020 to 2025 and a further joint 30% reduction in LCoE from 2025 to 2030. This decreasing trend is a result of the anticipated increasing level of experience in the Indian offshore wind sector as more and more OWF are expected to be contracted and constructed.

Tamil Nadu shows the lowest cost potentials, with an LCoE that could be as low as 7.4 INR/kWh in 2025 and 5.2 INR/kWh in 2030, as shown in Table 1. In Gujarat, the LCoE is expected to reach 11.2 INR/kWh in 2025 and 7,8 INR/kWh in 2030. By comparison the expected LCoE of future offshore wind farms in Denmark under very favorable conditions is expected to reach approximately 4.5 INR/kWh by the late 2020's.

	2020	2025	2030
TAMIL NADU ZONE B	10.3	7.4	5.2
GUJARAT	14.4	11.2	7.8

Table 1: Basic LCoE (INR/kWh, real-21)

There are still many uncertainties related to the offshore wind market, supply chain and project development in India that contribute to an LCoE level above what can be expected in Europe. As offshore wind development in India takes off, these uncertainties will be reduced and the LCoE could approach European levels at a more rapid pace.

For the first offshore wind projects in India, many components, as well as skilled offshore specific labour, will most likely be imported, hence the INR/USD exchange will have a major impact on the LCoE. It is not the objective of this report to predict the future exchange rate, but to highlight factors with a significant impact. The exchange rate used in this report is 72.8 INR/USD, which is an average of the monthly exchange rates over the last 3 years (2019-2021)[1].

Offshore wind projects are still more costly than other renewable energy technologies, such as solar PV and onshore wind and certain low cost fossil fuelled technologies, where the societal cost of CO_2 is not accounted for. In most electricity markets this means that it is necessary to rely on public subsidies in order to incentivise developers to construct offshore wind farms. The long term goal of kick starting the market with subsidies for offshore wind is to stimulate cost reductions through economies of scale, potentially build a solid local industry and de-risk the large investment projects such that the offshore wind becomes competitive.

Early indications from India suggest that offshore wind will need to compete at a price as low as 3.5 INR/kWh in order for it to be considered competitive in the Indian power system as of today. Such a low cost of energy will require a significant level of subsidies for the first offshore wind farms. In the following, the subsidies needed to reach an LCoE of 3.5 INR/kWh as well as 7 INR/kWh have been estimated. The 7 INR/kWh target is offered as an alternative to the very low 3.5 INR/kWh based on the expectation that offshore wind will displace the least efficient and most expensive fossil fuel based units in the whole power system first.

On the basis of the basic LCoE levels the subsidies have been estimated as either an investment subsidy or in the form of per unit generation based incentives (GBI) – both are defined in the section; “

Calculation of subsidy”. These are scenarios to illustrate the use of the FIMOI tool together with the new updated input parameters for generic offshore wind projects, and the results are shown in Table 2 below. For GBI the results are presented as the per unit cost, the total annual cost and the net present value of all GBI payments over the lifetime of the project. The investment subsidy is presented as the total subsidy needed during development and construction and the net present value of the subsidy.

	Target LCoE	*3.5 INR/kWh*		*7 INR/kWh*	
Subsidy type	***Site***	***Gujarat***	***Tamil Nadu Zone B***	***Gujarat***	***Tamil Nadu Zone B***
GBI (real-21)	*Per unit (INR/kWh)*	*7.7*	*3.9*	*4.2*	*0.43*
	Annual GBI (bn INR)	*20.2*	*15.5*	*10.9*	*1.7*
	NPV (bn INR)	*170*	*130.8*	*92.3*	*14.2*
	Subsidy (bn INR)	*191.6*	*147.6*	*104.1*	*9.24*

[1] Source: https://fred.stlouisfed.org/series/EXINUS

Investment subsidy *(real-21)*	*NPV (bn INR)*	*155.2*	*119.5*	*84.3*	*7.5*

Table 2: Government support to reach target LCoE of 3.5 INR/kWh and 7 INR/kWh (P50, FID 2025) with Basic LCoE values as starting point

For a 1000 MW offshore wind project with full scope and FID 2025 in Tamil Nadu Zone B the GBI per unit subsidy could be down to 3.9 INR/kWh or NPV 130.8 billion (arab) INR in order to reach a target LCoE on 3,5 INR/kWh. The subsidy levels are logically dependent on the LCoE levels of an offshore wind project, and would thus be higher for Gujarat for the same conditions with 7.7 INR/kWh or NPV of 170 billion (arab) INR. Measured by the net present value of the total subsidy, investment subsidies would appear to be the cheapest option. However, a GBI will require a much lower up front fiscal commitment from the Government of India. The LCoE or subsidy level is also to a large degree dependent on the de-risking of the project in terms of securing a revenue stream in the project business case. Table 2 shows the subsidy levels with a basic LCoE where VAT and duties are not accounted for. If these are put on the offshore wind projects the viability funding would go up. As this example shows there are a number of parameters to consider and decide upon when designing the terms and conditions for the PPA/subsidy scheme.

To highlight some of the factors playing a significant role in determining the LCOE for the first offshore wind farms various sensitivities are presented such as limiting the project developers scope of the offshore wind farm, changes in long term inflation rate and the interest rate.

There are inherent uncertainties in projecting future technology developments, cost of CAPEX and OPEX, and cost of financing. To further reflect this the report presents an accelerated scenario to illustrate a situation where India is able to reap the benefit of scale and existing knowhow on onshore wind to reach different cost reductions levels. One aspect that is in focus is if the operational expenditures could be reduced further than elsewhere due to Indian entrepreneurship.

Methodology

This section briefly describes the LCoE method and how the level of subsidies, needed to reach a specific cost of energy, can be estimated. Finally, the data collection process is documented.

LCoE method

The Levelized Cost of Energy (LCoE) is a method for evaluating the cost effectiveness of RE projects. The LCoE compares the present value of all project costs with the present value of all energy generated in the lifetime of the project.

$$LCoE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t: Investment cost in year t. For a developer's perspective, this would include investments in wind turbine generator and foundation though not the strengthening of the supporting infrastructure.

M_t: O&M costs in year t. For a societal perspective this would include externalities such as environmental costs and health costs.

E_t: Energy generation in year t

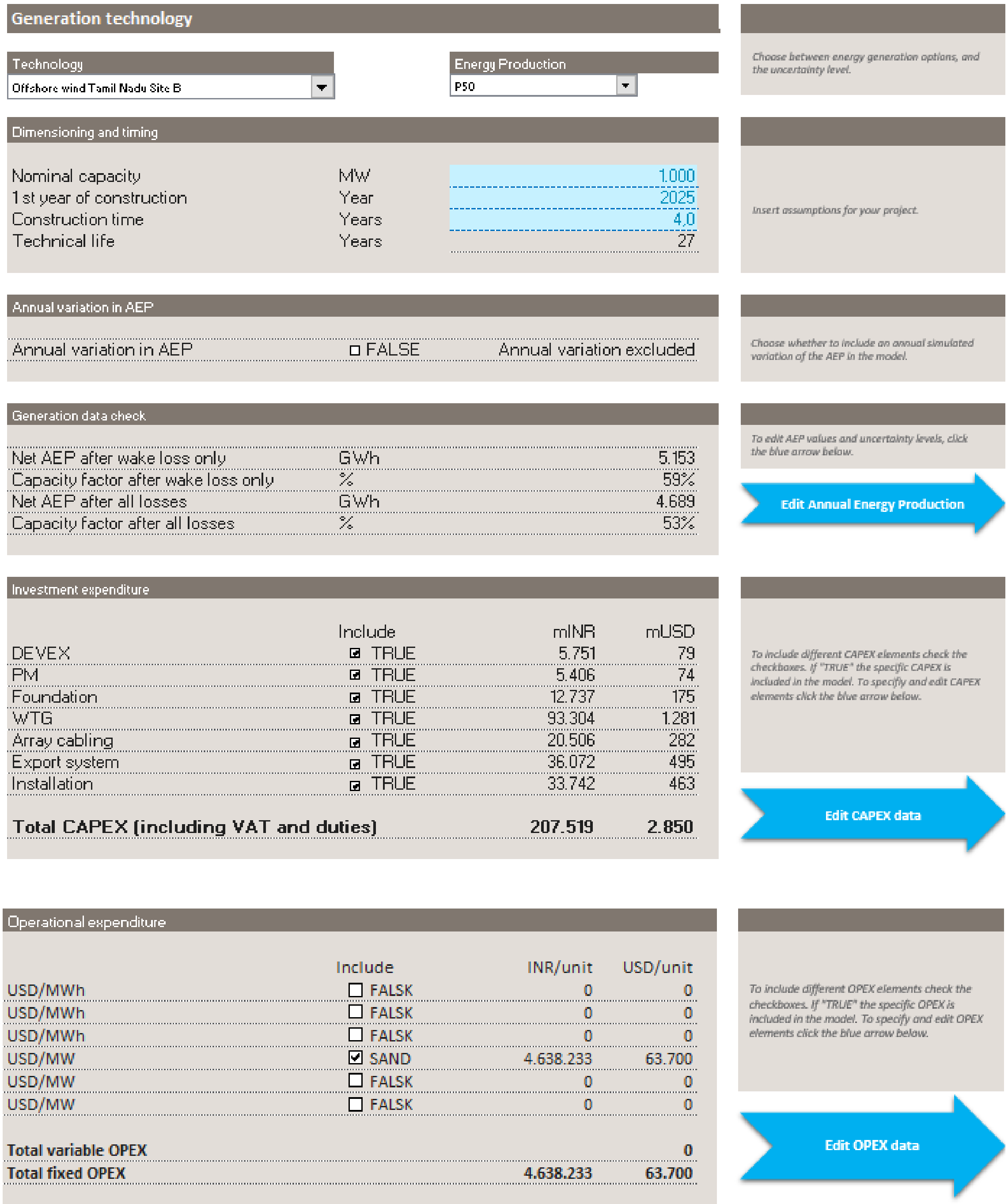
r: Discount rate. In the developer perspective the discount rate is typically the Weighted Average Cost of Capital. In the societal perspective, the discount rate is more complex and reflects a general hunger for cash in the entire economy.

n: project life

t: year

As mentioned in the first FIMOI report, the LCoE can be calculated from the developer's perspective, as well from a socio-economic perspective. Some of the differences between the two perspectives are the factors included in the calculations, for example for timeframes, discount rates, if taxes and subsidies are included or not, externalities and social infrastructure. In this FIMOI report the developer perspective is calculated.

Below is an overview of the interface of the FIMOI LCoE and VGF tool.



Generation technology

Technology	Energy Production
Offshore wind Tamil Nadu Site B	P50

Choose between energy generation options, and the uncertainty level.

Dimensioning and timing

Nominal capacity	MW	1.000
1 st year of construction	Year	2025
Construction time	Years	4,0
Technical life	Years	27

Insert assumptions for your project.

Annual variation in AEP

Annual variation in AEP	FALSE	Annual variation excluded

Choose whether to include an annual simulated variation of the AEP in the model.

Generation data check

Net AEP after wake loss only	GWh	5.153
Capacity factor after wake loss only	%	59%
Net AEP after all losses	GWh	4.689
Capacity factor after all losses	%	53%

To edit AEP values and uncertainty levels, click the blue arrow below.

Edit Annual Energy Production

Investment expenditure

	Include	mINR	mUSD
DEVEX	TRUE	5.751	79
PM	TRUE	5.406	74
Foundation	TRUE	12.737	175
WTG	TRUE	93.304	1.281
Array cabling	TRUE	20.506	282
Export system	TRUE	36.072	495
Installation	TRUE	33.742	463
Total CAPEX (including VAT and duties)		**207.519**	**2.850**

To include different CAPEX elements check the checkboxes. If "TRUE" the specific CAPEX is included in the model. To specify and edit CAPEX elements click the blue arrow below.

Edit CAPEX data

Operational expenditure

	Include	INR/unit	USD/unit
USD/MWh	FALSK	0	0
USD/MWh	FALSK	0	0
USD/MWh	FALSK	0	0
USD/MW	SAND	4.638.233	63.700
USD/MW	FALSK	0	0
USD/MW	FALSK	0	0
Total variable OPEX			**0**
Total fixed OPEX		**4.638.233**	**63.700**

To include different OPEX elements check the checkboxes. If "TRUE" the specific OPEX is included in the model. To specify and edit OPEX elements click the blue arrow below.

Edit OPEX data

Figure 1 Offshore wind project technical and cost inputs in the FIMOI tool

Financing			
Equity financing			
Cost of equity			10%
Equity share			25%
Loan financing			
Interest during construction			5%
Senior			
Financing share			75%
Interest rate			8%
Loan Tenor (years)			15
Subordinate			
Financing share			
Interest rate			15%
Loan Tenor (years)			25
Simple WACC			**8,50%**
Time variant WACC			**9,09%**
Choice of WACC for NPV calculation	☑ SAND	*Simple WACC*	

Figure 2 Offshore wind project financial inputs in the FIMOI LCoE and VGF tool

Calculation of subsidy

Subsidies remain an important part of offshore wind development. In Europe, the first offshore wind tenders without subsidies have been realized as a result of decades of development and many tenders with subsidies being awarded. In emerging offshore wind markets however, subsidies will be needed as local supply chains develop. The subsidies will serve to bring the energy cost of offshore wind in line with the general cost of electricity in the local grid.

In general, subsidies help cover the "gap" between the cost of energy from a specific site, and the price of electricity to the consumers. The concept of providing subsidies to cover such gaps is defined as Viability Gap Funding (VGF) and covers a diverse toolbox of economic incentives.

In the FIMOI framework, the need for and scale of VGF is explored through a number of archetypical subsidy schemes:

- Removal of vat and duties (tax incentives)
- Generation Based Incentives (GBI)
- Investment subsidies

Tax incentives remove a cost element from the project by providing full or partial exemption from VAT on goods and services and possibly exemption from duties on imported goods. Tax incentives are an indirect subsidy in the sense that the cost to the Government of India is a loss of extraordinary tax revenues.

Generation Based Incentives provide support to a project through an increased payment per unit of energy delivered. GBIs are often tied to PPA contracts that offer the developer a guaranteed price per unit, and a price which is higher than the average price of electricity in the grid. GBI has the advantage that the cost of the subsidy is spread over the project life making the fiscal burden much less pronounced for the Government of India.

Investment subsidies are subsidies that provide partial funding of the initial investment cost. Offshore wind projects are characterized by very large up-front investments that must be covered by revenues from energy generation over the subsequent 25-30 years. Reducing the burden of the initial investment cost can significantly lower the cost of energy over the project life. Investment subsidies would represent a substantial fiscal burden up front on the Government of India and would initiate discussions around ownership of the assets – especially in cases where the investment subsidy constitutes a significant share of the total investment. The benefit of the investment subsidy is that the net present value of the investment subsidy can be (highly project specific) lower than the net present value of the GBI over the lifetime of the project.

A new functionality has been added to the FIMOI tool to automate the calculation of subsidies. This calculation estimates the necessary subsidy based on the settings chosen in the tool and the target electricity price (target LCOE). In the FIMOI tool, the calculated subsidy is either an investment subsidy that lifts part of the investment burden up front or a generation-based incentive (GBI) applied per unit of energy produced.

In the formula for LCOE on pages 10, the two subsidy types can be added into the formula:

S_I: Investment subsidy

S_M: GBI

In this case the subsidies are measured as percentage reductions in either CAPEX or OPEX. The object is to solve the equation for either subsidy type given a fixed LCOE target value. Afterwards, the actual monetary value of the subsidy can be derived from the percentage values found.

$$LCoE = \frac{\sum_{t=1}^{n} \frac{I_t(1-S_I)+M_t(1-S_M)}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

The necessary viability gap funding (VGF) is calculated using a number of macro buttons in the Excel tool, see Figure 3 Viability gap funding in the FIMOI tool

below.

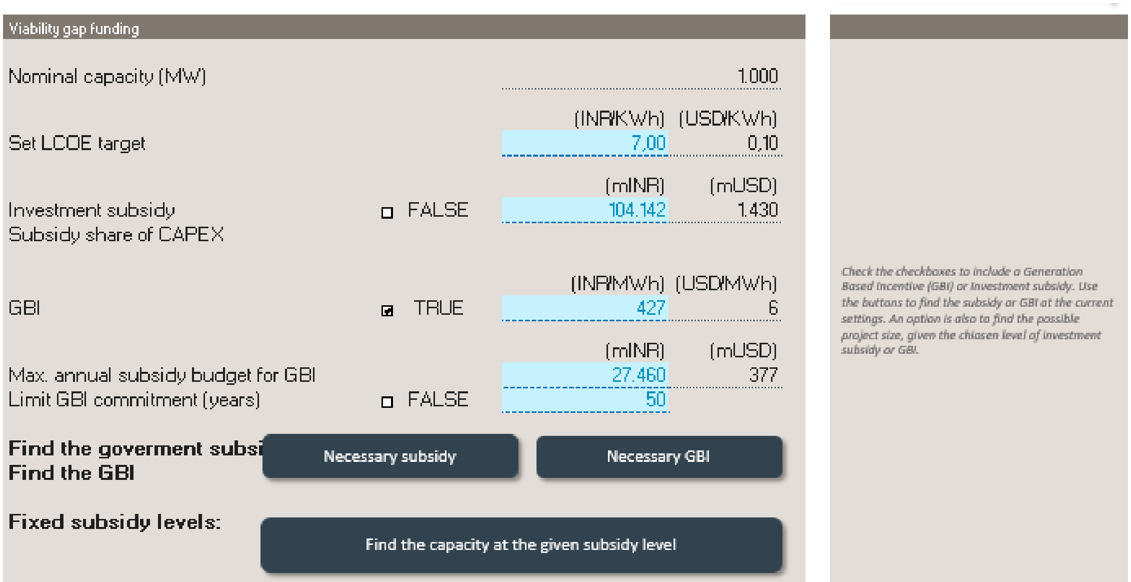


Figure 3 Viability gap funding in the FIMOI tool

The investment subsidy is calculated as the subsidy in the construction period that will lead to the target LCoE. The GBI is the average annual subsidy that will lead to the target LCoE.

It is also possible to turn the calculation around and use the input cells (the blue cells) to set a budget for either an investment subsidy or a GBI and find the possible capacity with the available funds. The tool can only calculate the capacity based on one type of VGF at a time.

Data collection

The FIMOI project started in 2019 and is one of the main activities under the Centre of Excellence for Offshore Wind and Renewable Energy, established as part of the India-Denmark Energy Partnership programme. FIMOI version 1 was conducted with large stakeholder engagement, a solid collection of data based on multiple collection methods, and built upon the best available literature. In February 2021 the FIMOI version 1 was launched at a dissemination workshop with 130 plus participants and great interest was shown in the results. The FIMOI version 2 report is an elaboration on this work, where the focus has been on strengthening cost estimates and yield estimations through stakeholder engagement and use of best available technical inputs.

There are many good reasons for a FIMOI version 2. In general, a cost estimation process is by nature an iterative process. It is always possible to collect new data, refining and improving the project. This is especially important in the offshore wind market, where new innovative technologies are developed and new players are entering the market, increasing competition and leading to significant reductions in prices. These decreases can be seen on an almost bi-annual basis. The FIMOI project started in 2019 and significant cost reduction in the offshore market and lower auction prices have been achieved in the meantime. Lastly, offshore wind farms do not yet exist in India, which makes it even harder to estimate costs. Since the start of the FIMOI work, the DEA has experienced a lot of attention to offshore wind in India and more stakeholders are monitoring the market. The intention of FIMOI version 2 is to bring the new insights into the report and adapt the estimates to an Indian context. This has been done by only focusing on Gujarat and Tamil Nadu Zone B as the most likely areas for initial projects, interviewing Indian-based stakeholders, and being physically present in India.

For FIMOI version 2, an extensive investor dialogue has been undertaken, with the clear aim of gathering knowledge and creating common assumptions for the future Indian market. The DEA has engaged with 15 different stakeholders for the first stage dialogue. All stakeholders were within the offshore wind sector and both Indian and international stakeholders were included. Interviewees ranged from offshore wind developers, industry conglomerates with interest in renewable energy, to OEM turbine manufacturers. In total 12+ deep dive interviews were held. Here the stakeholders provided specific feedback on the data and estimates, which was then refined into the data estimates used in the report. The data collected as to widest extended possible used a triangulation to get a coherent understanding and direction from the different stakeholders and their data input to the FIMOI numbers.

In addition to the interviews, the DEA has compared data has been to several international reports, such as the Danish and English Technology Catalogues[2], IEA's World Energy Outlook

[2] (DEA, 2022) and (BEIS, 2020)

2021[3], AEGIR Offshore Wind Market report India 2021[4], and GWEC Global Offshore wind report 2021[5].

[3] (IEA, 2021)
[4] (AEGIR, 2021)
[5] (GWEC, 2021)

Data and assumptions

Data inputs and assumptions

A key learning from the stakeholder dialogue is that developers expect to use state of the art turbines to optimise the power generation and lower the overall LCoE. As the graph below shows, for FID in 2025, turbines up to 15 MW have been announced for the market and this will also be the basic assumption for the Indian offshore wind market.

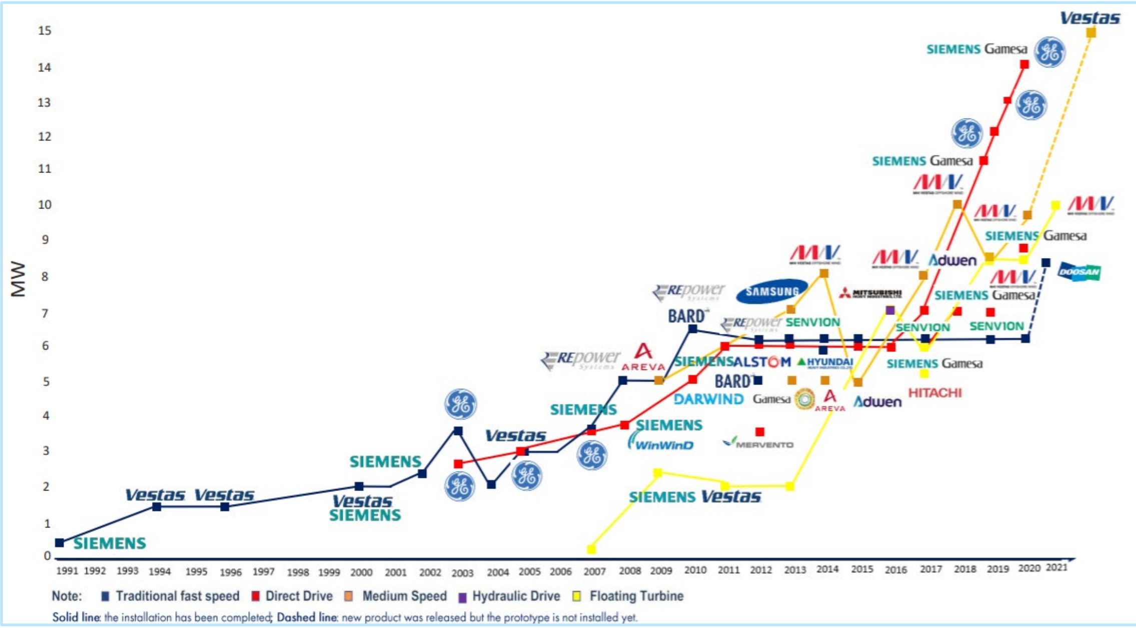


Figure 4 Offshore Wind Turbine Technology Road (excluding China) Source: (GWEC, 2021)

It is acknowledged that wind resources are different from Gujarat to Tamil Nadu Zone B, and that a turbine tailor-made for lower wind climates is more suitable for Gujarat. In order to harvest the full cost reductions that a 14-15 MW turbine platform would bring in balance of plant and on the OPEX, the large turbine is also used in the calculations for the Gujarat site. More detailed studies of a tailor-made turbine with a higher rotor-generator relationship could be done, when the suppliers develop these so-called "low wind offshore turbines".

Table 3Table 3 provides an overview of the technical and cost input for Gujarat and Tamil Nadu zone B. The previous FIMOI levels for 2020 have not been changed, as 2020 has already passed. However, the 2025 and 2030 data has been updated to reflect new technological developments and expectations.

Years of final investment decision	Unit	Gujarat			Tamil Nadu zone B		
		2020	2025	2030	2020	2025	2030
ENERGY / TECHNICAL DATA							
Capacity per turbine	MW	4.2	15	15	8	15	15
Gross capacity factor*	%	38	39	39	54	62	62
Project size	MW	1,000	1,000	1,000	1,000	1,000	1,000
Development time	years	1	1.5	1.5	1	1.5	1.5
Construction time	years	2	2.5	2.5	2	2.5	2.5
Technical lifetime	years	25	27	30	25	27	30
Electrical losses	%	5	5	5	5	5	5
Forced outages and planned outages	%	4	4	4	4	4	4
PROJECT COST DATA							
Nominal investment for developer (real-21)							
Total**	M INR/MW		207.5	146.4	243.9	207.5	146.4
- Of which management							
o Development including surveys***	M INR/MW	5.7	5.8	4.1	6.8	5.8	4.1
o Project execution	M INR/MW	2.9	5.4	3.8	6.4	5.4	3.8
- Of which equipment							
o Foundation	M INR/MW	36.6	12.7	9.0	15.0	12.7	9.0
o Wind turbine	M INR/MW	96.1	93.3	65.8	109.7	93.3	65.8
- Of which grid connection							
o Array cables	M INR/MW	10.0	20.5	14.5	24.1	20.5	14.5
o Export cables	M INR/MW	26.5	15.5	11.0	18.3	15.5	11.0
o Onshore windfarm substation	M INR/MW	6.8	5.6	3.9	6.6	5.6	3.9
o Offshore windfarm substation	M INR/MW	18.2	14.9	10.5	17.5	14.9	10.5
- Of which installation	M INR/MW	47.3	33.7	23.8	39.7	33.7	23.8
Fixed O&M	M INR/MW/year	7,027,652	4.64	3.79	7.14	4.64	3.79

Table 3: Data sheet with technical and cost date for the baseline estimates of LCoE.

Source: Based on stakeholder feedback
** Includes only wake losses and not electrical and outage losses. The values for Gujarat and Tamil Nadu are based on mesoscale data.*

*** Geo physic; UXO desk study; EIA required surveys; geotechnical survey; Metocean report; Morphology report; Geotech. Interpretation; others*

For the LCoE calculations the below project financial data have been used. This set of data might change over time, so there should be a monitoring if any development lead to a need for changes, when assessing the financing of the first offshore wind projects. The long term inflation is set at 5%, which reflects the average over the past 7 years of the latest reported CPI inflation figures from 2014-2020.[6]

Because of the impact from the inflation on specially the OPEX along the lifetime of the project some sensitivities will be presented later on. When looking over a span of 10 years the CPI inflation is averaging closer to 6.5% and this has been chosen as the sensitivity, when calculating the LCoE in the Sensitivities Chapter.

[6] Asian Development Bank: https://data.adb.org/dataset/india-key-indicators

In this phase of the FIMOI project, there has been no deep dive into these project financial data, but they will be the target of the next phase of the FIMOI project, where stakeholders perceived risks and mitigation of those will be in focus.

Years of final investment decision	Unit	India
PROJECT FINANCIAL DATA		
Loan tenor	years	15
Return on equity – developer	%	10
Interest during construction	% of inv.	5
Financing costs – Interest on loans	%	8
Relevant taxes		
- GST (VAT)	%	5
- Import duties	%	13
Inflation	%	5%

Table 4: Data sheet for the baseline estimates of LCoE. Source: Based on stakeholder feedback

Energy production

With the introduction of a 14-15 MW turbine platform, new AEP estimates have been produced for both Tamil Nadu zone B and Gujarat. This shows that AEP has increased for both sites.

The AEP estimates for the Tamil Nadu and Gujarat sites are based on ERA5 meso scale data and COWI's further assessment, which include a level of uncertainty. To increase certainty, the DEA recommends that the data is supplemented with actual measured wind data.

The new AEP estimates for the Tamil Nadu Zone B are an average value based on production estimates from four different scenarios of location and density of a 1050 MW wind farm. See Figure 5 below. The AEP is modelled using a Vestas V236-15 MW power curve with a 125 m hub height. The gross annual energy production is thus estimated to be 6,012 GWh/year. With an estimated wake loss of 10% this will give a gross capacity factor of 59% after wake losses, but without planned and unplanned outages, and electrical losses. This means that compared to FIMOI v1 the gross capacity factor increases from 54% to 59% with the new turbine size.

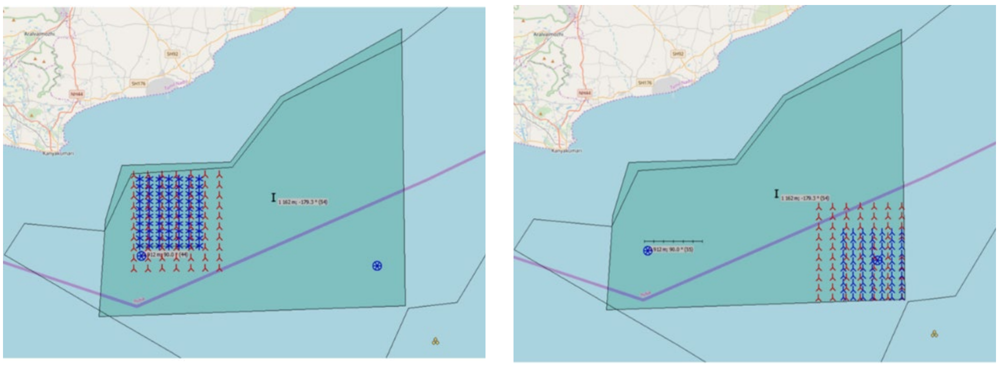


Figure 5 Tamil Nadu Zone B AEP modelleing site

The new AEP estimates for Gujarat are calculated for a designated zone of a 1050 MW wind farm using the same 15 MW Vestas V236-15 power curve as in Tamil Nadu. The estimated gross AEP for the Gujarat site is 3977 GWh/year. With an estimated wake loss of 9.5% and this will give a cross capacity factor of 39% after wake losses, not including planned and unplanned outages, and electrical loses.

A sensitivity analysis for Gujarat showed that a wind turbine better fitted for a lower wind climate with a more favourable and optimized generator-to-rotor ratio could increase the gross capacity factor to 44%. The sensitivity analysis was based on a power curve for a hypothetical 10 MW wind turbine with a 220 M rotor and is specifically simulated for this FIMOI assessment. Further assessments of this could be made when the suppliers are closer to having a so-called 'low wind turbine' ready for the market. See the Gujarat modelling site in Figure 6 below.

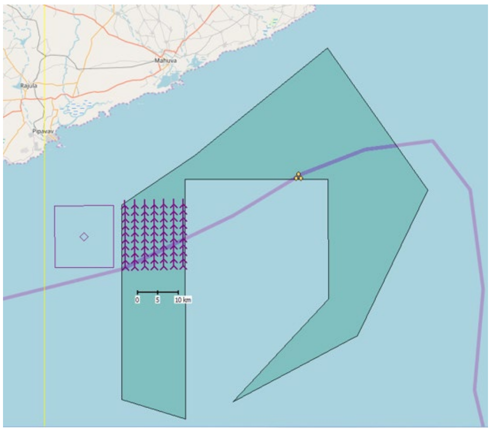


Figure 6 Gujarat AEP modelling site

The net AEP for the two sites and the wake loss, electrical losses and planned outages and capacity factors are summarised in Table 5: Updated summary of AEP estimates below. The capacity factors are calculated after electrical losses and planned and forced outages.

SITE	WAKE LOSS	ELECTRICAL LOSSES AND PLANNED OUTAGES	NET AEP (GWH)	CAPACITY FACTOR AFTER ELETRICAL LOSSES
GUJARAT	9,5%	9%	3,119	36%
TAMIL NADU ZONE B	10%	9%	4,689	53%

Table 5: Updated summary of AEP estimates

CAPEX assumptions

The CAPEX estimates are based on the development of a full scale offshore wind farm with a full transmission asset, including the offshore substation, export cable and onshore connection and substation. The assumption is that the developer will build a 1 GW wind farm, which allows for significant economies of scale in development expenditures (DEVEX), project management, installation, vessels and grid costs. Furthermore, a 14-15 MW turbine platform will on average lead to lower balance of plant costs. The new platform will not yet be subject to significant price reductions due to it being fairly new on the market in 2025.

Investment decisions on the first offshore wind projects are expected before 2025. As India does not currently have an offshore wind industry, many of the components will be imported until a local supply chain has been developed. In the short term, India is likely to be able to source the development, permitting and operation of the OWFs locally, as well as manufacturing of the towers and onshore infrastructure. It is less likely that India can manufacture the blades, foundations, array and export cables, nor operate and service the turbines in the short term. And it is unlikely that India can manufacture the nacelles or supply the offshore substations and installation or commissioning vessels in the short term.

Further, seabed geology is assumed to be suitable for monopile foundations, which is the cheapest foundation alternative. The water depth is estimated to be between 25-40 meters, and the need for steel for the foundation is assumed to be within normal ranges and will therefore not add additional costs.

The CAPEX estimates per MW are highlighted in under. The significant cost reduction on the 14-15 MW turbine platform starts after 2025 which will lead to cost reductions towards 2030.

	2020	2025	2030
CAPEX (mINR/MW)	243.9	207.5	146.4

Table 6: CAPEX estimates for Tamil Nadu zone B for FID year (real-2021)

As the CAPEX estimates over include the cost of the full transmission infrastructure, including the offshore substation, export cables and onshore substation there would be a cost decrease from the project developers business case point of view if the project cost would only be accountable for the offshore wind farm and offshore substation. This different split of the responsibilities and thereby the CAPEX costs is briefly illustrated in the sensitivities chapter and will be investigated further in a later phase of the FIMOI project.

OPEX assumptions

Based on the investor dialogue, OPEX is expected to decrease, compared to the first FIMOI report, by 8% for FID in 2025 and by 9% for FID in 2030. These reduction potentials are based on a prompt start of the Indian offshore wind market before 2025.

Once the Indian market kicks off, the sector is expected to gain momentum and achieve many of the learnings from other markets and could see relatively fast cost reductions. The Indian content share of the wind farms is likely to increase fast, though turbine components for repair and other critical infrastructure components will be imported until a local supply chain has developed.

The local harbours are expected to be upgraded to accommodate operation and maintenance activities (O&M). For the Tamil Nadu site, the Chinnamuttom Harbour could be a relevant O&M port, while the port of Pipavav may be suitable for the Gujarat site.

For OWFs with FID in 2025, the distance to shore is expected to be less than 30 km, and for projects with FID in 2030, less than 50 km.

OPEX estimates are highlighted for each FID year in Table 7: OPEX estimates in 2021 prices for FID yearTable 7 under. The technical lifetime of the OWF varies depending on the FID year as outlined in Table 3.

	2020	2025	2030
OPEX (mINR/MW/YEAR)	7.14	4.64	3.79

Table 7: OPEX estimates in 2021 prices for FID year

The OPEX costs are difficult to estimate as there are currently no offshore wind projects in India to benchmark from. Secondly, the scope of the projects and the specific components to include are not fully set yet. Furthermore, the technical lifetime of the OWF also means that some costs will occur 25-30 years into the future. However, the investor dialogue process gave some valuable indications on OPEX costs in a new market.

The OPEX estimates can generically be broken down into the following categories:

- Operations and scheduled maintenance
- Unscheduled services (depending on SWA with OEM)
- Other O&M activities (Monitoring environment, regulatory obligations)
- Insurance
- Seabed leases (in some markets)
- Transmission charges
- Fishery compensation

The unscheduled service costs will depend on the service warranty agreement (SWA) with the original equipment manufacturer (OEM).

How the regulatory framework round seabed leases, transmission charges and potentially fishery compensation will be settled will have an impact on the overall OPEX presented here. As the national regulatory framework is not yet clear there could be substantial variations in the fees, leases, charges and, the seabed lease is still not known in detail. The transmission charges are estimated to be non-existing as the government owns the grid and transmission charges would only result in a greater need for subsidies. In this assessment, the decommissioning guaranties and costs are also on a generic level included into the OPEX estimate.

Seabed lease is commonly used in offshore activities including offshore wind. The lease can cover many real costs associated with the use of an ocean area for offshore wind, e.g. administration, monitoring, loss of access for other marine activities. In some cases, the seabed lease is also used as a means for ensuring the commitment of the developers through a greater financial commitment at an early stage of development. Finally, the seabed lease is sometimes seen as a source of income for the local government or tax on the extraction of a natural resource (wind energy).

Whatever the purpose of the seabed lease, it is important to keep in mind that the lease will be transferred directly to the LCOE of the project. In cases where the offshore wind project depends on subsidies, the added costs of the seabed lease would simply result in higher subsidies. This dynamic may be acceptable if the seabed lease represents true costs associated with the project or when it is deemed necessary to secure the commitment of the developer.

CAPEX and OPEX assumptions

For creating a transparent comparison for the CAPEX and OPEX estimate, the FIMOI report compares the result of the stakeholder engagement with several internationally recognised sources. These sources include the World Energy Outlook, the Danish and British Technology Catalogues for offshore wind, and to cost projections made in the Dutch market. Overall, the move to a 15 MW turbine platform together with the continuous innovative offshore wind industry development and cost out in all parts of the value chain creates a higher capacity factor, lower CAPEX and lower OPEX. The graphs below with comparison to benchmark reports show the trend of a rapid cost decrease. The projection for India in the FIMOI report assume that CAPEX and OPEX costs gets down to the references for mature markets in Europe and even lower round 2030, which indicates India's large potential to get low cost for offshore wind in the future. These extra assessments aim to create a solid benchmark for the FIMOI report and ensure the reliability of the numbers.

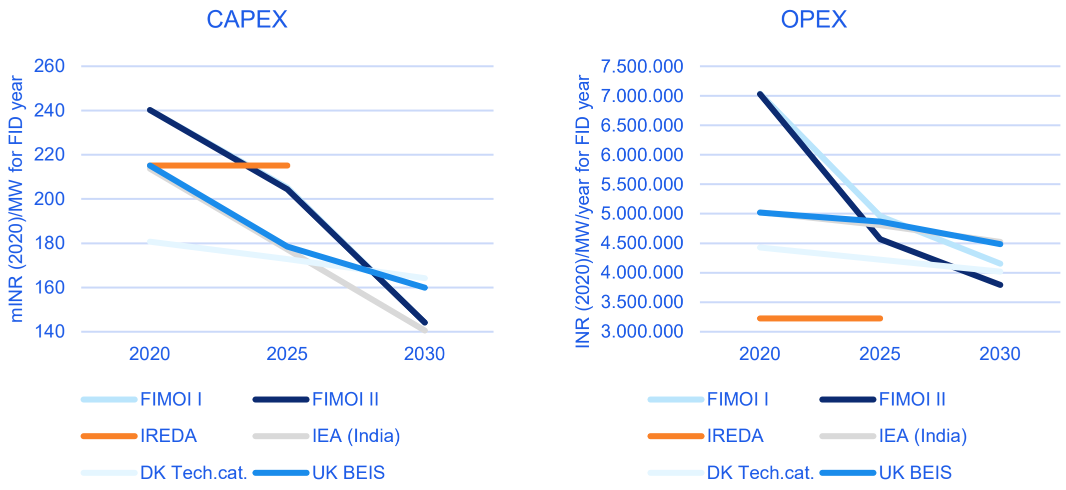


Figure 7 CAPEX and OPEX comparison between sources[7]

[7] Sources: ((IEA, 2021), (BEIS, 2020), (DEA, 2022), FIMOI version 1 and version 2, and data from IREDA)

Detailed Findings

Due to technological developments in the offshore wind market and following the investor dialogue, projections for AEP, CAPEX and OPEX for offshore wind in Gujarat and Tamil Nadu have been updated.

The focus in this report has been on the FID 2025 and 2030, because this is when the Indian offshore wind market is expected to really kick off.

The CAPEX and OPEX estimates for projects with FID in 2020 are unchanged from FIMOI version 1. CAPEX estimates on projects with FID in 2025 and 2030 are also similar. When introducing a new larger platform of WTGs there will be a cost saving based on lower balance of plant costs, but on the other hand a new platform is more expensive per MW in the first years compared to when there has been several years of cost out and mass production has been established. However, OPEX estimates on projects with FID in 2025 and 2030 are expected to be significantly lower in FIMOI version 2 based on the larger turbine sizes. AEP estimates have increased for projects with FID in 2025 and 2030 at both locations due to larger turbines with larger swept area that can harvest more of the wind resource.

On the financial parameters the exchange rate and the long term inflation projection have been updated to reflect the latest incoming data.

With the new AEP, CAPEX and OPEX inputs it should be mentioned that there are some basic uncertainties when doing projections on these key inputs that could have a significant impact on the expected LCoE. This is a substantial uncertainty and risk, which needs to be investigated and narrowed down during detailed studies on specific sites both for the potential developers and for the involved authorities.

To evaluate the cost level of an offshore wind project, the present value of all future costs and generated energy are compared in an LCoE calculation. In comparison to FIMOI version 1, this report shows that LCoE projections have decreased for both sites and for all the respective FID year assumptions.

Main LCoE results

One of the purposes of FIMOI version 1 was to showcase the many options available for de-risking and de-costing offshore wind projects through the PPA contract and other economic incentives. In this second phase of the FIMOI project, the purpose has shifted more towards providing solid input data for cost estimations of offshore wind projects and evaluating the need for public subsidies for the first offshore wind farms in India. The two reports should be seen as supplementing each other together with the FIMOI tool for making different scenarios and sensitivities.

This section presents a basic LCoE as it is typically provided in other publications such as marine spatial planning documents, energy modeling, World Bank roadmaps and World Energy Outlook. It is important to note that a basic LCoE like this does not typically include considerations of VAT and duties which the FIMOI version 1 results did. Like in the previous FIMOI report the focus has been kept on full scope as a starting point.

	2020	***2025***	***2030***
Tamil Nadu Zone B	10.3	7.4	5.2
Gujarat	14.4	11.2	7,8

Table 8: Basic LCoE for full scope offshore wind project (INR/kWh, P50)

For Tamil Nadu Zone B the CAPEX account for 5.52 INR/kWh and OPEX account for 1.91 INR/kWh for FID 2025. Likewise for Gujarat CAPEX account for 83 INR/kWh and OPEX account for 2.8 INR/kWh for FID in 2025.

When comparing to the previous FIMOI the LCoE estimates have gone down by a little more than 1 INR/kWh for both sites.

Most notable differences in assumptions from the old FIMOI to this update are lower CAPEX and OPEX, higher energy yield, longer development time and construction time, longer technical life in 2025 and 2030, together with updated values for exchange rate and inflation.

Subsidies

Offshore wind projects are still more costly than other renewable energy technologies such as solar PV and onshore wind and state of the art fossil fuelled technologies if the cost of CO_2 is not accounted for. In most electricity markets this means that it is necessary to rely on public subsidies in order to incentivise developers to construct offshore wind farms. The long term goal of subsidising offshore wind is to stimulate cost reductions through economies of scale and building a local industry such that the offshore wind becomes competitive.

In Europe, the LCoE of offshore wind is expected to reach 4.5 INR/kWh before 2030[8] for some of the best locations. This LCoE is achieved after 3 decades of research and development of offshore wind. At the same time, the spot market price of electricity in the NordPool (Scandinavia) area is expected to hover around the same 4.5 INR/kWh mark, making offshore wind potentially profitable without subsidies. This is the case when a cost on CO_2 are priced into fossil fuel technology costs.

[8] DEA fine screening 2021 of offshore wind sites in Danish territorial waters

Early indications from India suggest that offshore wind will as of today need to be priced down to 3.5 INR/kWh in order for it to be considered competitive in the Indian power system. Such a low cost of energy will require a significant level of subsidies for the first offshore wind farms. In the following, the subsidies needed to reach an LCoE of 3.5 INR/kWh as well as 7 INR/kWh have been estimated. The 7 INR/kWh target is offered as an alternative to the very low 3.5 INR/kWh based on the expectation that offshore wind will displace the least efficient and most expensive fossil fuel based units first.

Below in Table 9 the subsidies needed as either an investment subsidy or in the form of a per unit generations based incentive (GBI) have been estimated. Both types of subsidy are defined in sectiosn 2.2

The results for GBI are presented as the per unit cost, the total annual cost and the net present value of all GBI payments over the lifetime of the project. The investment subsidy is presented at the total subsidy needed during development and construction and the net present value of the subsidy. These subsidies are calculated on the 'Basic LCoE' scenario above, where VAT and duties are not accounted for.

	TARGET LCOE	*3.5 INR/KWH*		*7 INR/KWH*	
SUBSIDY TYPE	***Site***	***Gujarat***	***Tamil Nadu Zone B***	***Gujarat***	***Tamil Nadu Zone B***
GBI	*Per unit (INR/kWh)*	*7.7*	*3.9*	*4.2*	*0.43*
	Annual GBI (bn INR)	*20.2*	*15.5*	*10.9*	*1.7*
	NPV (bn INR)	*170*	*130.8*	*92.3*	*14.2*
INVESTMENT SUBSIDY	*Subsidy (bn INR)*	*191.6*	*147.6*	*104.1*	*9.24*
	NPV (bn INR)	*155.2*	*119.5*	*84.3*	*7.5*

Table 9: Government support to reach target LCoE of 3.5 INR/kWh and 7 INR/kWh (P50, FID 2025) with Basic LCoE starting point

The above table show that with the chosen scenario for FID in 2025 there will be a significant need for support to kick start the offshore wind industry, but that it depends on what is set as the benchmark price for the subsidy evaluation. The higher target cost of energy of 7 INR/kWh is closer to the actual LCoE of offshore wind in Tamil Nadu.

The FIMOI tool has been developed to make fast track scenarios on the viability funding gap needed to make offshore wind project investable and Table 9**Fejl! Henvisningskilde ikke fundet.** show one scenario. Other scenarios with different PPA structures and risk allocation between the developer and the state bodies would give different results on the basis of the updated input parameters.

The FIMOI version 1 report has already showed a number of sensitivities or scenarios outlining how the LCoE and subsidy levels will vary with PPA design and risk allocation, and here is a list of some to consider when doing deeper assessments:

- Indexing (Baseline long term inflation is assumed to be 5% per year, indexing of the tariff could be considered 3% for the first 15 years);
- No delay in payments from offtaker (otherwise 12 months). This will severely delay revenues to the project and reduce the NPV of the project;
- No requirements for energy commitment and penalties associated with deviations from committed energy (average AEP is committed, underproduction is penalized at 75% of PPA tariff, overproduction is paid 75% of PPA tariff);
- Full compensation for curtailment rather than no compensation (curtailment depends on the build out of the underlying high voltage grid close to point of connection);
- No delay in the date of commercial operations (otherwise 50% chance). There is no penalty associated with delays, but the delay of revenue can be a problem

Additionally, there should be considerations round how VAT and duties play into the LCoE and subsidy need. The FIMOI tool can for instance show scenarios where:

- VAT (5%) and duties (13%) on CAPEX are removed or not removed;
- VAT (5%) on OPEX is removed;
- Generation based incentive GBI (14 USD/MWh ~ 1 INR/kWh) is applied.

The target cost of energy of 3.5 INR/kWh for 2025 will require substantial subsidies. Whichever subsidy type is chosen, the cost of the subsidy over the lifetime of the project will be between

117 billion (arab) INR and 127,8 (arab) billion INR for Tamil Nadu zone B and 160 billion (arab) INR and 175 billion (arab) INR in net present value with the basic LCoE as the foundation. Measured by the net present value of the total subsidy, investment subsidies would appear to be the cheapest option. However, a GBI will require a much lower up front fiscal commitment from the Government of India.

The LCoE estimates in Table 8 assume that the CAPEX and OPEX estimates develop as expected. In this it is assumed that the development of the offshore wind industry in India happens at a speed that allows India to benefit from the experience of international developers and to obtain sufficient experience to decrease the construction costs along the way.

It should also be mentioned that the LCoE might go down for the individual projects to be financed by offshore wind developers, if they are only to build and operate the offshore wind farm and offshore substation, hence it is not a full scope project. This is an option that would be explored further in the next phase of the FIMOI project.

Sensitivities

There are many input parameters that affect the LCoE for offshore wind. This chapter would like to show some of the sensitivities regarding the LCoE results and how it affect the overall results.

Full scope versus connection point offshore

A significant determent of the LCoE level is the scope of an offshore wind farm. In the past FIMOI project a full scope offshore wind farm has been considered the base scenario. Full scope means that the developer has ownership of all the infrastructure from the wind turbines towards the offshore substation, the export cables to the connection point on land with an onshore substation. The latest consideration for the first offshore wind farm for India would be to have the metering point and interface between the developer and CTU/PGCIL at the offshore substation. In this scenario it would be the responsibility for CTU/PGCIL to build, own and operate the export cable from the offshore substation and the full onshore electrical infrastructure. This means that the costs for the export cables and onshore substation in this scenario would be socialized.

The FIMOI project has estimated the below costs for the export cable and onshore substation plus other embedded infrastructure onshore.

mINR/MW	***2025***
Export cable	15.56
Onshore substation	5.6

Table 10: Estimates for Export cable and Onshore substation, FID 2025 (mINR/MW)

By excluding these high-level approximated costs from CAPEX the LCoE numbers for this limited project scope will be 6.23 for Tamil Nadu Zone B and 9.37 for Gujarat for FID in 2025.

	2025	***Basic 2025***
Tamil Nadu Zone B	6.23	7.4
Gujarat	9.37	11.2

Table 11: None Full Scope LCoE calculations (INR/kWh, P50)

In the above estimate it has only been the CAPEX related impacts which has been included by moving the metering point for delivering power to the grid, but this will also have an impact on the measured loses. By moving the metering point to the offshore substation the losses from the offshore substation though the export cables offshore including the onshore part to the onshore substation can be disregarded in the LCoE calculations. The reduced loses would imply a higher production to be included in the LCoE calculations, which would result in lower LCoE figures. This reduction in the overall losses related to the meting point being at the offshore substation is currently not included in the calculations and above figures, and the smaller deviation is left for more detailed assessment when the details of the regulation is set.

Inflation sensitivities

One other parameter which affect the LCoE is the anticipated inflation rate during the lifetime of an offshore wind project. In some countries the risk of changes in inflation leading to higher OPEX cost during the years and potentially lower revenues needs to be considered. To illustrate the sensitivity of inflation on the LCoE below is an estimate including a projected life time inflation rate of 6.5% in contrary to the 5% in the base case.

	2025	**Basic 2025**
Tamil Nadu Zone B	7.88	7.4
Gujarat	11.85	11.2

Table 12: Basic LCoE with a projected long term inflation of 6.5% (INR/kWh, P50)

As Table 12 shows LCoE values for Tamil Nadu Zone B will go up by approximately 0.44 INR/kWh and 0.65 INR/kWh for Gujarat in 2025.

Financial numbers

This FIMOI report are based on generic consideration on financial input numbers from the investor dialogue. However, there has not been a deep dive into these parameters in this phase of FIMOI. The project has though had sufficient inputs to create a solid baseline for the financial numbers. There has been inputs considering a lower interest rate on 6% compared to 8% used in the FIMOI basic calculations. This has been turned into a sensitivity with a LCoE calculation with an interest rate on 6%, see table below:

	2025	**Basic 2025**
Tamil Nadu Zone B	6.71	7.24
Gujarat	10,1	11.2

Table 13: LCoE calculations based on 6% interest rate (INR/kWh, P50)

Annual variation in AEP

One key input parameter in the LCoE calculation is the AEP. Offshore wind is a renewable energy where the output varies year to year due to the annual wind conditions. The AEP in the FIMOI report are based on average value based on production estimates from four different scenarios of location and density of a 1050 MW wind farm as explained in the Energy production chapter. However, the FIMOI tool allows for creating an annual variation of the production to create a more realistic scenario. Therefore, a sensitivity with an annual variation of 10 percent and 20 percent estimated uncertainty from the Net AEP after all losses are outlined in order to show how it affects the LCoE.

	10% uncertainty	20% uncertainty	Basic 2025
Tamil Nadu Zone B	7.5	7.6	7.24
Gujarat	11.3	11.43	11.2

Table 14: LCoE calculated based on 10% & 20% uncertainty in AEP production for 2025 (INR/kWh, P50)

Accelerated scenario

The sensitivity analysis highlights some uncertainties that would need careful considerations. There are also inherent uncertainties in projecting future technology developments and cost of CAPEX and OPEX. To further reflect this an accelerated scenario is presented as was also the case for the first FIMOI report. For this FIMOI version 2 report the overall assumption is that India is able to reap the benefit of scale and existing knowhow on onshore wind to reach different cost reductions levels for the first projects. The accelerated cost reductions are especially anticipated to take place for the operational expenditures, where Indian entrepreneurship and experience from the large onshore wind market could come into play, but also other elements are considered as specified below.

The underlying hypothesis is that India through its ambitious offshore wind pipeline and considerable onshore wind experience is able to leapfrog many of the hurdles that other countries face when developing the first offshore wind farms. This accelerated scenario is also based on a scope of the offshore wind project that includes only the offshore wind farm and offshore substation, and not the export cable and any onshore electrical infrastructure.

For the accelerated scenario the interest rate is also set at 6% and the inflation at 5%. For the annual energy production a smaller turbine platform has been assumed giving net capacity factors of 38% for Gujarat and 47% for Tamil Nadu, which reflects the overall assumption of benefitting from scale, existing knowhow and anticipated lower operational expenditures. All together the following estimates have been used to calculate the accelerated scenario.

Estimates		
CAPEX	230	mINR/MW
OPEX	2.500.000	INR/MW
Insurance (nom.)	0.2 % per year of total project cost	
Interest rate	6	%
Inflation	5	%
AEP after all losses		
Gujarat	38	%
Tamil Nadu	47	%

Table 15: The accelerated scenario estimates in 2022 prices

When the accelerated scenario is applied into the FIMOI LCoE and subsidy tool with a 2 year construction time the below LCoE levels of 6.4 INR/kWh for Tamil Nadu and 7.9 INR/kWh for Gujarat comes out.

	2025
Tamil Nadu Zone B	6.4
Gujarat	7,9

Table 16: The accelerated scenario for 2025 (INR/kWh, P50)

This accelerated scenario and LCoE estimates rely on substantial de-costing through risk mitigation, lowering cost of capital and succeeding in rapidly maturing offshore wind in India.

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Abbreviations

AEP	Annual Energy Production
CAPEX	Capital Expenditure – investment costs
CPI	Consumer Price Index
FID	Final Investment Decision
FIMOI	FInancial Modelling of Offshore wind in India
GBI	Government Based Incentives
LCoE	Levelized Cost of Energy
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure – operation and maintenance costs
OWF	Offshore Wind Farm
O&M	Operation and Maintenance
SWA	Service Warranty Agreement
VGF	Viability Gap Funding
WACC	Weighted Average Cost of Capital
WTG	Wind Turbine Generator

Appendix

Figures

Tables