COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

MÁSTER EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

Development and Operation of a Greenfield Wind Farm in Spain

Autor: Ángel Sánchez-Cantalejo Hevia

Director: Javier Ruiz de Galarreta López

Madrid

Diciembre 2024

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título
Development and Operation of a Greenfield Wind Farm in Spain
en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el
curso académico **2024/25** es de mi autoría, original e inédito y
no ha sido presentado con anterioridad a otros efectos.
El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido
tomada de otros documentos está debidamente referenciada.

Fdo.: **Ángel Sánchez-Cantalejo Hevia** Fecha: **23 / 12 / 2024**

Autorizada la entrega del proyecto
EL DIRECTOR DEL PROYECTO

Fdo.: **Javier Ruiz de Galarreta López** Fecha: **31 / 12 / 2024**

MÁSTER EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

Development and Operation of a Greenfield Wind Farm in Spain

Autor: Ángel Sánchez-Cantalejo Hevia

Director: Javier Ruiz de Galarreta López

Madrid

Diciembre 2024

DESARROLLO Y OPERACIÓN DE UN PARQUE EÓLICO GREENFIELD EN ESPAÑA

Autor: Sánchez-Cantalejo Hevia, Ángel.
Director: Ruiz de Galarreta López, Javier.
Entidad Colaboradora: ICAI – Universidad Pontificia Comillas

RESUMEN DEL PROYECTO

Palabras clave: Emprendimiento en Energía Eólica, Evaluación del Recurso Eólico, Marco Regulatorio de las Energías Renovables, Desarrollo de Parques Eólicos, Operación de Parques Eólicos, Mercado Eléctrico Español, Modelización Financiera de Renovables.

1. Introducción

España está experimentando una transformación significativa en su sector energético, impulsada por la necesidad urgente de descarbonizar y alinearse con los objetivos de la Unión Europea. A partir de 2024, España se ha fijado el objetivo de generar el 81% de su electricidad a partir de fuentes renovables para 2030 (PNIEC), una meta que otorga una importancia enorme a la expansión de la capacidad de energía eólica. La energía eólica se ha convertido en un actor crucial en esta transición energética, proporcionando una fuente confiable de electricidad mientras reduce las emisiones de gases de efecto invernadero. Este cambio está en línea con la estrategia más amplia de España para reducir su dependencia de los combustibles fósiles, que actualmente representan una parte importante de su generación de energía. A pesar del progreso, sigue existiendo una necesidad urgente de desarrollar nuevos parques eólicos greenfield que ayuden al país a alcanzar sus ambiciosos objetivos. El desarrollo de estos proyectos no solo aborda los imperativos ambientales, sino que también abre importantes oportunidades empresariales, haciendo de la energía eólica una inversión atractiva para inversores y desarrolladores.

La combinación energética de España ha experimentado cambios sustanciales en los últimos años, con las energías renovables representando ahora una parte significativa de la producción eléctrica del país. En 2022, las fuentes de energía renovables generaron aproximadamente el 43% de la electricidad total de España, siendo la energía eólica responsable de un 21,5%. En enero de 2024, REE estima que la cifra de fuentes renovables ha superado el 50%. Sin embargo, aunque este es un logro notable, la dependencia de fuentes intermitentes como el viento y el sol ha creado nuevos desafíos para la red eléctrica. La variabilidad de la energía eólica, que fluctúa con las condiciones climáticas, puede provocar inestabilidad en la red, lo que requiere la integración de soluciones de almacenamiento y una gestión de red más inteligente para garantizar un suministro eléctrico constante. El desarrollo continuo de tecnologías de almacenamiento de energía, en particular los sistemas de almacenamiento de energía en baterías (BESS), está adquiriendo una importancia creciente para abordar estos problemas y estabilizar el suministro de energía renovable en España.

España se ha posicionado como un líder mundial en la producción de energía eólica, solo por detrás de Alemania dentro de la Unión Europea. Con más de 30,7 GW de capacidad eólica instalada en enero de 2024, el país ha demostrado su compromiso con la energía eólica como un pilar clave de su estrategia de energía renovable. Esta amplia capacidad coloca a España en una posición sólida para continuar su liderazgo en el mercado europeo de energías renovables. Sin embargo, para mantener este impulso, el país debe seguir invirtiendo en el desarrollo de nuevos parques eólicos y adoptar avances tecnológicos, incluida la hibridación y la integración de almacenamiento. Estas innovaciones serán esenciales para optimizar la producción de energía eólica y satisfacer la creciente demanda de electricidad renovable.

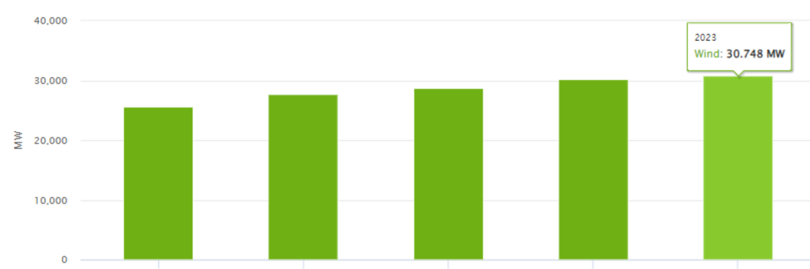


Figura 1: Evolución de la capacidad instalada de energía eólica en España (MW)

El sector de la energía eólica no solo es importante desde una perspectiva ambiental, sino que también desempeña un papel crucial en el desarrollo económico de España. Según la Asociación Empresarial Eólica (AEE), a partir de 2022 la industria eólica sostiene alrededor de 40,000 empleos en todo el país y contribuye aproximadamente con el 0,5% del PIB nacional. Los beneficios económicos de la energía eólica son particularmente significativos en las zonas rurales, donde se ubican muchos parques eólicos, proporcionando empleos y estimulando las economías locales. Esto convierte a la energía eólica en un motor clave del desarrollo regional, especialmente en áreas como Castilla y León y Aragón, que cuentan con algunas de las mayores capacidades de energía eólica en España. A medida que el país continúe expandiendo su infraestructura de energía eólica, se espera que estas regiones experimenten un mayor crecimiento económico y creación de empleo.

Los avances tecnológicos han desempeñado un papel fundamental en el éxito de la energía eólica en España. Los aerogeneradores modernos son más grandes, más eficientes y capaces de generar mayores cantidades de electricidad en comparación con sus predecesores. Los aerogeneradores con capacidades que van desde los 2 MW hasta más de 6 MW se han convertido en estándar para proyectos en tierra, y su diseño ha sido optimizado para mejorar el rendimiento y reducir los costos operativos. Las innovaciones en el diseño de las palas, los materiales y la aerodinámica han contribuido a estos avances, permitiendo a los parques eólicos generar más electricidad a un menor costo. Esta reducción del Coste Nivelado de la Energía (LCOE) es uno de los factores clave que impulsa la inversión continua en proyectos de energía eólica.

El proyecto tiene como objetivo proporcionar un manual integral para emprendedores que buscan ingresar al mercado de las energías renovables. Ese es el objetivo último y principal de la tesis. El proyecto está diseñado para servir como una guía práctica que cubre todos los aspectos del desarrollo de un parque eólico, desde la selección del sitio y el cumplimiento normativo hasta la modelización financiera y la operación. Al centrarse en las oportunidades empresariales que presenta la energía eólica, este proyecto destaca cómo los nuevos inversores pueden capitalizar el creciente mercado de energías renovables en España. Proporciona las herramientas y conocimientos necesarios para navegar los desafíos técnicos, financieros y regulatorios asociados con el desarrollo de un parque eólico desde cero.

El marco regulatorio de España ha desempeñado un papel fundamental en el apoyo al desarrollo de proyectos de energías renovables. Sin embargo, navegar por este entorno normativo puede ser complejo, especialmente para los emprendedores que son nuevos en el sector. El proyecto describe los pasos clave necesarios para obtener los permisos correspondientes, completar las evaluaciones de impacto ambiental y obtener las aprobaciones de conexión a la red. Estos procesos regulatorios son esenciales para garantizar que un parque eólico cumpla con las normativas nacionales y de la Unión Europea, que a menudo pueden ser una barrera significativa para el desarrollo del proyecto.

Al proporcionar una hoja de ruta clara para navegar por estas regulaciones, el proyecto tiene como objetivo simplificar el proceso de desarrollo para los emprendedores.

Además de las consideraciones de desarrollo y normativas, el proyecto pone un fuerte énfasis en los aspectos operativos a largo plazo del parque eólico. La fase operativa no solo implica la gestión diaria de los aerogeneradores, sino también la integración de la producción de energía en el mercado eléctrico español. Esto incluye la gestión de las ventas de electricidad a través de mecanismos como los Acuerdos de Compra de Energía (PPA) y la participación en estrategias de comercialización en el mercado. Asegurar que el parque eólico siga siendo financieramente viable durante su vida útil operativa requiere un monitoreo continuo de las condiciones del mercado y la adaptación de las estrategias operativas en consecuencia.

Otro aspecto crucial de este proyecto es el análisis técnico de la evaluación del recurso eólico. Evaluar con precisión los recursos eólicos es fundamental para determinar la viabilidad de un parque eólico. El proyecto utiliza herramientas avanzadas, como los Sistemas de Información Geográfica (GIS), para analizar los datos de velocidad del viento, la intensidad de la turbulencia y las variaciones estacionales. Este análisis garantiza que el sitio seleccionado proporcione condiciones óptimas para la generación de energía. Al comprender el comportamiento del viento a un nivel micro, el proyecto puede estimar con precisión el rendimiento energético potencial del parque eólico, lo cual es esencial para la planificación financiera y la obtención de la confianza de los inversores.

Además, uno de los elementos centrales de este proyecto es su enfoque en la estructuración financiera, un componente clave en cualquier proyecto de emprendimiento. Se ha desarrollado un modelo financiero dinámico que permite a los emprendedores probar varios escenarios de negocio y evaluar la viabilidad y rentabilidad de sus proyectos. Este modelo incorpora variables como los precios de la energía, los gastos de capital y los costos operativos, proporcionando una herramienta flexible para la toma de decisiones. Al permitir a los usuarios simular diferentes escenarios, el modelo ayuda a los emprendedores a comprender los riesgos y beneficios asociados con sus inversiones, garantizando que sus proyectos se mantengan financieramente sostenibles a largo plazo.

El proyecto también tiene como objetivo abordar los impactos socioeconómicos más amplios del desarrollo de parques eólicos. Además de los beneficios ambientales de la reducción de emisiones de gases de efecto invernadero, los proyectos de energía eólica pueden traer importantes beneficios económicos a las comunidades locales. Al crear empleos y estimular la actividad económica en las zonas rurales, los parques eólicos pueden desempeñar un papel vital en el desarrollo regional.

En última instancia, el proyecto de *Desarrollo y Operación de un Parque Eólico Greenfield en España* proporciona una hoja de ruta para los emprendedores que buscan capitalizar las oportunidades que presenta la transición energética renovable de España. Al combinar conocimientos técnicos, financieros y regulatorios, el proyecto equipa a los emprendedores con las herramientas que necesitan para desarrollar y operar exitosamente parques eólicos en España. Se enfatiza la rentabilidad a largo plazo a través de la planificación estratégica, la gestión de riesgos y el monitoreo continuo de las condiciones del mercado, garantizando que los nuevos proyectos de energía eólica prosperen en el competitivo mercado energético español.

2. Metodología

El proceso de desarrollo de un parque eólico greenfield en España comienza con la tarea crucial de la selección del sitio y la evaluación del recurso eólico. Esta fase inicial establece la base para todo el proyecto al identificar las ubicaciones potenciales donde las condiciones del viento son más favorables para la producción de energía. Los emprendedores deben considerar varios factores, incluidos la fuerza y la consistencia de los patrones de viento, la proximidad a la infraestructura de transmisión y el impacto ambiental. Los Sistemas de Información Geográfica (GIS) desempeñan un papel clave en esta fase al proporcionar mapas detallados que destacan áreas con potencial eólico óptimo y ventajas logísticas. El proceso de selección también implica evaluar los marcos regulatorios locales y obtener los permisos necesarios para cumplir con las leyes ambientales y energéticas de España. Al elegir estratégicamente un sitio que equilibre una alta disponibilidad de viento con facilidad regulatoria, los desarrolladores pueden maximizar la producción de energía y, al mismo tiempo, minimizar las complejidades relacionadas con la obtención de aprobaciones y la mitigación de los impactos ambientales.

Una vez seleccionado el sitio, el siguiente paso se centra en el diseño técnico y la ingeniería. Esta fase incluye la determinación del tipo, capacidad y distribución de los aerogeneradores. La selección de las turbinas se basa en factores como la altura del buje, el diámetro del rotor y la capacidad de generación, todos los cuales influyen en la eficiencia general de la generación de energía. La colocación de las turbinas también debe tener en cuenta los efectos de estela, que pueden reducir el rendimiento de las turbinas posteriores si están demasiado cerca unas de otras. Además del diseño de las turbinas, se considera la infraestructura eléctrica requerida para transmitir la electricidad generada a la red. Esto implica la planificación de subestaciones y líneas de transmisión que puedan manejar la producción variable típica de los parques eólicos. Al optimizar la configuración técnica del parque eólico, los desarrolladores pueden garantizar que el proyecto no solo produzca energía de manera eficiente, sino que también cumpla con los estándares operativos y ambientales.

En paralelo con el diseño técnico, deben abordarse el cumplimiento normativo y las consideraciones ambientales. El marco legal de España para proyectos de energías renovables exige evaluaciones de impacto ambiental integrales para garantizar que los parques eólicos no afecten negativamente a los ecosistemas locales o a las comunidades. Estas evaluaciones cubren una variedad de temas, incluidos la contaminación acústica, los efectos sobre la fauna (particularmente aves y murciélagos), y el impacto visual de las turbinas en el paisaje. Los emprendedores deben navegar cuidadosamente este panorama regulatorio para evitar retrasos costosos o multas que puedan surgir por incumplimiento. Además, la participación de la comunidad es esencial durante esta fase, ya que obtener el apoyo de las partes interesadas locales puede prevenir la oposición y fomentar una relación positiva con el área circundante. Esto no solo facilita el proceso de permisos, sino que también asegura el éxito a largo plazo del proyecto.

Después de completar las fases de selección del sitio y desarrollo, el proyecto entra en la etapa de construcción. Durante esta fase, la coordinación logística se vuelve vital para garantizar que las turbinas y la infraestructura se entreguen e instalen según lo programado. Los parques eólicos son proyectos a gran escala que implican el transporte de componentes masivos de las turbinas, a menudo a través de áreas rurales con infraestructura limitada. Como resultado, los desarrolladores deben trabajar en estrecha colaboración con las autoridades locales para planificar las rutas de transporte, evitar interrupciones y asegurar la entrega oportuna de los materiales. Una vez que llegan los componentes, los equipos de construcción comienzan a instalar las turbinas, subestaciones y conexiones a la red. Esta etapa requiere una planificación meticulosa para minimizar la perturbación ambiental y garantizar la seguridad, particularmente durante el levantamiento e instalación de las torres y las palas de las turbinas. La finalización de esta fase marca un hito importante a medida que el proyecto pasa de la planificación a la operación.

Una vez completada la fase de construcción, el parque eólico entra en plena operación, donde comienza a generar y vender electricidad. La fecha en la que el parque eólico comienza oficialmente sus operaciones comerciales se denomina Fecha de Operación Comercial (COD, por sus siglas en inglés). A partir de este momento, el parque se integra en el mercado eléctrico liberalizado de España, donde la energía se comercializa a través de varias plataformas. Estas incluyen el mercado diario y los acuerdos bilaterales, como los Acuerdos de Compra de Energía (PPA), que ofrecen estabilidad de ingresos a largo plazo al fijar los precios de la energía durante varios años. La gestión efectiva de las operaciones del parque requiere un profundo conocimiento de cómo fluye la electricidad a través de la red nacional. La electricidad generada se transmite primero a través de líneas de alta tensión gestionadas por Red Eléctrica de España (REE) y, finalmente, se distribuye a los consumidores.

La operación de un parque eólico no se trata solo de generar electricidad, sino también de tomar decisiones estratégicas sobre cómo optimizar las fuentes de ingresos. En España, los parques eólicos pueden participar en el mercado mayorista de electricidad (ingresos de mercado) o buscar ingresos más estables a través de esquemas de remuneración regulada. Los ingresos del mercado mayorista están sujetos a la volatilidad del mercado, donde los precios de la energía fluctúan en función de la oferta y la demanda. Esto crea un nivel de incertidumbre financiera que los operadores deben gestionar con cuidado. Por otro lado, los regímenes regulados españoles, como el Régimen Retributivo Específico o el Régimen Económico de Energías Renovables, ofrecen ingresos más predecibles al proporcionar pagos fijos por la energía producida. Estos regímenes a menudo requieren procesos de licitación competitiva donde los desarrolladores deben demostrar que sus proyectos pueden operar de manera eficiente con un apoyo gubernamental mínimo. La elección entre la participación en el mercado y los esquemas regulados depende de la tolerancia al riesgo del desarrollador y de las condiciones del mercado.

Gestionar los gastos operativos (Opex) es otro aspecto crítico de la operación de un parque eólico. El mantenimiento es uno de los costos continuos más grandes, ya que los aerogeneradores requieren inspecciones y servicios regulares para garantizar que continúen operando de manera eficiente. Por lo general, se emplean estrategias de mantenimiento preventivo para reducir el tiempo de inactividad y prolongar la vida útil de los aerogeneradores. Al monitorear componentes clave como las palas, los generadores y los sistemas de control, los operadores pueden identificar posibles problemas antes de que generen fallas costosas. Además del mantenimiento, otros costos operativos incluyen los acuerdos de arrendamiento de tierras, los seguros y las tarifas de conexión a la red. La gestión efectiva de estos gastos es crucial para mantener la salud financiera del parque eólico y garantizar que siga siendo rentable durante su vida operativa.

La sostenibilidad financiera de un parque eólico está estrechamente ligada a su capacidad para generar ingresos constantes mientras mantiene los costos bajo control. Como se mencionó anteriormente, las fluctuaciones en los precios de la electricidad pueden tener un impacto significativo en la rentabilidad, particularmente para los parques eólicos que dependen de los ingresos del mercado. Para mitigar este riesgo, los operadores pueden explorar el uso de sistemas de almacenamiento de energía en baterías (BESS), que permiten almacenar el exceso de energía durante los períodos de alta producción eólica y venderla cuando la demanda (y los precios) son más altos. Esta estrategia no solo estabiliza los ingresos, sino que también mejora la fiabilidad de la producción del parque eólico, haciéndolo una opción más atractiva para los operadores de redes. La integración de tecnologías de almacenamiento está adquiriendo cada vez más importancia a medida que las fuentes de energía renovable desempeñan un papel más importante en la mezcla energética de España.

Para proporcionar una comprensión completa de cómo estos procesos se integran, el proyecto incluye un estudio de caso que simula el desarrollo de un parque eólico en Burgos, una provincia con un alto potencial eólico. El estudio de caso comienza con el proceso de evaluación del recurso eólico, utilizando datos históricos del viento para evaluar el potencial de producción energética del sitio. Al analizar las velocidades del viento, la dirección y los patrones estacionales, el estudio determina si la ubicación es adecuada para el desarrollo de un parque eólico. Esta etapa es crítica para los emprendedores, ya que les ayuda a comprender cómo evaluar la viabilidad de los sitios potenciales para parques eólicos en función tanto de consideraciones técnicas como financieras.

El estudio de caso continúa probando diferentes escenarios operativos para estimar la producción de energía y los rendimientos financieros del parque eólico. Se analizan varias configuraciones de aerogeneradores, y los resultados se comparan para determinar qué disposición proporcionaría el mayor rendimiento energético. Además, se prueban hipótesis operativas como los costos de mantenimiento, las tarifas de integración a la red y los precios del mercado dentro del modelo financiero. Esto permite al desarrollador prever la tasa interna de retorno (TIR) y el valor actual neto (VAN) bajo diferentes condiciones de mercado. Al comparar estos escenarios, el estudio de caso proporciona información valiosa sobre cómo las decisiones operativas afectan los resultados financieros del parque eólico. Este proceso ayuda a los emprendedores a tomar decisiones informadas sobre cómo optimizar sus proyectos para maximizar la rentabilidad.

Básicamente, como se resume anteriormente, el estudio de caso sirve como una demostración práctica de cómo los emprendedores pueden aplicar los principios discutidos en el proceso de desarrollo y operación de parques eólicos. Integra todos los componentes clave (desde la evaluación del recurso eólico y el diseño técnico hasta la participación en el mercado y la modelización financiera) en una estrategia coherente para desarrollar un parque eólico exitoso. Como se explicará en la sección de resultados, el estudio de caso ilustra cómo cada decisión, desde la selección del sitio hasta la elección del modelo de ingresos, desempeña un papel fundamental en la determinación del éxito general del proyecto.

3. Resultados

El análisis financiero del proyecto de parque eólico del estudio de caso es clave para comprender la viabilidad y rentabilidad a largo plazo del desarrollo. Se proyecta que el proyecto comenzará a generar ingresos en 2029, una vez completada la fase de construcción. A partir de ese momento, los ingresos provendrán de dos fuentes principales: ingresos del pool del mercado mayorista de electricidad de España y Garantías de Origen (GoOs). También estará vigente un Acuerdo de Compra de Energía (PPA) a partir de 2032, lo que estabilizará los ingresos al garantizar un precio fijo para una parte de la energía producida. Esta estructura ayuda a mitigar la volatilidad del mercado, proporcionando flujos de efectivo predecibles para el desarrollador. Como resultado, se espera que los ingresos anuales oscilen entre 8 y 9 millones de euros desde 2029 hasta 2043, con fluctuaciones menores impulsadas por los cambios en los precios del pool y los coeficientes de captación del viento.

Se proyecta que los gastos operativos (Opex) se mantendrán relativamente estables durante toda la vida operativa del parque eólico, aunque aumentarán ligeramente con el tiempo debido a la inflación y al envejecimiento de las turbinas, lo que resultará en mayores costos de mantenimiento. Estos costos operativos incluyen la operación y el mantenimiento (O&M) continuos, los pagos de arrendamientos de terrenos y los seguros. El margen EBITDA del proyecto se mantiene sólido, situándose consistentemente entre el 60% y el 70% a partir de 2029. Este alto margen refleja los bajos costos operativos típicos de los proyectos de energía eólica, donde los principales gastos se producen durante las fases de desarrollo y construcción. Con sólidos márgenes EBITDA que oscilan entre 5 y 6 millones de euros anuales, el parque eólico está posicionado para generar flujos de efectivo operativos significativos durante su vida útil.

Los gastos de depreciación y amortización (D&A) se incluyen en los estados financieros, reflejando los gastos de capital (Capex) continuos necesarios para mantener las operaciones del parque eólico a lo largo del tiempo. Aunque se espera que las turbinas tengan una larga vida útil, será necesario realizar mantenimiento regular y actualizaciones ocasionales para garantizar una eficiencia continua. Estas inversiones de capital contribuyen a un ligero aumento en los gastos de D&A a lo largo de los años, que se reflejarán en el estado de resultados. Además, el proyecto está estructurado para reducir la deuda de manera constante a lo largo del tiempo, con los pagos de la deuda comenzando poco después de que el parque eólico se ponga en funcionamiento. Los pagos de intereses alcanzarán su punto máximo en 2029, cuando la deuda esté en su nivel más alto, pero disminuirán significativamente a medida que se reembolse el principal, alcanzando finalmente cero en 2045, cuando toda la deuda esté completamente pagada.

El estado de flujo de caja proporciona una visión detallada de la capacidad del proyecto para generar efectivo para el servicio de la deuda y las distribuciones a los accionistas. Después de cubrir todos los gastos operativos, el servicio de la deuda y los impuestos, se espera que el parque eólico genere suficiente efectivo para realizar distribuciones a los accionistas a partir de 2029. Estas distribuciones aumentarán de manera constante a medida que se amortice la deuda, y los tenedores de capital recibirán una mayor proporción de los flujos de efectivo del proyecto. Esta estructura financiera permite una asignación eficiente de capital, garantizando que se cumplan las obligaciones de deuda al mismo tiempo que se proporcionan atractivos rendimientos a los inversores en capital. Al aprovechar la deuda bancaria durante la fase de construcción y utilizar los flujos de efectivo estables del parque eólico para reembolsar esta deuda, el proyecto maximiza los rendimientos tanto para los tenedores de deuda como para los de capital.

Para evaluar el valor total del proyecto de parque eólico, se realizó una valoración utilizando dos métodos estándar en la industria: el enfoque de Flujo de Caja Descontado (DCF) y los múltiplos de valoración relativos. En el modelo DCF, los flujos de efectivo futuros del parque eólico, a partir de 2029, se descuentan al presente a una tasa del 7.5%, lo que refleja el rendimiento esperado de un activo eólico completamente operativo. Este método produce un valor patrimonial de 21,9 millones de euros para 2029, con un valor empresarial correspondiente de 61,4 millones de euros cuando se combina con la deuda neta proyectada de 39,4 millones de euros en ese momento. El múltiplo de valoración implícito es de 1,2 millones de euros por MW, lo que está ligeramente por encima de las normas del sector. Sin embargo, esta valoración más alta se justifica por el fuerte recurso eólico en el sitio seleccionado y los sólidos indicadores financieros del proyecto.

La tasa interna de retorno (TIR) y el valor total sobre el capital invertido (TVPI) también se calcularon para determinar el atractivo del proyecto desde la perspectiva del inversor. Se proyecta que la TIR alcanzará el 23.6%, un resultado sólido para un proyecto de infraestructura, particularmente dado el apalancamiento utilizado durante la fase de construcción. Esta alta TIR se debe a la relativamente baja inversión inicial de capital requerida por el desarrollador, ya que la mayor parte de la financiación del proyecto proviene de la deuda. Una vez que el parque eólico esté operativo, su perfil de riesgo disminuye significativamente, con el principal riesgo derivado de las fluctuaciones en los precios de la electricidad. Se estima que el TVPI sea de 1.55x, lo que significa que por cada 1 € invertido, el desarrollador puede esperar recibir 1,55 € en retorno. Este sólido retorno destaca el potencial del proyecto como una inversión rentable.

Para evaluar aún más la solidez de las proyecciones financieras del proyecto, se realizó una serie de análisis de sensibilidad. Estos análisis prueban cómo los cambios en las suposiciones clave (como el año de salida, la tasa de descuento y los términos de refinanciamiento) afectarían la valoración del proyecto y los rendimientos de los inversores. Por ejemplo, retrasar el año de salida de 2029 a 2033 reduce ligeramente la TIR, ya que la salida posterior disminuye el valor temporal del dinero. Sin embargo, el TVPI aumenta en este escenario porque el parque eólico habrá tenido más tiempo para generar y distribuir dividendos. Además, ajustar la tasa de descuento entre el 7.0% y el 8.0% muestra cuán sensible es la valoración del proyecto a los cambios en las expectativas de los inversores. Una tasa de descuento más alta reduce tanto la TIR como el TVPI, reflejando el aumento del costo de capital.

Otro análisis de sensibilidad clave se centró en los términos de refinanciamiento, en particular la relación de cobertura del servicio de la deuda (DSCR) y el margen en el instrumento de refinanciamiento. Aumentar la DSCR objetivo de 1.30x a 1.50x mejora la TIR del proyecto, ya que permite al desarrollador mantener más flujo de caja para las distribuciones de capital. Sin embargo, un margen más alto sobre la deuda de refinanciamiento reduce los rendimientos, particularmente en el peor de los casos, donde el margen alcanza el 3.0%. A pesar de estos cambios, el proyecto sigue siendo financieramente viable en todos los escenarios probados, con la TIR manteniéndose por encima del 18% incluso en los casos más pesimistas. Esta resistencia demuestra la solidez del modelo financiero del parque eólico.

Los análisis de sensibilidad también exploraron factores operativos, como las horas netas equivalentes (NEH) de producción de energía eólica y el número de turbinas instaladas. Aumentar las NEH de 2.400 a 3.000 horas por año mejora significativamente la TIR del proyecto, ya que una mayor producción de energía genera mayores ingresos. En contraste, cambiar el número de turbinas tiene un impacto más modesto en los rendimientos, lo que indica que la escala del proyecto ya está optimizada para el recurso eólico del sitio. Este análisis subraya la importancia de evaluar con precisión las condiciones del viento durante la fase de selección del sitio, ya que el éxito financiero del proyecto depende en gran medida de la producción de energía constante.

Finalmente, se realizó un análisis de sensibilidad sobre el precio del PPA y la proporción de energía vendida en el mercado pool frente al PPA. Los resultados muestran que aumentar el precio del PPA de 40 €/MWh a 60 €/MWh mejora significativamente los rendimientos del proyecto, mientras que vender un mayor porcentaje de energía en el mercado pool aumenta la exposición a la volatilidad de los precios. Este análisis ayuda al desarrollador a comprender cómo las diferentes estrategias de ingresos afectan el perfil riesgo-retorno del proyecto, lo que les permite optimizar su enfoque en función de las condiciones del mercado. En general, los resultados de estos análisis de sensibilidad demuestran que el proyecto de parque eólico es financieramente resistente y capaz de ofrecer fuertes retornos a los inversores bajo una variedad de escenarios.

Las siguientes tablas, que muestran el análisis de sensibilidad realizado sobre el precio del PPA (eje vertical) y la proporción de energía vendida en el mercado pool frente al PPA (eje horizontal), ejemplifican el tipo de análisis que se puede encontrar en los resultados del estudio de caso del proyecto:

Exit IRR	40%	50%	60%	70%	80%
40.0	13.8%	16.2%	18.5%	20.7%	23.0%
45.0	17.9%	19.5%	21.1%	22.6%	24.2%
50.0	21.7%	22.7%	23.6%	24.5%	25.4%
55.0	25.5%	25.8%	26.1%	26.4%	26.7%
60.0	29.1%	28.8%	28.5%	28.2%	27.9%

Tabla 1: Sensibilidad (i) % de energía vendida al pool vs. PPA & (ii) Precio del PPA sobre la TIR de salida

Exit TVPI	40%	50%	60%	70%	80%
40.0	1.30x	1.36x	1.42x	1.48x	1.54x
45.0	1.40x	1.44x	1.48x	1.53x	1.57x
50.0	1.50x	1.53x	1.55x	1.58x	1.61x
55.0	1.61x	1.62x	1.63x	1.63x	1.64x
60.0	1.72x	1.71x	1.70x	1.69x	1.68x

Tabla 2: Sensibilidad (i) % de energía vendida al pool vs. PPA & (ii) Precio del PPA sobre el TVPI de salida

LT IRR	40%	50%	60%	70%	80%
40.0	8.6%	9.0%	9.3%	9.7%	10.1%
45.0	9.2%	9.5%	9.8%	10.0%	10.3%
50.0	9.9%	10.0%	10.2%	10.3%	10.5%
55.0	10.5%	10.5%	10.6%	10.6%	10.7%
60.0	11.1%	11.0%	11.0%	10.9%	10.9%

Tabla 3: Sensibilidad (i) % de energía vendida al pool vs. PPA & (ii) Precio del PPA sobre la TIR a largo plazo

4. Conclusiones

El desarrollo y operación de un parque eólico greenfield en España ofrece una oportunidad única para que los emprendedores contribuyan a la transición hacia las energías renovables, al tiempo que capitalizan un mercado maduro y de apoyo. El liderazgo de España en energía eólica, junto con marcos regulatorios favorables y una cadena de suministro robusta, crea un entorno óptimo para el desarrollo de parques eólicos. Los emprendedores deben comprender la importancia de la selección del sitio, la colocación de las turbinas y la evaluación del recurso eólico como determinantes clave del éxito general del proyecto. Estos fundamentos técnicos y regulatorios son cruciales para optimizar la producción de energía y garantizar que el parque eólico opere de manera eficiente en un mercado altamente competitivo.

Una conclusión importante del proyecto es la relevancia de integrar la sostenibilidad financiera con el rendimiento técnico. Los emprendedores deben desarrollar modelos financieros dinámicos que puedan incorporar variables como los precios de la energía, los gastos operativos (opex) y acuerdos a largo plazo como los PPAs. Estos modelos son esenciales para predecir la viabilidad del parque eólico en diferentes condiciones de mercado y garantizar rendimientos estables para los inversores. Además, los análisis de sensibilidad destacan cómo los cambios en las condiciones del mercado, las tasas de descuento y los factores operativos pueden afectar significativamente la rentabilidad del proyecto. Comprender y mitigar estos riesgos es vital para maximizar los rendimientos y mantener la resiliencia financiera a lo largo de la vida operativa del parque eólico.

Otra conclusión clave es la importancia de navegar de manera efectiva por el panorama regulatorio en España. Obtener los permisos necesarios, como las evaluaciones de impacto ambiental y las aprobaciones de conexión a la red, es una de las fases que consume más tiempo en el desarrollo de un parque eólico. Los emprendedores deben interactuar con las autoridades locales y los organismos reguladores desde el principio del proceso para evitar retrasos y garantizar el cumplimiento de los estándares nacionales y de la Unión Europea.

Los resultados del proyecto también subrayan la importancia de la eficiencia operativa y la gestión de costos. Los emprendedores deben implementar estrategias de mantenimiento preventivo y monitorear de cerca los opex para asegurarse de que el parque eólico continúe operando a niveles óptimos durante toda su vida útil. Prestar especial atención al mantenimiento de las turbinas, las tarifas de conexión a la red y los costos de seguros ayudará a gestionar estos opex, al mismo tiempo que se maximiza la producción de energía y la rentabilidad. Además, innovaciones como la hibridación con energía solar y los sistemas de almacenamiento de energía en baterías pueden mejorar la eficiencia operativa del parque eólico, mitigar la intermitencia de la energía renovable y estabilizar los flujos de caja durante períodos de fluctuaciones en la demanda del mercado.

Desde una perspectiva financiera, el proyecto demuestra cómo aprovechar la deuda durante la fase de construcción y estructurar planes de amortización a largo plazo puede aumentar los rendimientos tanto para los tenedores de deuda como de capital. Los pagos de intereses y el servicio de la deuda también deben gestionarse cuidadosamente. Los emprendedores deben considerar opciones de refinanciamiento y ajustar las relaciones de cobertura del servicio de la deuda (DSCR) para optimizar su estructura de capital y mejorar la rentabilidad. Además, el fuerte TIR y los sólidos indicadores de valoración del estudio de caso del proyecto sugieren que las inversiones en parques eólicos son realmente atractivas para los inversores, especialmente cuando están respaldadas por acuerdos de ingresos a largo plazo (PPAs).

Finalmente, el proyecto se alinea con varios Objetivos de Desarrollo Sostenible (ODS), en particular aquellos centrados en la energía limpia, la innovación en la industria y la acción climática. Al generar energía renovable, reducir las emisiones de gases de efecto invernadero y fomentar el crecimiento económico en las zonas rurales, los parques eólicos contribuyen a los esfuerzos de sostenibilidad global. Los emprendedores deben priorizar estos impactos ambientales y sociales más amplios al desarrollar proyectos de energía renovable, asegurando que sus emprendimientos no solo generen retornos financieros, sino que también contribuyan positivamente a la transición energética global y a la lucha contra el cambio climático.

DEVELOPMENT AND OPERATION OF A GREENFIELD WIND FARM IN SPAIN

Author: Sánchez-Cantalejo Hevia, Ángel.
Supervisor: Ruiz de Galarreta López, Javier.
Collaborating Entity: ICAI – Universidad Pontificia Comillas

ABSTRACT

Keywords: Wind Energy Entrepreneurship, Wind Resource Assessment, Renewables Regulatory Framework, Wind Farm Development, Wind Farm Operation, Spanish Electricity Market, Renewables Financial Modelling.

1. Introduction

Spain is undergoing a significant transformation in its energy sector, driven by the pressing need to decarbonize and align with European Union targets. As of 2024, Spain aims to achieve 81% of its electricity generation from renewable sources by 2030 (PNIEC), a goal that places immense importance on the expansion of wind energy capacity. Wind energy has become a crucial player in this energy transition, providing a reliable source of electricity while reducing greenhouse gas emissions. This shift aligns with Spain's broader strategy to reduce its dependence on fossil fuels, which currently account for a significant portion of its energy generation. Despite the progress, there remains an urgent need to develop new greenfield wind farms that can help the country meet its ambitious targets. The development of such projects not only addresses environmental imperatives but also opens significant entrepreneurial opportunities, making wind energy an attractive venture for investors and developers.

The Spanish energy mix has undergone substantial changes in recent years, with renewable energy now accounting for a significant share of the country's electricity production. In 2022, renewable energy sources generated approximately 43% of Spain’s total electricity, with wind energy alone contributing 21.5%. As of January 2024, REE estimates the renewable sources figure to have breached the 50%. However, while this is a remarkable achievement, the reliance on intermittent sources such as wind and solar has created new challenges for the electricity grid. The variability of wind power, which fluctuates with weather conditions, can lead to instability in the grid, requiring the integration of storage solutions and smarter grid management to ensure a consistent electricity supply. The ongoing development of energy storage technologies, particularly battery energy storage systems (BESS), is becoming increasingly important to address these issues and stabilize the renewable energy supply in Spain.

Spain has positioned itself as a global leader in wind energy production, second only to Germany within the European Union. With over 30.7 GW of installed wind capacity as of January 2024, the country has demonstrated its commitment to wind energy as a key pillar of its renewable energy strategy. This extensive capacity places Spain in a strong position to continue its leadership in the European renewable energy market. However, to maintain this momentum, the country must continue to invest in the development of new wind farms and embrace technological advancements, including hybridization and storage integration. These innovations will be essential to optimize wind energy production and meet the growing demand for renewable electricity.

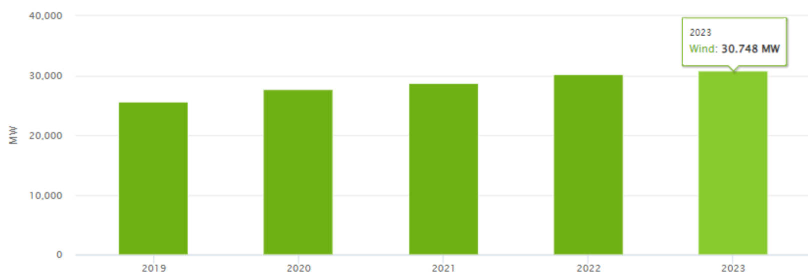


Figure 1: Wind installed capacity evolution in Spain (MW)

The wind energy sector is not only important from an environmental perspective but also plays a critical role in Spain's economic development. According to Asociación Empresarial Eólica (AEE), as of 2022 the wind industry supports c. 40,000 jobs across the country and contributes approximately 0.5% of the national GDP. The economic benefits of wind energy are particularly significant in rural areas, where many wind farms are located, providing jobs and stimulating local economies. This makes wind energy a key driver of regional development, particularly in areas such as Castilla y León and Aragón, which boast some of the highest wind energy capacities in Spain. As the country continues to expand its wind energy infrastructure, these regions are expected to see further economic growth and job creation.

Technological advancements have played a vital role in the success of wind energy in Spain. Modern wind turbines are larger, more efficient, and capable of generating greater amounts of electricity compared to their predecessors. Turbines with capacities ranging from 2 MW to over 6

MW have become standard for onshore projects, and their design has been optimized to improve performance and reduce operational costs. Innovations in blade design, materials, and aerodynamics have contributed to these advancements, enabling wind farms to generate more electricity at a lower cost. This reduction in the Levelized Cost of Electricity (LCOE) is one of the key factors driving the continued investment in wind energy projects.

The project aims to provide a comprehensive manual for entrepreneurs looking to enter the renewable energy market. That is the ultimate and main objective of the thesis. The project is designed to serve as a practical guide that covers all aspects of wind farm development, from site selection and regulatory compliance to financial modeling and operation. By focusing on the entrepreneurial opportunities presented by wind energy, this project highlights how new investors can capitalize on Spain’s growing renewable energy market. It provides the necessary tools and insights to navigate the technical, financial, and regulatory challenges associated with developing a wind farm from scratch.

Spain's regulatory framework has played a critical role in supporting the development of renewable energy projects. However, navigating this regulatory landscape can be complex, particularly for entrepreneurs who are new to the sector. The project outlines the key steps required to secure the necessary permits, complete environmental impact assessments, and obtain grid connection approvals. These regulatory processes are essential for ensuring that a wind farm complies with national and European Union regulations, which can often be a significant barrier to project development. By providing a clear roadmap for navigating these regulations, the project aims to simplify the development process for entrepreneurs.

In addition to development and regulatory considerations, the project places a strong emphasis on the long-term operational aspects of the wind farm. The operation phase involves not only the day-to-day management of the wind turbines but also the integration of energy production into Spain’s electricity market. This includes managing electricity sales through mechanisms like Power Purchase Agreements (PPAs) and participating in market trading strategies. Ensuring that the wind farm remains financially viable over its operational lifetime requires continuous monitoring of market conditions and adapting operational strategies accordingly.

Another crucial aspect of this project is the technical analysis of wind resource assessment. Accurately assessing wind resources is critical for determining the feasibility of a wind farm. The project uses advanced tools, such as Geographic Information Systems (GIS), to analyze wind speed data, turbulence intensity, and seasonal variations. This analysis ensures that the selected site provides optimal conditions for energy generation. By understanding wind behaviour at a micro-level, the project can accurately estimate the potential energy yield of the wind farm, which is essential for financial planning and securing investor confidence.

Additionally, one of the central elements of this project is its focus on financial structuring, key in every entrepreneurship project. A dynamic financial model is developed to allow entrepreneurs to test various business scenarios and assess the viability and profitability of their projects. This model incorporates variables such as energy prices, capital expenditure, and operational costs, providing a flexible tool for decision-making. By enabling users to simulate different scenarios, the model helps entrepreneurs understand the risks and returns associated with their investments, ensuring that their projects remain financially sustainable in the long term.

The project also aims to address the broader socio-economic impacts of wind farm development. In addition to the environmental benefits of reducing greenhouse gas emissions, wind energy projects can bring significant economic benefits to local communities. By creating jobs and stimulating economic activity in rural areas, wind farms can play a vital role in regional development.

Ultimately, the *Development and Operation of a Greenfield Wind Farm in Spain* project provides a roadmap for entrepreneurs looking to capitalize on the opportunities presented by Spain’s renewable energy transition. By combining technical, financial, and regulatory insights, the project equips entrepreneurs with the tools they need to successfully develop and operate wind farms in Spain. It emphasizes long-term profitability through strategic planning, risk management, and continuous monitoring of market conditions, ensuring that new wind energy projects can thrive in Spain’s competitive energy market.

2. Methodology

The process of developing a greenfield wind farm in Spain begins with the crucial task of site selection and wind resource assessment. This initial phase sets the foundation for the entire project by identifying potential locations where wind conditions are most favorable for energy production.

Entrepreneurs need to consider various factors, including the strength and consistency of wind patterns, proximity to transmission infrastructure, and environmental impact. Geographic Information Systems (GIS) play a key role in this phase by providing detailed maps that highlight areas with optimal wind potential and logistical advantages. The selection process also involves assessing local regulatory frameworks and obtaining the necessary permits to comply with Spain's environmental and energy laws. By strategically choosing a site that balances high wind availability with regulatory ease, developers can maximize energy output while minimizing the complexities involved in acquiring approvals and mitigating environmental impacts.

Once the site is selected, the next step focuses on technical design and engineering. This phase includes determining the type, capacity, and layout of wind turbines. Turbine selection is based on factors such as hub height, rotor diameter, and power capacity, all of which influence the overall efficiency of energy generation. The placement of turbines must also account for wake effects, which can reduce the performance of downstream turbines if they are too closely spaced. In addition to turbine design, the electrical infrastructure required to transmit the generated electricity to the grid is also considered. This involves planning substations and transmission lines that are capable of handling the variable output typical of wind farms. By optimizing the technical configuration of the wind farm, developers can ensure that the project not only produces energy efficiently but also adheres to operational and environmental standards.

In parallel with technical design, regulatory compliance and environmental considerations must be addressed. Spain's legal framework for renewable energy projects requires comprehensive environmental impact assessments to ensure that wind farms do not adversely affect local ecosystems or communities. These assessments cover a range of issues, including noise pollution, effects on wildlife (particularly bird and bat populations), and the visual impact of turbines on the landscape. Entrepreneurs must navigate this regulatory landscape carefully to avoid costly delays or fines that can arise from non-compliance. Furthermore, community engagement is essential during this phase, as gaining the support of local stakeholders can prevent opposition and foster a positive relationship with the surrounding area. This not only facilitates the permitting process but also ensures the long-term success of the project.

After completing the site selection and deverlopment phases, the project enters the construction stage. During this phase, logistical coordination becomes vital to ensure that the turbines and infrastructure are delivered and installed on schedule. Wind farms are large-scale projects that involve the transportation of massive turbine components, often through rural areas with limited infrastructure. As a result, developers must work closely with local authorities to plan transportation routes, avoid disruption, and ensure timely delivery of materials. Once the components arrive, construction teams begin installing the turbines, substations, and grid connections. This stage requires meticulous planning to minimize environmental disturbance and ensure safety, particularly during the lifting and installation of turbine towers and blades. The completion of this phase marks a significant milestone as the project transitions from planning to operation.

Upon completion of the construction phase, the wind farm moves into full operation, where it begins generating and selling electricity. The date when the wind farm officially starts commercial operations is referred to as the Commercial Operation Date (COD). From this point onwards, the farm is integrated into Spain's liberalized electricity market, where energy is traded through various platforms. These include the day-ahead market and bilateral agreements such as Power Purchase Agreements (PPAs), which offer long-term revenue stability by fixing energy prices over several years. Managing the farm's operations effectively requires a deep understanding of how electricity flows through the national grid. The generated electricity is first transmitted via high-voltage lines managed by Red Eléctrica de España (REE) and eventually distributed to consumers.

The operation of a wind farm is not just about generating electricity, it also involves strategic decisions on how to optimize revenue streams. In Spain, wind farms can participate in the wholesale electricity market (merchant revenues) or seek more stable income through regulated remuneration schemes. Merchant revenues are subject to market volatility, where energy prices fluctuate based on supply and demand dynamics. This creates a level of financial uncertainty that operators must manage carefully. On the other hand, Spanish regulated regimes, such as the Specific Remuneration Regime or the Economic Regime for Renewable Energy, offer more predictable income by providing fixed payments for energy produced. These regimes often require competitive bidding processes where developers must demonstrate that their projects can operate efficiently with minimal government support. The choice between market participation and regulated schemes depends on the developer's risk tolerance and market conditions.

Managing operational expenditures (Opex) is another critical aspect of wind farm operation. Maintenance is one of the largest ongoing costs, as wind turbines require regular inspection and servicing to ensure they continue to operate efficiently. Preventive maintenance strategies are typically employed to reduce downtime and extend the operational life of the turbines. By monitoring key components such as blades, generators, and control systems, operators can identify potential issues before they lead to costly failures. In addition to maintenance, other Opex costs include land lease agreements, insurance, and grid connection fees. Effective management of these expenses is crucial to maintaining the financial health of the wind farm and ensuring that it remains profitable over its operational lifetime.

The financial sustainability of a wind farm is closely tied to its ability to generate consistent revenue while keeping costs under control. As stated above, market fluctuations in electricity prices can have a significant impact on profitability, particularly for wind farms that rely on merchant revenues. To mitigate this risk, operators may explore the use of battery energy storage systems (BESS), which allow excess energy to be stored during periods of high wind production and sold when demand (and prices) are higher. This strategy not only stabilizes revenue but also enhances the reliability of the wind farm's output, making it a more attractive option for grid operators. The integration of storage technologies is becoming increasingly important as renewable energy sources play a larger role in Spain's energy mix.

To provide a comprehensive understanding of how these processes come together, the project includes a case study that simulates the development of a wind farm in Burgos, a province with high wind potential. The case study begins with the wind resource assessment process, using historical wind data to evaluate the site's energy production potential. By analyzing wind speeds, direction, and seasonal patterns, the study determines whether the location is suitable for wind farm development. This stage is critical for entrepreneurs, as it helps them understand how to assess the viability of potential wind farm sites based on both technical and financial considerations.

The case study continues by testing different operational scenarios to estimate the energy output and financial returns of the wind farm. Various turbine configurations are analyzed, and the results are compared to determine which setup would provide the highest energy yield. Additionally, operational hypotheses such as maintenance costs, grid integration fees, and market prices are tested within the financial model. This allows the developer to forecast the internal rate of return (IRR) and net present value (NPV) under different market conditions. By comparing these scenarios, the case study provides valuable insights into how operational decisions impact the financial outcomes of the wind farm. This process helps entrepreneurs make informed decisions on how to optimize their projects for maximum profitability.

Basically, as summarized above, the case study serves as a practical demonstration of how entrepreneurs can apply the principles discussed in the wind farm development and operation process. It integrates all the key components (from wind resource assessment and technical design to market participation and financial modelling) into a cohesive strategy for developing a successful wind farm. As it will be explained in the results section, the case study illustrates how each decision, from selecting the site to choosing the revenue model, plays a critical role in determining the overall success of the project.

3. Results

The financial analysis of the case study wind farm project is key to understanding the long-term viability and profitability of the development. The project is projected to begin generating revenue in 2029, once the construction phase is complete. From that point, revenues will come from two primary sources: pool revenues from Spain’s wholesale electricity market and Guarantees of Origin (GoOs). A Power Purchase Agreement (PPA) will also be in place starting in 2032, which will stabilize revenues by guaranteeing a fixed price for a portion of the energy produced. This structure helps to mitigate market volatility, providing predictable cash flows for the developer. As a result, annual revenues are expected to range between €8m and €9m from 2029 to 2043, with minor fluctuations driven by changes in pool prices and wind capture coefficients.

Operating expenditures (Opex) are projected to remain relatively stable throughout the operational life of the wind farm, although they will increase slightly over time due to inflation and the aging of the turbines, which will result in higher maintenance costs. These operating costs include ongoing operation and maintenance (O&M), land lease payments, and insurance. The project’s EBITDA margin remains robust, consistently falling between 60% and 70% from 2029 onwards. This high margin reflects the low operating costs typical of wind energy projects, where the primary expenditures occur during the development and construction phases. With strong EBITDA figures ranging from €5m to €6m annually, the wind farm is positioned to generate significant operational cash flows throughout its lifespan.

Depreciation and amortization (D&A) expenses are factored into the financial statements, reflecting the ongoing capital expenditures (Capex) needed to maintain the wind farm's operations over time. Although the turbines are expected to have long lifespans, regular maintenance and occasional upgrades will be necessary to ensure continued efficiency. These capital investments contribute to a slight increase in D&A expenses over the years, which will be reflected in the income statement. Additionally, the project is structured to reduce debt steadily over time, with debt repayments beginning shortly after the wind farm becomes operational. Interest payments will peak in 2029 when the debt is at its highest but will decrease significantly as the principal is repaid, eventually reaching zero by 2045 when all debt is fully repaid.

The cash flow statement provides a detailed view of the project's ability to generate cash for debt service and shareholder distributions. After covering all operating expenses, debt service, and taxes, the wind farm is expected to generate enough cash to make distributions to shareholders starting in 2029. These distributions will steadily increase as debt is repaid, with equity holders receiving a growing share of the project's cash flows. This financial structure allows for the efficient allocation of capital, ensuring that debt obligations are met while also providing attractive returns to equity investors. By leveraging bank debt during the construction phase and using the wind farm's stable cash flows to repay this debt, the project maximizes returns for both debt and equity holders.

To assess the overall value of the wind farm project, a valuation was conducted using two industry-standard methods: the Discounted Cash Flow (DCF) approach and relative valuation multiples. In the DCF model, the future cash flows from the wind farm, starting in 2029, are discounted back to the present at a rate of 7.5%, which reflects the expected return for a fully operational wind asset. This method produces an equity value of €21.9m by 2029, with a corresponding enterprise value of €61.4m when combined with the projected net debt of €39.4m at that time. The implied valuation multiple is €1.2m/MW, which is slightly above industry norms. However, this higher valuation is justified by the strong wind resource at the selected site and the project's solid financial metrics.

The internal rate of return (IRR) and total value to paid-in capital (TVPI) were also calculated to determine the attractiveness of the project from an investor's perspective. The IRR is projected to reach 23.6%, a strong result for an infrastructure project, particularly given the leverage used during the construction phase. This high IRR is driven by the relatively low initial equity investment required from the developer, as the bulk of the project's financing comes from debt. Once the wind farm is operational, its risk profile decreases significantly, with the primary risk coming from fluctuations in electricity prices. The TVPI is estimated at 1.55x, meaning that for every €1 invested, the developer can expect to receive €1.55 in return. This solid return highlights the project's potential as a profitable investment.

To further evaluate the robustness of the project's financial projections, a series of sensitivity analyses were performed. These analyses test how changes in key assumptions (such as the exit year, discount rate, and refinancing terms) would impact the project's valuation and investor returns. For example, shifting the exit year from 2029 to 2033 decreases the IRR slightly, as the later exit reduces the time value of money. However, the TVPI increases in this scenario because the wind farm will have had more time to generate and distribute dividends. Additionally, adjusting the discount rate between 7.0% and 8.0% shows how sensitive the project's valuation is to changes in investor expectations. A higher discount rate reduces both the IRR and the TVPI, reflecting the increased cost of capital.

Another key sensitivity analysis focused on the refinancing terms, particularly the debt service coverage ratio (DSCR) and the margin on the refinancing facility. Increasing the target DSCR from 1.30x to 1.50x improves the project's IRR, as it allows the developer to maintain more cash flow for equity distributions. However, a higher margin on the refinancing debt reduces returns, particularly in the worst-case scenario where the margin reaches 3.0%. Despite these changes, the project remains financially viable across all tested scenarios, with the IRR staying above 18% even in the most pessimistic cases. This resilience demonstrates the robustness of the wind farm's financial model.

The sensitivity analyses also explored operational factors, such as the net equivalent hours (NEH) of wind energy production and the number of turbines installed. Increasing the NEH from 2,400 to 3,000 hours per year significantly boosts the project's IRR, as higher energy production leads to greater revenues. In contrast, changing the number of turbines has a more modest impact on returns, indicating that the scale of the project is already optimized for the site's wind resource. This analysis underscores the importance of accurately assessing wind conditions during the site selection phase, as the project's financial success is highly dependent on consistent energy production.

Finally, a sensitivity analysis was conducted on the PPA price and the proportion of energy sold to the pool market versus the PPA. The results show that increasing the PPA price from €40/MWh to €60/MWh significantly improves the project's returns, while selling a higher percentage of energy to the pool market increases exposure to price volatility. This analysis helps the developer understand how different revenue strategies affect the project's risk-return profile, allowing them to optimize their approach based on market conditions. Overall, the results of these sensitivity analyses demonstrate that the wind farm project is financially resilient and capable of delivering strong returns to investors under a range of scenarios.

The following tables, which show the sensitivity analysis conducted on the PPA price (vertical axis) and the proportion of energy sold to the pool market vs. PPA (horizontal axis), exemplify the type of analysis that can be found in the results of the case study of the project:

Exit IRR	40%	50%	60%	70%	80%
40.0	13.8%	16.2%	18.5%	20.7%	23.0%
45.0	17.9%	19.5%	21.1%	22.6%	24.2%
50.0	21.7%	22.7%	23.6%	24.5%	25.4%
55.0	25.5%	25.8%	26.1%	26.4%	26.7%
60.0	29.1%	28.8%	28.5%	28.2%	27.9%

Table 1: Sensitivity (i) % of energy sold to pool vs. PPA & (ii) PPA price on Exit IRR

Exit TVPI	40%	50%	60%	70%	80%
40.0	1.30x	1.36x	1.42x	1.48x	1.54x
45.0	1.40x	1.44x	1.48x	1.53x	1.57x
50.0	1.50x	1.53x	1.55x	1.58x	1.61x
55.0	1.61x	1.62x	1.63x	1.63x	1.64x
60.0	1.72x	1.71x	1.70x	1.69x	1.68x

Table 2: Sensitivity (i) % of energy sold to pool vs. PPA & (ii) PPA price on Exit TVPI

LT IRR	40%	50%	60%	70%	80%
40.0	8.6%	9.0%	9.3%	9.7%	10.1%
45.0	9.2%	9.5%	9.8%	10.0%	10.3%
50.0	9.9%	10.0%	10.2%	10.3%	10.5%
55.0	10.5%	10.5%	10.6%	10.6%	10.7%
60.0	11.1%	11.0%	11.0%	10.9%	10.9%

Table 3: Sensitivity (i) % of energy sold to pool vs. PPA & (ii) PPA price on LT IRR

4. Conclusions

The development and operation of a greenfield wind farm in Spain offers a unique opportunity for entrepreneurs to contribute to the renewable energy transition while capitalizing on a mature and supportive market. Spain's leadership in wind energy, coupled with favorable regulatory frameworks and a robust supply chain, creates an optimal environment for wind farm development. Entrepreneurs must understand the significance of site selection, turbine placement, and wind resource assessment as key determinants of the project's overall success. These technical and regulatory foundations are crucial for optimizing energy output and ensuring that the wind farm operates efficiently in a highly competitive market.

A major takeaway from the project is the importance of integrating financial sustainability with technical performance. Entrepreneurs should develop dynamic financial models that can incorporate variables such as energy prices, opex, and long-term agreements like PPAs. These models are essential for predicting the viability of the wind farm under different market conditions and ensuring stable returns for investors. Furthermore, sensitivity analyses highlight how changes in market conditions, discount rates, and operational factors can significantly impact the project's profitability. Understanding and mitigating these risks is vital for maximizing returns and maintaining financial resilience throughout the wind farm's operational life.

Another key conclusion is the importance of navigating Spain's regulatory landscape effectively. Obtaining the necessary permits, such as environmental impact assessments and grid connection approvals, is one of the most time-intensive phases of wind farm development. Entrepreneurs must engage with local authorities and regulatory bodies early in the process to avoid delays and ensure compliance with national and European Union standards.

The project's results also underscore the importance of operational efficiency and cost management. Entrepreneurs must implement preventive maintenance strategies and closely monitor opex to ensure that the wind farm continues to perform at optimal levels throughout its lifespan. Careful attention to turbine maintenance, grid connection fees, and insurance costs will help manage these opex, while maximizing energy production and profitability. Furthermore, innovations such as hybridization with solar energy and battery energy storage systems can enhance the wind farm’s operational efficiency, mitigate the intermittency of renewable energy, and stabilize cash flows during periods of fluctuating market demand.

From a financial perspective, the project demonstrates how leveraging debt during the construction phase and structuring long-term repayment plans can enhance returns for both debt and equity holders. Interest payments and debt service must also be carefully managed. Entrepreneurs should consider refinancing options and adjust debt service coverage ratios (DSCR) to optimize their capital structure and improve profitability. In addition, the project’s case study strong IRR and valuation metrics suggest that wind farm investments are indeed attractive to investors, particularly when supported by long-term revenue agreements (PPAs).

Finally, the project aligns with several Sustainable Development Goals (SDGs), particularly those focused on clean energy, industry innovation, and climate action. By generating renewable energy, reducing greenhouse gas emissions, and fostering economic growth in rural areas, wind farms contribute to global sustainability efforts. Entrepreneurs should prioritize these broader environmental and social impacts when developing renewable energy projects, ensuring that their ventures not only generate financial returns but also contribute positively to the global energy transition and the fight against climate change.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION ..... - 6 -

1.1 CONTEXT: ..... - 6 -
1.2 MISSION ..... - 7 -
1.3 IMPORTANT TERMINOLOGY ..... - 8 -

CHAPTER 2. OVERVIEW OF THE ENERGY MARKET IN SPAIN ..... - 11 -

2.1 PRESENT OF THE RENEWABLES IN SPAIN ..... - 11 -
2.1.1 Context of the Renewables Sector ..... - 11 -
2.1.2 Overview of the Key Technologies in Spain ..... - 18 -
Wind presence in Spain ..... - 18 -
Solar presence in Spain ..... - 20 -
Hydropower presence in Spain ..... - 23 -
Other renewables presence in Spain ..... - 26 -
2.2 PIPELINE OF RENEWABLES IN SPAIN ..... - 28 -
2.2.1 Development and Investment Rationale in Spanish Renewables Sector ..... - 28 -
2.2.2 Goals and Objectives in the Spanish Renewables Sector ..... - 31 -
2.2.3 Key Players in the Spanish Renewables Space ..... - 34 -
2.3 REGULATION OF RENEWABLES IN SPAIN ..... - 36 -
2.3.1 European Union Regulation of Renewables ..... - 36 -
2.3.2 Spanish Regulation of Renewables ..... - 38 -
2.4 MAIN TRENDS OF RENEWABLES IN SPAIN ..... - 45 -
2.4.1 Repowering ..... - 45 -
2.4.2 Hybridization ..... - 46 -
2.4.3 Battery Energy Storage System (BESS) ..... - 47 -

CHAPTER 3. WIND FARM DEVELOPMENT PROCESS ..... - 49 -

3.1 DEEP DIVE IN WIND TECHNOLOGY ..... - 49 -
3.1.1 Wind Turbine ..... - 49 -
3.1.2 Wind Turbine Specifications ..... - 54 -
3.1.3 Spanish Wind Industry ..... - 60 -
3.1.4 Key Differences Onshore vs. Offshore ..... - 61 -
3.2 DEVELOPMENT PROCESS ..... - 63 -
3.2.1 Land Study and Securement ..... - 64 -
3.2.2 Access and Connection to the Grid ..... - 67 -
3.2.3 Permitting phase ..... - 72 -
3.3 CONSTRUCTION PROCESS ..... - 79 -

CHAPTER 4. WIND FARM OPERATION ..... - 87 -

4.1 SOURCES OF REVENUES ..... - 89 -
4.1.1 Pool – Merchant revenues ..... - 89 -
4.1.2 Remuneration scheme for regulated assets ..... - 94 -
4.1.3 PPAs – Purchase Power Agreements ..... - 103 -
4.1.4 GoOs – Guarantees of Origin ..... - 109 -
4.2 POWER PRICE CURVES ..... - 111 -
1.1.1 Projections and consultants ..... - 112 -
1.1.2 Usage ..... - 115 -
4.3 SOURCES OF COSTS ..... - 117 -

4.3.1 Levelised Cost of Electricity (LCOE) ... - 117 -
4.3.2 Operating Expenses ... - 122 -

CHAPTER 5. CASE STUDY ... - 126 -

5.1 WIND RESOURCE ASSESSMENT ... - 126 -
5.2 OPERATIONAL ASSUMPTIONS ... - 145 -
5.3 FINANCIAL ASSUMPTIONS ... - 150 -

CHAPTER 6. ANALYSIS OF RESULTS ... - 153 -

6.1 MODEL CIRCULARITIES ... - 153 -
6.2 FINANCIAL STATEMENTS ... - 155 -
6.3 VALUATION ... - 167 -
6.4 SENSITIVITIES ... - 169 -
6.5 MACROS ... - 175 -

CHAPTER 7. SDG'S ... - 180 -

7.1 ALIGNMENT WITH SUSTAINABLE DEVELOPMENT GOALS (SDGS) ... - 180 -

CHAPTER 8. CONCLUSIONS ... - 183 -

CHAPTER 9. REFERENCES ... - 190 -

APPENDIX A ... - 197 -

APPENDIX B ... - 202 -

LIST OF FIGURES

FIGURE 1: 2022 GLOBAL ELECTRICITY MIX .... - 12 -
FIGURE 2: 2010 GLOBAL ELECTRICITY MIX .... - 13 -
FIGURE 3: 2005 – 2022 EVOLUTION OF THE GLOBAL ELECTRICITY GENERATION MIX .... - 14 -
FIGURE 4: 2022 SPANISH ELECTRICITY MIX .... - 15 -
FIGURE 5: 2010 SPANISH ELECTRICITY MIX .... - 16 -
FIGURE 6: 2010 - 2022 EVOLUTION OF THE SPANISH ELECTRICITY GENERATION MIX .... - 16 -
FIGURE 7: EVOLUTION OF RENEWABLE INSTALLED CAPACITY IN SPAIN (% & MW) .... - 17 -
FIGURE 8: WIND INSTALLED CAPACITY EVOLUTION IN SPAIN (MW) .... - 18 -
FIGURE 9: SPANISH DISTRIBUTION OF WIND INSTALLED CAPACITY (MW) .... - 19 -
FIGURE 10: SOLAR PV INSTALLED CAPACITY EVOLUTION IN SPAIN (MW) .... - 20 -
FIGURE 11: SPANISH DISTRIBUTION OF SOLAR PV INSTALLED CAPACITY (MW) .... - 21 -
FIGURE 12: AVERAGE HOURLY PROFILE OF SOLAR PV GENERATION AS % OF TOTAL GENERATION IN SPAIN .... - 22 -
FIGURE 13: SOLAR THERMAL INSTALLED CAPACITY EVOLUTION IN SPAIN (MW) .... - 22 -
FIGURE 14: SPANISH DISTRIBUTION OF SOLAR THERMAL INSTALLED CAPACITY (MW) .... - 23 -
FIGURE 15: HYDROPOWER INSTALLED CAPACITY EVOLUTION IN SPAIN (MW) .... - 24 -
FIGURE 16: SPANISH DISTRIBUTION OF HYDROPOWER INSTALLED CAPACITY (MW) .... - 25 -
FIGURE 17:AVERAGE HOURLY PROFILE OF HYDROPOWER GENERATION AS % OF TOTAL GENERATION IN SPAIN .... - 26 -
FIGURE 18: OTHER RENEWABLES INSTALLED CAPACITY EVOLUTION IN SPAIN (MW) .... - 26 -
FIGURE 19: SPANISH DISTRIBUTION OF OTHER RENEWABLES INSTALLED CAPACITY (MW) .... - 27 -
FIGURE 20: TECHNOLOGY SPLIT OF OTHER RENEWABLES INSTALLED CAPACITY IN SPAIN .... - 28 -
FIGURE 21: WIND TURBINE COMPONENTS .... - 50 -
FIGURE 22: BLADE FORCES .... - 51 -
FIGURE 23: LIFT FORCE EXPLANATION .... - 51 -
FIGURE 24: VERTICAL AXIS WIND TURBINE (VAWT) .... - 53 -
FIGURE 25: POWER VS WIND SPEED CURVE .... - 55 -
FIGURE 26: WIND TURBINE HUB HEIGHT EVOLUTION .... - 56 -
FIGURE 27: WIND TURBINE BLADE LENGHT EVOLUTION .... - 58 -
FIGURE 28: SCHEME TO DEMONSTRATE BETZ' LAW .... - 59 -
FIGURE 29: CONNECTION OF WIND FARM TO THE GRID .... - 69 -
FIGURE 30: TSA + BOP CONTRACTUAL MODEL .... - 80 -
FIGURE 31: EPC CONTRACTUAL MODEL .... - 81 -
FIGURE 32: HEAVYGOODS' SIMULATION VS REAL TRANSPORTATION OF WIND BLADE .... - 82 -
FIGURE 33: WIND TURBINE FOUNDATION: ANCHOR CAGE SYSTEM .... - 84 -
FIGURE 34: BOTH ASSEMBLY OPTIONS (I) AND (II) RESPECTIVELY .... - 85 -
FIGURE 35: ELECTRICITY FLOW CHART .... - 87 -
FIGURE 36: DAY-AHEAD MARKET MATCHING .... - 92 -
FIGURE 37: CORPORATE PPA VOLUMES BY REGION .... - 104 -
FIGURE 38: PPA'S EUROPEAN MARKET LEADERS IN 2023 .... - 105 -

FIGURE 39: VOLUME PROFILE PAY-AS-PRODUCED VS BASELOAD PPA ..... - 107 -
FIGURE 40: VIRTUAL PPA GRAPHICALLY EXPLAINED ..... - 108 -
FIGURE 41: POWER PRICE CURVES METHODOLOGY ..... - 116 -
FIGURE 42: POWER PRICE CURVES CASES ..... - 117 -
FIGURE 43: 2023'S LCOE ACROSS TECHNOLOGIES COMPARISON ..... - 121 -
FIGURE 44: LCOE EVOLUTION ACROSS TECHNOLOGIES (2009-2023) ..... - 121 -
FIGURE 45: SPANISH DATA LOCATIONS OF THE NCEI ..... - 127 -
FIGURE 46: FILTERED WIND DATA ILLUSTRATION ..... - 128 -
FIGURE 47: WIND DATA ANALYSIS BY YEARS ..... - 129 -
FIGURE 48: WIND DATA ANALYSIS BY MONTHS ..... - 130 -
FIGURE 49: WIND DATA ANALYSIS BY MONTHS (DAY VS NIGHT) ..... - 130 -
FIGURE 50: COMPASS ROSE ..... - 131 -
FIGURE 51: WIND SPEED PROFILE WITH VARYING HEIGHT ..... - 133 -
FIGURE 52: ADJUSTED WIND DATA ANALYSIS BY YEARS ..... - 134 -
FIGURE 53: ADJUSTED WIND DATA ANALYSIS BY MONTHS (DAY VS NIGHT) ..... - 134 -
FIGURE 54: ADJUSTED WIND DATA FREQUENCY DISTRIBUTION ..... - 135 -
FIGURE 55: ADJUSTED WIND DATA FREQUENCY (2019) ..... - 136 -
FIGURE 56: LEAST SQUARE METHOD FOR WEIBULL'S PARAMETERS ..... - 137 -
FIGURE 57: WIND FARM'S WEIBULL FUNCTION ..... - 138 -
FIGURE 58: VESTAS V150/4000 WIND-POWER CURVE ..... - 139 -
FIGURE 59: SIEMENS-GAMESA SG 2.1-114 WIND-POWER CURVE ..... - 139 -
FIGURE 60: GENERAL ELECTRIC GE 5.3-158 WIND-POWER CURVE ..... - 140 -
FIGURE 61: POLYNOMIAL PROXY TO VESTAS V150/4000 WIND-POWER CURVE (MATLAB) ..... - 141 -
FIGURE 62: POLYNOMIAL PROXY TO SIEMENS-GAMESA SG 8.0-167 WIND-POWER CURVE (MATLAB) ..... - 142 -
FIGURE 63: POLYNOMIAL PROXY TO GENERAL ELECTRIC 5.3-158 WIND-POWER CURVE (MATLAB) ..... - 142 -
FIGURE 64: COMPARISON OF POLYNOMIAL PROXIES WIND-POWER CURVES ..... - 143 -
FIGURE 65: GRAPHICAL DESCRIPTION OF CIRCULARITY 1 ..... - 154 -
FIGURE 66: GRAPHICAL DESCRIPTION OF CIRCULARITY 2 ..... - 155 -
FIGURE 67: SUSTAINABLE DEVELOPMENT GOALS LOGO ..... - 180 -
FIGURE 68: DETAIL OF THE SUSTAINABLE DEVELOPMENT GOALS INVOLVED IN THE PROJECTT ..... - 182 -

LIST OF TABLES

TABLE 1: WIND INSTALLED CAPACITY BY AUTONOMOUS COMMUNITIES (GW) - 19 -
TABLE 2: SOLAR PV INSTALLED CAPACITY BY AUTONOMOUS COMMUNITIES (GW) - 21 -
TABLE 3: SOLAR THERMAL INSTALLED CAPACITY BY AUTONOMOUS COMMUNITIES (GW) - 23 -
TABLE 4: HYDROPOWER INSTALLED CAPACITY BY AUTONOMOUS COMMUNITIES (GW) - 25 -
TABLE 5: OTHER RENEWABLES INSTALLED CAPACITY BY AUTONOMOUS COMMUNITIES (GW) - 27 -
TABLE 6: COMPARISON TABLE HAWT VS VAWT - 54 -
TABLE 7: COMAPARISON ONSHORE VS. OFFSHORE WIND TECHNOLOGIES - 63 -
TABLE 8: INTRADAY AUCTIONS SCHEDULE LIMITS - 94 -
TABLE 9: DATA VALIDATION ANALYSIS - 129 -
TABLE 10: ROUGHNESS LENGTH ACCORDING TO EUROPEAN WIND ATLAS - 133 -
TABLE 11: WIND RESOURCE GROSS RESULTS FOR THE DIFFERENT TURBINE MODELS - 143 -
TABLE 12: WIND RESOURCE NET RESULTS FOR THE DIFFERENT TURBINE MODELS - 144 -
TABLE 13: SENSITIVITY EXIT YEAR & DISCOUNT RATE ON EXIT IRR - 171 -
TABLE 14: SENSITIVITY EXIT YEAR & DISCOUNT RATE ON EXIT TVPI - 171 -
TABLE 15: TABLE 14: SENSITIVITY EXIT YEAR & DISCOUNT RATE ON IMPLICIT €M/MW MULTIPLE - 171 -
TABLE 16:SENSITIVITY TARGET DSCR & REFINANCING MARGIN ON EXIT IRR - 172 -
TABLE 17:SENSITIVITY TARGET DSCR & REFINANCING MARGIN ON EXIT TVPI - 172 -
TABLE 18: SENSITIVITY TARGET DSCR & REFINANCING MARGIN ON LT IRR - 172 -
TABLE 19: SENSITIVITY NEH & # OF TURBINES ON EXIT IRR - 173 -
TABLE 20: SENSITIVITY NEH & # OF TURBINES ON EXIT TVPI - 173 -
TABLE 21:SENSITIVITY NEH & # OF TURBINES ON LT IRR - 173 -
TABLE 22: SENSITIVITY % POOL & PPA PRICE ON EXIT IRR - 174 -
TABLE 23: SENSITIVITY % POOL & PPA PRICE ON EXIT TVPI - 174 -
TABLE 24: SENSITIVITY % POOL & PPA PRICE ON LT IRR - 174 -

CHAPTER 1. INTRODUCTION

1.1 Context:

The renewable energy sector in Spain has undergone a profound transformation over the past two decades, driven by both national initiatives and broader European Union (EU) policies aimed at reducing greenhouse gas emissions and combating climate change. Spain, with its favorable geographic and climatic conditions, has emerged as a leader in the deployment of renewable energy technologies, particularly wind and solar power. This transition is part of a broader global movement towards sustainable energy systems, but Spain's approach is distinctive due to its early adoption of aggressive renewable energy targets and its integration of these goals within its broader economic and industrial policies.

Historically, Spain's energy sector was heavily reliant on imported fossil fuels, making the country vulnerable to energy price volatility and geopolitical risks. The energy crises of the 1970s and the growing environmental awareness in the late 20th century laid the conditions for a shift towards renewable energy. This shift was formalized through a series of legislative and regulatory measures. These policies set ambitious targets for renewable energy generation, aiming for 74% of electricity to be generated from renewable sources by 2030 and 100% by 2050.

The development of wind energy in Spain has been particularly successful, positioning the country as the second largest producer of wind power in Europe and the fifth largest globally. The vast wind resources, particularly in regions such as Galicia, Castilla y León, and Aragón, have been effectively harnessed through large-scale wind farms. The combination of political will, favorable regulatory frameworks, and advances in wind turbine technology has led to rapid growth in this sector. However, the expansion of wind energy has also brought challenges, including grid integration issues, environmental concerns, and the need for ongoing technological innovation to maintain Spain's competitive edge.

In this evolving landscape, the concept of greenfield wind farm development (construction of new wind farms on previously undeveloped land) has gained importance. Greenfield projects are crucial for expanding renewable energy capacity, particularly as the potential for further development on existing sites (brownfield projects) becomes more limited. These projects are complex, requiring careful site selection, rigorous environmental impact assessments, and substantial financial investment. Moreover, they must navigate a dynamic regulatory environment that is continuously adapting to new technological advancements and shifting energy markets. The development and operation of these greenfield wind farms are not just technical endeavors but are also deeply intertwined with broader economic, social, and environmental objectives.

The broader context for renewable energy in Spain is also shaped by global trends such as the push towards decarbonization, the digitalization of the energy sector, and the increasing importance of energy security. Spain's strategic position in the global energy transition is enhanced by its commitment to research and development in renewable technologies, its active participation in international climate agreements, and its role as a testing ground for innovative energy solutions. As the country continues to invest in and develop its renewable energy infrastructure, the lessons learned from these efforts will be critical not only for Spain but also for other countries seeking to transition to sustainable energy systems. The successful development and operation of greenfield wind farms, therefore, represent a key component of Spain's energy strategy, contributing to the achievement of national and international energy and climate goals while also fostering economic growth and job creation.

1.2 Mission

The primary mission of this project is to serve as a comprehensive guide for wind farm developers, providing them with all the critical information necessary to successfully develop and operate a greenfield wind farm in Spain. This document aims to be a practical resource that addresses the various stages of wind farm development, from initial planning and site selection through to construction, operation, and eventual decommissioning or repowering. By compiling detailed insights and analyses, the project seeks to equip developers with the knowledge required to navigate the complex technical, regulatory, and economic landscape of the Spanish renewable energy sector.

The project is structured to achieve this mission through several key objectives. First, it provides an in-depth analysis of the current energy market in Spain, including an overview of the regulatory framework, the role of renewable energy in the national energy mix, and the specific opportunities and challenges associated with wind energy development. This section is essential for understanding the broader context in which wind farms operate and for identifying the most promising locations and strategies for new projects.

Second, the project delves into the technical aspects of wind farm development, offering detailed guidance on the selection of appropriate sites, the specifications of wind turbines, and the logistical considerations involved in connecting a wind farm to the national grid. This technical analysis is complemented by a review of the financial aspects of wind farm development, including cost estimation, financing options, and revenue generation strategies such as Power Purchase Agreements (PPAs) and participation in the Spanish electricity market.

Third, the project addresses the operational phase of wind farms, focusing on the challenges of maintaining high levels of efficiency and reliability over the long term. The goal is to provide developers with practical advice on how to optimize the performance of their wind farms, ensuring they remain competitive and financially viable in the evolving energy market.

Ultimately, this project aims to be a valuable tool for wind farm developers, offering a comprehensive roadmap for the successful development and operation of wind farms in Spain. By synthesizing the latest industry knowledge and best practices, the project seeks to support the growth of the wind energy sector in Spain, contributing to the country's renewable energy targets and its transition towards a more sustainable and resilient energy system.

1.3 Important terminology

Before deepening into the specifics of wind farm development and operation in Spain, it is essential to clarify some key terms that will be frequently used throughout this project. Understanding these concepts is crucial for fully following the technical, regulatory, and financial considerations involved in the development and operation of a wind farm:

- **Greenfield wind farm**: A greenfield wind farm refers to a new wind energy project that is developed on previously undeveloped land. Unlike brownfield projects, which are built on sites that have been used for other purposes in the past, greenfield projects require a comprehensive assessment of the land's suitability for wind energy generation, including environmental impact studies, wind resource assessments, and land use planning.
- **Wind turbine**: A device that converts the kinetic energy from wind into electrical power. Wind turbines are the primary technology used in wind farms and are typically composed of blades, a rotor, a nacelle (which houses the generator and other components), and a tower. The design and efficiency of wind turbines are crucial for maximizing the energy output of a wind farm.
- **Purchase Power Agreement**: A long-term contract between a wind farm developer and a buyer, securing a guaranteed revenue stream for the electricity generated by the wind farm.
- **Environmental Impact Assessment (EIA):** A mandatory process that evaluates the potential environmental effects of a wind farm, including impacts on local wildlife, ecosystems, and human communities. This assessment is essential for obtaining permits and ensuring compliance with environmental regulations.
- **Permitting Process:** The series of approvals and licenses required from various governmental and regulatory bodies before a wind farm can be constructed and operated. This process includes land use permits, environmental clearances, and construction licenses, all of which are crucial for project development.
- **Power Prices**: The cost of electricity in the market, which can fluctuate based on supply and demand dynamics, regulatory changes, and market conditions. Power prices are a

critical factor in the financial viability of a wind farm, influencing revenue and return on investment.

- **Pool**: The electricity market where energy producers, including wind farms, sell their generated electricity. In Spain, this refers to the day-ahead and intraday markets where electricity prices are determined based on supply and demand dynamics. The "pool" price is the market price at which electricity is traded and is a crucial factor in the financial planning and profitability of a wind farm, as it directly impacts revenue from electricity sales.

CHAPTER 2. OVERVIEW OF THE ENERGY MARKET IN SPAIN

Once the motivation of the project has already been explained, it is the time to see at which state is currently the energy sector in order to later deduct: (i) why it is suitable to develop and operate a greenfield wind farm in Spain, and (ii) why it is so important to keep researching on these kinds of projects.

2.1 Present of the Renewables in Spain

2.1.1 Context of the Renewables Sector

As of January 2024, almost every person living in Spain and other developed countries has studied during primary school that there are two main types of energy sources:

1. **Non-Renewable Energy Sources**: Those sources that can be extracted from the Earth but that can be depleted if they are consumed in an unresponsible manner. These resources typically take million of years to form and are finite on a human timescale. Typically, these resources are classified into two subtypes: (i) Fossil fuels such as coal, oil, and natural gas, and which are extracted from Earth to later be combusted and transformed into energy. (ii) Nuclear resources such as uranium, which once extracted and enriched can be used in nuclear reactions to produce energy.
2. **Renewable Energy Sources**: Basically, these resources cannot be depleted in a human timescale as they can be replenished quickly and typically from natural sources. That is, these energy sources are expected to be able to be used during the whole human existence. Although there are plenty forms of renewable sources and it is expected to be discovered many more in the future, the most common ones (which are used in a global scale) are: (i) Solar Energy (Thermal or Photovoltaic), (ii) Wind Energy, (iii) Hydropower, (iv) Geothermal Energy, and (v) Biomass Energy.

One of the main reason why energy sources are so important is because it is what human beings use to create electricity. In the same way, electricity is one of those important resources that allow developed countries to be so and which hold the global economy as it is. This means that without electricity, the society and global economy as we know it would not hold.

As of January 2024, Repsol has already released the *2023 Energy Yearbook*, which is a publication prepared by their Economic Research Department which has "the aim to provide a tool that will aid objective analysis on energy markets" such as the one looked for in this project. According to the outlook, the data that will be analysed represents the situation of the world energy sector covering more than 90% of global energy consumption.

As it will be later be analysed, Spain has a strong position regarding renewable energy sources. The main way to justify its strength is comparing the global situation to the national one. According to the following figure extracted from Repsol's Outlook from Power BI, in 2022 the total electricity produced worldwide was of 29.03k TWh with the following energy mix:

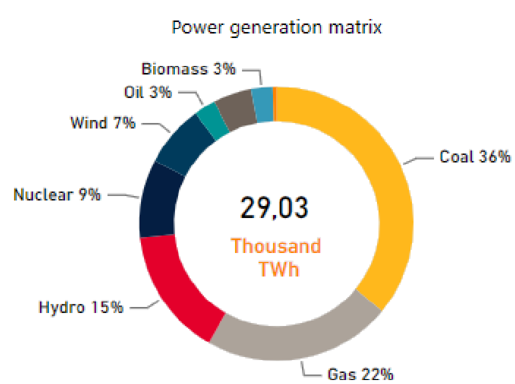


Figure 1: 2022 Global electricity mix

Hence, in 2022, the production of electricity from renewable sources was in this order: (i) Hydropower: 15.15% of global electricity for a total of 4.48k TWh, (ii) Wind: 7.34% of global electricity for a total of 2.11k TWh, (iii) Solar: 4.50% of global electricity for a total of 1.30k TWh, (iv) Biomass: 2.56% of global electricity for a total of 0.74k TWh, and (v) Other renewables: 0.45% of global electricity for a total of 0.14k TWh. Adding all these figures, it can be concluded that 8.77k TWh were produced by renewable technologies, or that 30% of global electricity came from renewable sources.

As of the figures above, is it acceptable to say that there has been a global boom in the renewables sector? This can only be answered comparing the actual context to the global electricity mix present more than 10 years ago. Checking 2010's figures from the same exact source for consistency the following results are obtained:

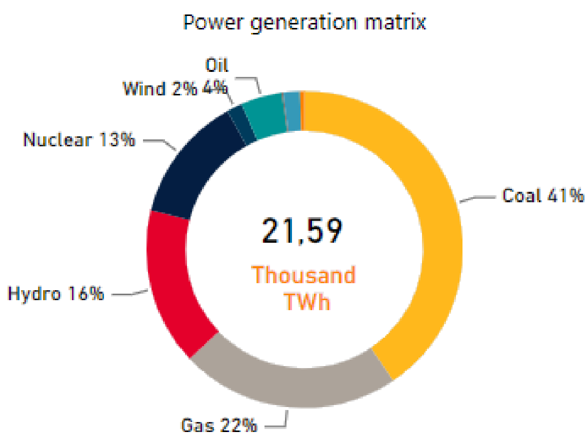


Figure 2: 2010 Global electricity mix

In 2010, it is true that the electricity generation was approximately 1/3 lower than what it was in 2022. However, it is also true that back in those days only 4.37k TWh, i.e. c.20% of global electricity, were produced from renewable sources. Hence, renewable electricity production has doubled since 2010 and it is continuously growing its presence against now-renewable sources in the global electricity mix as can be proved in the following figure with the evolution of the electricity generation by source:

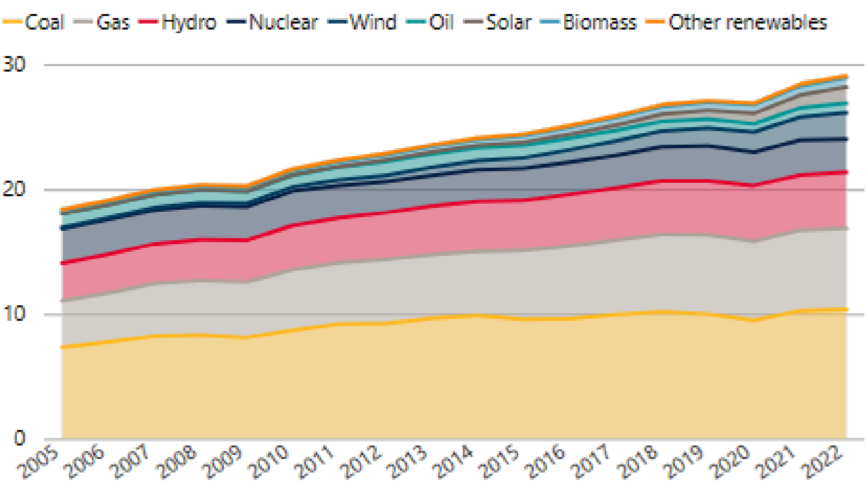


Figure 3: 2005 – 2022 Evolution of the global electricity generation mix

From this figure, it can be clearly seen that the slope of the growth in the electricity generation is clearly steeper than the growth in the coal source. Additionally, it can be concluded that, although the hydropower technology has kept approximately the same importance in the mix since 2010, the wind has increased significantly since that year, the solar since 2016, while oil (non-renewable) has gradually decreased.

Additionally, according to Repsol's *2023 Energy yearbook*, it is possible to further analyse the behaviour in terms of energy mix by regions. If, as explained above, the global mix of renewable energy is 30%, the European Union has managed to step up further on this number reaching a maximum level of c. 40% in the generation mix. Moreover, it is interesting to highlight that China, a country typically know for being reluctant to join in international sustainability objectives, surpassed in 2022 a 30% share of renewable generation. This last figure is especially important as China is the largest producer of electricity on the world with c. 9k TWh. Once said this, China has still much to improve to reduce its generation from coal which share (5k TWh) surpasses the total electricity produced by the second largest producer, the US.

Once understood the global context of electricity generation and its renewables mix, it is possible to compare it to the Spanish mix and hence analyse the behaviour of this market against the rest of the world. From the 29.03k TWh of electricity generated in the world in 2022, Spain generated 0.29k TWh with the following power generation matrix:

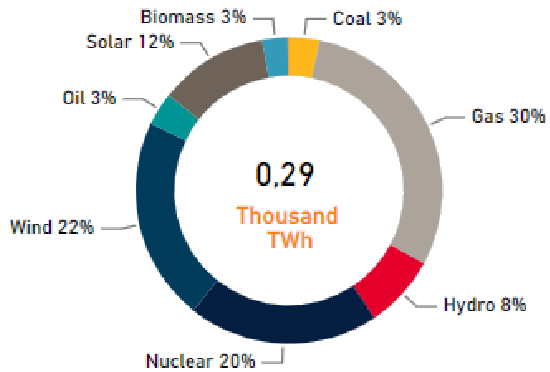


Figure 4: 2022 Spanish electricity mix

Hence, in 2022, the Spanish production of electricity from renewable sources was in this order: (i) Wind: 21.52% of Spanish electricity for a total of 0.06k TWh, (ii) Solar: 11.54% of Spanish electricity for a total of 0.03k TWh, (iii) Hydropower: 7.70% of Spanish electricity for a total of 0.02k TWh, and (iv) Biomass: 2.67% of Spanish electricity for a total of 0.01k TWh. Adding all these figures, it can be concluded that c. 0.13k TWh were produced by renewable technologies, or that +43% of Spanish electricity came from renewable sources.

This figure itself is already a huge achievement for the Spanish electricity generation market as positions Spain clearly above the global average of renewables production (as analysed above c. 30%), and above the European Union which renewables share was c. 40% in 2022. However, it is important to understand from which context the Spanish renewables space comes from to better value this figure. For this purpose, as it has been done in a global level, the 2010's Spanish electricity mix is going to be analysed:

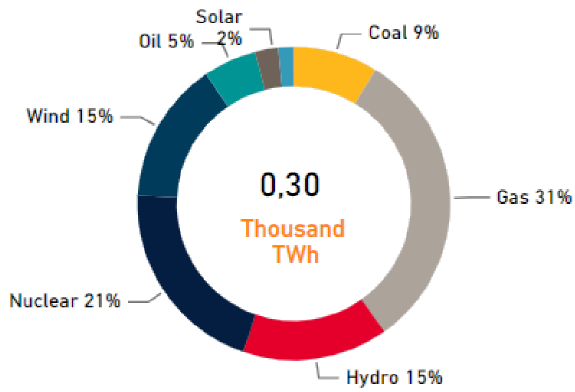


Figure 5: 2010 Spanish electricity mix

The first thing that should create an impact from 2010's Spanish electricity generation is that it was higher than the one from 2022 (0.29k TWh). This is surprising taking into account the evolution seen globally in the electricity generation (+30% since 2010) and has its explanation analysing again the Chinese generation which not only doubled during this period but jumped from being the second generator behind the US to be the first one doubling the US in 2022. Going back to the Spanish generation mix analysis, already in 2010 Spain was advanced to its epoque compared to rest of the world as it generated 33.7% of its total electricity from renewable sources, well above from the global figure of c. 20% back in those days. To further analyse what has happened with the generation mix during this period it is interesting to analyse the evolution of the different resources in the Spanish electricity generation market:

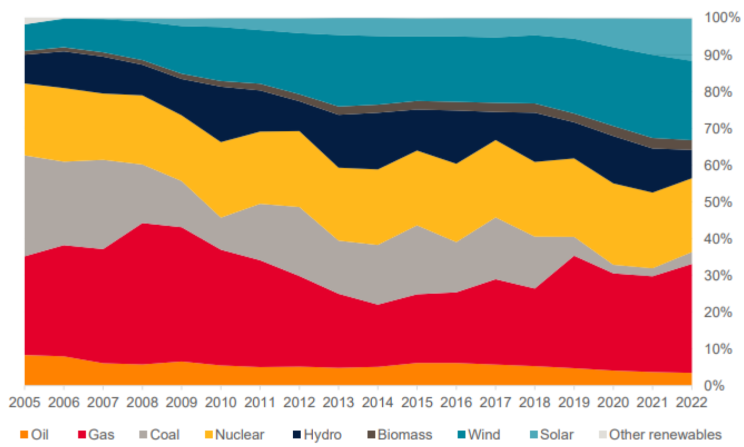


Figure 6: 2010 - 2022 Evolution of the Spanish electricity generation mix

As it can be seen in the figure above, the Spanish electricity generation mix has suffered important changes during the last decades:

- In terms of non-renewable sources of production, coal has suffered the greatest decrease from being one of the predominant resources in 2005 to be almost residual in 2022. The nuclear resource has maintained almost constant during this period but it is expected to be reduced significantly in the next years due to the schedule of plants shut downs elaborated by the government and the (inexplicably) bad fame that this technology has acquired in the Spanish society. Oil, which never was a big resource in the Spanish market, is evolving downwards. Finally, gas remains as the largest non-renewable resource share (30%) mainly due to its high efficiency, low emissions compared to coal, and the geography that allows gas pipeline connection with Argelia (a predominant producer).
- In terms on renewable resources, the greatest evolution has clearly been the solar technology, inexistent in Spain in 2008 and now being responsible of c. 12% of the total generation. Wind production has also increased gradually positioning itself as the main renewable energy source in Spain and the second technology of the country after gas. Biomass has maintained its share during the period, slightly increasing in the last decade. Finally, the hydropower technology has experienced a considerable decrease during the period moving from 15% of the total generation in 2010 to 8% in 2022.

A final comment regarding the context of the renewables in the Spanish electricity generation is about the total installed capacity (in MW). According to *Red Eléctrica Española* (REE), in 2019 the renewable's total installed capacity surpassed for the first time the share of non-renewable resources installed capacity share as can be seen in the figure below.

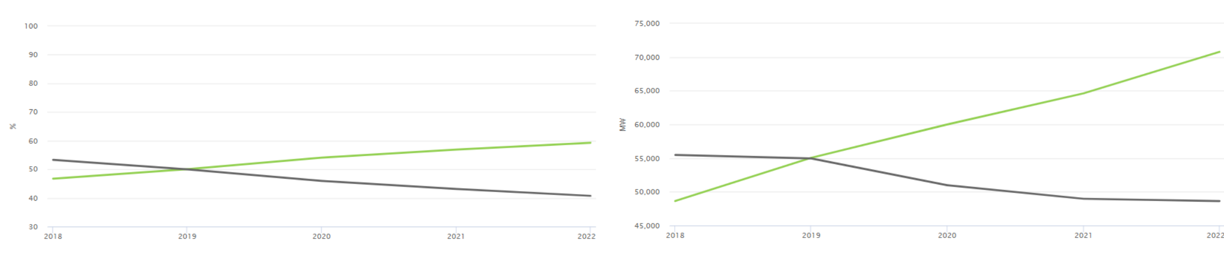


Figure 7: Evolution of renewable installed capacity in Spain (% & MW)

Additionally, although this data has not been confirmed yet, REE estimates as of January 2024 that renewable energy production can break records accounting for more than 50% of electricity generation in Spain in 2023, being almost nine percentage points higher than the described 2022 values.

2.1.2 Overview of the Key Technologies in Spain

Once analysed the context that the renewables live worldwide and concretely the evolution that they have suffered in the Spanish electricity market, it is time to deepen what is the current situation of each of the technologies in Spain, how they have evolved individually and what advantages and disadvantages they present in this market. The technologies will be developed in strict order of generation share (%) as of 2022: (i) wind, (ii) solar, (iii) hydropower, (iv) other renewables. However, as the information in this case will be obtained from REE, some of it will be updated as of December 2023 thanks to their advanced data analysis platform.

Wind presence in Spain

Wind is the #1 renewable technology in the Spanish electricity generation market and responsible for 21.52% of its production in the country in 2022, concretely 61.2 TWh in that year. Additionally, according to REE, it is the technology (including non-renewable and renewable sources) with the highest installed capacity growing from 25.7 GW in 2019 to 30.7 GW in 2023, representing as of January 2024 a share of 24.6% of the total installed capacity of the country:

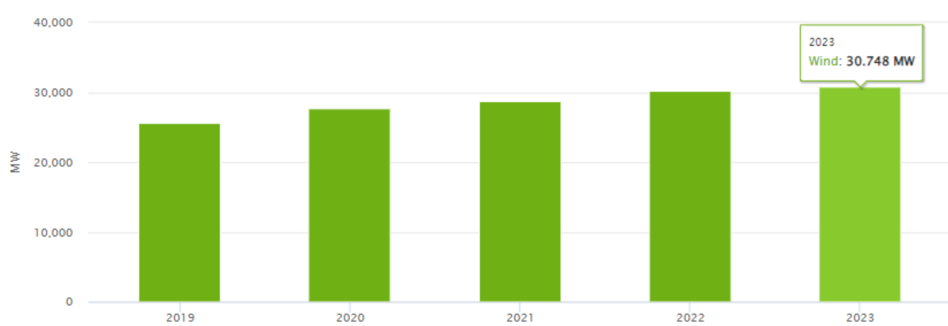


Figure 8: Wind installed capacity evolution in Spain (MW)

Regarding the current presence in Spain from the installed capacity described above, according to REE, in 2022 the five autonomous communities with the highest amount of wind installed capacity are #1 Castilla y León (6.63 GW), #2 Aragón (5.04 GW), #3 Castilla la Mancha (4.78 GW), #4 Galicia (3.89 GW), and #5 Andalucía (3.61 GW). All of them located in the Iberian Peninsula, with an only significant representation of this technology in the Canary Islands (0.6 GW):

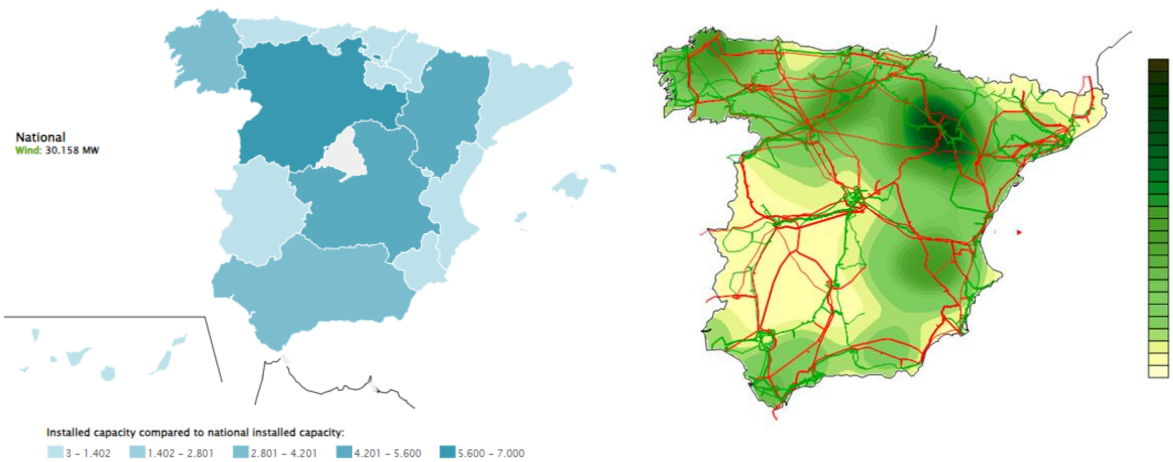


Figure 9: Spanish distribution of wind installed capacity (MW)

2022 Wind Installed Capacity in Spain (GW)			
Andalucía	**3.61**	**Galicia**	**3.89**
Aragón	**5.04**	**Islas Baleares**	**0.00**
Asturias	**0.70**	**Islas Canarias**	**0.60**
Cantabria	**0.04**	**La Rioja**	**0.45**
Castilla La Mancha	**4.78**	**Madrid**	**-**
Castilla y León	**6.63**	**Melilla**	**-**
Cataluña	**1.37**	**Murcia**	**0.26**
Ceuta	**-**	**Navarra**	**1.36**
Comunidad Valenciana	**1.24**	**País Vasco**	**0.15**
Extremadura	**0.04**	**TOTAL**	**30.15**

Table 1: Wind installed capacity by Autonomous Communities (GW)

Some additional final comments regarding wind energy in Spain, according to the 2021 data of the Spanish Wind Energy Association (AEE), in Spain there are +21,500 wind turbines installed across +1,300 wind farms in +850 municipalities in which these installations are a driving force in the rural communities. Additionally, Spain is the fifth country worldwide with the highest amount of wind installed capacity just after China, USA, Germany and India, meaning Spain holds the second position in this technology in Europe. Finally, AEE holds that as of 2022, the wind sector is responsible of +39,000 employments in the country and contributing 0.5% of the national GDP.

Solar presence in Spain

Solar is the #2 renewable technology in the Spanish electricity generation market and responsible for 11.54% of its production in the country in 2022, concretely 32.0 TWh in that year with the split of 27.9 TWh in solar photovoltaic and 4.1 TWh in thermal solar. According to REE, it is the #2 source (including non-renewable and renewable sources) with the highest installed capacity growing from 11.0 GW in 2019 to 27.4 GW in 2023, representing as of January 2024 a share of 21.9% of the total installed capacity of the country. REE splits the solar renewable source into two different technologies with presence in Spain:

- **Solar Photovoltaic (PV):** Responsible for the 10.0% of the total electricity generation in 2022 in Spain (27.9 TWh), it is the major solar technology in Spain and worldwide. As of January 2024, it is by itself the #3 source with the highest installed capacity, after wind (30.7 GW) and the combined cycle (26.3 GW), totalling 25.1 GW. This figure is specially relevant taking into account that the solar PV installed capacity has grown from 8.7 GW in 2019 to 25.1 GW in 2023, almost tripling its capacity in only 5 years and growing at a CAGR of 23.6%. As of January 2024, this technology represents 20.1% of the total installed capacity of the country:

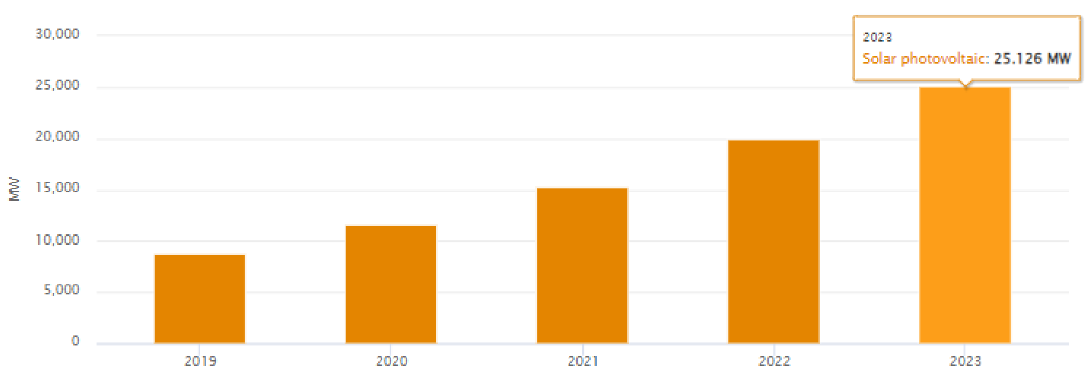


Figure 10: Solar PV installed capacity evolution in Spain (MW)

Regarding the current presence in Spain from the installed capacity described above, according to REE, in 2022 the five autonomous communities with the highest amount of solar PV installed capacity are #1 Extremadura (5.35 GW), #2 Andalucía (4.21 GW), #3 Castilla la Mancha (4.11 GW), #4 Aragón (1.85 GW), and #5 Castilla y León (1.45 GW). All of them located in the Iberian Peninsula, with an only significant representation of this technology in the Balearic Islands (0.22 GW) and the Canary Islands (0.21 GW):

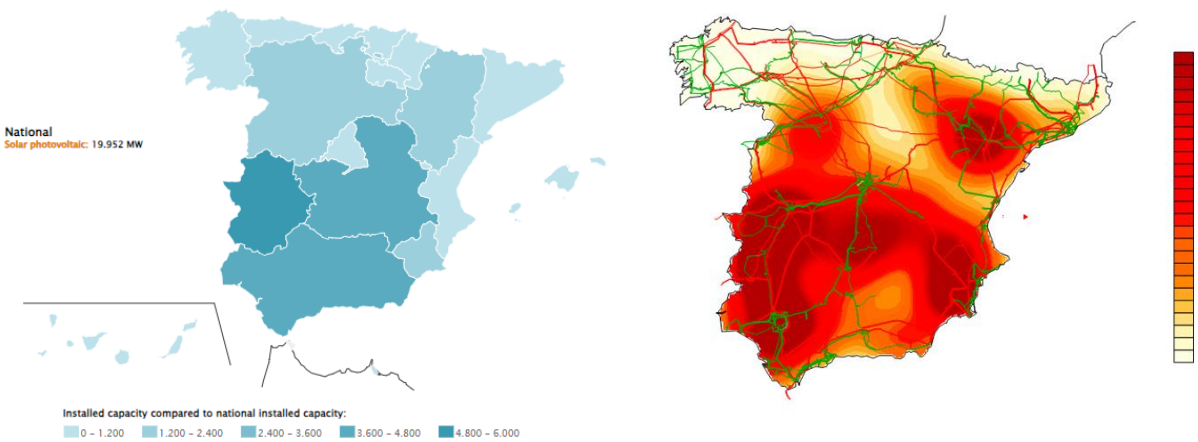


Figure 11: Spanish distribution of solar PV installed capacity (MW)

2022 Solar PV Installed Capacity in Spain (GW)			
Andalucía	**4.21**	**Galicia**	**0.02**
Aragón	**1.85**	**Islas Baleares**	**0.22**
Asturias	**0.01**	**Islas Canarias**	**0.21**
Cantabria	**0.00**	**La Rioja**	**0.10**
Castilla La Mancha	**4.11**	**Madrid**	**0.06**
Castilla y León	**1.45**	**Melilla**	**0.00**
Cataluña	**0.30**	**Murcia**	**1.41**
Ceuta	**-**	**Navarra**	**0.17**
Comunidad Valenciana	**0.42**	**País Vasco**	**0.05**
Extremadura	**5.35**	**TOTAL**	**19.95**

Table 2: Solar PV installed capacity by Autonomous Communities (GW)

A final comment regarding solar PV, REE publishes a yearly average on the hourly profile of which % of the total generation of electricity comes from solar PV. Although not surprising, it is interesting to see the profile of this source of energy and it is the perfect example to understand renewable generation in Spain. In the country, during 2022 and according to REE, c.25% of the total generation of electricity from 12-4pm (main sunny hours in Spain) came from solar PV sources. This figure is significant taking into account that solar PV was responsible for 10% of total Spanish generation in 2022:

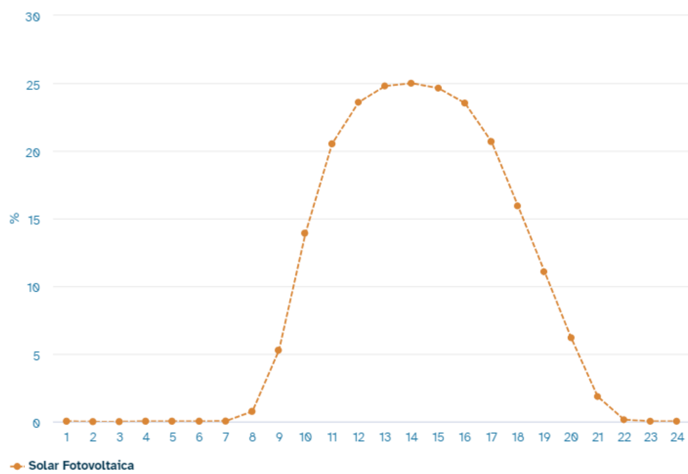


Figure 12: Average hourly profile of solar PV generation as % of total generation in Spain

- **Solar Thermal:** Responsible for the 1.5% of the total electricity generation in 2022 in Spain (4.1 TWh), it is the minor solar technology in Spain. As of January 2024, its total installed capacity is of 2.3 GW. This figure has not suffered any growth nor decrease in the last 5 years according to REE, as in 2019 the total installed capacity of solar thermal was already of 2.3 GW. As of January 2024, this technology represents 1.8% share of the total installed capacity of the country:

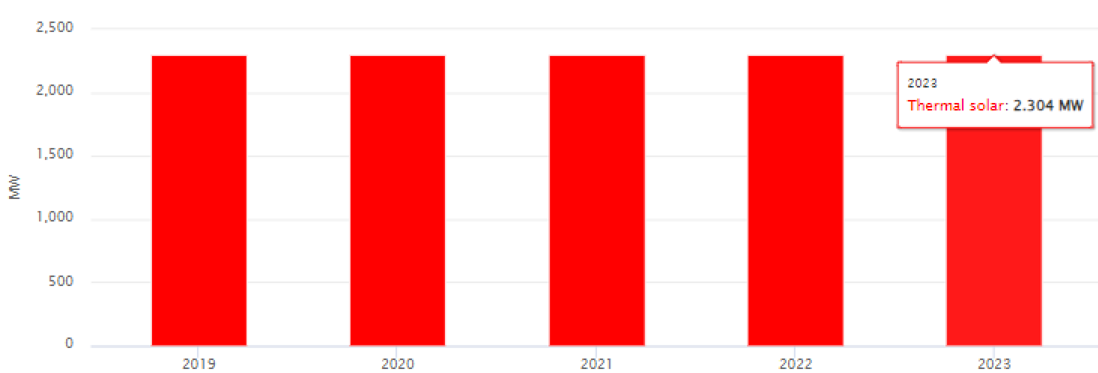


Figure 13: Solar Thermal installed capacity evolution in Spain (MW)

Regarding the current presence in Spain from the installed capacity described above, according to REE, in 2022 the five autonomous communities with the highest amount of solar thermal installed capacity are #1 Andalucía (1.00 GW), #2 Extremadura (0.85 GW), #3 Castilla la Mancha (0.35 GW), #4 Comunidad Valenciana (0.05 GW), and #5 Murcia (0.03 GW). All of them located in the Iberian Peninsula, with no significant representation of this technology in the Balearic or Canary Islands, nor Ceuta and Melilla:

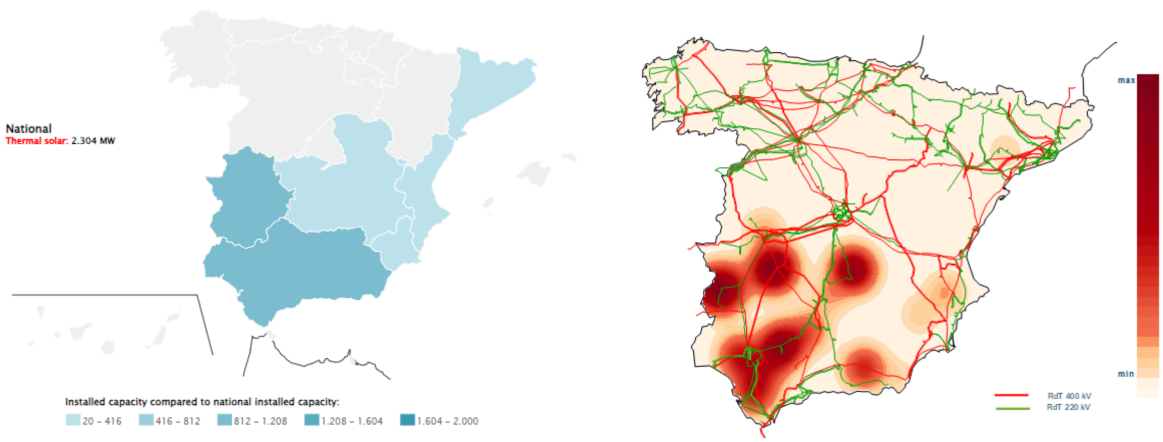


Figure 14: Spanish distribution of solar thermal installed capacity (MW)

2022 Solar Thermal Installed Capacity in Spain (GW)			
Andalucía	**1.00**	**Galicia**	**-**
Aragón	**-**	**Islas Baleares**	**-**
Asturias	**-**	**Islas Canarias**	**-**
Cantabria	**-**	**La Rioja**	**-**
Castilla La Mancha	**0.35**	**Madrid**	**-**
Castilla y León	**-**	**Melilla**	**-**
Cataluña	**0.02**	**Murcia**	**0.03**
Ceuta	**-**	**Navarra**	**-**
Comunidad Valenciana	**0.05**	**País Vasco**	**-**
Extremadura	**0.85**	**TOTAL**	**2.30**

Table 3: Solar thermal installed capacity by Autonomous Communities (GW)

Hydropower presence in Spain

Hydropower is the #3 renewable technology in the Spanish electricity generation market and responsible for 7.70% of its production in the country in 2022, concretely 21.7 TWh in that year with the split of 17.9 TWh in pure hydropower and 3.8 TWh in pumped storage. Additionally, according to REE, it is the #4 technology (including non-renewable and renewable sources) with the highest installed capacity, after wind (30.7 GW), combined cycle (26.25 GW) and solar PV (25.1 GW), totalling 17.1 GW in 2019. This figure has remained constant in the last 5 years as the total capacity installed from this technology in 2019 was already of 17.1 GW. Even though Spain has additional possibilities mainly due to its geography (specially in Cataluña and Aragón) to install more hydropower capacity, there are not relevant projects under construction and the expectation is that the installed capacity will remain the same for the next decade. Hydropower represents as of January 2024 a share of 13.7% of the total installed capacity of the country:

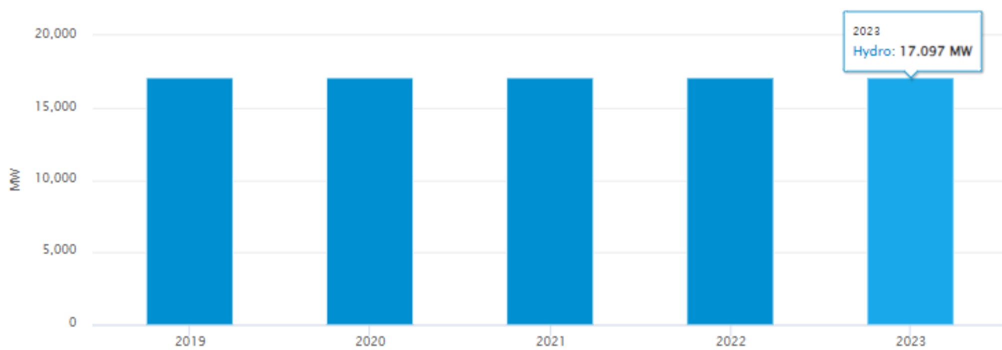


Figure 15: Hydropower installed capacity evolution in Spain (MW)

Regarding the current presence in Spain from the installed capacity described above, according to REE, in 2022 the five autonomous communities with the highest amount of hydropower installed capacity are #1 Castilla y León (4.40 GW), #2 Galicia (3.73 GW), #3 Extremadura (2.28 GW), #4 Cataluña (1.92 GW), and #5 Aragón (1.33 GW). All of them located in the Iberian Peninsula, with no significant representation of this technology in the Balearic or Canary Islands, nor Ceuta and Melilla:

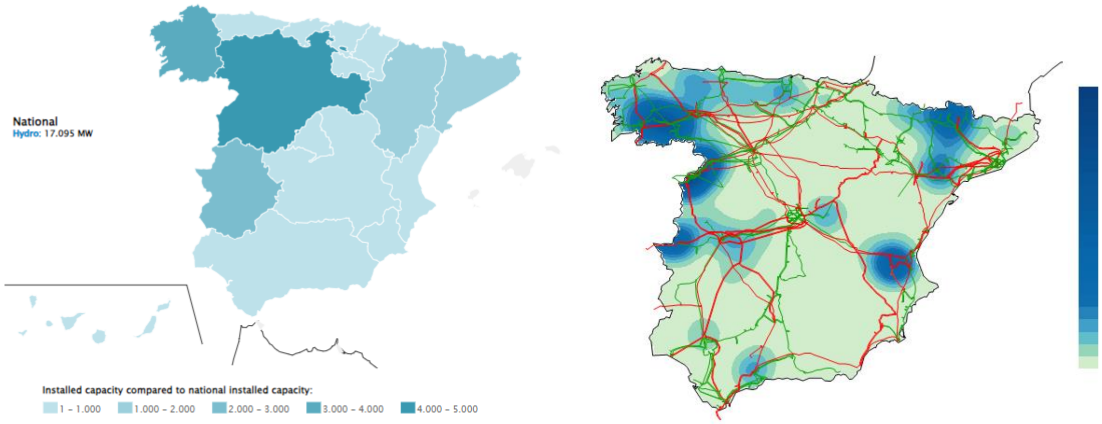


Figure 16: Spanish distribution of hydropower installed capacity (MW)

2022 Hydropower Installed Capacity in Spain (GW)			
Andalucía	**0.62**	**Galicia**	**3.73**
Aragón	**1.33**	**Islas Baleares**	**-**
Asturias	**0.80**	**Islas Canarias**	**0.00**
Cantabria	**0.10**	**La Rioja**	**0.05**
Castilla La Mancha	**0.65**	**Madrid**	**0.11**
Castilla y León	**4.40**	**Melilla**	**-**
Cataluña	**1.92**	**Murcia**	**0.04**
Ceuta	**-**	**Navarra**	**0.24**
Comunidad Valenciana	**0.64**	**País Vasco**	**0.18**
Extremadura	**2.28**	**TOTAL**	**17.09**

Table 4: Hydropower installed capacity by Autonomous Communities (GW)

One additional comment regarding hydropower, it is interesting to see again the average hourly profile of hydropower generation as a proportion of total Spanish generation in 2022. The profile shows an inverse shape than the previously explained curve of solar PV. This is mainly due to the share inputted by other technologies (mainly solar PV and wind) in the central hours of the day. However, in the early night and early morning hours (which are off-peak in the solar and wind technologies) it is when the hydropower energy can play its key role in the generation mix:

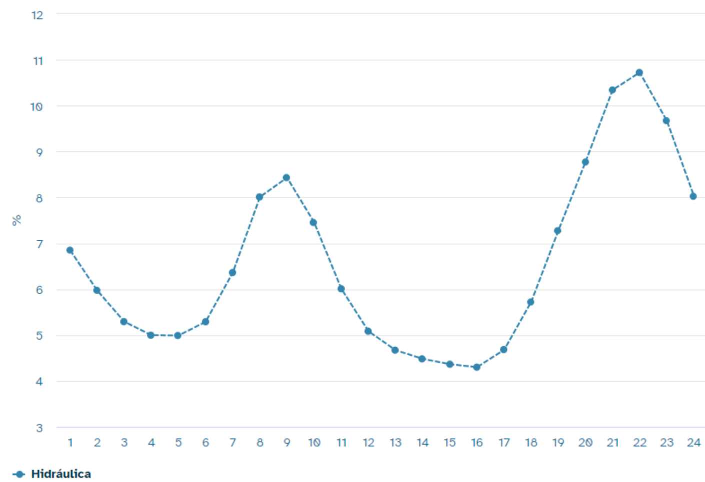


Figure 17:Average hourly profile of hydropower generation as % of total generation in Spain

Other renewables presence in Spain

"Other renewables" is a category stablished by REE which includes a set of different renewable sources (biogas, biomass, marine hydraulics and geothermal) that together stand for the #4 renewable technology (after wind, solar PV, and hydropower) in the Spanish electricity generation market and responsible for 1.70% of its production in the country in 2022, concretely 4.7 TWh in that year. Additionally, according to REE, this set of technologies has not grown much in installed capacity since 2019, keeping as of 2023 the level of 1.1 GW and representing as of January 2024 a share of 0.9% of the total installed capacity of the country:

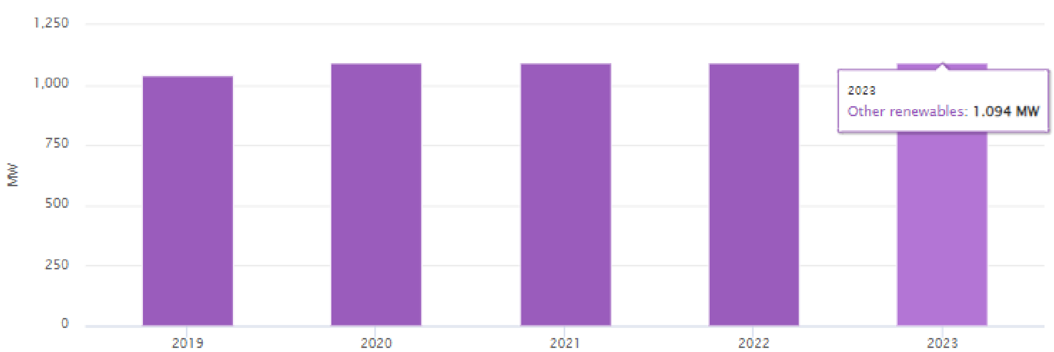


Figure 18: Other renewables installed capacity evolution in Spain (MW)

Regarding the current presence in Spain from the installed capacity described above, according to REE, in 2022 the five autonomous communities with the highest amount of other renewables installed capacity are #1 Andalucía (0.45 GW), #2 Castilla la Mancha (0.11 GW), #3 Castilla y León (0.10 GW), #4 Asturias (0.09 GW), and #5 Galicia (0.07 GW). All of them located in the Iberian Peninsula, with no significant representation of this technology in the Balearic or Canary Islands, nor Ceuta and Melilla:

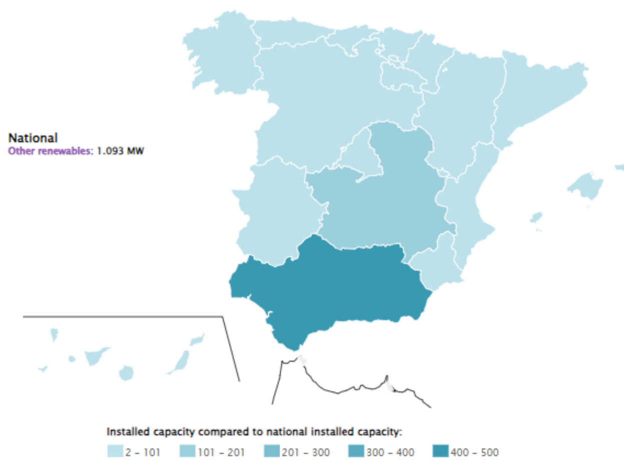


Figure 19: Spanish distribution of other renewables installed capacity (MW)

2022 Other Renewables Installed Capacity in Spain (GW)			
Andalucía	**0.45**	**Galicia**	**0.07**
Aragón	**0.01**	**Islas Baleares**	**0.00**
Asturias	**0.09**	**Islas Canarias**	**0.00**
Cantabria	**0.01**	**La Rioja**	**0.00**
Castilla La Mancha	**0.11**	**Madrid**	**0.05**
Castilla y León	**0.10**	**Melilla**	**-**
Cataluña	**0.06**	**Murcia**	**0.01**
Ceuta	**-**	**Navarra**	**0.04**
Comunidad Valenciana	**0.01**	**País Vasco**	**0.03**
Extremadura	**0.04**	**TOTAL**	**1.09**

Table 5: Other renewables installed capacity by Autonomous Communities (GW)

These "Other renewables" category created by REE with a total 1.1 GW installed capacity in Spain is composed of the following technologies: Biomass (615 MW), Biogas (473 MW), Miscellaneous renewable waste (170 MW), Hydro-wind (also known as off-shore wind, 11 MW), and Marine hydro and Geothermal (5 MW):

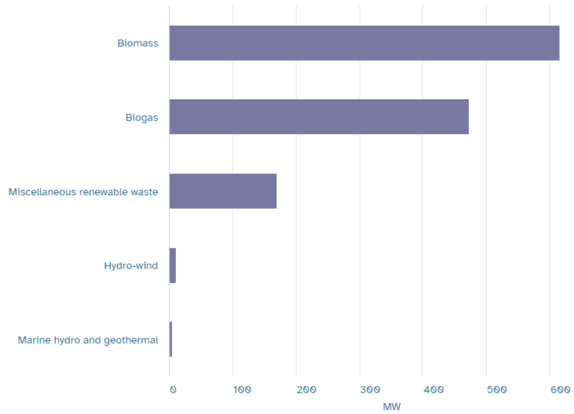


Figure 20: Technology split of Other Renewables installed capacity in Spain

2.2 Pipeline of Renewables in Spain

In the previous section, it was explained which is the present of the whole renewable sector in Spain and the huge share that these technologies currently represent not only in the total installed capacity in the country but also in the generation mix. Once understood this, it is time to understand which is going to be the future of these technologies in Spain in order to assess why it can make sense to potentially develop and operate a greenfield wind farm in the country.

2.2.1 Development and Investment Rationale in Spanish Renewables Sector

This section has a double aim. On one hand, it aims to demonstrate why bidding on the renewables sector makes sense for an investor when they have to choose if they are willing to take the risk of investing in building a wind farm (as in this thesis) or any other technology that is renewable. On the other hand this section aims to explain why making the investment in Spain and not in another country makes sense. This section hence is key to understand why this project is important and regular in the engineering and finance space. The development and investment rationale in the Spanish renewables sector (with focus on wind) is summarized in the following 10 points main:

1. Spain possesses one of the largest energy markets in Europe, with a total generation of +270 TWh in 2022 according to REE and a total installed capacity of +119 GW as of 2022. From this installed capacity, almost 60% of it (70.5 GW) comes from renewable sources and increased 5.9 GW in 2022.
2. Although the total renewable generation in 2022 was already very high reaching +116TWh and meaning a share of c.43% from the total national generation, latest expectations as of January 2024 from REE confirm that in 2023 the renewable generation breached the 50% barrier. This level is well above (i) world's renewable generation which is currently c.30% and (ii) Europe's which is currently c.40%. In addition, Spain has an ambitious target to increase the renewable share of energy generation by +80% in 2030.
3. Wind is already the energy technology with the largest amount of installed capacity reaching +30 GW in 2023. In this matter, according to AEE, Spain holds the privilege of being the top 5 country worldwide after China, US, Germany and India in wind installed capacity. In this line, Spain holds the second European position. Additionally, there are currently new strategies being put in place in the Spanish onshore wind space in order to increase the total installed capacity of a wind farm (hybridization), rise its operating useful life (repowering) leveraging the space and grid connection, and increasing the potential investment return (battery energy storage system).
4. In terms of solar PV, the latest confirmed data of 2022 show that it was a peak year for the sector in Spain reaching +25 GW of total installed capacity. In terms of new additions, in 2022 +4.7 GW were installed meaning a 25% increase comparing it to the 2021 figure of 3.5 GW. According to *Green Rhino Energy*, Spain has solar irradiation levels in the range of 1,600 – 1,950 kW/m2 positioning the country as the one with the greatest capabilities for harvesting photovoltaic energy. In addition, the costs of this technology are continuously lowering.
5. Although regulation is a topic to be covered with detail in a section below, a key reason to assess the potential development of a renewable plant in Spain is the favourable regulation context not only from European but also from Spanish authorities on this matter. In addition to promoting renewable energy transition through the later described regulation, according

to ICEX (España Exportación e Inversiones) from the Spanish Economy Ministry, the country intends to limit the award of new licenses for extraction and fracking activities and to lead to a fair transition for regions that are coal industry dependent.

6. One of the main learnings of the occidental countries as consequence of the Russian invasion of Ukraine in the macroeconomic level is the desire of energy independence of countries. After the war conflict, many countries have realized to be energy dependent from others. In this way, Spain would like to become independent in the long term of the Algerian gas at least in regards of energy production. For this reason, the country is fostering many initiatives to increase energy self-sufficiency and take advantage of Spanish natural resources.
7. Spain is key location to take advantage of the new renewables trends that will be developed in following sections. Concretely, Spain aims to reach 22 GW of storage capacity by 2030. Additionally, other technologies such as synchronous condensers are increasingly gaining market share and are expected to be able to generate revenue from the ancillary market in the future. Moreover, Spain is a leading country in Purchase Power Agreements (PPAs) which are contracts between a generator and another party (mainly distributors or end-consumers) and which increase the safety and low-volatility feature desired in the investment.
8. Spain is a leader in the wind industry, not only by the amount of installed capacity and share of electricity generated from wind, but also in terms of wind technology. According to AEE, Spanish wind energy sector is internationally recognized for its strength, size and latest technology advancement. Wind industry in Spain holds 250 manufacturing centres in 16 out of 17 autonomous communities. This has made Spain to become the fifth exporting country in wind turbines. Additionally, Spain holds the sixth position worldwide (third European) in wind patents and industry intelligence investing +€135m in research and development in the industry. Wind technology by itself stands for 0.5% of total national GDP and creates c. 40k employments (of which 70% are qualified).
9. Although the high capacity installed of wind and solar PV energy, in Spain there is scarcity of sizeable renewable portfolios creating a huge business opportunity to big developer

corporations and investors. Additionally, in the wind sector in concrete, it is a market worth investing as there are not many greenfield developments mainly due to de scarcity of suitable and worthy zones remaining to do so. In this way, once into it, is a market with high entry barriers due to complexity of the market and scarcity of locations protecting investors from competence.

10. To conclude, Spain holds an appealing macroeconomic profile in terms of political and regulatory stability, strategic location and connectivity. Spain is a gateway to both Europe and the Mediterranean region, holds an excellent transportation infrastructure, and guarantees access to a larger consumer market within the rest of the European Union. In addition, the country has demonstrated strong resilience during the last two main crisis (financial and sanitary) that specially impacted the Spanish economy fundamentals (economy and tourism).

2.2.2 Goals and Objectives in the Spanish Renewables Sector

First of all, it is important to remark that the main goals and objectives in terms of energy transition and climate policies of Spain are determined by the European Union (EU), which requirements in its turn are based on the Paris Agreement from 2015: an international agreement to fight against climate change and greenhouse effect gasses in which countries committed to develop policies to maintain global warming at a maximum of 2ºC above pre-industrialization levels.

The EU ratified the Paris Agreement in 2016 and developed the main objective guidelines for its member states for 2030: (i) 40% reduction of greenhouse effect gasses with respect to 1990 levels, (ii) 32% of renewables from the final total consumption of energy, (iii) 32.5% improvement in energy efficiency, and (iv) 15% electric interconnection between member states. Additionally, the UE requested to each member state (including Spain) the elaboration of a National Integrated Energy and Climate Plan (*Plan Nacional Integrado de Energía y Clima: PNIEC*) which according to IDAE (*Instituto para la Diversificación y Ahorro de la Energía*) defines the national objectives of reduction of greenhouse effect gasses, renewables energy penetration and energy efficiency.

This plan, which applies from 2021-2030, must be updated every 5 years and establishes that member states must present to the European Commission a monitoring report on the progress every 2 years.

In this way, the main Spanish objectives in terms of renewable energy are regulated in the PNIEC, which was approved by the government in March 2021. The main goals for 2030 on this matter stated in the PNIEC are the following: (i) 23% reduction of emissions of greenhouse effect gasses with respect to 2019 levels, (ii) 42% from renewables of the final energy consumption, (iii) 39.5% of energy efficiency improvement, and (iv) 74% from renewables of the total electric generation. Other secondary objectives for 2030 are: (v) Lower the level of energy dependency to 61%, (vi) Increase the number of electric vehicles to 5m, and (vii) reach a total capacity installed of 161 GW out of which 113 GW renewables.

To give a further detail of renewables installed capacity from the Spanish PNIEC, the plan targets for 2030 161 MW of installed capacity split as follows: 50 GW of wind (currently 30.7 GW as of January 2024), 39 GW of solar PV (currently 25.1 GW as of January 2024), 27 GW of CCGT (currently X GW as of January 2024), 16 GW of hydropower (currently 17.0 GW as of January 2024), 9.5 GW of pumping (currently 3.3 GW as of January 2024), 7 GW of solar thermal (currently 2.3 GW as of January 2024), 3 GW of nuclear (currently 7.1 GW as of January 2024), and other minor technologies. Additionally, the plan targets adding 2.5 GW of battery storage technologies.

In terms of renewable generation, PNIEC aims to reach 74% of the total electricity generation by 2030, which is in line with the main objective of reaching the 100% renewable target by 2050. According to the simulations performed by REE, if this target is reached the marginal generation cost could be reduced in c. 31% meaning a save of +€6bn in the electric system by 2030. Additionally, the PNIEC targets an overall importance of renewables in Spain so that 42% of the final energy consumption comes from these sources as consequence of the high penetration of electric and thermal renewables in all sectors.

Regarding the economic impact, the PNIEC estimates that the investment needed to reach these objectives is of +€241bn between 2021-2030. From this total quantity, 80% of it is expected to come from private investors (mainly renewables deployment) and the remaining 20% from the public sector (mainly energy efficiency and sustainable mobility). Additionally, PNIEC expected to generate a GDP increase of c. €16.5bn yearly, reaching a 1.8% of total GDP by 2030.

In June 2023, the government of Spain released an update of the 2021 PNIEC which has been approved by the European Commission in January 2024. In this new ambitious update the following objectives have been revised: (i) 32% reduction of emissions of greenhouse effect gasses with respect to 2019 levels (23% in PNIEC-2021), (ii) 48% from renewables of the final energy consumption (42% in PNIEC-2021), (iii) 44% of energy efficiency improvement (39.5% in PNIEC-2021), and (iv) 81% from renewables of the total electric generation (74% in PNIEC-2021). Other secondary objectives for 2030 are: (v) Lower the level of energy dependency to 51% (61% in PNIEC-2021), (vi) Increase the number of electric vehicles to 5.5m (5m in PNIEC-2021), and (vii) reach a total capacity installed of 214 GW out of which 160 GW renewables (161 GW and 113 GW respectively).

Again, giving a further detail of renewables installed capacity from the Spanish PNIEC-2023 update, the plan targets for 2030 214 MW of installed capacity split as follows: 62 GW of wind (50 GW in PNIEC-2021) from which 3 GW are estimated to be offshore, 76 GW of solar PV (39 GW in PNIEC-2021) from which 19 GW are expected to be from self-consumption, 27 GW of CCGT (same in PNIEC-2021), 14.5 GW of hydropower (16 GW in PNIEC-2021), 4.8 GW of solar thermal (7 GW in PNIEC-2021), 3 GW of nuclear (same in PNIEC-2021), and other minor technologies. In regards, with storage, the government increases the installed capacity in 2 GW reaching 22 GW from the previous 20 GW, however, it is still to be detailed the split between batteries and pumping storage.

In terms of renewable generation, the updated PNIEC aims to reach 81% (74% in PNIEC-2021) of the total electricity generation by 2030. Additionally, the PNIEC targets an overall importance of renewables in Spain so that 48% (42% in PNIEC-2021) of the final energy consumption comes from these sources as consequence of the high penetration of electric and thermal renewables in all sectors.

Finally, regarding the economic impact, the updated PNIEC estimates that the investment needed to reach these objectives is of +€294bn (+€241bn in the original PNIEC-2021) until 2030. From this total quantity, 85% (80% in the original PNIEC-2021) of it is expected to come from private investors (mainly renewables deployment) and the remaining 15% from the public sector (mainly energy efficiency and sustainable mobility) of which 70% is aimed to be financed by the Next Generation Fund of the EU.

2.2.3 Key Players in the Spanish Renewables Space

In the first part of this section (2.2.1) it was explained the reasons why renewables market in Spain is a key sector to look at due to the high number of opportunities and possibility of making profit at the same time of contributing to develop a more sustainable country. In the second part (2.2.2) it is concluded that, according to Spanish PNIEC-2023, 85% of the total investment needed to reach the goals of Spain in the renewables space is expected to come from the private sector. In this section, the aim is to have an overall understanding of which are the main industries on the renewables market of Spain and their main private players.

According to report *Getting the Deal Through – Renewable Energy Spain* from *King & Wood Mallesons*, the principal private players in the renewables electricity sector in Spain could be classified into five main categories: (i) Principal operators, (ii) Independent generators, (iii) Project development companies, (iv) Traditional oil and gas companies, and (v) Investment funds and investors of different nature:

1. Principal operators correspond to those companies that operate vertically in the Spanish electricity market in the whole supply chain (generation, distribution and commercialization). According to CNMC (*Comisión Nacional del Mercado y la Competencia)* these companies cumulate up to 81% of the total Spanish electricity market. These principal operators are: Iberdrola, Endesa, Naturgy, and EDP. As of January 2024, Iberdrola (leader in renewables) has 30.8 GW of installed capacity in Spain of which 21.6 GW are from renewable sources (with hydropower 10.8 GW and wind onshore 6.5 GW as leading technologies). Endesa manages 9.3 GW renewable installed capacity in Spain, Naturgy 4.4 GW, and EDP c. 2 GW.
2. Independent Power Producers (IPP) are companies, predominantly private, that have one or varies power plants under management that generate electricity which the IPP injects to the national electric pool. They are independent as they are just responsible of the electricity generation and power plant operation, but do not hold distribution or transmission infrastructure. These companies are also well-known as non-utility generators (NUG). Some important IPP of the Spanish renewable sector are Ignis (400 MW in operation and +10 GW pipeline in Spain), Opdenergy (742 MW in operation and 508 MW under construction in Spain), FRV (500 MW in operation and 665 MW under construction in Spain), or Saeta Yield (950 MW in operation in Spain).
3. Project development companies have a business model based on their expertise in the technical side of the renewable sector and dedicate their efforts to the research of potential projects to later develop and construct them, and typically sell them at COD (Commercial Operation Date). Hence, these companies do not typically decide to operate the assets they develop although there are exceptions depending on the business strategy and company expertise. These companies benefit from the Spanish world leadership in expertise and pioneering knowledge in the equipment manufacturing of renewable components. Some important Spanish examples of these companies are: Enerside (6.9 GW international pipeline of which 140 MW are in Spain), Grupo Cobra (global leader in development, creation and maintenance of electric infrastructure with presence in 45 countries), or

Siemens Gamesa (global leader in manufacturing renewables equipment with special focus on wind technology).

4. Traditional oil and gas companies are those that have a business strategy focused on the extraction and commercialization of petrochemical components. However, due to the recent changes in world's energy dynamics and the need of de-risking its core business strategy these companies have been forced to flip to a more sustainable business model in which renewables play a key role on their strategies. Main examples of Spanish companies in this situation are Repsol (c. 4 GW of renewable installed capacity mostly in Spain and a pipeline of 6 and 20 GW for 2025 and 2030 respectively), Galp (1.2 GW of solar PV under operation in Spain and a 2.2 GW pipeline under development), or TotalEnergies (3 GW of solar PV plants under development in Spain).
5. Private Equity firms and investor funds do also play a key role in the development and operation of renewable power plants in Spain mainly due to the nature of these assets. Investment firms such as pension or infrastructure funds which typically pursue long-term assets that are regulated, with low level of risk and return of c. 10-15% see on renewable energy operation a key opportunity to have safe returns. In this way, these funds are key players in Spanish renewable space as they see the country as an investment opportunity. Some of the key investment firms in the Spanish sector are Cubico, Macquarie, KKR, Brookfield, Cerberus, GIP and Ardian.

2.3 Regulation of Renewables in Spain

As demonstrated in the previous sections, renewable energy development is a key topic that all countries in the world must face and hence, as an important space for a country development, it is subject to a regulatory framework. Spain is not an exception. However, Spain regulation is subject and determined by the regulatory framework of the European Union. In this way, first of all the EU's regulation will be analyzed to later better develop the main points of the Spanish one.

2.3.1 European Union Regulation of Renewables

The European Union typically regulates its important matters through a legal instrument called European Directive. In this way, the most important law of the regulatory framework developed by the EU for the renewables sector is the Renewable Energy Directive, also known as RED. This legislation contains the targets and sustainability criteria of the EU. As the renewable sector has been progressing in the previous decades, the RED has been progressing with it:

- In 2009 the first RED (**RED I**) was approved by the European Commission and set the target of 20% share of renewable energy in total consumption of energy by 20202. This regulation was binding for each of the member states of the EU setting targets for them.
- In 2018, the European Commission revised the RED developing what was known as **RED II**. In this new regulation, the EU increased to 32% the total consumption of energy that had to come from renewable sources by 2030. The RED II also made important progress in the self-consumption of renewable energies prohibiting all kinds of barriers on this matter. In this way, the known as "Sun tax" that was controversial in countries such as Spain and Italy was eliminated. This new target set by the EU considered a revision period by 2023 in case the target had to be modified.
- As just mentioned, in 2023 there was a new revision of the energy directive that resulted in **RED III**. According to the Spanish law firm Garrigues, the new Directive responds to the need to accelerate energy efficiency, increase the use of renewable energies, and reduce emissions generated in the European Union with the ultimate goal of achieving an energy system independent of third countries. Among other measures with these objectives, the share of energy from renewable sources in the EU was again revised to increase at least 42.5% of gross final energy consumption by 2030. Additionally, RED III incorporates changes in order to reduce the bureaucracy in renewable permits to accelerate development, and also sets new targets for new renewables such as green hydrogen and others.

Other important regulations in the renewables space according to the European Commission include:

- **The European Green Deal**: Approved in 2020 with the main objective of making the EU climate neutral by 2050. The key intention of the Deal was to adapt EU's climate, energy, transportation and taxes to the main aim of reducing greenhouse effect gas emissions by 55% in 2030 with 1990's emissions as the comparison base. This regulatory framework is also known as "Fit for 55". According to Iberdrola, other additional objectives of the regulation aimed (i) To protect human life, animals and plants by reducing pollution, (ii) To contribute to guaranteeing a fair and integrated transition, (iii) To develop clean energies, reliable and affordable and developing the transition funding, and (iv) The conversion of agriculture and rural regions.

- **Plan REPowerEU**: In May 2022 as a consequence of the Russian invasion of Ukraine, the European Commission (EC) presented a package of regulation measures with the aim of stopping EU's energy dependence on the Russian fossil fuels which cost c. €100bn yearly to European residents. One of the key measures was on energy savings as was seen as the fastest and cheapest way to reduce gas bills, increasing from 9% to 13% the binding objective of energy efficiency in the framework of Fit for 55 of the European Green Deal. Another key measure was on the deployment of renewables to drive energy independence. The EC proposed the rise of the gross energy consumption that is aimed to come from renewables by 2030, which was at 42.5% and was proposed to be risen to 45%, again in the framework of Fit for 55. Other measures included: (i) Duplicate the solar PV installed capacity by 2025, (ii) Legal obligation of installing solar PV panels in new buildings (public, commercial and residential), (iii) Duplication of the speed of deploying heat pumps (geothermal energy), (iv) Recommendation of accelerating the bureaucracy for renewables deployment, and (v) Establish national objective of production of 10m tons of green hydrogen by 2030 to drive fossil fuels substitution.

2.3.2 Spanish Regulation of Renewables

Once the EU sets the regulatory framework for energy and renewables for its member states, it is the time for these to coordinate the national policies to reach and be compliant with the established European objectives. In this way, Spain has developed in the last decades its own energy regulation which follows the following timeline:

- **RD 2018/1998**: This Royal Decree establishes the initial governmental criteria for updating premiums and tariffs for renewable energy production in Spain. It introduces the concepts of Feed-In Premium and Feed-in Tariff, providing a regulatory framework for the remuneration of electricity generated from renewable sources. The regulation allowed hence two ways of selling the electricity that affected the remuneration: (i) Selling it directly to the pool market having as remuneration the pool price plus a regulated premium (Feed-in-Premium, FiP), or (ii) Sell it to a national distributor at a regulated tariff for kWh generated (Feed-in-Tariff, FiT). Hence, with RD 2018/1998, remuneration is determined centrally, following the principles of Law 54/1997 of the electricity sector, with the aim of guaranteeing reasonable compensation for renewable investors.
- **PFER 1999**: Known as the *Plan de Fomento de Energías Renovables*, this plan gave the guidelines on the growth expected on each of the renewables technologies in Spain with the main objective of reaching a 12% of the primary energy consumption coming from renewables by 2010.
- **RD 436/2004**: This Royal Decree addresses the updating of premiums (of FiP) and tariffs (of FiT) for renewable energy production, linking them to the increase in the reference tariff, as opposed to the previous situation in which premiums and tariffs were directly updated by the Government.
- **PER 2005-2010:** Know as the *Plan de Energías Renovables*, this plan substitutes the previously explained PFER which results were determined as insufficient. This plan, in addition to maintaining the 12% objective of PFER, incorporated two measures in line with the EU's objectives: (i) Reaching 29% of electric generation through renewables by 2010 and (ii) Reaching c. 6% of biofuels in the transportation sector by 2010. In this way, the plan increased the objectives in installed capacity of renewables (specially wind and solar PV).
- **RD 7/2006:** The CTE (*Código Técnico de Edificación*) is approved establishing the mandatory installation of thermal solar and solar PV in certain buildings.
- **RD 661/2007**: In this Royal Decree, premiums and tariffs are adjusted according to the Consumer Price Index (CPI). Additionally, this RD sets: (i) The Autonomous Communities

are the institutions responsible of issuing the inscription of a new renewable plant into the regulated revenue regime, and (ii) The new installations will be able to join the regulated revenue regime only if the maximum objective of installed capacity set by the PER for each technology has not been yet reached.

- **RD 1578/2008**: Specifically for solar PV installations, introduces a predefined rule for tariff revision based on pre-registered power and the power quota established by the regulator.
- **PANER 2010-2020:** Known as *Plan de Acción Nacional de Energías Renovables*, this plan was presented to the European Commission in 2010. It incorporated the objectives in renewables set by RED I.
- **PER 2011-2020:** Again known as *Plan de Energías Renovables*, this plan was approved in 2011 and substituted the PER 2005-2010 and the PANER 2011-2020. The main objective of the new plan was to make possible that the renewables represented by 2020 the 20.8% of the total energy consumption, hence surpassing the binding objective set by RED I (EU) for Spain.
- **Spanish Context 2012:** Spain was one the most affected countries in Europe by the great economic crisis that began in 2008. In 2012, with Rajoy in already in the government, the macroeconomic situation of the country was critical and several measures were undertaken in order to reconduct the situation and avoid the country's bankruptcy. Of course, this measures affected the electric system and hence the renewable energy impulse.
- **Electric System Context 2012:** A key topic to understand the next policies undertaken by the government in renewables was tariff deficit. According to *Expansion*, the tariff deficit signifies the disparity between electricity tariffs and the actual cost of production and distribution. This gap had been widening since 2002, as successive governments had raised electricity prices below the true cost. By 2012, the accumulated deficit had soared to €24bn, owed collectively by users to electricity providers. To address the tariff deficit, electricity companies proposed increasing prices by 15 to 20%, yet the government hesitated to burden consumers entirely due to political implications. Instead, alternatives like reducing

subsidies to renewables, fostering competition, and implementing new taxes on electricity generation were considered.

- **RD 1/2012**: As the tariff deficit was a huge problem in the context of the economic crisis of Spain, this Royal Decree aimed to put on hold the economic incentives to the development of new renewable projects. In addition, this law also suspended the inscription of new renewable projects into the regulated revenue regime that the RD 661/2007 and RD 1578/2008 (solar) had boosted in the past.
- **RD 15/2012**: In order to keep releasing regulations to stop the increase in the tariff deficit, the government approved this Royal Decree with fiscal measures to the renewable generators. With this RD, a new tax to the (i) electric generation and (ii) introduction of the electricity into the system is introduced with the only aim of collecting more taxes and start reducing the tariff deficit. This new tax was initially of 7%. In addition, for hydropower technology, it introduced a new tax of 22% for those plants which had an installed capacity lower or equal to 50 MW.
- **RD 2/2013**: After the urgent measures taken in the previous yearm this Royal Decree shifts the basis for adjustments in premiums and tariffs (of those plants that still can utilize the regulated revenue regime) to the underlying CPI at constant taxes.
- **RD 9/2013**: This Royal Decree was the beginning of a great readjustment of the remuneration regime of the electricity system in Spain, especially for the renewable technologies. Since 1997, renewables had enjoyed of a special remuneration regime based, as explained, on FiT and FiP. This regime was eliminated with this RD and all electric installations passed to be regulated by the same conditions. However, in order for renewables to be able to compete in the same conditions as the rest of technologies and to make sure that they could obtain a reasonable return of the project, a compensation plan is elaborated with two terms:
    - (i) A term on €/MW for installed capacity that covers (when needed) the investment costs of an installation that cannot be recovered through the sell of electricity. This compensation only applies for those renewables plants that at the moment of the publication of this RD had not yet reached the reasonable return.

  - (ii) A term on €/MWh for operation that covers the difference between the exploitation costs and the revenues for market participation for that installation. This compensation does not apply to those renewables plants which revenues from market participation are higher than the exploitation costs.

- **RD 24/2013**: This Royal Decree confirms the basis of the previously approved RD 9/2013. In addition, it quantified that, for those renewable plants that were regulated through the premium regime prior to the release of this law, the new remuneration system guaranteed a reasonable return for those installations estimated, before taxes, as the 10-year Spanish Treasury Bonds (in secondary market) increased by a spread of 300 bps (3%) to be reviewed every 6 years, hence leaving the next review for 31st of December of 2019.
- **RD 413/2014:** This new Royal Decree consolidated the policies from the previous RD 9/2013 and RD 24/2013 in terms of renewable energy production and cogeneration. It must be considered that although these three last policies were considered as necessary to make the renewables expansion sustainable and in order to avoid a financing collapse due to the tariff deficit, they were also highly criticized by the foreign investors as brought great uncertainty to their current and future returns as the measures were seen as changing the game’s rules after they had taken the risk of investing.
- **Auctions Context:** As just stated, the new established regulations brought to the renewables market a lot of uncertainty that dropped significantly the amount of renewables projects due to the reticence of investors of taking the risk of investing or financing a market with such successive regulatory changes. In this way, the government had to think about new measures to incentive (i) the deployment of renewables in order to meet the objectives previously set by the RED (EU) and PER (national), and (ii) the leading track that Spain had held on this matter globally. To do so, auctions were convoked in order to establish for certain projects a specific remuneration regime.
- **RD 947/2015**: In this first auction, a especial remuneration regulation was granted for the biomass and wind technologies, 200MW and 500MW respectively, for a total of 700 MW. However, the results of these auctions were considered as doubtful as all the MW were

granted without any premium, just remunerating them with the pool price. For this matter, the next auctions were more complex in terms of regulation.

- **Next Auctions:** As just explained, the first auction was a bit doubtful and hence the regulation in order to be able to participate and how to do it change significantly for the next auctions. To clearly understand it, the aim of the auction was to ensure the construction of new renewable installed capacity benefitting at the same time the market and consumers. In this way, the winners of the auctions were those that offered the best bids in the terms of the auction which main topic was typically a competitive price in its offer. According to information provided by EDP, to be able to participate in the auctions a company must be part of the REER (*Régimen Económico de Energías Renovables*). Once being part, the way it works is that there is a certain quantity (in MW) auctioned with different technologies to cover it (mainly wind, solar PV, and others). The participating companies submit their offers of capacity to install with a remuneration they would be willing to receive (€/MWh) for each MWh injected into the grid. For this calculation, the company must have considered all the costs of its project, so that with this amount, profitability is ensured for them. In the auctions, the administrator sets a confidential maximum price (al known as reserve price), which is the price from which the offers will be evaluated. That is, those offering prices higher than the established one are not considered. A minimum price is also set (typically at €0/MWh). In the auction, the offers between the minimum and maximum prices are ordered from lowest to highest until reaching the capacity in MW being auctioned. The result of the process, therefore, is the allocation of power to each winner at their offered price: "pay-as-bid". The entity administering the auctions is OMIE, and the supervising entity is the National Commission of Markets and Competition (CNMC).
- **RD 15/2018:** This Royal Decree aimed to fight against the rise in the electricity prices protecting consumers and boosting the energy transition. The main measure in renewables was the elimination of the known as the “Sun tax” which imposed to the self-consumer a tax expense for the energy generated and self-consumed in its own installation. Additionally, this RD tried to simplify the bureaucratic and technical requirements imposed to those installations that had higher installed capacity than 100kW.

- **RD 17/2019:** As mentioned in the explanation of the RD 24/2013, the reasonable return established in that law for the renewable technologies was to be revised every six years, hence in 2019 it had to be revised. Following the proposal of the CNMC (*Comisión Nacional de Mercados y Competencia*), the reasonable return applicable to renewable installations had to be slightly dropped for the period comprising 2020-2025 from the previous 7.398% (2014-2019 period) to the new 7.09%. This return applied to investors that had already been awarded regulated remuneration prior to RD 9/2013. Additionally, it let those investors maintain that return for two consecutive regulatory periods if they wished (hence until 2030) and if the assets were still operating.
- **PNIEC 2021:** Already deeply explained in the previous section.
- **RD 23/2020:** This Royal Decree regulates the criteria to be followed to set a clear order in the assessment of access and connection permits. The decided criteria is in terms of the viability and solidity of a project in order to accelerate the deployment of renewables.
- **RD 960/2020:** This Royal Decree introduces a new economic regime for renewables (REER). To benefit, installations must result from new investments made after the auctions. This regime replaces the previous remuneration system, focused on recognizing a fixed price for energy in the long term, and is granted through competitive bidding procedures where the auctioned product can be installed capacity, electricity, or both. Additionally, it stipulates that the auctioned price cannot be updated and requires auction winners to sell their energy in the electricity market at a freely determined price.
- **RD 1183/2020:** This Royal Decree establishes a new procedure for obtaining access and connection permits streamlining the process by establishing clear timelines and requirements. As a summary, after submitting an application, the grid operator has 20 days to assess and notify the applicant of admission or rejection. If the application is viable, the operator presents a preliminary proposal including technical specifications and economic details. The applicant then has 30 days to accept or request revisions, with acceptance leading to the issuance of permits within 20 days. In terms of economic guarantees, this RD establishes that they are mandatory, with a deposit required equivalent to €40/kW installed, exempting small installations and self-consumption setups under certain

conditions. The presentation of this guarantee is a prerequisite for initiating the access and connection process. This RD also included some regulation about hybridization that is explained in the following section.

- **RD 12/2021:** In a context of a high rise in electricity prices, not only in Spain but also in the rest of Europe, the government approved a package of fiscal measures in order to protect consumers. The most important ones include: (i) Reduction of the VAT in the electricity bill of consumers from the initial 21% to 10%, and (ii) Suspension of the IVPEE (*Impuesto sobre el Valor de la Producción de Energía Eléctrica*) which, as described previously in RD 15/2012, it was set at 7% of the revenues obtained from the sale of electricity and is hence rebounded in the electricity market and hence in the final bill.
- **RD 6/2022:** In the context the recent invasion of Ukraine by Russia and its effects on economy and electricity price rises, this Royal Decree aims to mitigate its effects by: (i) Accelerating de regulatory process of renewable installations, and (ii) Updating for 2022 the especial remuneration regime conditions for renewables to adapt them to the electricity prices of that time.
- **RD 10/2022:** In line with the fight against the high power prices but also a context of high inflation, the government released this Royal Decree in which they put a cap on gas as a result of the known “Iberian exception”. This cap did not affect renewable generation as it does not use gas, but it did impact on carbon plants, CCGT and cogeneration plants.
- **TED 741/2023:** This law, once again, updated the especial remuneration parameters of the renewables installations for the half-period beginning in 2023 until 2025.

2.4 Main Trends of Renewables in Spain

2.4.1 Repowering

Repowering has emerged as a significant trend in Spain's renewable energy sector, particularly in the wind energy domain. As some of the country's earliest wind farms reach the end of their operational life cycles, there is a growing emphasis on upgrading existing installations with modern, more efficient technologies. This approach not only maximizes energy production but also optimizes land use by generating more power from the same or even smaller footprints. By replacing outdated turbines with newer models that have higher capacities and improved performance, Spain is able to bolster its renewable energy output without the need for extensive new developments.

The economic benefits of repowering are substantial. Upgrading existing infrastructure is often more cost-effective than building new facilities from scratch, as many of the necessary permits, grid connections, and site preparations are already in place. This leads to reduced investment costs and shorter project timelines, making renewable energy projects more financially viable and attractive to investors. Additionally, repowering can extend the operational life of wind farms, ensuring continued revenue streams and job preservation within local communities.

From an environmental perspective, repowering contributes to Spain's sustainability goals by reducing the ecological impact associated with new construction. Modern turbines are designed to be more wildlife-friendly and produce less noise, mitigating some of the concerns associated with older models. Furthermore, increased efficiency means that fewer turbines are needed to produce the same amount of energy, leading to less visual impact and lower interference with local ecosystems.

Policy support has been instrumental in advancing repowering initiatives in Spain. Government incentives, streamlined regulatory processes, and supportive legislation have created a favorable environment for repowering projects. These efforts align with Spain's commitment to the European Union's renewable energy targets and its own national objectives to transition towards a more sustainable and resilient energy system.

2.4.2 Hybridization

Hybridization in renewable energy refers to the integration of multiple energy generation technologies to optimize efficiency and reliability, and this trend is gaining momentum in Spain.

By combining resources such as wind, solar, and hydroelectric power, hybrid systems can mitigate the intermittent nature of individual renewable sources, ensuring a more consistent and stable energy supply. For instance, when solar production dips during cloudy periods, wind or hydro resources can compensate, effectively balancing the grid and reducing reliance on fossil fuels.

Spain's abundant natural resources make it an ideal candidate for hybrid renewable systems. Regions with high solar irradiance and consistent wind patterns are particularly suitable for combined installations. These hybrid projects maximize the utilization of available land and infrastructure, leading to better economic returns and more efficient energy production. Additionally, the integration of different technologies can reduce transmission losses and lower overall system costs by sharing components such as inverters and grid connections.

The implementation of hybrid renewable systems also aligns with Spain's strategic goals to enhance energy security and achieve carbon neutrality. By diversifying the energy mix and increasing the share of renewables, Spain can reduce its dependence on imported fuels and decrease greenhouse gas emissions. Hybrid systems contribute to grid stability and resilience, which is especially important in the face of increasing energy demands and the challenges posed by climate change.

2.4.3 Battery Energy Storage System (BESS)

Battery Energy Storage Systems (BESS) are becoming an integral part of Spain's renewable energy infrastructure, addressing the critical need for energy storage and grid stability. As the country continues to expand its renewable energy capacity, particularly in solar and wind, BESS provides a solution to the intermittent and variable nature of these energy sources. By storing excess energy generated during peak production times and releasing it during periods of high demand or low generation, BESS ensures a consistent and reliable energy supply.

The deployment of BESS in Spain offers numerous benefits beyond balancing supply and demand. These systems enhance grid flexibility and resilience by providing services such as frequency regulation, voltage support, and peak shaving. This leads to improved efficiency and reduced operational costs for the energy system as a whole. Additionally, BESS facilitates the integration of higher percentages of renewable energy into the grid, accelerating Spain's transition towards a sustainable and low-carbon energy future.

Technological advancements and decreasing costs have made BESS increasingly viable and attractive for large-scale and distributed energy applications in Spain. Innovations in battery technologies, such as lithium-ion and emerging alternatives like flow batteries, have improved performance, lifespan, and safety profiles. Coupled with supportive government policies and financial incentives, these developments have spurred investment and rapid growth in the energy storage sector.

CHAPTER 3. WIND FARM DEVELOPMENT PROCESS

In the previous section, the current status of renewables, with especial focus in Spain, was deeply explained. In this chapter, the aim is to deeply focus on the wind technology and the process of developing a greenfield wind farm in Spain.

3.1 Deep Dive in Wind Technology

3.1.1 Wind Turbine

Clearly, in the last section it has been seen that wind energy not only is one of the most important ones in global energy transition, but it is the leading technology in Spain. It has been deeply developed that this energy technology is key in the development of the country and that Spanish society should keep investing on it to reach net zero objectives and to ensure the political and economic energy independence in the long-term. However, how does this technology work? What are the engineering principles behind it? This section aims to solve this natural doubts.

Starting with the basics, a wind turbine should not be seen as a technology that “creates” energy. Instead, it should be seen as a mechanism that is able to transform the kinetic energy of the wind into electric energy. This is exactly why this technology is renewable, because it utilizes a natural resource that cannot be depleted (in human time-life terms) to create other sources of energy useful for human beings. In order to explain the functioning of a wind turbine, each of the key elements of it will be explained. The following two images serve as a clear guide in order to distinguish each of the parts of a wind turbine and their function:

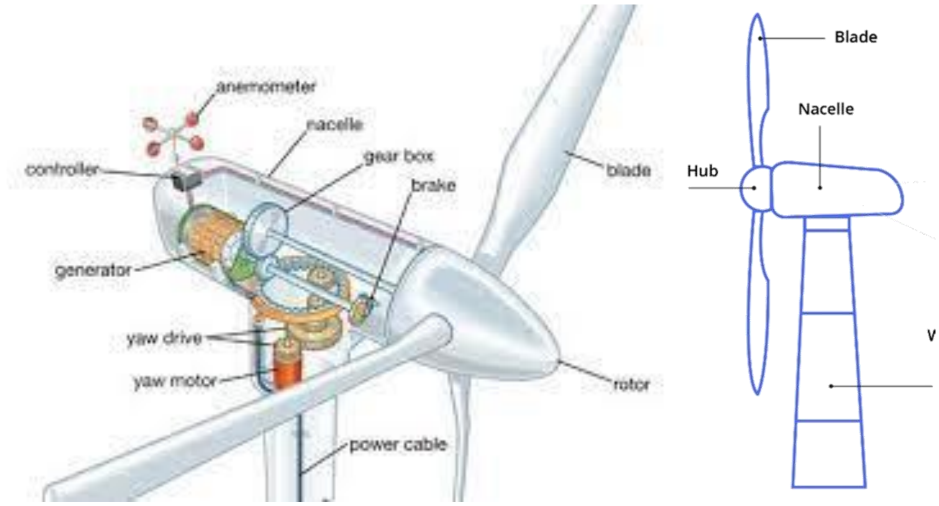


Figure 21: Wind turbine components

- **Hub or Rotor:** This component is typically known as the hub or rotor and it is the part that joints the blades to the shaft of the wind turbine. The hub is connected to the mechanism and together with the blades, it is responsible of transforming the wind energy into mechanical energy (which will later be transformed into electric energy). An interesting detail is that although the most common hubs seen and built are for three blades, one should not think that one of the blades fell if he sees it with only two blades. In fact, with two blades the wind turbine is cheaper and faster, however they are noisier and can vibrate.
- **Blades:** These are the components that give the wind turbines the shape they have. The blades are responsible of creating the movement of the hub when the wind passes perpendicularly across them. But if the wind passes perpendicularly, how is it possible that it makes the blades rotate? The answer to this question is found in the shape of the blades, also called the aerodynamic profile. Basically, the shape of the blades is built so that when the wind passes perpendicularly a lift force is generated that creates the movement. As deeply explained by Windmills Tech, the blades are subject to the following four forces:

Figure 22: Blade forces

Drag, centrifugal and gravitational forces are very intuitive and not responsible of generating the rotation by which the kinetic energy of the wind is later transformed into mechanical energy. The lift force, however, is less intuitive and key for understanding the functioning of a wind turbine. Basically, when the wind passes over the blade, the pressure difference between the front and back of the blade causes the lift force (exactly the same reason why planes fly) and creates the torque that provokes blades spinning movement:

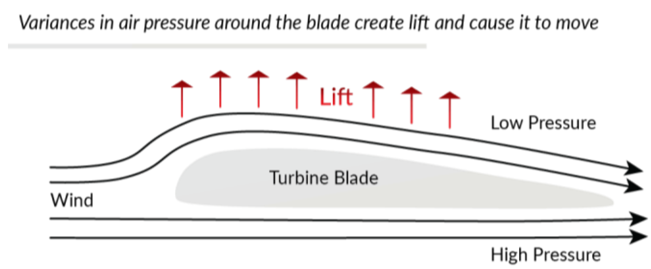


Figure 23: Lift force explanation

- **Nacelle:** It is the name of the box located at the top of the wind turbine that houses all the electromechanical components that transform the mechanical to electric energy. As explained below, the nacelle is able to rotate in its own axis in order to make the blades face perpendicularly the wind. Its main function is ensure the protection of the components inside of it in case of meteorological adverse conditions.
- **Wind vane:** Although not indicated in the components figure, a key element in the top of the nacelle is the wind vane. Its main function is determining the wind direction so that, with this information, the wind turbine can face the wind perpendicularly. As it is obvious, the wind vane must be able to rotate and determine the wind direction across the 360º possible directions with no gaps to ensure optimal functionality.

- **Yaw system:** Once the wind vane has determined the wind direction, the yaw system is responsible of making sure that the wind turbine faces that direction. This system is composed of (i) Yaw drive that makes the turbine face the direction transmitted by the wind vane, and (ii) Yaw motor that powers the yaw drive.
- **Anemometer:** As it is explained in the section below, wind turbines can only operate on certain wind speed conditions. In this way, not only is important to know the wind direction but also to know the wind speed. This is the function of the anemometer located in the top of the nacelle.
- **Controller:** The anemometer measures the wind speed but has not data processing features. In this way, the information captured by the anemometer is transmitted to the controller, located inside the nacelle, that processes the wind speed and shuts on or off the wind turbine.
- **Brake:** As just mentioned, if the wind conditions (typically very high winds) are not suitable for the wind turbine operation, the controller gives the order of not operation. However, in this situation, as blades are still subject to wind conditions, the lift force still appears and makes the rotor spin. To stop this spin of the rotor, a brake is needed. It can be mechanical, electrical or hydraulic. It is not only key when the wind speeds are too high to operate, but also when there is an emergency or during maintenance of the wind turbine.
- **Gearbox:** The process on how to transform the wind's kinetic energy into mechanical energy is now clear. However, the aim of the wind turbine is to transform it to electrical energy. This process is done in the generator when the mechanical movement is at a rotation speed of up to 1800 revolutions per minute (rpm). Clearly, the rotor does not reach this high speed, but an average rotation of 20-50 rpm. Hence, the function of the gearbox is to transform the slow rotation of the hub into the desired rotation by the generator to produce electricity.
- **Generator:** As described above, the generator transforms the mechanical energy into electrical energy. Typically, wind technology utilizes asynchronous generators which means that the rotor of the generator (connected to the hub through the gearbox) spins at a different speed than the magnetic field of the stator. Concretely, the rotor spins at the speed

determined by the gearbox after transforming the low speed of the hub into the desired speeds of the generator. The main reasons to utilize a asynchronous generator instead of a synchronous are: (i) Cost: Synchronous generators are more expensive, (ii) Maintenance: Induction (asynchronous) machines are less subject to failures, (iii) Better adaptability to variable wind speeds, (iv) Smaller size and lighter machines.

- **Tower:** It consists of the structure that holds the nacelle, the hub and the blades. It is typically built joining several pieces and assembled on site. Clearly, the minimum height of the tower must be the radius of the circumference built by the blades. However, typically the height is close to the diameter between 100-120 meters (although there are wind turbines +200 meters high). Through the tower, the power cable passes by to reach the generator inside the nacelle. Additionally, the tower has the essential function of ensuring that it is able to give stability to the structure given the strong forces that the wind and the movement of the blades provoke.

An additional comment in terms of wind turbines. Although this explanation has been focused on Horizontal Axis Wind Turbines (HAWT) there is actually another type known as the Vertical Axis Wind Turbines (VAWT):

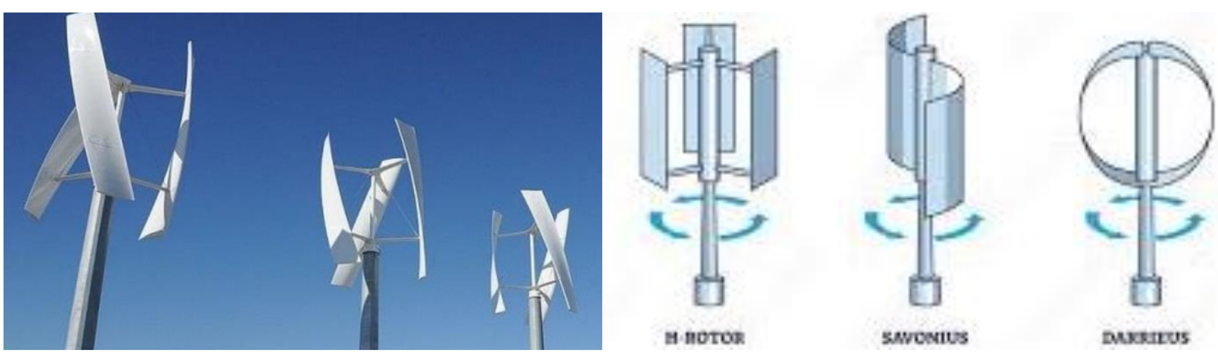


Figure 24: Vertical Axis Wind Turbine (VAWT)

The main difference with the traditional wind turbine described above is that the VAWT operates rotating in the vertical axis, while the traditional HAWT blades rotate in the horizontal axis:

Comparison Table HAWT vs. VAWT		
Difference	**HAWT**	**VAWT**
Axis plane	Horizontal	Vertical
Generator location	Inside the nacelle in the top of the wind turbine tower	It is installed in the ground
Yaw mechanism	Needed to face the blades in the perpendicular direction of the wind	No needed as there is no need to face wind's direction
Design	Complex	Simple
Space of the blades	Requires large space for blades' operation	The operation does not need much space
Height	Large distance from the ground to the nacelle	Comparatively smaller distance from the ground
Power coefficient	High	Low
Noise	Noisy	Less noisy
Birds	High obstruction for birds	Less obstruction
Cost	Expensive	Less expensive

Table 6: Comparison table HAWT vs VAWT

3.1.2 Wind Turbine Specifications

Once understood which are the key components of a wind turbine, it is important to understand which are the functioning specifications of it. Deepening into these functional specifications is important not only to understand the wind technology itself but also to take them into account while designing a wind farm:

1. **Wind speed:**

As introduced in the previous section, a wind turbine is able to operate only at certain wind conditions that must be known to have an estimation of how much power it would be able to produce with the wind speeds of the land where the wind farm would be located. The following diagram eases the explanation of the possible status in which a wind turbine could be depending on the wind conditions:

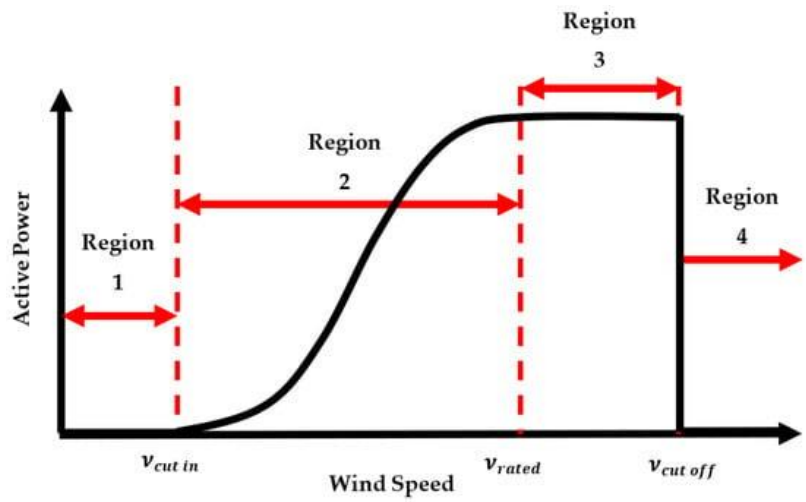


Figure 25: Power vs Wind Speed Curve

- Region 1: A wind turbine would be in this region if the wind speed is between 0 and the cut-in speed (Vcut-in). In this condition, it is assumed that the force exercised by the wind in the blades is not enough in order to spin the rotor, or said in another way, the wind speed is not high enough to break the wind turbine's statism. Although the cut-in speed of the wind varies between wind turbines, a proxy is between 3 and 4 meters per second (m/s).
- Region 2: In this region, the wind speed has increased and has passed beyond the cut-in speed (Vcut-in). In this way, the rotor of the wind turbine already spins and active power is generated. This region 2 has the characteristic of being the only one in which the electricity generated by the wind turbine is not constant. The energy generated increases with the increase of the wind speed until reaching what is known as the rated speed (Vrated). Again, although rated speed of the wind varies between wind turbines, a proxy is between 12 and 17 m/s.
- Region 3: In economic terms, this would be the optimal status at which a wind turbine should be operating as in this region the wind turbine is producing the maximum amount of electricity that it is able to generate. This limit is also known as the rated power output and it is only reached once the wind speed is above the rated speed. When the wind turbine operates in this region, it is operating at a constant energy output which means that no matter how above the wind is above the rated speed that the electricity generated will be

the same. However, there is an exception, if the wind speed keeps increasing well above the rated speed it can reach cut-off speed (Vcut-off) which is the wind speed at which this region stops being active. Again, although the cut-off speed of the wind varies between wind turbines, a proxy is between 25 and 30 m/s.

- Region 4: In this region, the wind turbine is not generating electrical energy as the wind speed has exceeded the maximum (Vcut-off).

2. Tower height

The known as tower height or hub height is a key factor in the design of a wind farm. Starting with the definition, the tower height is the distance from the ground (base of the wind turbine) to the location of the nacelle. As it can be seen in the following graph, during the last decades there has been an evolution that shows an increasing trend on the average height of wind hubs. While in the late 90s the hubs were on average 50m high, currently they average c.120m and it is expected that in the future they will average +160m in the future:

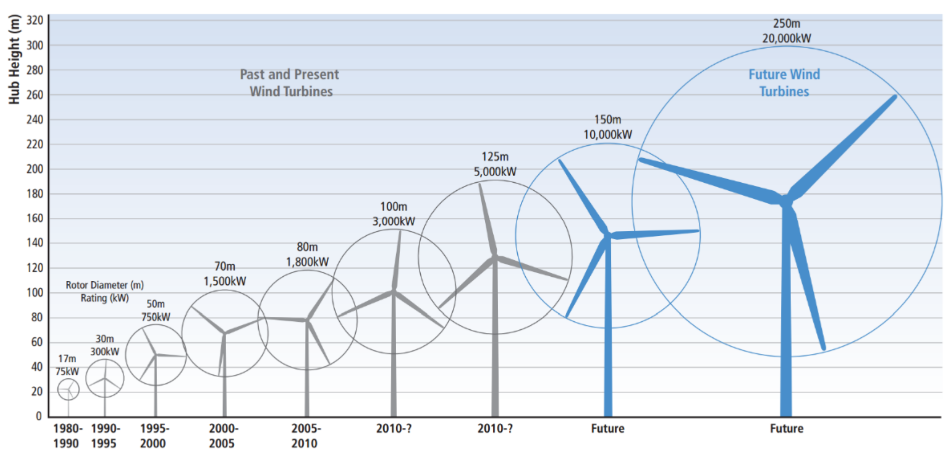


Figure 26: Wind turbine hub height evolution

As an interesting fact, as of February 2024, the world's highest wind turbine is from the Danish company Vestas and is the model V236-15.0MW. As its name indicates, it has an installed capacity of 15 MW and has a height of 280 meters.

As it can be imagined, there is not a mathematical formula that relates the height of a wind hub with the total energy produced by the wind turbine. However, it is also obvious that the height of the hub can have a direct effect on the energy produced and hence it is important that the optimal height is determined prior to the construction.

Important facts to consider when deciding the height of a wind turbine are the wind speed and the air's density. In terms of wind speed, the highest the wind speed the highest the energy that the wind turbine will be able to produce (except if it is in the explained region 4 in the previous section). However, wind speed is not constant at all heights as it increases with height due to the fewer friction and turbulence that floor and obstacles provoke (wind shear). Secondly, air's density must also be considered when deciding the wind turbine height because the higher the density the higher the force that the wind will be able to exercise in the wind turbine blade and the highest the energy that it will be able to generate. Air's density decreases with height due to the effect of temperature and the lowest atmospheric pressure.

Hence, as just explained, there are different kinds of effects to be considered when deciding the wind turbine height. In order to optimize this decision, there exist several tools and methods such as maps and wind data bases, wind profiles and curves, wind turbine simulations, algorithms and optimization software that can be used.

3. Blade length

The length of the wind blades determines the diameter of the rotor, that is, the distance from one extreme of the circle drawn by the blades spinning to the opposite one. According to the US Energy Efficiency & Renewable Energy Office, back in 2010 no wind turbines in the US employed rotors that were 115 meters in diameter or larger. However, as of their data from 2022, the average rotor diameter of newly-installed wind turbines was +130m. For reference, a professional football field has a maximum length of 110m. The following graph shows the evolution of the average blade length across the years linked with its capacity:

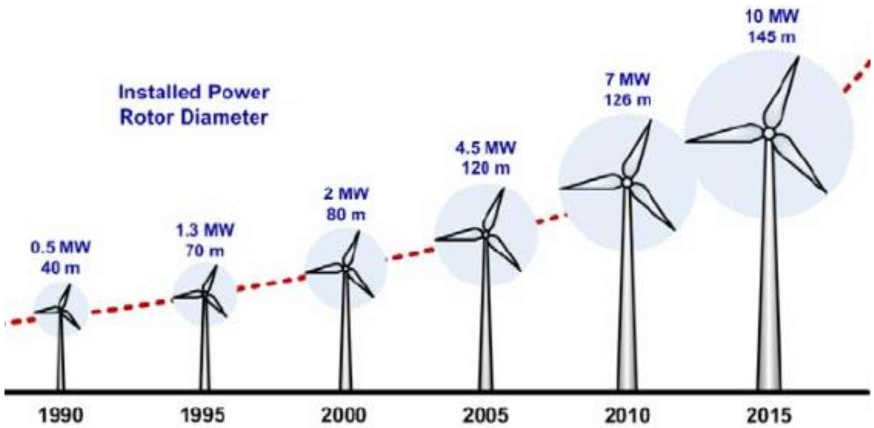


Figure 27: Wind turbine blade lenght evolution

As described with the height of the hub, there is not a mathematical formula that directly relates the length of the blades of the wind turbine with the total energy produced by it. However, in this case, it is easy to defend that the longer the blades the higher the energy output that the wind turbine can extract. The reason for it is that when the blades are longer, the rotor diameter is longer as well, meaning that the area swept by the wind turbine is bigger, hence more wind is captured. This means that more kinetic energy from the wind can be transformed into mechanical energy and this one into electrical energy.

Additionally, there is an important factor to consider. Being able to produce wind turbines with longer blades makes it possible for developer companies to determine as suitable new places to install the wind farms where in previous conditions those places would have been disregarded due to low wind speeds. To make this clear, if previously a land would have not been found as suitable for a wind farm due to low wind speeds and hence low energy produced, now, utilizing turbines with longer blades makes possible to extract higher energy quantities making the same lands suitable for wind projects.

As an interesting fact, as of February 2024, the world's highest wind turbine commented before (Vestas) has three blades with a total length of 115.5 meters, meaning a total rotor diameter of 236 meters, allowing the wind turbine to encompass a total area of c. 44k square meters.

4. Efficiency – Betz's Law

When addressing the topic of wind turbine specifications, one of the key technical matters that a developer should look at is the wind turbine efficiency. This concept can be defined as the amount of electrical energy that can be extracted from the total kinetic energy captured from the wind. Dividing the output energy (electrical) by the input energy (kinetical), a developer would be able to exactly know which efficiency the wind turbine has.

However, questioning the efficiency of wind turbines is not something new. Since the foundations of the wind technology it was a question asked by several investigators. In 1919, a German physicist called Albert Betz utilized his knowledge in fluid mechanics and aerodynamics to develop a thesis that would later be called as Betz' law. Basically, according to Betz' demonstration, there is a maximum theoretical efficiency that a wind turbine can have and which is independent of its design. As Betz demonstrated, no wind turbine of any mechanism can capture more than 16/27 (59.3%) of the kinetic energy in wind.

In this way, Betz' law sets the cap of 59% of the theoretically possible efficiency that a wind turbine can hold. In fact, wind turbines' efficiency is usually referred as an "x"% efficiency (typically "x" is between 75-80%) of Betz cap.

Betz demonstrated this 59% maximum efficiency in a wind turbine as follows. It utilized the basic principles of physics known as the conservation of mass and momentum of the air stream flowing through an open-disk actuator which is basically what a wind turbine does:

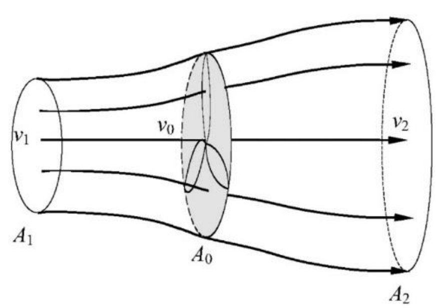


Figure 28: Scheme to demonstrate Betz' law

3.1.3 Spanish Wind Industry

This topic has been mostly covered in the previous chapter. However, there are some additional pieces of information that it is important to highlight in order to better understand the relevance of the wind industry in Spain and among other renewables technologies.

As explained, Spain is in fifth position in terms of global wind installed capacity, and second in Europe after Germany. The wind industry in Spain is present in 47 provinces representing the wind technology 25% of the Spanish installed capacity and 24% of annual the energy produced. According to the latest update of AEE, in Spain there are +22k wind turbines distributed in 1.3k wind farms in +1k municipalities.

In economic terms, AEE estimates that the total contribution of the wind industry to the Spanish GDP is of 5,896m€, meaning a 0.5% of GDP. Wind industry also affects positively to Spanish employment through +39k of employments in 2022 (+14% increase compared to 2021). In terms of taxes, in 2022 the wind industry paid 851m€ (57% more than the personnel cost).

Regarding research and development (R&D), in 2022 it totalled 135m€ keeping high the research for wind related patents which have totalled in Spain +1.2k since 2004. In terms of wind turbines exports, Spain is on the fifth position globally totalling 2,512m€. According to Reoltec (Wind Technology Platform), Spanish wind turbine manufacturers have a market share of 85% in the country. Additionally, 99% of the wind turbines manufactured in Spain are exported. From those wind turbines, the 90% of their components are also manufactured in Spain.

Spanish industry has manufactured 12% of total wind turbines utilized globally. In terms of patents, Spain is positioned as the seventh country in the world in generated intellectual property in wind industry (as of 2014). Currently, in Spain there exist 12 investigation centres and 14 universities performing activities in the wind industry.

Deepening more into the wind patents, according to Reoltec once again, in 2021 there were 493 patents related to the wind industry solicited. From those, the leading solicitor was Vestas with 97 patents, followed by General Electric (90), Siemens Gamesa Renewable Energy (78), and Nordex Acciona (31). It is not coincidence that, according to AEE, these companies do also lead the manufacturing installed capacity ranking of wind technology in Spain. The leader, according to Energética as of 2022, is Siemens Gamesa with 15.4GW, followed by Vestas (5.1GW), General Electric (4.9GW), Nordex Acciona (3.2GW), and Enercon (0.9GW).

3.1.4 Key Differences Onshore vs. Offshore

During the whole thesis so far, all the information in regard of wind renewable technology has been focused mainly on wind turbines that are located in the land. The exact name for this technology is onshore wind. However, not all wind installed capacity globally is located in the main land, but also the technology has advanced in order to allow the installation of wind turbines in water masses such as lakes, seas, and oceans. This technology is known as offshore wind and is becoming more and more relevant reaching a global scale.

Although the rest of the thesis is going to be kept focused on onshore wind, it is important to understand which are the main differences with the offshore technology, and the main advantages and disadvantages. Not only it is important to understand the wind market itself, but also to know which possibilities this market offers in order to better assess investment and development opportunities. The key differences are summarized in the following table:

Comparison Onshore vs. Offshore Wind Technology		
Difference	**Onshore**	**Offshore**
Location	Located in the land, typically rural areas and open plains	Located in bodies of water, manly oceans and seas
Wind regularity	Less consistent and higher direction variability	Higher level of wind consistency and often in the same direction

Wind speeds	Standard wind speeds due to obstacles, less predictable	Stronger wind characterized by higher wind speeds, very predictable
Turbine size	Smaller due to height restrictions and space limitations on land	Larger turbines due to absence of height restrictions and larger available space
Market penetration	High	Low
Distance from grid	Short. Land allows the wind farm to be at a distance <10km from the grid	Long. 33 km away from the coast on average at 27.5 m depth on average
Installation	Simpler process with lower installation costs	Complex and specialized procedures resulting in higher installation costs
Foundations	Simpler. Typically steel towers anchored to the ground	Very complex requiring high investments. Can be floating or fixed
Ecosystem Impact	Especially impactful in birds. Typically local wildlife protected through strong environmental requirements	Significant in marine ecosystems and with potential effects on fishing activities
Visual impact	Very high. Opposition of local communities also due to noise pollution effect	Less intrusive. Very limited visual impact due to far distance from coast. No noise effects
Location suitability	Few obstacles, regular wind and high wind speeds	Bigger areas available, easy to find wind strength suitability and less competition
Location challenge	Environmental impact, few locations with optimal wind conditions, agriculture zones	Sea depth, coast distance, fishing zones, shipping lanes
Economic impact	Very positive for development of rural areas benefitting local economy	Impactful only for industries related to offshore deployment
Maintenance cost	Lower cost due to easy access to perform routine maintenance and reparations. Shorter downtime and lower risks	Very high maintenance costs due to bigger difficulties to access turbines' location. Need of very specialized equipment
Construction timeline	Shorter due to simpler logistics and permitting processes	Longer due to complex procedures and regulatory approvals
Construction challenge	Simpler. Main difficulties in land transportation of blades due to their length	Need of very specialized vessels, helicopters, offshore accommodation

		facilities, dependence on severe weather
Technology maturity	Very mature and established. Longer history of operational experience and established supply chain	Less mature and in constant evolution
Turbine capacity	Lower turbine capacity, c. 3-5 MW on average	Higher turbine capacity, +8MW on average
Grid integration	Relatively simple	Significant investment in grid infrastructure: subsea cables and onshore substations
BESS integration	Suitable and favourable to mitigate intermittency issues and improve grid stability	Challenging due to remote location and additional costs associated with subsea infrastructure
Energy production	Standard but lower than offshore due to lower wind speeds	Higher amount of energy can be captured
Reliability	More reliable due to better accessibility to operate, maintainance and repairs	Must account for corrosion due to salty environment and marine environmental difficulties. More challenging operating conditions
Global leaders	China (1º), US (2º), Germany (3º)	UK (1º), China (2º), Germany (3º)
Current capacity in Spain	30.7 GW	Objective to reach 3.0 GW in 2030

Table 7: Comaparison Onshore vs. Offshore wind technologies

3.2 Development Process

Once understood the key concepts of the wind technology, it is suitable to develop and operate a wind farm in Spain which is the aim of this thesis. This process has three main phases which are going to be developed. The first phase is the development process and it is followed by the construction process and the operation phase.

In the development process phase, as its name indicates, takes place all the relevant studies and processes needed to be able to reach the construction phase. Hence, it includes all the relevant milestones from the moment in which there is the idea of developing a wind farm to the moment in which everything is ready to start its construction. This is a phase mainly characterized by three actions: (i) Conducting research on where and how the wind farm is aimed to operate, (ii) Evaluating the viability of its operation and studying its impact and potential challenges, (iii) Performing, requesting and obtaining the approvals, authorizations and licenses to be able to start the construction of the farm.

In order to explain the key steps to consider in the development process, the following three topics are going to be covered: (i) Land study and securement, (ii) Access and Connection to the Grid, (iii) Permitting phase.

3.2.1 Land Study and Securement

Although all the processes inside the development phase are important, this is probably one of the most critic parts as selecting the right place to develop the wind farm will determine the future profits that it will be able to generate. In this process of land study and securement, first it is important to understand why a certain location is better than others, then where to place the wind turbines inside the decided optimal land, and finally understand which land securement mechanism exist in order to address and negotiate the most suitable one for the project.

In the process of studying which places are more suitable than others in order to develop a wind farm, it is clear that there will be several important criteria to take into account such as environmental impact, topography, natural land protections, geological and geotechnical conditions, legal and territorial availability, among others. However, the most important one is, of course, the availability of wind resource. In general terms, a suitable place to establish a wind farm will be the one in which there are average winds of at least 4.5 meters per second (m/s) if the aim is to place small wind turbines, and at least 6 m/s if the aim is to place standard wind turbines. It can be said that these metrics are a minimum in terms of wind resource in order for those locations to be considered.

During the land studies, it is very important to deeply evaluate the wind conditions of the considered location. Not only in terms of wind potential but also in terms of the potential energy efficiency obtained. For this matter, when a certain location is seriously considered it is recommended to perform on-site studies in which the wind speed, regularity, direction and potential is measured. Additionally, it is recommended that if there are wind farms located in the surrounding areas of the considered locations, these are also studied to estimate the potential wind resource through a comparable mechanism. With all this information, wind reports are prepared which, in addition to topography, access to the grid, environmental conditions and obstacles, will be especially relevant to decide between different potential locations.

It is important to highlight that in this process, if the developer has no direct means to perform several wind reports of different locations at the same time, there are companies that are specialized in these matters. Additionally, to obtain wind information, there are several data sources where it can be found: meteorological institutions, airports, public information from local or national institutions, and wind associations. According to Iberdrola, there already exist meteorological tools and models that make it possible to determine the best sites for installing wind turbines and to estimate, before building the farm, its production capacity throughout its useful life.

Once the site has been decided, during the development phase also takes place the decision on where to exactly place each of the wind turbines in the decided location. If the location is well suited for the wind farm, this decision, though important, should not change significantly the potential energy production of the farm. However, especially favourable locations to place the turbines include: hilltops and ridgelines with smooth topographies, summits of softly contoured hills, ravines, expansive flatlands, and other wind-concentrating areas. Although there is not a regulated distance at which wind turbines should be located between each other, there are technical recommendations made by experts, such as the company ABB, which indicated that wind turbines should be located at a suitable distance between each other that ensures the avoidance of aerodynamical interference, increase of turbulence, and the loss of power. In this way, ABB recommends that if there is one predominant wind direction, the optimal separation of the rotor should be between 8 and 12 times the rotor's diameter in the wind direction, and 2 and 4 times the rotor diameter in the perpendicular wind direction.

With all the location's planning already clear, it is the moment to secure the land in which this site sits. Whether the landowners are private (most common case) or public, if a developer aims to place a wind farm on that land, they will expect from the developer to compensate them for it. In this way, the developers and the landowners must reach to a certain agreement which will end up having a contractual base. In this process, it is important that the developers transmit to the landowners what procedures the construction of the wind farm would entail for their land. Hence, developers in this situation must consider that in the land they will have to construct roads, transmission equipment, maintenance infrastructure, among other elements. The construction of a wind farm requires the utilization of heavy industrial equipment for which adequate roads must be developed, landowners must agree to it, and land must be suitable for.

There exist several business and legal ways to proceed with the land securement to develop a wind farm on it. The most common ways are:

- **Land lease**: This is typically the most preferred option for developers. It consists of a rental (lease) agreement with the landowners by which the developer commits to pay a certain rental quantity monthly or yearly for the duration of the contract or until the developer sells the wind assets located on it. It also includes the possibility of paying royalties.
- **Direct buyout**: As its name indicates, this method entails the direct investment in the land where the wind farm is aimed to be developed. It entails a change in the propriety of the land from the landowner to the developer company for a certain agreed quantity. This is typically the least preferable option for developers as it is the costliest and riskiest as the wind farm has not been constructed or may still not have all the remaining permits approved.
- **Buying the rights to wind power**: Very similar option to the land lease with the main difference that the developer, instead of paying a recurrent quantity to the landowners, it

would calculate how much the total quantity of lease would be for a certain period and pay it all upfront.

3.2.2 Access and Connection to the Grid

Once the location has already been secured, it is the right moment to proceed with the second stage of the development process which consists of requesting the access and connection to the grid. In this way, linking it with the previous section, while selecting the location of the wind farm, the proximity to the transmission grid must also be considered in order to reduce as much as possible the costly installation of transmission infrastructure from the generation location (wind turbines) to the already existent distribution and transmission lines.

An obvious but very relevant fact about wind farms (and most of the generation plants worldwide) is that the electricity they produce is not consumed nor demanded at that place, but hundreds or thousands or kilometres away. In this way, it exists a transmission and distribution infrastructure responsible for transporting the energy to where it is demanded. While developing a wind farm this must be taken into account and the developer must in consequence find the means in order to connect its production plant to the grid.

According to Red Eléctrica Española (REE), the distribution and transportation network are available for every infrastructure that wants to connect to the electrical system in safety and quality conditions, as stated in the Spanish Electrical Sector Law. However, there is a procedure that a generation facility, in this case a wind farm, must follow in order to get permission of access and connection to the grid. It is important to differentiate transportation from distribution. Although very similar, in the case of this thesis only the access and connection to the transportation network is going to be considered.

The access and connection permits (A&C) are granted by the electric system operator and transmission network manager, as well as from the carrier, who is responsible for conducting the necessary studies to ensure, first of all that the connection of the requested installation meets all established regulatory requirements, and secondly, that there is sufficient capacity in the network for that installation. For the purpose of this thesis, the A&C permits are focused for a wind farm located in Spain. Hence, the responsible authority for processing the permissions is REE as the manager of the transmission network and operator of the Spanish electric system. This authority is also known as the Transmission System Operator (TSO).

The procedure basically consists of presenting an application through REE's portal with all the requested documentation of the project that will be explained below. According to REE, the application is forwarded to the Transmission Network Manager, who acts as the sole intermediary with the applicant for A&C permits. The developer's request is evaluated by REE from two perspectives: (i) Access procedure perspective, and (ii) Connection procedure perspective:

- **Access**: From this procedure perspective, the existence of sufficient capacity for the installation of the wind farm is assessed, as well as whether it meets the necessary requirements for its connection to the transmission network, ensuring the safety and quality of the electrical supply.
- **Connection**: From this second perspective, the connection procedure verifies the technical and engineering feasibility of the wind farm.

Once understood this, it is important to highlight that the A&C permits cannot be requested at any desired point of the transportation infrastructure, and this is why the previously section of location of the wind farm plays a key role. REE only allows requests of A&C permits where an electrical power substation exists or it is planned to exist, and in those positions of the substation that already exist or are planned to exist. The following diagram explains the way the electrical energy follows since it is generated until it reaches the transmission grid:

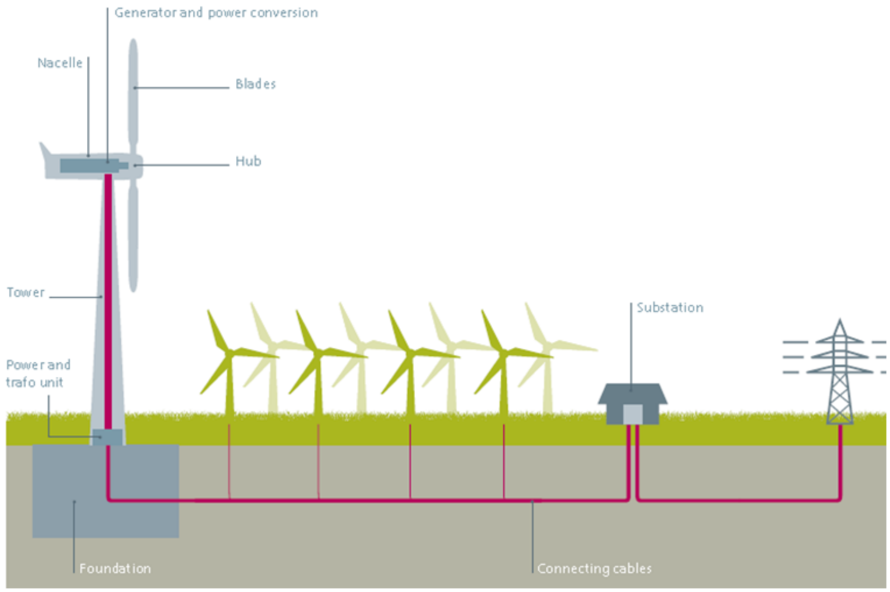


Figure 29: Connection of wind farm to the grid

When the developer company of the wind farm applies through the REE portal to request the A&C permits, it must submit the following documents: (i) REE application form, (ii) Location plans of the installation (minimum detail: 1:50,000, and general situation 1:200,000), (iii) Single-line electric diagram of the wind farm, (iv) Preliminary project report, (v) Detailed single-line electric diagram, (vi) General layout plan of the set of facilities to be connect to the georeferenced transmission network, (vii) Execution program with dated relevant milestones, (viii) Budget, (ix) Accreditation of environmental impact study scope request, (x) Agreement of common infrastructure development, (xi) Proof of deposit guarantee, and (xii) Communication from the competent administration of the adequate constitution of the guarantee.

The last two required documents in the application (xi) and (xii) mention a mandatory bank guarantee. As stated previously in the regulatory framework of the previous chapter, the Royal Decree 1183/2020 established that, in terms of economic guarantees, when requesting the A&C permits it is mandatory to present a deposit equivalent to €40/kW (€40k/MW) installed, exempting small installations (<15 kW) and self-consumption setups under certain conditions. In case of hybridization, this guarantee is reduced 50% (€20/kW).

The economic guarantee is mandatory in order to apply for the A&C permits. The reason behind is to ensure an orderly and stable growth of the renewable energy sector. Presenting the guarantees for the wind farm confirms and ensures the viability of the project and the true intention of the developer company to continue with the project. The guarantees cover the Administration in case of voluntary abandoning the application (are exercised). Additionally, they would be exercised in case of expiration of the granted A&C permits with no administrative exemption. However, in normal situations, the economic guarantees are returned to the developer company in case of rejection of the A&C permits or once the applicant obtains the authorization of operation of the wind farm in a timely manner.

Once the A&C application is submitted through REE's portal, the TSO has 20 days to solve it. If the TSO required anything back, the developer company would have 20 days to answer the requirement. If the application is approved, the applicant would have 30 days to accept it, deny it or ask for a revision on certain technical aspects for which the TSO would have again 15 days to answer back. It is important to know that the A&C permits are revised by REE in the order they arrive (First-in-first-served). If there are two applications that come on the same day at the same time, the TSO will process first the one that had presented first the economic guarantees.

The application, however, can also be considered as non-admissible and hence be rejected by REE. The reason for the TSO to reject an application is typically among these three possibilities: (i) The applicant did not present the communication from the competent administration of the adequate constitution of the guarantee, (ii) The applicant has not initially presented one or more of the documents required in the application procedure, or (iii) The applicant is soliciting A&C permits in one of the nodes in which there is no access capacity left.

The third reason explained above is especially significant. According to the TSO, the access capacity to the grid for generation at a node or area of the transmission network constitutes the limit for granting access permits to generation facilities connected to the transmission network at said node or area. The developer company of the wind farm must know that the access capacity granted by REE to a generation facility should not be understood as guaranteed production capacity, and it may be necessary to apply restrictions to evacuation derived from real-time operational situations.

REE conducts specific studies to determine the access capacity of generation facilities. The assessment of access capacity for these facilities connected to the transmission network and the corresponding granting or denial of the permit by the system operator will be based on compliance with the technical criteria of safety, regularity, quality of supply, and sustainability and economic efficiency of the electrical system established in current regulations. These studies are conducted based on scenarios representative of the final horizon of current planning and result in the possibilities of access to the grid depending on the type of generation, Synchronous Electricity Generation Modules (MGES), and Electricity Park Modules (MPE) in different topological areas (nodal and zonal).

In the case of this thesis, as the aim is to develop and operate a wind farm, this one is included in the Electrical Park Modules (MPE) category. In this way, the developer should check in the TSO’s must updated results of access capacity studies if there is indeed available access capacity for MPEs in the node or zone where the developer aims to construct the wind farm. REE monthly updates the results of the access capacity studies of every single node and zone of the country. The developer must take into account this check before submitting the A&C application, as if it is rejected by the TSO due to capacity unavailability, only 80% of the economic guarantees are given back unless the developer can prove that at the moment of submitting the application there was available capacity in the requested node or zone. If the presented proof is valid, 100% of the economic guarantees are given back.

The developer company of the wind farm must also take into account that if REE approves the A&C permits, these are not forever but have certain expiration clauses that the developer must consider. There are four main reasons why the A&C permits typically expire:

(i) The A&C permits expire if 5 years after obtaining them the developer company has not yet obtained the Administrative Operation Permit.

(ii) For an already operating plant, the A&C permits expire if, for causes attributable to the operator company, there are no energy vessels to the grid for a period longer than 3 years.

(iii) The expiration of the A&C permits is also exercised if the periods of the following permits (next section) pass by: (i) Preliminary Administrative Permit request admitted, (ii) Favourable Environmental Permit, (iii) Preliminary Administrative Permit awarded, (iv) Administrative Construction Permit awarded, and (v) Administrative Operation Permit awarded.

(iv) A&C permits will also expire if the required payments or guarantees are not respectively realized or accredited.

Finally, in the next section the different permit procedures are explained. As it is reflected, these permits may cause the variation of the initially estimated installed capacity for the wind farm. If this happens, the TSO must be informed as, according to them, when the main characteristics of the generation facility are modified during the processing of the permits or until their commissioning, it is necessary to inform REE as the manager and owner of the Transmission Network through a request for updating the A&C permits. This update must be processed again through REE's web portal.

3.2.3 Permitting phase

Reaching this new phase is the result of a previous success in securing the land and obtaining the access and connection permits from the Spanish TSO (REE). This phase aims to obtain all the necessary permits that the developer company must have to confirm that the construction of the wind farm is authorized to begin. When all the permits are obtained, the standard in the industry is to say that the plant is in "Ready-to-Build" status (RtB).

When a plant reaches RtB, the installation is already in a very de-risked status as the construction phase does not typically jeopardize the success of the wind farm reaching the operation status. However, the permitting phase that leads to RtB is the period in which the development of the renewable project is more subject to risks and changes mainly due to the different nature of permits that authorize the project.

There is a clear order and timeline that a developer must follow in this new permitting phase. This timeline is composed of five major milestones that were introduced in the previous section and will be explained below. These milestones (and abbreviations) are: (i) Preliminary Administrative Permit request (AAP: *Autorización Administrativa Previa*), (ii) Favourable Environmental Permit (DIA: *Declaración de Impacto Ambiental*), (iii) Preliminary Administrative Permit awarded (AAP), (iv) Administrative Construction Permit awarded (AAC: *Autorización Administrativa de Construcción*), and (v) Administrative Operation Permit awarded (AAE: *Autorización Administrativa de Explotación*).

The Spanish renewable regulation framework sets the amount of time in which each of the milestones should be completed. The timer for each of the milestones starts in the moment in which REE approves the A&C permits of the project. The developer must accredit compliance with each of the administrative milestones within the established deadlines. Otherwise, the A&C permits will automatically expire, and the financial guarantees required when applying for authorisation will be executed.

The Royal Decree 23/2020 established that each of the milestones to be met had to be successfully completed in the following specific deadlines since the achievement of the A&C permits: (i) Requested AAP: 6 months, (ii) Favourable DIA: 22 months, (iii) Awarded AAP: 25 months, (iv) Awarded AAC: 28 months, and (v) Awarded AAE: 5 years. However, on the 21st of December 2021, Royal Decree 29/2021 was approved by the Spanish Government introducing a 9-month extension (except AAP request) of the previously described deadlines for wind projects such as the wind farm of this thesis. The reason to do so was to allow the materialization of viable projects that were paralyzed due to the inability of the local administrations to evaluate and process the high number of projects and requests, motivated by the unanimous request of the regional energy and environmental advisors.

In a country such as Spain, in which the main competences are distributed between the central government and the regional governments of the autonomous communities, it would make sense for the developer to ask itself with whom the different administrative milestones should be processed. According to the Spanish National Commission of Markets and Competence (CNMC), the competence to authorize the electric generation plants corresponds to the respective regional autonomous community in which the plant is located excepting the cases in which the total installed capacity of the plant surpasses 50 MW. In this case, the competence corresponds to the General State Administration (national level).

1- Preliminary Administrative Permit (AAP):

According to CNMC, the AAP refers to the preliminary project of the installation. The competent administration for its processing (Autonomous Community or General State Administration) publishes the project in various official bulletins (state, regional, bulletin board, 20-30 days) and requests information from the rest of the potentially affected administrations and organizations or entities, including the municipality, to express their opinion on the technical and environmental aspects of the project within their competencies. In most municipalities, regulations consider this report from the municipality mandatory.

Obtaining the AAP grants the developer company the right to carry out a specific installation under certain guidelines. Additionally, with the AAP, the developer of the wind farm can initiate the conditioning of the installation site.

2- Environmental Permit (DIA):

This milestone is certainly the most critic one as it is subject to a high amount of variabilities and different scenarios that are unpredictable for the developer company but which can jeopardize the deployment of the wind farm. According to Spanish Law 21/2013, "environmental impact assessment" is defined as the process through which the significant effects of plans, programs, and projects are analysed, before their adoption, approval, or authorization, on the environment. This analysis includes the effects on factors such as (i) population, (ii) human health, (iii) flora, (iv) fauna, (v) biodiversity, (vi) geodiversity, (vii) land, (viii) soil, (ix) subsoil, (x) air, (xi) water, (xii) climate, (xiii) climate change, (xiv) landscape, (xv) material goods including cultural heritage, and (xvi) the interaction between all the mentioned factors.

The Spanish DIA is not only applied in the deployment of renewables context, but in any project that somehow affects the environment and natural resources. The DIA is basically a report in which the competent authority presents the environmental impact assessment and the authorization to realize the project or activity subject to the predictable environmental effects. According to the Spanish Ministry of Ecologic Transition, the DIA is defined as a preceptive and decisive report from the environmental authority, which concludes the ordinary environmental impact assessment, evaluating the integration of environmental aspects in the project and determining the conditions that must be established for the adequate protection of the environment and natural resources during the execution and operation of, in this case, a wind farm. The DIA can have three possible results:

- **Favourable or Positive DIA**: If the resolution is positive, the permit holder obtains the favourable environmental impact statement. In this way, the developer company can continue with the wind farm towards obtaining the next milestone (AAC).
- **Unfavourable or Negative DIA**: In the case of an unfavourable environmental impact statement, the disagreement of the competent environmental authority is presented, and the projected wind farm is rejected. The negative DIA means a clear prohibition to execute the wind farm as presented.
- **Conditioned DIA**: In this case, corrective measures are determined. The conditionally positive environmental impact statement is the most common response and makes the

developer company to execute some measures in order to be able to continue with the project.

As previously explained, the developer company is subject to losing the deposited economic guarantees if one of the permitting milestones is not positively awarded within the regulated timeline. However, in the case of an unfavourable DIA, the economic guarantees are not executed if the reasons for this result are not attributable to the developer company.

Although there is not a clear guideline from the Ministry of Ecologic Transition to develop the environmental impact assessments that will then be analysed by the competent authority to issue (or not) a positive DIA, there are environmental consulting firms specialized on this matter. In order to better understand these studies and processes, an example of an environmental consulting firm specialized in renewables has been selected: *Sfera Proyecto Ambiental*. According to this company, the assessment of the environmental impact during the development and construction process of a wind farm follows three main phases:

- **Phase I: Preliminary analysis of project feasibility: Environmental-Archaeological-Urban Pre-feasibility Study.** To obtain a first approximation of the project's feasibility and to understand its possible limitations regarding implementation, Sfera conducts the Pre-feasibility Study. This document aims to analyze the various environmental variables that may be affected by the construction of the power generation plant and evaluates the degree of impact to identify possible severe impacts that may condition the project's construction. Additionally, the urban planning regulations outlined in the general planning of the municipality where the project is located are analyzed, and advice is provided to obtain a positive Urban Compatibility Report, the first step to initiate the subsequent environmental assessment of the project.
- **Phase II: Environmental and archaeological analysis of the project. Associated sectoral studies.** Sfera also conducts the necessary Environmental Impact Study for the approval of the project execution by the competent environmental authority. In this way, this study is tailored to the needs of the specific project, and it may be aimed at an

Environmental Impact Assessment through either the simplified or ordinary procedure according to current regulations, as each autonomous community has its own legislation based on Law 21/2013 on environmental assessment. Furthermore, Sfera conducts all the necessary sectoral studies for the proper evaluation by the various agencies involved in the process of obtaining a positive Environmental Impact Statement. In this regard, this consulting firm has full scope in renewables environmental impact assessment: (i) Environmental inventory. Detailed botanical and faunal study, (ii) Acoustic Study, (iii) Hydrological-Hydraulic Study, (iv) Preventive Archaeological Activity. Surface Archaeological Prospection (v) Study of Synergistic and Cumulative Effects, (vi) Landscape Integration Study, (vii) Annual Avifauna Cycle, (viii) Specific fauna studies: mammals, herpetofauna, bats, (ix) Specific Analysis of Impact on the Natura 2000 Network, (x) Any other study necessary for project approval.

- **Phase III: Obtaining the Environmental Impact Statement. Project execution begins.** Once the positive environmental authorization has been obtained, the construction work of the wind farm begins. Sfera also analyzes in detail the conditions present in this authorization and advises on the necessary studies prior to the construction of the project, as well as offering environmental and archaeological monitoring services during the construction and operation phases: (i) Environmental coordination on site, (ii) Acoustic study on site, (iii) Archaeological control of earth movements, (iv) Electromagnetic study, (v) Fauna monitoring, (vi) Monitoring the implementation of compensatory measures, (vii) Verification of the correct implementation of corrective measures, (vii) Monitoring during the operation phase of the plant using specific software.

3- Administrative Construction Permit (AAC):

Once achieved the AAP and DIA milestones, the developer company modifies the wind farm project according to the requested specifications and proceeds to request the AAC, which refers to the specific project for the execution of the installation and allows its holder its construction or establishment according to the information published by the CNMC. The responsible administration (state or regional according to capacity being higher or lower 50MW) submits the modified project for consultation again to the different administrations and organizations, including the affected municipality. Subsequently, the developer must request sectoral reports, which are mandatory, addressing each of the administrations and organizations that may be affected (as examples: Hydrographic Confederation, Directorate General of Highways, livestock trails, etc.), and these organizations may consult the municipality again.

Although it is not considered a milestone for the TSO, there is an additional necessary authorization that the developer must have in order to be able to officially start the construction which is the Building Permit (with possible land use modification). This urban planning procedure is under the jurisdiction of the municipality. The developer company of the wind farm submits the detailed project to obtain the building permit and, if necessary, the modification of land use. The building permit requires a report from the municipal technician and a legal report from the municipal secretary. It proceeds to publication in the corresponding bulletins (provincial and bulletin board) and is sent to the urban planning section of the province to resolve, if applicable, the change of land use. With this, the municipality will decide on the building permit. Once this is approved, the developer can start the construction of the wind farm.

4- Administrative Operation Permit (AAE):

According to CNMC, the approved AAE is the last milestone required to energize the facilities and proceed with their operation. It is necessary to obtain the commissioning certificate from the competent authority (state or regional), for which it is necessary to sign a Technical Access Contract (CTA: *Contrato Técnico de Acceso*) with the network owner (REE if connected to the transmission network as is the case of this thesis). This operating authorization allows for the cancellation of the initial economic guarantee deposited by the developer company.

As just introduced, in addition to the other milestones it is also necessary to have a Technical Access Contract signed for the approval of the AAE. The CTA, according to REE, must be formalized for each generation facility with A&C permits that share the same position at a node in the transmission network. Hence, it would be necessary to formalize for the wind farm of this thesis. The TSO also states that if the same generation holder has several generation facilities at the same connection point in the transmission network, a single CTA may be formalized grouping these facilities.

3.3 Construction Process

As explained above, a wind farm passes through three main phases during its life. As just explained, the development phase is the first one, followed by the construction phase and the operating phase. In this section, the construction phase is going to be developed as it is important to understand which is the bridge between all the different studies and permits performed during the development of the wind farm and its operation. In addition, understanding the different procedures that must take place during the construction phase can help a developer company to anticipate to them and hence shorten the timeline of this phase as much as possible in order to start operating as soon as possible.

As explained in the previous section, once the wind farm has obtained the Administrative Construction Permit (AAC), the construction phase can officially start. Hence, as the development phase does not end until the reception of the Administrative Operative Permit (AAE), which cannot be obtained until the wind farm is constructed, it can be said that the development and construction phases interlap each other.

The construction phase can start when the company reaches RtB (Ready-to-Build) status, however, this does not mean that there are not processes related to this phase that can be anticipated. One important milestone that can start previous to the obtention of the AAC is the contractual phase in which the main objective is finding the right contractors to perform the construction of the wind farm and supply the main materials needed for it. In this way, it is important to distinguish the main two blocks in which the construction of a wind farm is broken down:

- **Turbines:** This first block includes the manufacturing, materials, supply and installation of the wind turbines themselves.
- **Balance of Plant**: Also known as BoP, which includes all the different work stages that take place during the construction of the wind farm from both, a civil and electric sides, and excludes everything related to the supply and installation of the wind turbines. Hence, it refers to access paths, foundations, electrical components, substations, etc.

When a developer company is in the contractual phase, it must choose between two different contractual models: (i) Separated contracts for the turbines and BoP, or (ii) EPC contract:

(i) In this model, the developer company signs two contracts with different companies so that they perform one of the two blocks of the construction phase. The two contracts are know as Turbine Supply Agreement (TSA) and the Balance of Plant Agreement (BoP agreement). On one side, the TSA is typically signed between the developer company and the wind turbine manufacturer and includes all the different works needed for the design, manufacturing, transportation and installation of the wind turbine generators (WTG). On the other side, the BoP agreement includes all the civil and electrical works that take place during the construction phase of a wind farm including the cabling, crane pads, foundations, grid connection, internal electrical system, roads and substations, hence everything but the wind turbines. This contractual model makes the developer company take a higher risk as it is its responsibility to coordinate these two companies in their different activities. However, it is also true this model allows for savings as it is cheaper than the EPC model.

Figure 30: TSA + BoP contractual model

(ii) In the EPC model, the whole construction process is in charge of the same company, responsible for both the wind turbine supply and the balance of plant of the wind farm. In fact, EPC contract stands for Engineering, Procurement and Construction contract in which, according to the *Wind Farm BoP scientific blog*, three main phases are distinguished: (i) Engineering: project in which technical choices, drawings and calculations are made, (ii) Procurement: phase in which electric and civil works are subcontracted to one or more companies, (iii) Construction: Works of all the different subcontractors is monitored and led to a compliant status not only with the technical specifications, but also toward the time and budget constraints of project management. In this case, there is less risk for the developer company as they are not in charge of any coordination and there is just one point of contact, the EPC contractor, with which they set a fixed price and fixed delivery date. As a downside for this risk advantage, this contractual model is typically more expensive.

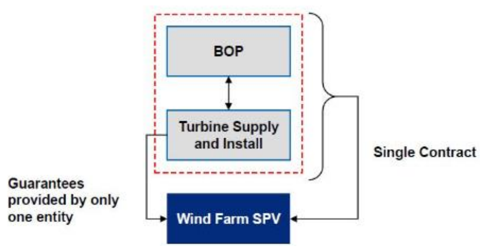


Figure 31: EPC contractual model

Once the contractual phase has finished, the manufacturing phase of the wind turbine components takes place according to the TSA or EPC contract. This typically consists of a long process of 6-7 months in which not only the manufacturer procures the materials and builds the components, but also they are in charge of performing in the factory the stress tests to ensure the future right operation of the wind turbine. According to Iberdrola the process of manufacturing the wind turbine blades follows these steps: (i) Manufacturing of the girder: It is the inner part of the blade and it is composed of materials formed of fibreglass and carbon pre-coated with epoxy resin (a thermostable polymer that hardens when mixed with a catalyst agent), (ii) Manufacturing of the shells: In charge of covering the girders and are made of fibreglass. In addition, they are covered by a layer of protective paint. (iii) Assembly and curing: After obtaining the two shells, the girder is bonded between both. After that, the assembly is passed through an oven to form a single firm and strong structure. (iv) Finishing: Once the leading and trailing edges of the blade are finished, the structure undergoes a new inspection prior to the blade being moved to the wind farm's location.

In terms of on-site construction, the first step is to make sure that there exist adequate access paths in order for the heavy machinery to reach the exact locations of the wind turbines and also the components of the wind turbine itself. This access roads process has two main parts: (i) External access and (ii) Internal access.

The external access point to consider includes all the different existing national and local roads that will need to be used in order to ensure the transportation of the heavy machinery and wind turbine components. Once again according to Iberdrola, it must be considered that components such as the blades of a wind turbine are very heavy and massive structures. In the case of one of their wind turbines, the blades are 67.5 meters long and require specialised forms of transport that are capable of loading these structures and carry them to their destination. However, not only the load of the materials can be a problem from the existing roads point of view, but also the length itself. In order to know if the specialised transportation will be able to take the needed access curves, there exist transportation simulation softwares (such as heavygoods.net) that allow to perform a detailed planning in order to ensure the transported materials safety.

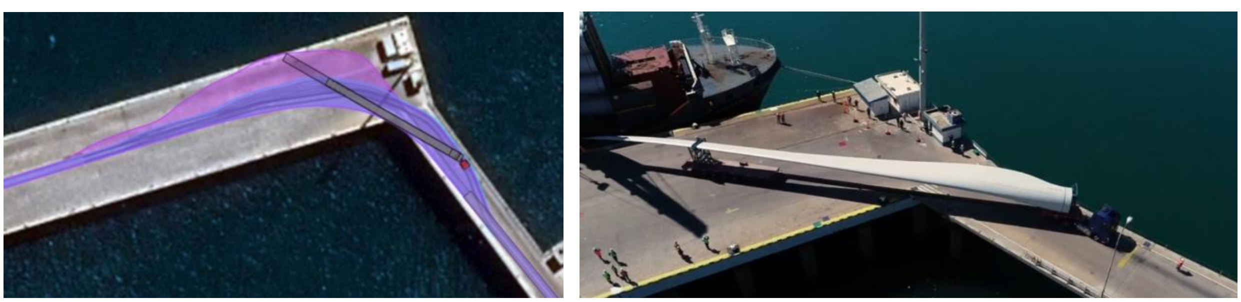


Figure 32: HeavyGoods' simulation vs real transportation of wind blade

From an internal access perspective, once the materials and machinery arrive to the wind farm location, they must also be able to arrive to the exact location of the different wind turbines. For this reason, it is typical to see an adequation of the existing land to open new access paths towards the exact desired position of the wind turbines. This adequation includes: (i) Clearing from trees and vegetation the surface to become a roadway, (ii) Earthworks to prepare the terrain and making it, if suitable, flat, (iii) Road surface construction using typically gravel (hence avoiding asphalt), (iv) Marking off work zones to restrict the circulation of vehicles external to construction. All these adequation processes follow technical criteria to ensure certain minimum curvature radius, widths, lengths, and other restrictions.

As the internal access roads are developed, crane pads are simultaneously constructed at each wind turbine location. Their size is variable depending on the relative size of the wind turbine, however, they are not smaller than a 24m x 16m surface (c. 400 sqm). These pads serve as designated areas for the large crane required to install the turbine components. Following the erection of the wind turbine, the crane pad is typically retained and regularly maintained to support ongoing operational and maintenance activities.

Once the heavy machinery has arrived to the exact location where the wind turbine is located, the first step to build it consists of working on the foundations of it. According to the specialized engineering firm long Long International, due to the remote locations of most wind farms, mobile mixing plants are erected to produce concrete for wind turbine foundations and other concrete elements necessary for the farm operation. Given the large size of the sites, mixing plants can be relocated as construction progresses and wind turbines are installed. Depending on the construction schedule, site size, and personnel availability, the use of more than one mixing plant may be required.

The foundations for a wind turbine do not differ much from foundations for other structures and consist of concrete and steel reinforcement. The foundation design is based on the size and weight of the wind turbine and the loads due to blade rotation. Depending on the load and geotechnical conditions, foundations may be designed and built with piles or drilled piers. A unique aspect of wind turbine foundation design and construction is the anchor cage system. This system was designed as a more effective method for transferring loads from the wind turbine to the foundation. The anchor cage consists of upper and lower anchor plates, located at the top and bottom of the foundation. The two plates are connected by anchor bolts, housed within PVC protective pipes. During concrete placement, the PVC sleeve protects the anchor bolt from corrosion caused by water and concrete.

Figure 33: Wind turbine foundation: Anchor cage system

However, as can be easily imagined, the foundation does not only consist of the anchor cage, but also a footing is built around it. This can have different shapes depending on the constructor (from 4 to 10 sides typically). If it has a square shape, the minimum dimensions are 8 meters per side and between 2.5 to 6 meters of depth. On top of the footing and aligned with the anchor case, a solid concrete pedestal is built, typically with octagonal shape, upon which the wind turbine's tower will be placed. This pedestal is at least 1 meter height.

Once the foundation is built and the wind turbine's components are effectively transported to the turbine's location, the first step of the erection is the tower. As explained above in the wind turbine component's section, the tower is not composed of a single piece, but it is assembled putting together one piece on top of another. In order to assemble the tower, a specialized crane is utilized. Once all the pieces of the tower have been assembled on-site, the nacelle is assembled to it. Typically, the manufacturing company transports the nacelle to the turbine's location with already all its components installed inside it. Hence, the nacelle only needs to be installed on top of the tower. Once the tower and nacelle have been erected, only the blades and rotor are yet to be assembled and erected. At this point, it is important to highlight that there are two possibilities to do this and choosing between them depends on the contractor company. First of all, what is common from both possibilities is to transport separately the blades and rotor to the turbine's location, hence they are never transported already assembled together as there is not infrastructure to do this. Once the components arrive is when there are two techniques to choose from: (i)

Assemble all the components of the hub (rotor + blade) on the ground to later erect the whole unit as an only piece to mount to the nacelle, or (ii) Install the different components one at a time, starting with the rotor to later continue with each blade.


Figure 34: Both assembly options (i) and (ii) respectively

In addition to the mechanical side of the installation of the wind turbines, there is also an electrical side which is equally important to ensure that the wind's kinetic energy is properly transformed into useful electrical energy. For this purpose, an electricity system is developed across the whole wind farm that allows the electricity produced in the generator inside the nacelle to reach the distribution or transmission network. In general terms, this electricity system is composed of:

- Internal circuits within the wind turbine, connecting the generator output to the transformer substation which is in charge of raising the electrical potential output from low voltage (about 690 V) to medium voltage (20 kV). This transformer can be located inside the tower. However, when transformer substations are located outside the tower, they are usually prefabricated buildings of modular composition and concrete structure, with dimensions varying depending on the type of wind turbine or the number of turbines grouped around it (generally from 1 to 5 turbines). The one receiving energy from 5 wind turbines will have an approximate surface area of 4 m x 2.5 m and a height of 2.3 m. It can be placed on the same anchor footing as the wind turbine or immediately beside it. Pipelines are also needed to connect the wiring of each wind turbine to its transformer substation.
- A medium voltage (20kV) underground network that connects the wind turbines to each other and to the wind farm's substation. Therefore, it is advisable for the cable trench to run parallel to the access roads to these turbines, based on the arrangement of the wind turbines. The depth of the cables, usually slightly more than 1 m, results from a balance between two conditioning factors from a technical point of view: (i) Proximity to the

surface that favours heat dissipation into the atmosphere, (ii) Moisture tends to increase with depth. The trenches, with an average width of 0.60 m, typically have cables directly buried in them.

- A collector substation that transforms the medium voltage level from the wind farm's transmission lines into high voltage (400 kV in Spain). This adjustment enables aligning the electricity generated in the farm with the required levels for its integration into the distribution or transmission network.

Once all the required mechanical and electrical installations have been finished, the last step in the construction process is the testing. Initially, the contracted EPC or BoP company conducts visual inspections, assembly validations, and high-voltage checks. Later, the known as “cold commissioning” tests are conducted, often utilizing a diesel generator to validate equipment functionality before subjecting them to load tests. If these first tests are passed, during the known as “hot commissioning”, the installation is energized, and comprehensive tests of control systems, protection mechanisms, and communication networks are carried out. Finally, if these tests are passed and in collaboration with the TSO, in Spain REE, there are additional tests to ensure seamless integration with the larger electrical grid.

CHAPTER 4. WIND FARM OPERATION

As explained above, it can be said that a wind farm passes though three main phases during its life which are (i) Development, (ii) Construction and (iii) Operation. Once the wind farm has successfully completed its development and construction phases, it reaches the operational one. The date in which a generation project, in this case a wind farm, reaches the operational status and starts generating and selling electricity and hence cash flow at full rate is known as the Commercial Operation Date, or COD. This chapter will be focused on understanding which are the ways in which a Spanish wind farm can generate not only electricity but also money, also understanding which are the key drivers of electricity prices and which are the main operational expenditures that renewable plants face in Spain.

In this way, the first point to understand the operations of a wind farm is understanding which is the flow of electricity since it is generated to when it reaches the final consumer. In general terms, the electricity follows the following phases: (i) Generation, (ii) Transmission, (iii) Distribution, (iv) Commercialization:

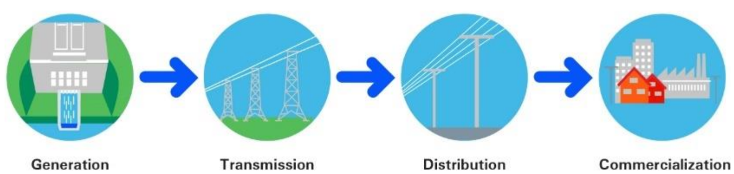


Figure 35: Electricity Flow chart

(i) **Generation**: In this phase, to which the wind farm directly belongs, the electricity is generated. In Spain, this activity is liberalized. Hence, any person or company can decide to enter to this generation sector and freely produce electricity.

(ii) **Transmission**: Also known as transportation phase, as mentioned in the previous chapter, once the electricity is generated in a plant it flows into the transmission network in which the electricity is transported closer to the final customer. In this phase electricity is at high voltage, in Spain typically at 400 kV. The reason for it is that when electricity flows through the cables there are energy losses in the form of heat (known as Joule effect) which can be reduced at high voltage. It is important to understand that this phase in Spain is regulated and managed exclusively by the TSO, *Red Eléctrica de España*. REE ensures the safe and immediate transportation of electricity through more than 44,000 km of high voltage lines.

(iii) **Distribution**: Through the transmission network, the electricity reaches the electrical distributors substations in which the voltage is reduced to levels typically between 1 and 66 kV. The main function of these substations is distributing the electricity to nearby population centers, where there are transformation substations that will again reduce the voltage level to make it suitable for household use at low voltage (between 230 V and 400 V). The main agent in this phase is the electric distribution company. In Spain, there are c. 300 electrical distributor companies and there cannot be more created as this phase is not liberalized. Additionally, it is important to highlight that the final consumer cannot choose electrical distributor as it is assigned directly depending on the residence.

(iv) **Commercialization**: In this phase the main agents are the electrical commercialization companies which buy energy in the electricity market or reach to bilateral agreements with generators. The function of commercialization companies is to sell the electricity to end customers. This activity is once again liberalized, meaning that any person or company can create a commercialization company and join the sector. According to CNMC, in Spain there are +500 retailers that can belong to one of the following classes:

- Reference retailers: These belong to a regulated market in which the price of electricity is set by the Spanish government. Their customers are those Spanish households or businesses that freely choose to have a regulated electricity tariff based on the known as Volunteer Price for the Small Consumer (*Precio Voluntario al Pequeño Consumidor PVPC*). It is available for consumers whose contracted power does not exceed 10 kW and this method replaces the previous Last Resort Tariff (TUR). In the PVPC, the electricity bill has two components: (i) The cost of producing electricity (indexed to the spot market results), and (ii) An amount fixed by the Ministry of Industry to recover all the regulated costs: payment of all the regulated activities necessary to supply electricity, as well as other policy driven costs.

- Free market retailers: These companies directly negotiate the conditions and costs of the electricity supply with the end consumer. For this one, there is not much negotiation power and must finally choose between the different existing tariffs

4.1 SOURCES OF REVENUES

A wind farm, once it enters into the operation phase, has different ways in which it can generate income. It is very important for a wind farm developer company to know and understand them in order to ensure the optimal operation of its renewable plant. These sources of revenue, which will be explained in the following sections, are not independent one from the others as they might be compatible, meaning that they can co-exist in the same plant and hence signify each of them a share of total revenues. As a consequence, knowing each of the sources not only is important to reach an optimal economic situation for the company operating the wind farm, but also to choose the optimal diversification strategy in case the company operates several wind farms. Additionally, as it is explained below, these revenue strategies have different risk profiles that a wind farm developer must understand in order to undertake the optimal farm strategy.

4.1.1 Pool – Merchant revenues

Merchant is the most common and known way for an energy generation wind farm to obtain revenues. It consists of selling the electricity generated by the wind farm in the national pool in which the electricity is paid at a variable price. Through this way, the renewables developers assume all the volatility risks of the market. As it is key that a potential Spanish developer understands the basic functioning of the Spanish electricity market, this one is going to be explained in the following pages with contrasted information from its operator: OMIE (*Operador del Mercado Ibérico de Energía*).

Day-ahead market:

The first thing to know is that the Spanish electricity market in fact consists of several markets that operate at the same time with different functioning basis and responsibilities. The most important market is the day-ahead market which has the main objective of performing the energy transactions for the following day by submitting offers to sell and offers to acquire electricity by market agents. These agents, in order to be able to operate on this market, must accept and comply with the Electricity Market Activity Rules. The offers these agents submit to the market operator will be included in a matching procedure affecting the daily programming horizon of the following day to the one of the offer reception session. This is why this market is known as the day-ahead market. For a wind farm developer, it is important to know that in Spain all available generators must submit an offer to the day-ahead except for the energy already committed in a bilateral contract (PPA) that will be explained in the following sections. Hence, the sellers in the pool are the generators or producers of energy and the buyers are the commercialization companies or direct consumers. These market agents, both from Spain or Portugal, submit their offers to the day-ahead market through OMIE, which is the only designated market operator for both countries. This responsibility must not be confused with system operator (TSO) which, as explained above, is held in Spain by *Red Eléctrica de España* (REE).

Every day of the year at 12:00 CET (Central European Time), the day-ahead market session takes place. On it, electricity prices and volumes are set for the next twenty-four hours throughout Europe. The price and energy volume for a specific hour of the next day are determined by the intersection between supply and demand curves built by the offers of sellers and buyers. Sales and purchase offers can be made considering 1 to 25 segments, one for each hour of the next day. In each of the segments, the buyers and sellers bid specifying a certain amount of energy and its price. For each of the segments (hours), the price of the energy offered is organized in increasing order for sale bids and decreasing order for purchase bids.

The offers for the sale of electricity that producers present to OMIE can be (i) simple, or (ii) incorporate complex conditions based on their content. Simple bids are economic offers for the sale of energy that generators present for each hourly period and production unit they own, expressing only a price and a quantity of energy. Offers that incorporate complex selling conditions are those that, while meeting the requirements for simple offers (price and quantity), they do also incorporate at least one (can be more) of the following technical or economic conditions:

- **Load gradient**: Allows for the establishment of the maximum difference between the energy supplied at one hour "h" and the energy supplied in the next hour "h+1" by the production unit. This condition sets a limit to the maximum energy to be matched in the segment "h" based on the results of the matching of the previous "h-1" and next hour "h+1" to avoid abrupt changes in production units that cannot be technically assumed.
- **Minimum revenue**: This condition allows for offers to be made in all hours, but ensuring that the production unit does not participate in the day's matching result if it does not achieve for its entire production in the day an income greater than a fixed amount, established in €, plus a variable remuneration established in euros for each matched MWh (€/MWh matched).
- **Scheduled shutdown (Ramps)**: This condition would allow the hypothetical wind farm withdrawn from the matching for not meeting the required minimum revenue condition to perform a scheduled shutdown within a maximum time of three hours, avoiding shutting down from its scheduled program in the last hour ("h25") of the previous day to zero in the first hour of the following day ("h1"). The way to do is by accepting the bids of the first three segments of the day as simple offers. It has the only condition that the offered energy during those three hours must be decreasing in each.

Once the bids (simple and complex) have been sent to OMIE, from both sellers and buyers, the matching takes place utilizing a matching algorithm called "Euphemia" (Pan-European Hybrid Electricity Market Integration Algorithm). This has the aim to optimize the economic surplus, which corresponds to the sum, for all hourly periods within the scheduling horizon, of the benefit from purchase offers plus the benefit from sale offers. The benefit from purchase offers is understood as the difference between the matched purchase offer price and the received marginal price (last accepted purchase bid), and the benefit from sale offers is understood as the difference between the resulting marginal price (last accepted sale bid) and the matched sale offer price.

Figure 36: Day-ahead market matching

The Euphemia algorithm considers aggregated step curves, which correspond to curves where the start price for accepting a segment of energy and the complete acceptance price for that energy segment coincide, and interpolated aggregated curves, which are those where the start price for accepting a segment of energy and the complete acceptance price for that energy segment differ by at least the minimum jump between offer prices. For the treatment of both types of curves, the Euphemia algorithm performs the matching process with precision in price and energy values, exceeding the decimal limit established for offer presentation. Once the matching process is completed, rounding of energy and price values is carried out for each market, according to the precision established for each market which is, for the Iberian market, of two decimals for prices (in €/MWh) and one decimal for energy quantities (in MWh).

The result of the Euphemia algorithm is limited to the exchange conditions established in each market between the bidding zones. In this regard, the net flow between bidding zones (flow between Spain and Portugal, between Spain and France, and between Spain and Morocco) will be limited to the available capacity for the market as communicated by the corresponding system operators (in Spain REE). The Euphemia algorithm treats all simple offers as a single offer which is the sum of all simple offers within the bidding zone. Once the matching process is completed, the market operator (OMIE) will proceed to allocate the values for the matched and unmatched energy segments of all offers that have declared any complex conditions as well as the values for the matched and unmatched energy segments for the set of offers that have not declared any complex conditions (simple bids).

It is very important to understand that these matching results obtained through the Euphemia algorithm do correspond to the optimal economical surplus. However, they might not be suitable from a technical point of view due to the existing limitations of the transportation and distribution networks and the network's stability in terms of frequency and voltage. For this reason, once Euphemia finishes the matching process, the results are remitted to the system operator, in Spain REE, for their technical validation. This process is also known as management of the system's technical constraints and ensures that Euphemia's results are technically feasible in the transportation network. This is the main reason why the day-ahead market results can suffer small variations as consequence of the technical constraints analysis realized by REE resulting in a new feasible day-ahead allocations.

Intraday market:

After the day-ahead market final results, the market agents can still buy or sell electricity in the intraday market through two mechanisms: (i) Intraday auction markets, or (ii) the continuous market. These markets are an important tool for market agents in order to adjust, through the submission of new buying or selling bids, the results obtained in the day-ahead market according to potential new necessities that they expect to have in real time.

The intraday auction markets are organized in the MIBEL (*Mercado Ibérico de Electricidad*) context and they allow a market agent adjust with easy and equal conditions with other agents their market position from the physical results of the day-ahead market. These auctions tend to result in similar electricity prices than the ones obtained in the day-ahead market and allow buyers and sellers to readjust their purchasing and generating commitments up to four hours before the real time. The mentioned auctions are six and they take place in different programming timings. The resulting programming of each auction session of the intraday market is the Basic Intraday

Program of Incremental Matching (PIBCI – *Programa Intradiario Básico de Casación Incremental*). As with the day-ahead market, these PIBCI results are sent to REE that checks its technical validity and publishes the final resulting the Final Schedule Program (PHF – *Programa Horario Final*). The intraday auctions schedules are those uploaded in the Electricity Market Activity Rules. However, in the following table it appears the possible schedule limits:

	SESSION 1º	SESSION 2ª	SESSION 3ª	SESSION 4ª	SESSION 5ª	SESSION 6ª
Auction Opening time	14:00	17:00	21:00	1:00	4:00	9:00
Auction Closing time	15:00	17:50	21:50	1:50	4:50	9:50
Matching Process	15:00	17:50	21:50	1:50	4:50	9:50
Results publication (PIBCA)	15:07	17:57	21:57	1:57	4:57	9:57
TSOs Publication (PHF)	16:20	18:20	22:20	2:20	5:20	10:20
Schedule Horizon (Timing periods included in the horizon)	24 hours (1-24 D+1)	28 hours (21-24 y 1-24 D+1)	24 hours (1-24 D+1)	20 hours (5-24)	17 hours (8-24)	12 hours (13-24)

Table 8: Intraday auctions schedule limits

In regards with the continuous intraday market, it is organized in a European context that allows the negotiation with market agents that are in the same bidding zones or even different ones if there is interzonal available capacity. What is interesting of this market is that there can be negotiations up to one hour before the energy supply. If there was an incident in the following hour, there exist other markets managed by the TSO (REE) which ensure that at every moment there is an equilibrium between energy demand and supply. These markets, in which a wind farm could also participate and earn income, are managed by REE are the (i) Technical Constraints market, (ii) Secondary Regulation, (iii) Balancing markets, and (iv) Tertiary Reserve.

4.1.2 Remuneration scheme for regulated assets

As explained in the previous section, the current regulation in Spain states that available generators must submit an offer to the day-ahead except for the energy already committed in a bilateral contract (PPA). Knowing this, a wind farm developer can have three different retributive regimes for selling its renewable energy in the market: (i) The ordinary regime in which the developer sells the energy in the market in equal conditions as the rest of producers (independently of them being non-renewable generators), (ii) The Specific Remuneration Regime, and (iii) The recent Economic

Regime for Renewable Energy. The first regime was explained in the previous section, while the last two correspond to regulated assets and are going to be explained in this section.

Specific Remuneration Regime:

As introduced in the section of Spanish regulatory framework of renewables, when the Electric Sector Law was approved in 1997, renewable technologies were unable to compete with other existing generation technologies due to the high investment costs compared to these technologies. In the way the market is organized, the producers bid to sell the electricity at a price equal to the marginal cost of generating it. In this way, renewable plants could not recover their investments and obtain returns at the average marginal prices of the wholesale market by then. However, in the Spanish energy context of 1997, it was already clear the need to develop renewable energy technologies in order to diversify the generation mix and support the climate protection initiatives. This is why the law of 1997 already considered paying premiums to renewable developers in order to ensure them a reasonable return. This system was known as Fit-in-Premium (FiP).

Although the system ensured the deployment of renewables that began making Spain one of the current worldwide leaders in renewables, it also had a great cost for electricity end-consumers which were at the end the ones that paid the premiums as part of their electricity bills. According to the book *Estudios sobre cambio climático y transición energética* (J.F. Alenza and L. Mellado, 2022), the two main reasons for this extremely high cost were: (i) These incentives were not updated when they resulted in important technology advances which decreased significantly investment and operation costs of renewables, and (ii) There was no regulatory limitation to the access of these incentives by renewable developers even in times in which the target installed capacity had been surpassed by c. 10 times for some technologies. To avoid the high costs of the premiums of renewables, these incentives were abolished for new renewable installations in the Royal Decree 1/2012 and finally abolished for all installations in the new Electricity Sector Law approved by the Spanish Parliament in December 2013.

As explained in the regulatory framework section of renewables, the Specific Remuneration Regime for renewables was develop in the RD 413/2014. On it, it was made clear that the new electricity law also aimed to incentivise the production of renewable energy but in this case only in those plants in which the ordinary merchant remuneration would not allow them to compete in equal conditions as the other technologies and obtaining what is called as "reasonable return". Through this new concept, the electricity law aimed that the additional retribution that the Specific Remuneration Regime incorporated was enough so that a renewable installation could obtain the reasonable return in accordance "with the activity realized by an efficient and well-managed company".

The reasonable return was set to be, before taxes, around the return of the Spanish 10-year Treasury Bond plus a spread. The reasonable return would stay the same for regulatory periods of six years, hence being updated at the beginning of each regulatory period. In the RD 413/2014, it was stated that for the first regulatory period (2014-2019) the reasonable return would be of 7.398%. For the second regulatory period (2020-2025), the reasonable return was updated to 7.09% through RD 17/2019 and, in this case, it stops being linked to the Spanish Treasury 10-year bond as proposed by the CNMC. As an extraordinary measure, those assets with regulated remuneration at entry in force of RD 9/2013 which are not involved in litigations with the country, the reasonable return of 7.398% is kept until 2031, meaning the current regulatory period (2020-2025) and the next one (2026-2031).

In terms of the specific retribution, the plants which hold this special regime would receive an additional income apart from the one that corresponds to its participation in the merchant electricity pool. Hence, their income can be summarized in the following formula:

$$Rtotal = Rmarket + Rspecific$$

- Rmarket corresponds to the ordinary income obtained from the pool market and it is: Rmarket (€) = Pool price (€/MWh) x Energy volume (MWh). These are the ordinary revenues that would obtain a non-renewable plant that cannot apply to this regime.

- Rspecific is the regulated additional remuneration through which the renewable plant reaches the previously explained reasonable return. It is composed of two components related through the following formula:

  Rspecific = Rinv + Ro

  - Rinv, known as Return on Investment, is a fixed amount per installed MW and it is expressed in €/MW. It aims to cover the investment costs that cannot be recovered through the sale of electricity to the market. Through this additional remuneration, the wind farm developer should be able to reach the established reasonable return of the regulatory period.
  - Ro, known as Return on Operations, is a fixed amount per volume of energy produced in MWh and it is expressed in €/MWh. It aims to cover the gap between operating costs and revenues from electricity sales. Through this additional remuneration, a renewable plant can recover from high operating costs (above expected market price) up to a maximum number of hours per facility.

As explained above, one of the main issues that led to the collapse of the regulated remuneration regime previous to the current electricity law approved in 2013 was that there was no regulatory limitation to the access of the incentives by renewable developers. To avoid this happening again, not all applicants to the specific remuneration regime were granted the condition. This time, competitive auctions were convoked following the principles of transparency, objectivity and non-discrimination. For this reason, to choose the granted facilities of the specific remuneration regime between all applicants, the same priority criterion was followed for each of the auctions: the lowest additional remuneration bids. Thus, this means that the lower the additional remuneration requested in the bid, the higher the chances of being finally being granted with it. With these measures, the government tried to keep promoting the deployment of renewables with the guarantee of the reasonable return but also with the lowest overrun for the electricity end-costumer to avoid the collapse of the regulated regime once again.

For example, let's imagine that for the wind farm of this thesis (wind farm A) the developer company wants to reach a regulated status according to the Spanish Specific Remuneration Regime. To reach this status, wind farm A must be granted the condition bidding in an auction and potentially winning it against other wind farms (for example wind farm B, C and D). As explained above, the lower the additional regulated remuneration requested in the bid, the higher the possibility to be granted the condition. In this ideal example, let's say the government convokes an auction to grant 600 MW of regulated wind technology and each of the wind farms have an installed capacity of 200 MW. Only three out of the four wind farms will be granted the regulated condition. Which one of the three is left aside? The one that requests the highest regulated remuneration, and that is the wind farm that bids the highest reduction regulated coefficient of initial investment from the standard investment proposed by the government. Imagine wind farm A bids showcasing a reduction of -5% of the initial investment, and wind farms B, C and D reductions of -2%, -10% and -7% respectively. In this example, the granted wind farms would be A, C and D as they are the ones that, with the least additional regulated remuneration requested, cover the total installed capacity of the auction. In this example, it is also important to highlight that as the auctions are marginalists, all the granted wind farms are remunerated according to the conditions of the last of the granted bidders. In this example, wind farms A, C and D will be granted with the additional regulated remuneration of wind farm A.

In case that a wind farm is granted with the Specific Remuneration Regime, aside from the pool market revenues, it will receive Rspecific = Rinv + Ro:

- Return on investment revenues are calculated with the following formula: Revenues = Rinv (€/MW) x Installed capacity (MW).
- Return on operation revenues are calculated with the following formula: Revenues = Ro (€/MWh) x Energy sold to the pool during the period (MWh). In the recent industry situation, this term tends to be equal to zero as it is subject to the unusual condition that operating expenses are higher than the revenues obtained from selling the energy to the pool (EBITDA < 0).

Hence, as return on operation revenues tend to be zero, the regulated revenues are mainly return on investment revenues. As the installed capacity is known, the missing figure to be able to calculate the revenue is Rinv. This term is not the same for each renewable plant in Spain, but it is concrete for every type of installation. Every renewable plant according to its characteristics has an installation type assigned. An installation type groups a set of renewable installations that have common characteristics (for instance technology, installed capacity and COD). In order for a renewable plant, for example the wind farm of this thesis, to know the installation type to which it belongs to it must:

(i) Classify the installation in the group and subgroup to which it belongs to according to article 2 of the RD 413/2014.

(ii) Consult the latest TED (currently TED 741/2023) to know the exact installation type and its identifier code IT-XXXXX (for example IT-20244).

For each installation type the government releases a set of retributive parameters that apply to all the renewable installations that belong to that classification. These retributive parameters are calculated by the government under the assumption of the installation being an efficient and well managed company. The Rinv figure is found as one of the retributive parameters.

Economic Regime for Renewable Energy:

In November 2020, the government of Spain released the Royal Decree 960/2020 by which the known as Economic Regime for Renewable Energy (REER) was approved. This regulation is different to the Specific Remuneration Regime of renewables just explained and did not aim to substitute but to add another way of having regulated revenues for a renewable installation. While the Specific Remuneration Regime aimed to retribute the investment and operation in the renewable sector, this new regulation aimed to remunerate the energy generated. This new regulation was focused on accomplishing the renewables commitments that the country had planned through the PNIEC already explained above.

Although the REER did not abolish the Specific Remuneration Regime, it was set not to be compatible with it. Hence, a renewable installation that was participating in the Specific Remuneration Regime had to renounce to it to start operating under the REER. As with the Specific Regime, in order to be granted with the right of regulated revenues under the REER, the renewable installation had to bid and win an auction. However, an important fact about the new regulation is that not only an installation had to be renewable in order to be candidate to apply to the REER, but also had to commit to realize an investment after the auction that granted the operation under it. These investments comprised those related to a new installation or those investments related to an adjustment or increase of an existing facility. In the case of an investment related to a modification of a facility, the REER only applies to the new investment corresponding part.

Before entering in the auctions mechanism there is an additional very important difference with the Specific Remuneration Regime in which the installations were remunerated for the realized investment. Under the new regulation, the installations perceive a remuneration for the energy sold at the pool but not at the previously explained volatile price as a result of selling the energy at the marginal cost of production, but at a long-term fixed price in €/MWh. This price is the result of the auction in which the installation has been granted the right of operating under the REER.

Regarding the auctions, there is another important difference with the Specific Remuneration Regime is the calendar. The REER designs an indicative calendar for the auctions in the following five years that is updated yearly and which contains the indicative timelines, calls frequency, technologies and installed capacity. The institution in charge of the auctions is OMIE and its supervisor is CNMC. The auctions are convoked through a Ministerial Order which also defines the product to be auctioned: (i) Installed capacity, (ii) Energy, or (iii) A combination of both.

In the auctions of the REER, the renewable developers bid at the price (in MWh and with two decimals) at which they are willing to sell their energy in the long-term period contemplated in the auction terms. These terms will also fix a maximum (also known as reserve price) and a minimum price (also known as risk price and typically 0€/MWh) between which bidders must place their prices. These prices limit prices can be confidential and are also expressed in €/MWh with two decimals. Clearly, the bids that are below the minimum price or above the maximum are not considered in the auction. Once the deadline expires for a certain auction all the submitted bids are ordered from the lowest to the highest price. The auction winners start to be selected commencing with the lowest offer and following the incremental order until the quota of the auctioned product (capacity, energy or combination) is reached. No bid that would signify the surpass of the quota is selected. Additionally, the regulation stipulates that no company or business group can surpass more than 50% of the total volume regardless of the auctioned product.

It is very significant to understand that, unlike the auctions of the Specific Remuneration Regime, these auctions do not follow a marginal but a Pay-as-Bid mechanism. In a marginal mechanism, all the awarded installations of a same auction would be paid the same long-term price for the sell of energy equal to the price of the last awarded installation (higher price). In the Pay-as-Bid mechanism, if an installation is one of those awarded in the auction, this one will be paid at the price at which it bade independently of the price at which the other awarded installations bade.

As explained above, the REER remunerates energy. For this reason, it is important to understand the concept of auctioned energy: the negotiated energy during the maximum delivery time limit by the renewable plants that are under the REER through their participation in the pool without exceeding the maximum auctioned energy:

- The maximum delivery time limit is the temporary frame that REER installations have to sell the minimum committed auctioned energy in the pool. This maximum delivery time limit is typically between 10 and 15 years and the beginning terms are mentioned in the terms of the auction.
- The minimum auctioned energy is the minimum amount of energy (in sold MWh) at which the awarded installation has committed to sell. When the auctioned product is energy, the minimum auctioned energy coincides with the maximum. When the auctioned product is capacity, the minimum amount of energy is installed calculated through the following formula: Minimum auctioned energy = Installed capacity of the installation (MW) x

Minimum number of annual equivalent hours of production of the installation (h) x Maximum delivery time limit (years).

- The maximum auctioned energy is the maximum amount of energy (in sold MWh) at which the awarded installation can benefit from the REER regulated remuneration. It is calculated through the following formula: Maximum auctioned energy = Installed capacity of the installation (MW) x Maximum number of annual equivalent hours of production of the installation (h) x Maximum delivery time limit (years).

The way REER works is that the installations under it must sell in the pool the minimum auctioned energy before the expiration of the maximum delivery time limit. In case the installation does not reach the minimum auctioned energy in the stated time limit, a penalty is applied. Once an installation reaches the minimum auctioned energy within the maximum delivery time it can optionally keep selling energy under the REER remuneration regime until it reaches the maximum auctioned energy. If the installation decides to keep selling under the REER regime, it will benefit from it until it reached the maximum auctioned energy. Once this limit is surpassed, the installation stops being linked to the REER regime and starts selling to the pool at its varying price.

Finally, it is important to add a comment regarding the price at which the energy is remunerated under the REER regime. As explained above, the remuneration of the installation for the energy sold in the market is equal to: Revenues = Energy sold in the pool (MWh) x Auction bid price (€/MWh). Although this would mean an absolute independence of the price at which the energy is sold in the day-ahead an intraday markets, the regulation does also consider the correction of this price according to an adjustment percentage of the market price through the following formulas:

- REER price for the energy sold in the day-ahead market (€/MWh) = Auction price (€/MWh) + % of market adjustment x (Price of the day-ahead market (€/MWh) – Auction price (€/MWh)
- REER price for the energy sold in the intraday market (€/MWh) = Auction price (€/MWh) + % of market adjustment x (Price of the day-ahead market (€/MWh) – Auction price (€/MWh)

The percentage of market adjustment is fixed under the regulation of the auction mechanism according to several parameter such as technology maturity, competitivity, and management. This percentage is between 0% and 50%. If the price is corrected, the price is not absolutely fixed and is slightly exposed to the varying market price. In this way, the bidder can partially assume the risk of the market fluctuations in favor or against its interests. Additionally, this measure can promote the bidder to offer its energy to the market at the hours in which the energy is more expensive in the market in order to try to maximize its revenues. However, for this to happen, the installation must have invested first in a mechanism that allows it to storage the energy.

4.1.3 PPAs – Purchase Power Agreements

Another way in which a generator, in this case a wind farm, can generate revenues is through Purchase Power Agreements, usually known as PPAs. These are contracts for the purchase of electrical energy in the long term at an agreed price between two parties, on one side a generator (typically renewable), and from the other side a consumer or commercialization company. In the energy industry, PPAs are becoming more and more popular, especially after the situation of high electricity wholesale prices derived from Ukraine's war.

What is especially interesting from PPAs is that it has advantages for both parties involved in the agreement. From the selling side, a PPA ensures a regular revenue stream and from the buying side the PPA ensures a reliable supply of energy. According to Iberdrola, the main benefits of PPAs are:

- From the consumer side: (i) They constitute a clean supply of energy which can be traced from a specific asset, (ii) PPAs generate additionality, which means that they make feasible to invest in renewable assets, thereby reducing the amount of power generated from polluting sources, (iii) The renewable asset has the possibility of branding with the customer's name, (iv) PPAs agree on competitively priced energy with potential significant discounts on current and future energy prices, (v) They provide electricity to the customer at a stable and predictable price, (vi) Customers can adapt the PPAs conditions to their needs.

- From the generator side: (i) PPAs allow the generator to stablish an strategy in which they can invest in new assets because of the long-term revenue that they certainly provide, (ii) They allow investment decisions to be made based on the criteria of profitability vs risk, (iii) PPAs make the project bankable, (iv) They are helpful to establish long-term relationships with end-customers, (v) PPAs are an alternative way of investment in renewable assets, in addition to participating in auctions or selling to the pool.

According to BloombergNEF's (BNEF) *1H 2024 Corporate Energy Market Outlook*, the explained PPA's have increased since 2008 in 198 GW of capacity only considering those corporate PPAs related to sun and wind energy sources. Since 2015, the report highlights that the corporate PPA capacity has had a 33% of compounded annual growth rate until 2023 materializing safe revenue streams for developers and hence making possible further investment in renewables.

Figure 37: Corporate PPA volumes by region

As shown in the previous figure, according to BNEF's report, America (20.9 GW) was the leading region in signed corporate PPA capacity in 2023, followed by Europe, Middle East and Africa (15.4 GW), and the Asia Pacific Region (9.7 GW). The report highlights that the European region was the one that grew the most in capacity compared to 2022 (+74%) with Spain as one of its leading countries mainly due to the stabilization once again in PPA prices after the energy crisis suffered in 2022 which led the PPA prices to peak following the trend in power prices. Spain, together with the UK, the Netherlands, and Germany, implied more than half of the annual corporate 15.4 GW signed through PPAs in 2023.

According to *European PPA Market Outlook 2024* report from Pexapark, which does not only include corporate PPAs but also utility ones, in 2023 the PPA deal flow disclosed contracted capacity 2018-2023 grew by +41% in Europe with 16.2 GW in the 272 deals disclosed. According to the report, 10.5 GW were from solar technology (160 deals) and 2.3 GW onshore wind (58 deals), among other technologies. The top buyer was Amazon and the top seller was Iberdrola. In terms of countries, Spain led the disclosed contracted capacity (4.6 GW) and the number of deals (41 deals) followed by Germany, Italy, Greece, and the UK.

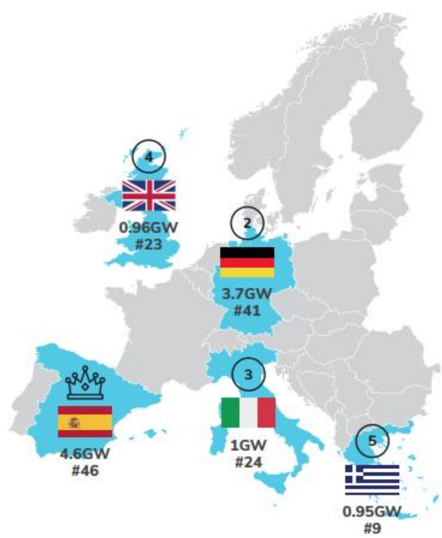


Figure 38: PPA's European market leaders in 2023

There exist two main types of PPAs: (i) Physical PPAs, and (ii) Virtual PPA:

(i) **Physical PPA**: This are PPAs in which there is an actual supply of renewable energy. This means that through this PPAs a certain price for the electrical energy is negotiated between the seller and buyer sides, and the contract remains in force for an agreed period of time, typically long-term (years). These contracts typically contain the following conditions: commercial operating dates, PPA operating timeline, payment conditions, or sanctions in case of insufficient supply of energy. There are two main typologies of physical PPAs:

a. **On-site PPA**: This contractual structure takes place when the generator and the end-consumer share a physical connection. As its name indicates, generally this PPA corresponds to renewable plants that are directly installed at the end-customer facilities. A common example of this situation are renewable plants that are developed and constructed next to big industries that need significant energy supplies. Another typical example are solar PV plants that are built ad-hoc in the customer facilities and that are connected to its internal network. The renewable developer develops the installation and provides the electrical energy at a more competitive price to the customer which stops the demand to the usual network.

b. **Off-site PPA**: This contractual structure takes place when the direct connection between the producer and the end-consumer is not feasible but both are connected to the same transportation or distribution network. Through this PPA, the generator party commits to produce the energy and incorporate it to the distribution or transportation network, from the end-consumer side its commitment is to extract the energy it needs from that distribution or transportation network. The keys of this agreement are (i) the negotiated economic terms as the consumer pays the energy at the agreed price with the generator, which also receives that price, (ii) the quantity of energy agreed to be provided or requested by both sides, and (iii) the knowledge from the end-costumer of the source of the energy it utilizes, typically renewables. It is important to highlight that typically these type of contracts are not only formalized between a renewable developer and the end-consumer, but also with a third party: the previously explained commercialization companies. The reason to do so is that in case of there is a shortfall of the energy generated by the renewable generator, the commercialization company can supply the missing energy. For this risks to be tackled in a proper way, there are three main types of Off-site PPA typologies:

I. **Pay-as-Produced:** This is the typical PPA for small renewables plants as the main risk is assumed by the buyer side (end-consumer) and the availability risk is mitigated for the developer. Through this PPA, the consumer buys the gross energy produced by the renewable asset or an agreed percentage of it independently of the generation profile of the producer. Only a minimum volume of energy (typically annually) is guaranteed, hence including an adjustment mechanism in case the minimum agreed energy is not reached. Prices are usually lower as the risk is in the buyer's side.

II. **Pay-as-Consumed:** On it, the PPA volume is the actual demand of the buyer and the seller must be ready to supply that demand. Through this PPA, the risk is opposed to the Pay-as-Produced as it is totally moved to the seller's side. Only sellers with a large and diversified generation portfolio can assume this PPAs.

III. **Baseload PPAs:** In this PPAs, a fixed production is agreed upon and evenly distributed during all hours of the year. The delivery of energy can be hourly, monthly or quarterly. The generator is responsible if production is insufficient to cover contractual obligations, and hence the prices are usually higher as the risk is the seller's side. This typology of PPA requires a very constant source of energy if it has to supply a certain amount of energy hourly in which case, for example, a solar PV would not be able to support it unless it had batteries to storage the energy.

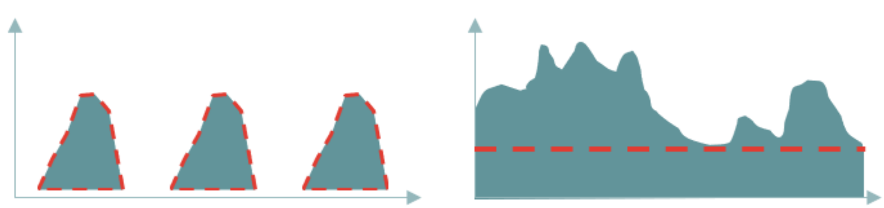


Figure 39: Volume profile Pay-as-Produced vs Baseload PPA

(ii) **<u>Virtual PPA</u>**: These type of PPA is also known as financial or as synthetic PPA. The main difference with the physical PPA is that on this one the agreement does not directly involve a physical exchange of electricity between the two parties involved. Instead, these are contracts in which the two sides, typically a renewable generator and a commercialization company, agree on a certain price at which the energy is going to be paid during a long-term period of time. At the end of each month or year of the PPA period, the agreed price of the PPA and the price of the pool are compared. If the agreed price is higher than the average of the pool during the period, the buyer side pays the producer the difference of prices. In the other hand, if the agreed price of the PPA is lower than the pool's average, then the producer must pay the difference in price to the commercialization company. Hence, the producer is being remunerated at the agreed price upon all pool conditions meaning a constant revenue stream from it.

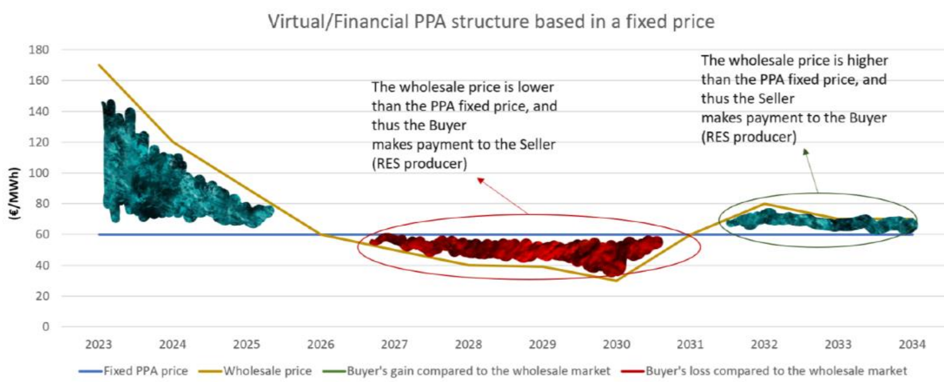


Figure 40: Virtual PPA graphically explained

In a Purchase Power Agreement there are several conditions that must be negotiated and reflected in the final contract. A list of the most important terms to agree on is:

- Sides that intervene in the PPA. These means clearly stating which are the assets or sponsors involved, the buyer of the energy, the commercialization company involved (if any) and each of the responsibilities that each of the parties acquire.
- Tenor of the PPA and termination conditions. This involves stating when the PPA finishes and which conditions can mean its termination (such as event of default) and the termination payment associated to it.

- Payment conditions. Not only includes the agreed price, but also any undertaken indexing conditions, the amount of days in which the payment should be due (monthly, quarterly or yearly), credit support and bank guarantees.
- Volume of energy involved. This includes the quantity of energy subject to PPA whether in MWh or in percentage of the total energy produced, the volume profile commitment (if any) and the minimum volume guarantee.
- Others. Such as the change of control clause (if any) or dispute resolution clause (if any).

4.1.4 GoOs – Guarantees of Origin

Another possible source of revenue, compatible with all the rest, for a wind farm in Spain is the Guarantee of Origin, also known as GoO. According to the *Comisión Nacional de Mercados y Competencia* (CNMC), the GoOs are accreditations, in electronic format, that ensure that a certain amount of energy, in MWh, produced in a certain plant during a certain period has been produced from renewable sources or from cogeneration of high efficiency.

The way GoOs work in Spain is that renewable developers generate electricity and they receive guarantees of origin that certify that that electrical energy has been produced through renewable sources. Each GoO is linked to a specific quantity of energy and to the renewable source to which it belongs. Once the developer receives the GoOs, these are sold to energy commercialization companies, general companies, institutions or even individuals that want to prove the renewable origin of the electricity they utilize. These buyers of GoOs can utilize the certifications to show their support to renewables, comply with specific regulations or improve their ESG or sustainability image.

Purely, the electricity that reaches the buyer is not 100% renewable because the electricity transported by the network can come from renewable and non-renewable sources. As the network does not differentiate the electricity's origin the buyer of the GoO can not guarantee that the exactly consumed energy is 100% renewable. However, what it does guarantee is that renewable energy is produced at the exact same amount of the consumed energy.

The guarantees are administered in Spain through the CNMC through its *GoOs System* which is in charge of overseeing the issuance and management of the generated GoOs. This System was introduced in Spain in 2007 with the objective of informing the consumers of the origin of the electricity they use and what is the associated environmental impact. The GoOs are regulated in Spain through the *Intrucción Técnica Complementaria (ITC)* 1522/2007, Royal Decree 413/2014, and *Circular* 1/2018.

According to this last regulation, the most important procedures that can be undertaken through the CNMC portal related to the obtention and commercialization of the GoOs are:

- **Expedition Request**: The renewable developer company can voluntarily request to the CNMC the issuance of the GoOs for a certain period of time that must be in monthly multiples (can request GoOs for the next 4 years and 10 months but not for the next 4 years, 10 months and 2 weeks). The CNMC, after verifying the generation information, proceeds with the issuance of the GoOs which consist of a note in the generator plant's account in the national generators register assigning to it a unique identifier for each GoO.
- **Transfer Request**: The transfer of the GoOs can be requested directly by its owner through the CNMC so that this administration can directly assign them to the commercialization account to which these are transferred.
- **Income Plan Accreditation**: The income obtained from the transference of the GoOs must be justified in a report remitted to the CNMC in which the plan of utilization of those revenues will also be detailed. The income can only be destined to new renewable installations or to R&D for the improvement of global environment.
- **Import or Export Request**: The GoOs can be imported or exported to other countries such as any other good or service. The main reason why these are exported to international commercialization companies is that typically the price willing to price by them for each GoO is higher than the price offered by national commercialization companies. However,

exporting GoOs has the disadvantage that, only if the plant is perceiving the regulated specific remuneration for renewables, it must renounce to the remuneration applicable to the MWh applicable to the exported GoOs.

- **Expiration of GoOs**: The guarantees that have been issued or imported corresponding to the energy generated in the month "n" will automatically expire in the month "n+12". GoOs are only valid the twelve later months of the energy associated to those GoOs having been generated.

It is important to highlight in terms of GoOs prices that these are not traded in an organized market that sets their price. GoOs are traded in non-organized markets (secondary markets) in which exchanges are made through bilateral contracts that are aside form the regulator's (CNMC) responsibility. In these non-organized markets, the GoOs can be sold inside the country in which they are generated or exported to other countries. Hence, this leads to a low liquid and volatile market in which the prices according to the buyer offer can vary significantly. However, the prices tend to be between 2€/MWh and 10€/MWh and expected to increase in the upcoming years.

Finally, it is important to highlight that the main benefits of the GoOs market are: (i) Transparency: GoOs provide a transparent mechanism to verify the renewable origin of the electricity allowing consumers and companies to undertake informed decisions, (ii) Incentives to investment in renewables, and (iii) Regulation compliance: In some countries, GoOs are an important piece in the consumption regulation and policies of renewable energy.

4.2 POWER PRICE CURVES

As it has been explained in the section above, there exist variable sources of revenues that directly depend on the price of electricity of the Spanish pool. As highlighted, in the day-ahead and the intraday markets, the seller market agents offer a certain quantity of energy at a certain price and the buyer agents bid at a certain price for a certain quantity of electrical energy. At the end of the auction, as it is marginalist process, there is a single price paid for electricity at every hour of every day of the year because all the sellers are remunerated in the same price conditions as the last of the matched generators. Clearly, the higher the matching price of the electricity auction of the Spanish pool the higher the revenues of the producers. As the price of the pool is variable (changes for every hour of the year), the auction process leads to a market risk that a wind farm developer must try to handle in order to decide whether it wants to invest in a wind farm or not, to calculate which are the potential revenues it can obtain and to calculate the potential return on the renewable investment.

1.1.1 Projections and consultants

Once understood the importance of being able to handle the market risk at which a wind farm developer would be subject to in case of investing in a wind farm, it is the time to understand which tool developers utilize to do so: power price curves. Basically, the power price curves are graphical representations of the expected prices of electricity in the future. If a wind farm developer knows how much electricity it will be able to sell in the pool in the next years and the estimated price at which that future electricity will be paid, the producer can have an accurate estimation of the revenues it will generate during the operation of the wind farm and hence can decide on its potential investment.

These future electricity price estimations are not performed by the wind farm developers themselves, but by specialized energy consultants which elaborate monthly or quarterly reports in which they release their electricity prices expectations for the future and the basis of their analysis. These reports are strictly private and confidential as many different types of companies pay high quantities of money in order to have access to them: renewable developers, electricity commercialization companies, investment banks and private funds among several other kinds of companies. Three of the most relevant energy consultant players that perform these type of analysis are:

- **Afry**: Headquartered in Stockholm, Sweden, was founded in 1895. The company specializes in engineering, design, and advisory services in the energy sector, offering comprehensive solutions for sustainable energy projects worldwide.

- **Baringa**: Headquartered in London, United Kingdom, was founded in 2000. Primarily focusing on management consulting, Baringa assists energy companies in strategy development, operational improvements, and regulatory compliance to navigate the evolving landscape of the energy industry.
- **Aurora**: Headquartered in Oxford, United Kingdom, was founded in 2013. As a leading energy market analytics firm, Aurora provides research, data analysis, and strategic insights to help clients make informed decisions in areas such as renewables integration, market modeling, and investment planning.

Given the importance of an accurate estimation of electricity prices in the future to be performed by the described energy consultants, it is also key to understand which main drivers lie behind their assumptions to estimate them. A non-exhaustive list of the most relevant drivers includes:

- **Gas price**: Energy consultants deeply analyze gas prices because they exercise a significant influence on the electricity costs. Fluctuations in gas prices directly impact on the operating expenses of the gas power plants which, excepting Spain, are key in many regions of the world. Higher gas prices can hence lead to higher electricity production costs which finally impact on the electricity consumers bills. For this reason, energy consultants not only take into account gas prices expectations but also their fundamentals and the geopolitical factors that may influence them.
- **Oil price**: This case is different to the gas prices effect because oil is not directly used to generate electricity. However, it still has an indirect effect on electricity prices and hence it is crucial for energy consultants to analyze it. Basically, oil is used in many different contexts of the economy, including transportation or manufacturing, and hence indirectly impacts on the electricity demand and its price. For instance, a rise in oil prices can provoke higher transportation costs, which affects to the services and assets prices and can potentially reduce economic activity and impact on the electricity consumption habits.
- **Coal price**: Similarly to the gas price, energy consultants perform detailed analysis on the price of coal due to its direct effect in the operating expenses of the coal power plants. As with the gas, the higher the price of the coal the higher the cost of generating electricity

with this natural resource and this is reflected in the electricity price. Additionally, fluctuations in the price of coal can have wider implications for energy markets, not only the direct competitivity of coal as an energy source, but also the effect on investment decisions in other technology power plants or the modernization of the existing ones.

- **Demand**: Energy consultants do also perform exhaustive analysis of the main electricity demand drivers to understand the implications of future price tendencies. Variations in demand of electricity, driven by factors such as economic growth, demographic and climate trends and technological progress, directly influence in the equilibrium of supply and demand in the energy markets, and these in the future consumption of electricity and hence its price.
- **Generation availability**: In a similar way to the described impact of electricity demand, the availability of generation sources does also affect to the equilibrium of supply and demand of electrical energy and hence to its price. Energy consultants perform deep analysis on the reliability and availability of the wide diversity of generation technologies, including renewables, nuclear and conventional fossil fuels. Fluctuations in availability of generation sources can impact on electricity prices affecting to the general capacity mix and market's competitivity. In this way, key generation drivers such as resource availability, maintenance schedules and regulatory restrictions can impact in electricity pricing.
- **Power plant costs**: As it will be detailed below in this chapter (LCOE section), energy investors perform an integral analysis of the expected cost of developing and operating a power plant considering topics such as capital expenditures, fuel costs, operating expenses and management costs. Changes in power plant costs directly influence in the electricity generation economy and in how prices are established, giving shape to investment decisions and market dynamics. For example, as it will be described below, technological improvements and economies of scale can reduce renewable generation costs making it more competitive compared to conventional technologies. On the contrary, regulation and volatility in fuels prices can increase operating costs of certain technologies and hence impact on its cost effectiveness and market volatility.

- **Others**: In addition to the drivers explained above, there are others which energy consultants also utilize to estimate electricity prices such as weather, climate policies, regulations, technological progress, electrical infrastructure, geopolitical events, electricity storage availability and emerging energy technologies.

1.1.2 Usage

Not only is important for a wind farm developer to understand the importance of power price curves, who performs them and what are the drivers to estimate them, but also to know how to interpret and use them while examining an investment or assessing future revenues during the wind farm operation.

In this way, it is key to have the following concepts clear:

- **Wholesale price (€/MWh)**: This figure reflects the price at which electricity is sold by generators and bought by commercialization companies in the Spanish pool. As explained above, the electricity price fluctuates hourly in the market. This is the reason why, if the wholesale price is expressed in a unit different to hours, it reflects in fact the average price. For example, in the figure below, as the wholesale price is expressed in years, it must be understood that this price is in fact reflecting the average price in that year.
- **Wind capture rate (%)**: This figure quantifies the volume-weighted average price that wind production assets can secure compared to the overall average electricity price over a specific timeframe. It must be taken into account that although pool prices are the classic way in which electricity prices are compared, it is in fact the wind capture price of electricity the one that determines the revenues that a wind farm can have selling energy to the pool. The formula to calculate the wind capture rate is:

$$Wind\ Capture\ Rate\ (\%) = \frac{Avg\ price\ earned\ by\ wind\ technology\ (\frac{€}{MWh})}{Avg\ market\ price\ (\frac{€}{MWh})} x100$$

- **Wind capture price (€/MWh)**: This figure corresponds to the product of the electricity pool multiplied by the wind capture rate. At the end, this figure is key as it is the one at which the energy sold in the market by the wind farm is multiplied to get the total revenues from selling to the pool of that farm:

$$Wind\ Capture\ Price\ \left(\frac{€}{MWh}\right) = Wholesale\ Price\ \left(\frac{€}{MWh}\right) x\ Wind\ Capture\ Rate\ (\%)$$

The following figure graphically reflects the three concepts explained above and which are key to estimate the revenues of a wind farm in the long term: (i) In dark blue the wholesale price which is the expected price of electricity sold at the Spanish pool (as it is a yearly figure it reflects in fact the average electricity price in a year), (ii) In red the wind capture rate expected for a Spanish wind farm, it is measured in % (right-side axis), and (iii) In light blue the wind capture price which corresponds to the multiplication of the wholesale price and the wind capture rate (the lowest the capture rate the more separated is the wind capture price of the wholesale price):

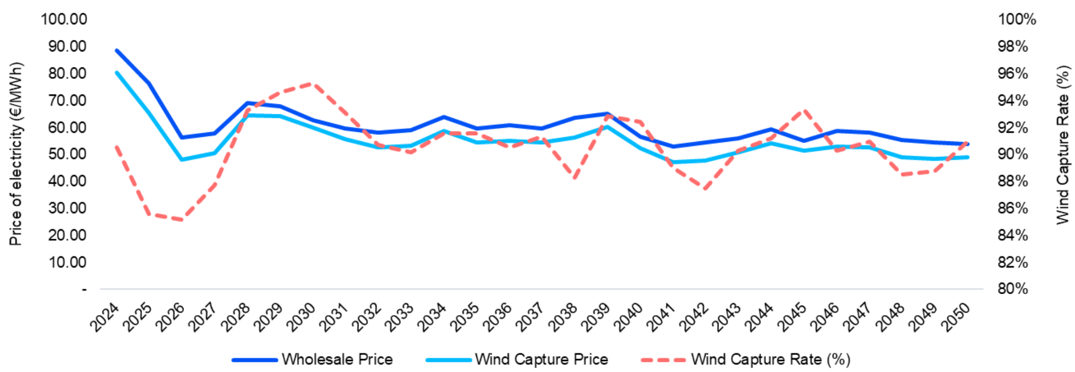


Figure 41: Power price curves methodology

It is important to note that, although the numbers reflected on the figure have as seed real estimations from an energy consultant in order to accomplish the aim of reflecting the way power price curves work, these have been randomized with a percentage in order not to break the confidentiality agreement from the consultant reports.

Finally, it is important to also know that energy consultants typically provide various curve cases in order to reflect the different hypothesis taken while estimating the future electricity prices. The way energy consultants name each of the curves varies between the brands, however, for this example, the simple names of high, low and central have been chosen to reflect which of the curves reflect the high, middle and low estimation hypothesis. As with the previous explanatory figure, for confidentiality purposes, although the reflected numbers have a real report seed they have been randomized with a percentage:

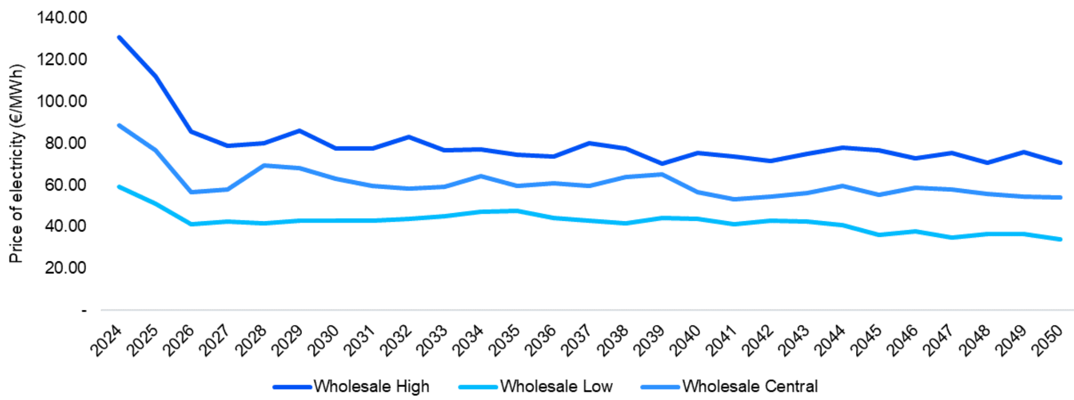


Figure 42: Power price curves cases

4.3 SOURCES OF COSTS

4.3.1 Levelised Cost of Electricity (LCOE)

Although the Levelised Cost of Electricity (LCOE) is not a direct cost that must be considered as part of a wind farm operation, it is a very useful cost concept in order to identify and compare among different entrepreneurship opportunities in the renewables sector. According to *Projected Costs of Generating Electricity*, from the International Energy Agency, LCOE serves as the primary method for evaluating the unitary costs of various technologies throughout their operational durations. It reflects economic expenses associated with a general technology rather than the financial aspects of individual projects within particular markets.

Although the abbreviation LCOE is the standard in the electricity industry, the concept can also be found in other sectors such as LCOH (Levelised Cost of Heating or, also, Levelised Cost of Hydrogen). Therefore, it is important to know that the meaning of the concept "Levelised Cost of X" refers to the cost of producing 1 unit of X during the operational life of a project of a certain technology. The units in which the LCOE is usually expressed are currency/energy, that is in the case of a Spanish wind farm: €/MWh. The reason for the standard in the industry to utilize these units is to fulfil the purpose why the LCOE is calculated which is to compare the cost of generating a unit of electrical energy with a certain technology against other technologies.

What LCOE does is cumulating all the projected costs during the operating life of a project and discount them to the present obtaining a net actual cost of generating electricity. This net cost is later annualized (with the amortization factor explained below) in order to obtain a uniform cost throughout the whole life of the project. It is important to understand that the concept of LCOE considers all the costs. Hence it includes not only those that are incurred at the moment of developing and constructing the installation, but also the ones that are incurred during the operation of the renewable plant. In the case of installations that generates electricity as the one studied in this thesis, the LCOE can be calculated utilizing the following simplified formula:

$$LCOE = INV \cdot f_a + C_F \cdot f_a \cdot f_{\sum F} + C_{O\&M} \cdot f_a \cdot f_{\sum O\&M}$$

Each of the terms of the LCOE formula has the following meanings:

- **INV**: Refers to the total investment that it is made in the plant before it reaches the beginning of its operation. This investment of a plant can be expressed in the following units: total currency utilized (for example €), or it can be expressed as currency/power (€/kW), or it can be expressed directly as currency/energy (€/MWh). Whichever is the case, it is important that the given investment is normalized dividing it by the total amount of energy produced in the plant in a year. For example, in the most simplistic case in which the investment is expressed in the local currency (€), the developer of the renewable plant must normalize the investment by the total amount of energy produced in a year, hence dividing the investment by the hours of operation and the power of the plant. This leads to €/MWh.
- **C_F**: Refers to the cost of the fuel utilized to generate the electricity. For example, this fuel can be carbon, gas, biomass or whichever fuel is utilized to produce the electrical energy. This cost is typically already expressed in €/MWh.
- **$C_{O\&M}$**: Refers to the operation and maintenance (O&M) cost of the generation facility. As with the cost of the fuel, it is typically expressed in €/MWh.

- **f_a:** This term is known in the industry as amortization factor or CRF (Capital Recovery Factor). The reason why it is multiplying to the INV in the formula is because, although the investment is made at the beginning of the project, it must be returned throughout the life of the project so that at the end of it the investment has been restored together with the accrued interests. When the investment is multiplied to the factor, the result is the normalized investment cost. Additionally, this factor is utilized in order to annually distribute the actual value of a cost at a certain discount rate as with the fuel or the O&M costs. The amortization factor is calculated through the following formula, in which “i” corresponds to the discount rate (typically the weighted average cost of capital, WACC), and “N” corresponds to the amount of years of operating life of the plant:

$$f_a = \frac{i \cdot (1+i)^N}{(1+i)^N - 1}$$

- **f_Σ:** This term is known in the industry as accumulation factor. Those costs that are annual, such as the fuel or O&M, are planned for the first year of operation of the plant. To know the future value of those costs, these are projected at the nominal rate (r) of cheapening or increase in price of the costs. However, once known the future value of the costs, this must be valued as of today in order to know what amount of money should be deposit in a fund at an interest “i” to face the payment in the future years. What the accumulation factor does is to cumulate, during the whole life of the project, the future annual value of the initial cost and discount it to the current time. Hence, the accumulation factor includes in this order three different and consecutive effects: (i) Projects the cost in the future at a nominal rate (r), (ii) Discounts them to reach to the present value of those future costs at a discount rate (i) equal to the weighted average cost of capital (WACC), and (iii) adds up all those values. The accumulation factor can be calculated with the following formula:

$$f_\Sigma = \frac{k \cdot (1-k^N)}{1-k}$$

In which k is calculated through the nominal (r) and discount (i) rates:

$$k = \frac{1+r}{1+i}$$

Although the LCOE formula has been described for a general technology, it is important to highlight that for the case of this thesis in which a wind farm is being studied, the cost of the fuel is cero as it refers to the wind (free).

As for the purpose of this thesis the onshore wind technology of the project has already been decided. It is interesting hence to compare how the LCOE's of the chosen technology is compared to the rest of possible technologies. Every year, the well-known investment boutique Lazard performs an analysis of the LCOE of the predominant generation technologies which is helpful not only to compare them against each other but also to see the evolution of the levelised cost of a certain technology across the years. The latest published report has the title *Lazard's Levelised Cost of Energy Analysis – Version 16.0* and was published in April of 2023.

According to Lazard's analysis, onshore wind technology's LCOE is currently in a range between $24-75 per MWh. This figure is the lowest according to Lazard's 2023 report comparing it to other technologies. From the renewable energy classification, the least costly technologies are onshore wind and solar PV at utility scale ($24-96 per MWh). On the other hand, solar PV for rooftop residential ($117-282 per MWh), solar PV community & C&I ($49-185 per MWh), and offshore wind ($72-140 per MWh) are the most costly renewables. These renewable sources prove to be cheaper than conventional technologies which are highly dependant on gas and fuel prices as can be seen in the following graph from Lazard's report:

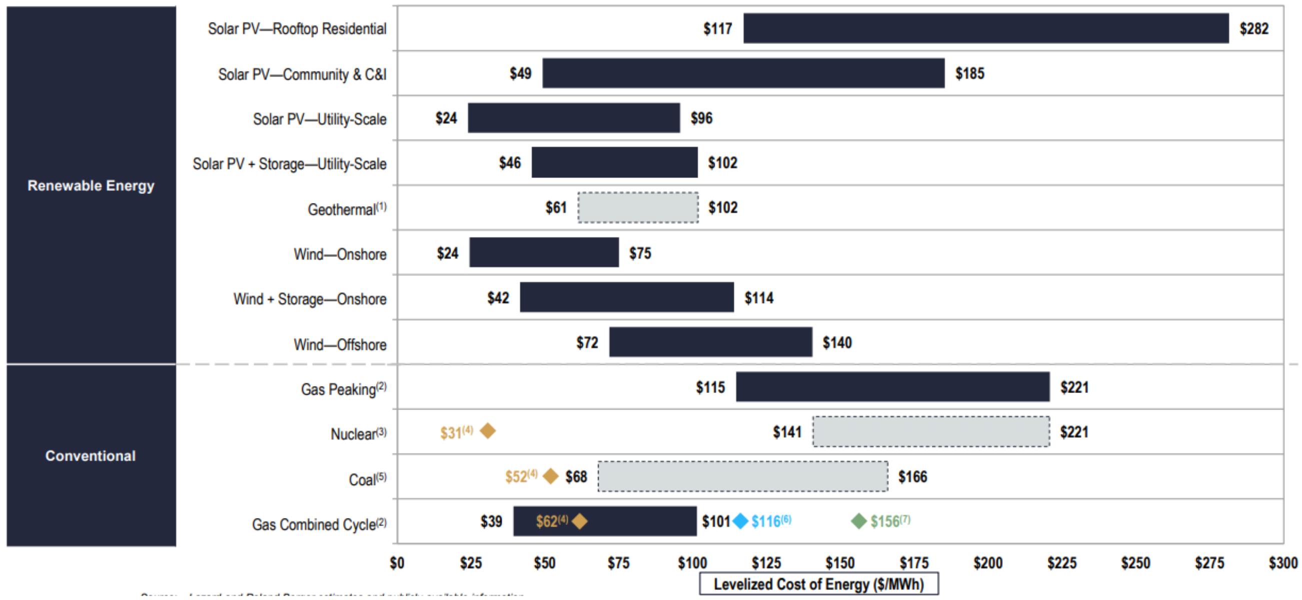


Figure 43: 2023's LCOE across technologies comparison

It is also interesting to analyse how the LCOE of the different technologies has evolved across the last 15 years. As it can be observed on the following graphs of the same report, onshore wind's LCOE has continuously been decreasing in the last decades from the $135/MWh of 2009 to the current $50/MWh. It is in fact interesting to see that this figure was even lower in 2022 ($38/MWh). The slight increase is the figure is attributed to inflation and supply chain challenges faced from 2022 to 2023:

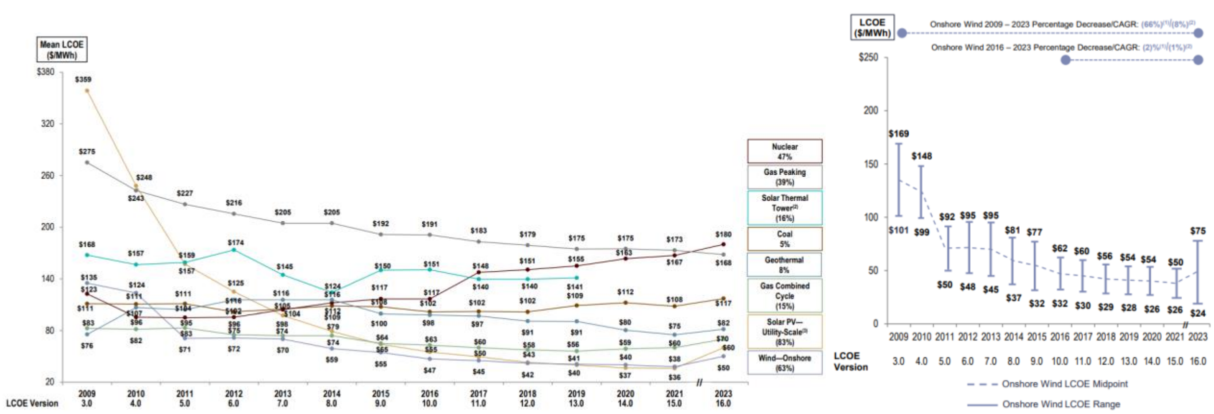


Figure 44: LCOE evolution across technologies (2009-2023)

Finally, it is important to highlight that the high increase in deployment of the onshore wind and solar PV technologies that has been explained in previous chapters can be attributed to the low

LCOE compared to the rest of renewable and conventional technologies. Having said that, the effect should also be seen in the other way around, the increasing deployment of these technologies is what also drives the decreasing trend of their LCOE.

4.3.2 Operating Expenses

The previous chapter detailed on the capital expenditure (Capex) costs which are those mostly incurred during the development (Devex) and construction process. These costs, as its name indicates, are costs that are capitalized during the operating life of the plant as they are invested in a long-term basis (longer than a year). They do not appear in the income statement (P&L) as they are costs that must not be expensed for a certain concrete year. Although most of the project's capex is incurred in the development and construction phases, there is also part which is recurrent and hence capitalized during the remaining operating life.

In this chapter, however, the focus is put on the operating expenses, also known in the industry as Opex. The operating expenses are those that are incurred in a short-term basis, shorter than a year. This kind of costs, differently from the Capex, have the main characteristic of being recurrent, ordinary and appear in the income statement as they are tax-deductible in the year they are incurred. In a normal company, these costs typically involve rent, salaries, utilities, and other regular costs.

As a wind farm is not a regular company, its Opex involves several costs that are specific for a renewable plant. The most common ones are:

- **Operation & Maintenance**: Also known in the industry as O&M cost. As its name indicates, these are the costs related to the operation and management of the wind farm:
    - Operation: Refers to the costs that are incurred in order to sophistically monitor and remotely control every technical and operational aspect of the wind farm such as hours of operation, wind speed, wind direction, energy produced, turbine performance, environmental conditions or any incident that may occur during the daily functioning of the farm.

- <u>Maintenance</u>: Involves every aspect related to maintaining the wind turbines in optimal operational shape. It is key to understand that this cost does not only involve repairing a part of a turbine that is not optimally operating, but also to utilize preventive and predictive analysis to avoid serious damages or lack of production due to its potential inoperability. The maintenance of a wind turbine typically involves: (i) Cleaning, (ii) Ordinary inspections, (iii) Repairs, and (iv) Lubrication. This cost is of high importance given that the right maintenance of the turbines guarantees that these can operate at full capacity during the whole operating life of the plant.

- **Land lease**: As explained in the previous chapter, although there are other kinds of land securements, this is the most common one in the industry. This cost involves paying a rental (lease) fee to the landowner of the land in which the wind turbines are located. The paid quantity can be on a monthly, quarterly or yearly basis and typically it depends directly to the rented surface, the land availability, its location and the regulations.
- **Insurance**: This cost involves all the payments that are made to insurance companies to protect the wind farm from the different types of risks to which the plant is exposed. In case that any of the covered risks is materialized, the insurance company pays for them according to the insurance contracted conditions. In regards to the different types of insurances that a wind farm can have it is important to highlight the following: (i) Property insurance (covers physical damage of the wind turbines, transmission lines, and any other infrastructure that could be damage by environmental conditions, fire or vandalism), (ii) Business insurance (covers for lost of revenue in case of interruptions of ordinary activity due to equipment breakdown or natural disasters), (iii) Liability insurance (covers for any type of extraordinary liability incurred by the wind farm such as accidents during construction or maintenance, legal fees, pollution incidents, etc). Although there are specific insurance companies that cover all these individual kinds of costs, it is an standard in the industry to cover from all these risks utilizing a common insurance. As it is clear, the cost of the insurance increases with the risk at which the farm is subject. The higher the risk, the higher the insurance costs that the wind farm has to pay to be covered. Some of

the main topics that determine the risk of a wind farm are: turbines age, environmental conditions of the plant's area or status of the land.

- **Selling, General & Administrative**: Known in the industry as the SG&A cost, this category typically involves:
    - Labor: This includes all the costs related to the staff that work in or for the wind farm such as salaries, benefits, training or performance bonuses. The staff of a wind farm includes engineers, asset managers, technicians, supervisors and any other administrative or technical staff involved in the project.
    - Administrative: These costs pay for all the activities that take place in the back office to ensure the correct management and operation of the wind farm. These costs include a wide variety of accounting, legal, audit, regulatory, human resources, overhead and marketing topics.
- **Grid access costs:** As explained in previous sections, there are two figures that ensure the well-functioning of the market and the system. These are the TSO (REE) that acts as system operator and OMIE which acts as market operator. As both institutions must be retributed for their services, there exist the figure of grid access cost which consist of certain fees that all the generator facilities must pay in order to be able to access the grid to inject the energy they produce and later sell it in the wholesale market. The OMIE's retribution must be paid by all renewable generators that have an installed capacity higher than 1 MW and it is a monthly fee expressed in €/MW. In the case of REE, 50% of its retribution must be paid by generators and the other 50% is paid by commercialization companies and direct consumers.
- **Other costs:** This category includes all the costs related to the wind renewable plant that are not present in every facility but which could ordinary appear in a wind farm. These costs include environmental impact assessments, decommissioning preparations, technology research and development, community engagement initiatives, emergency preparedness, transmission infrastructure improvements, landscape mitigation efforts, data management systems, and external consultancy services.

- **Taxes:** In Spain, a wind farm is subject to the following taxes that must be paid as part of the operating expenses:
    - IBI: In Spanish known as the *Impuesto sobre Bienes Inmuebles*. It is paid yearly and for the whole renewable plant. It is applied over the cadastral value of the property and determined by tax authorities (*Hacienda*). According to industry experts, for a standard renewable wind farm of 50 MW the IBI is yearly around €40k and €130k (c. €1.7k per MW). Recently, the IBI that wind farms pay has been restructured to the following name: IBICE (*Impuesto sobre Bienes Inmuebles de Características Especiales*).
    - IAE**:** In Spanish known as the *Impuesto sobre Actividades Económicas*. According to Spanish tax authorities, IAE applies taxes over the economic, professional and artistic activities in the national territory. A wind farm is subject to the IAE as it develops an economic activity grouped inside the industrial category. As with the IBI, IAE is a periodic tax that in the case of a wind farm it coincides with the natural year.
    - Environmental tax: In some autonomous communities such as Galicia, Castilla la Mancha or Castilla y León, there exist and special tax called in Spanish: *Canon eólico*. The aim of this tax is to avoid or reduce the visual and environmental impact caused as consequence of the deployment of wind turbines across the places where this tax applies.
    - Generation tax: In Spanish known as the IVPEE: *Impuesto sobre Valor de la Producción de Energía Eléctrica*. It consists of an environmental fee that taxes the production and supply of electrical energy in Spain. The applicable tax rate is of 7% across the total revenues originated by the wind farm in the production activity of electrical energy. Due to the consequences of the pandemic and the increase in following increase of the energy prices, the Spanish government suspended the application of this tax in 2021. However, in the Royal Decree 8/2023 of December 2023, this tax was restored once again.

CHAPTER 5. CASE STUDY

The objective of this chapter is to illustrate with a simulated case study how a real investment in a wind farm would be for an investment firm or wind farm developer. Basically, this chapter aims to simulate an entrepreneurship process in a wind farm taking the following steps:

1. Wind resource assessment process to determine where the wind farm to be developed will be located and which are the wind conditions that determine its operational capability.
2. Research and make decisions on the operational hypothesis that must be assumed to assess the potential of the wind farm.
3. Undertake a financial analysis to decide on the financial assumptions that can be plugged into a financial model and which will assist the investor to decide on the potential investment according to its return.

5.1 Wind Resource Assessment

The first part of the analysis corresponds to deciding where the wind farm would be located. As it is clear, this directly depends on the availability of the wind resource in the potential location to be examined. The higher the wind availability (with the previously described wind speed limits) the higher the potential of the farm of being worth investing.

Hence, the first step is deciding on a tool that permits the investment firm to access real historical data of the wind conditions of several locations in Spain. The utilized tool is called *Hourly/Sub-Hourly Observational Data* from the *National Centers for Environmental Information* (NCEI, department of the National Oceanic and Atmospheric Administration NOAA) of the United States. This tool possesses the data from several atmospheric stations spread across the whole country as can be seen in the following figure:

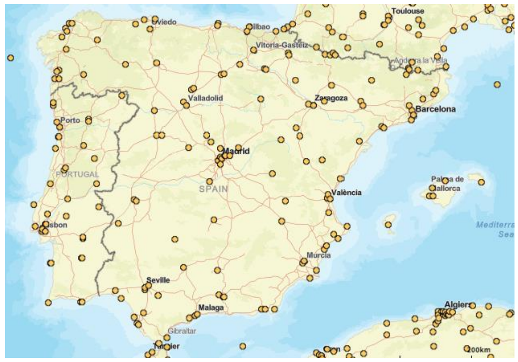


Figure 45: Spanish data locations of the NCEI

Although the wind analysis research was performed on several different locations in order to decide on the place that presented the best wind conditions, the following location was decided as optimal: Burgos, a province in the Castilla y León autonomous community. The reasons for this decision was: (i) As explained in the introduction chapter, Castilla y León is the region of Spain with the highest installed capacity of wind technology, and concretely Burgos is one of the provinces with greatest presence of it meaning that, if other investors have decided on it in the past, it is likely to be a worth location, (ii) The decided location must have enough historical wind data so that the one utilized is up to date and it is significant, (iii) Once analysed, the data must be valid, meaning that it must cover practically all the hours of every day, of every month of at least the past five years.

The selected location, Burgos, holds the wind information since the 1st of January of 1973 to the current date, and its atmospheric station (ID 08075099999) is located away from the city (next to Aeropuerto de Villafría) to avoid perturbance of the wind data. Once the data is downloaded in .csv, several corrections must be performed in order to transform it into an excel (.xlsx) document in which the wind analysis can be done: (i) Separate the information into columns, (ii) Avoid data repetition filtering to have just the FM-12 (report of surface observation form a fixed land station) data type, (iii) Separate the hour, day, month and year in different columns, (iv) And only select the data needed for the wind analysis. In this way, the document *Federal Climate Complex Data Documentation for Integrated Surface Data (ISD)* from the NCEI has been utilized as guidance.

At the end of this data selection process, the wind analysis is to be performed with the following information:

- **Time:** Exact time at which the wind data has been measured, including the day, month, year and exact hour. For significance purposes in the wind analysis, the selected information covers from the 1st of January 2017 to the 31st of December 2023.
- **Wind Angle:** According to ISD, it corresponds to the angle, measured in a clockwise direction, between true north and the direction from which the wind is blowing. It has a minimum of 001 and a maximum of 360 and the unit is angular degrees.
- **Angle Quality:** According to ISD, it reflects a code that denotes a quality status of a reported wind observation direction angles. If it is a 1, it denotes that the figure has passed all quality control checks. If different from 1, the wind angle figure should not be considered as valid.
- **Wind Speed:** According to ISD, it corresponds to the rate of horizontal travel of air past a fixed point. It has a minimum of 000 and a maximum of 900, being the unit meters per second (m/s) with an scaling factor of 10, hence dm/s.
- **Wind Speed Quality:** According to ISD, as with the angle quality figure, this one reflects a code that denotes a quality status of a reported wind speed rate. Similarly to the angle quality, if it is a 1 it means that the measured wind speed has passed all quality control checks. If is different to 1 the associated wind speed figure should not be considered in the analysis.

To illustrate this, the following figure shows some of the rows of the filtered data (60,109 rows in total):

DAY	MONTH	YEAR	HOUR	WIND ANGLE	ANGLE QUALITY	WIND SPEED (m/s x10)	WIND SPEED QUALITY	WIND SPEED (m/s)
8	1	2017	7	80	1	21	1	2.1
8	1	2017	8	40	1	57	1	5.7
8	1	2017	9	30	1	62	1	6.2
8	1	2017	10	50	1	72	1	7.2
8	1	2017	11	50	1	77	1	7.7
8	1	2017	12	50	1	77	1	7.7
8	1	2017	13	50	1	87	1	8.7
8	1	2017	14	60	1	77	1	7.7

Figure 46: Filtered wind data illustration

The first step in the wind resource analysis is to check the validity of the information to be analysed in order to assess if it is sufficiently significant to extract from it relevant conclusions for the entrepreneurship decision. The following table summarizes the data validation analysis:

Year	Possible Data	Valid Data	%Valid	%Non-Valid
2017	8,760	8,722	**99.57%**	0.43%
2018	8,760	8,660	**98.86%**	1.14%
2019	8,760	8,732	**99.68%**	0.32%
2020	8,760	8,632	**98.54%**	1.46%
2021	8,760	8,521	**97.27%**	2.73%
2022	8,760	8,500	**97.03%**	2.97%
2023	8,760	8,297	**94.71%**	5.29%

Table 9: Data validation analysis

As it can be seen in the table, from the seven years (2017-2023) analysed, all of them show a percentage of valid data above 97% which leads to the conclusion that the data is significant and reliable enough for the wind resource analysis. The percentage of validity is calculated dividing the valid data (all the hours of the year which show to have angle and wind speed data with the correct quality standards) by the total amount of hours of the year (possible data). Although all the years would be reliable for the analysis, the most valid data percentage is found in the year 2019, in which only 0.32% of the hours of the year do not show significant measurements for the analysis.

Once the data is confirmed as valid, it is the moment to perform a deep analysis on it. As can be imagined, the first step is to perform a brief analysis of the average wind speed in the year and its standard deviation:

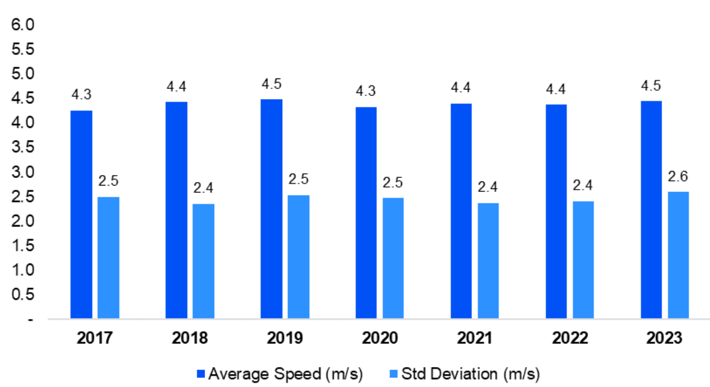


Figure 47: Wind data analysis by years

As it can be seen, at the height at which the wind speed has been measured (which does not correspond to the height at which the wind turbine hub would be located as it will be adjusted below), the average speeds and standard deviations of the wind are quite regular around 4.4 m/s and 2.5 m/s respectively. It must be clear that these figures have been calculated only considering the valid data. To have a deeper understanding of the wind resource, a monthly analysis has also been performed:

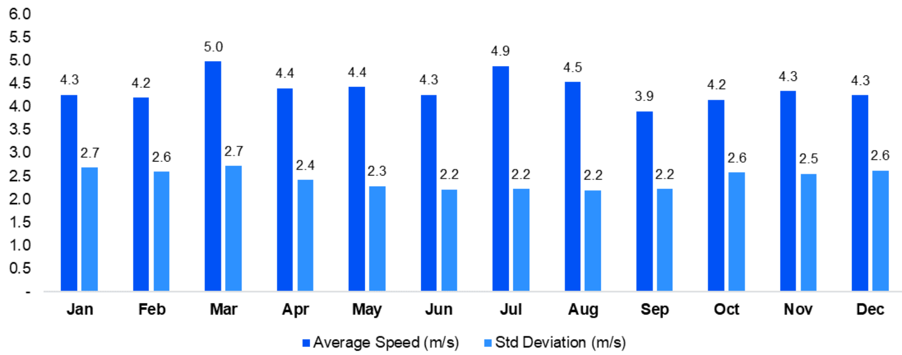


Figure 48: Wind data analysis by months

In a monthly basis, it can be seen that there are fluctuations in the average wind speed depending on the part of the year examined. Concretely, March and July show to have an average wind speed above the rest of months reaching 5 m/s, while September show to have an average speed lower than usual by nearly reaching 4 m/s. Standard deviations show lower fluctuations than average speeds. In terms of month analysis, it is also interesting to see the difference between the day (7am – 8pm) and night (9pm – 6am) average wind speeds to understand the behaviour of energy production of the wind farm. For this reason, the following analysis has been performed:

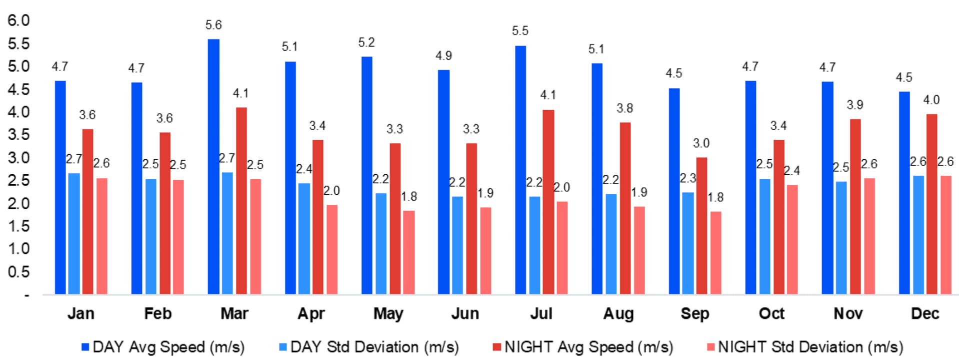


Figure 49: Wind data analysis by months (day vs night)

It is interesting to see for a wind farm developer that according to the wind conditions showed in the figure above, the wind farm would be able to produce a higher amount of electricity during the day than during the night. While during the day the average wind speeds are around 5.1 m/s, during the night these wind speeds decrease on average to 3.9 m/s.

In terms of wind direction, the easier and more visual way to analyse the wind angle direction is through what is called as compass rose, also known as wind rose or rose of the winds:

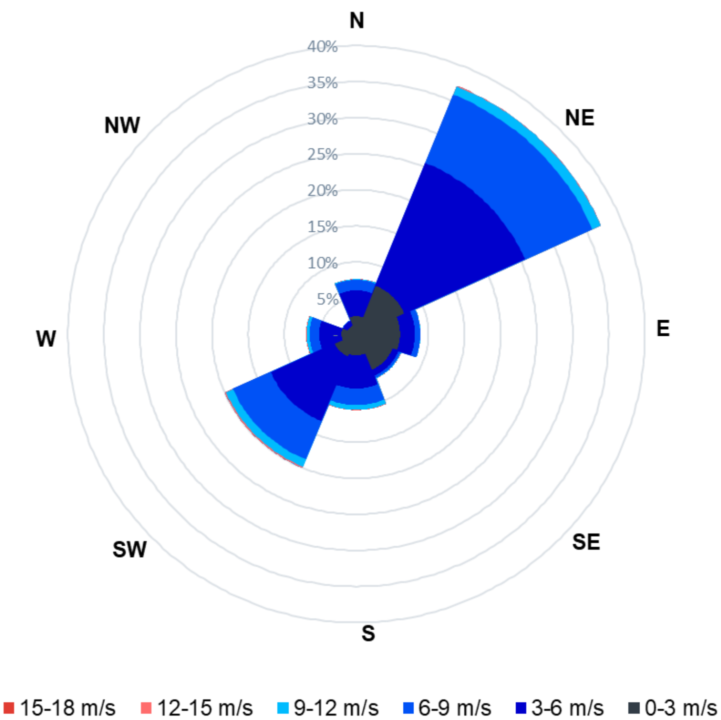


Figure 50: Compass rose

The figure aims to describe, on average, what is the probability for the wind to face a concrete cardinal direction or another, considering as well in the analysis the wind speeds. In order to avoid confusion on how this figure should be interpreted, the following guidance is provided:

- It exists a 37% probability for the wind to blow from the North-East (NE) direction, 15% from the South-West (SW) direction and so on.
- On one hand, in terms of the wind speeds that are around 0-3 m/s, there is a high variability from where these winds are blowing. On the other hand, wind speeds around 3-6 m/s show

a more likely component from the NE and SW directions. In addition, as it can be seen in the compass' area colour, wind speeds between 3-6 m/s are more likely than wind speeds between 0-3 m/s.

- Wind speeds between 6-9 m/s are less common than the speeds between 3-6 m/s (light blue surface is lower than dark blue surface), but when the wind speed is between that range, it is more likely to come from the NE direction as the share (c. 10%) of light blue in that direction is wider than for example the second one which is the SW direction (c. 7%).

Once the deep analysis of the wind resource in the decided location of Burgos is performed, it is the time to determine what wind conditions would be found at the wind turbine's hub in order to decide whether the wind conditions are suitable for a farm to be a reliable investment in the selected location. As it can be imagined, the wind speed measured at a low height above the ground is not the same as the wind speed that can be found at heights such as the one in a wind turbine hub. The wind speed increases logarithmically with the height above the ground following a profile such as the one described by the following formula:

$$v_2 = v_1 \; x \; \frac{\ln \frac{h_2}{z_0}}{\ln \frac{h_1}{z_0}}$$

On the formula, v1 and v2 correspond to the wind speed at the reference and desired heights respectively, and h1 and h2 correspond to the heights at the reference and desired points. The component z0 corresponds to the surface roughness length which, according to the *European Wind Atlas* and as stated in the book *Understanding Wind Power Technology (Alois Schaffarczyk)*, can have the following values:

Roughness class	Roughness length	Type of landscape
0	0.0002 m	Water surfaces
0.5	0.0024 m	Open terrain with smooth surface, e.g. concrete, landing strips at airports, mown lawn
1	0.03 m	Open agricultural land without fences and hedgerows, possibly with well spaced houses well apart, very gentle hills
1.5	0.055 m	Agricultural land with some houses and 8 m high hedges with spacing of approximately 1250 m
2	0.1 m	Agricultural land with some houses and 8 m high hedges with spacing of approximately 500 m
2.5	0.2 m	Agricultural land with many houses, bushes, plants or 8 m high hedges with spacing of approximately 250 m
3	0.4 m	Villages, small towns, agricultural land with many or high hedges, woods and very rough and uneven terrain
3.5	0.8 m	Large towns with high buildings
4	1.6 m	Large towns with high buildings, skyscrapers

Table 10: Roughness length according to European Wind Atlas

Before adjusting the previously described wind analysis to the expected height of the turbine's hub, it is interesting to understand the effect that height has on a given speed. In order to do so, the following experiment is undertaken with the average wind speed of, for example, year 2019 (4.48 m/s). With that speed as the constant v1, and with h1 as constant reference height at which it is assumed that the wind speed has been measured at Burgos' wind station, and assuming as z0 an average between 0.03 m (open agricultural land) and 0.0024 m (open terrain with smooth surface), the h2 is varied between 0 and 300 m in order to see the changes in the wind speed profile:

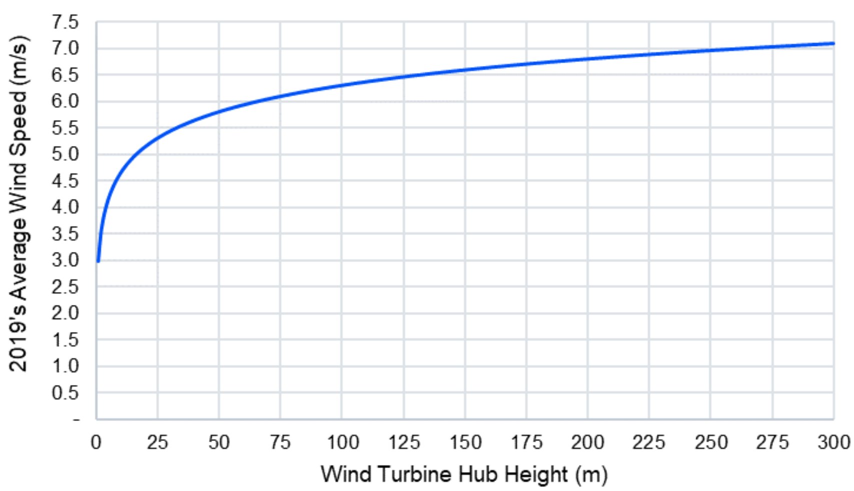


Figure 51: Wind speed profile with varying height

As expected, the wind speed results in logarithmic profile with the variation of height. From the 4.48 m/s from the reference height at 8 m, the wind speed passes to 6.59 m/s and 7.10 m/s at wind turbine's hubs of 150 m and 300 m respectively.

In order to adjust the measured wind speeds by the atmospheric stations from the reference height of 8 m to the desired wind turbine hub height of 150 m, the previous formula is applied with the same z0 as the wind speed profile. Hence, as the wind speed is higher at that height, the wind analysis previously described is repeated with the following results:

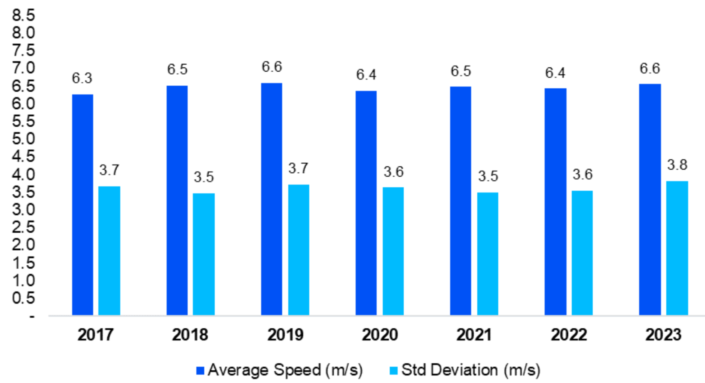


Figure 52: Adjusted wind data analysis by years

In this way, it can be seen that the average wind speed has increased from the initial 4.5 m/s at the reference height to 6.5 m at the wind turbine's height. In terms of the monthly analysis, directly showing the distinction between day and night periods, the following results are obtained:

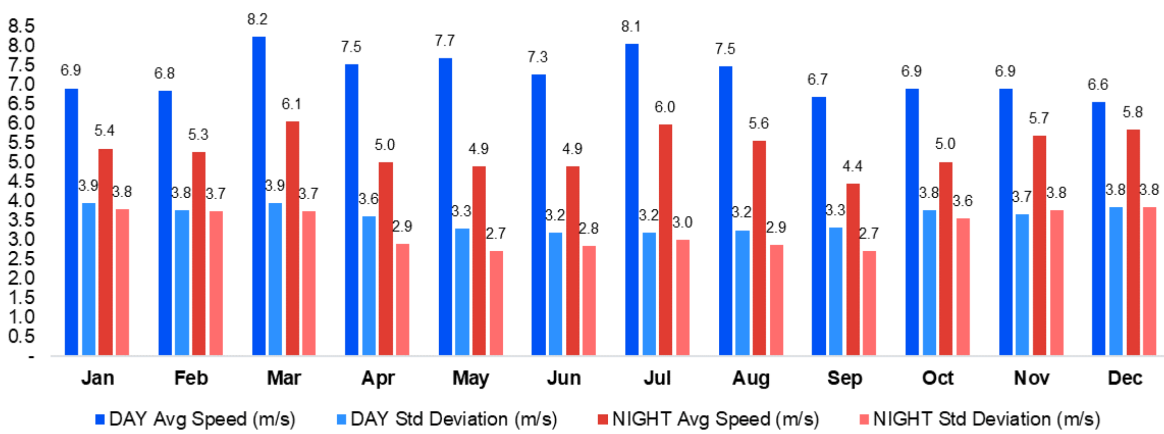


Figure 53: Adjusted wind data analysis by months (day vs night)

As it can be seen in the previous figure, the results at the hub's height are in comparison very similar to the ones extracted from the reference station height. The wind farm is hence able to produce more electrical energy during the day, although it seems to have enough wind resource available to keep producing during the nights.

Once the wind data has been adjusted to the wind turbine's hub, it is the time to estimate the energy that a turbine would be able to extract from this wind resource in a given year in order to ensure that it is enough for the renewable plant to be productive. In this way, as energy is the multiplication of power and time, and taking into account that power of a wind turbine varies with the wind speed as explained in previous chapters, the first step is to get to know how much time in a year there is a certain wind speed or another. In this way, ordering the adjusted wind speed data, the following frequency distribution is obtained:

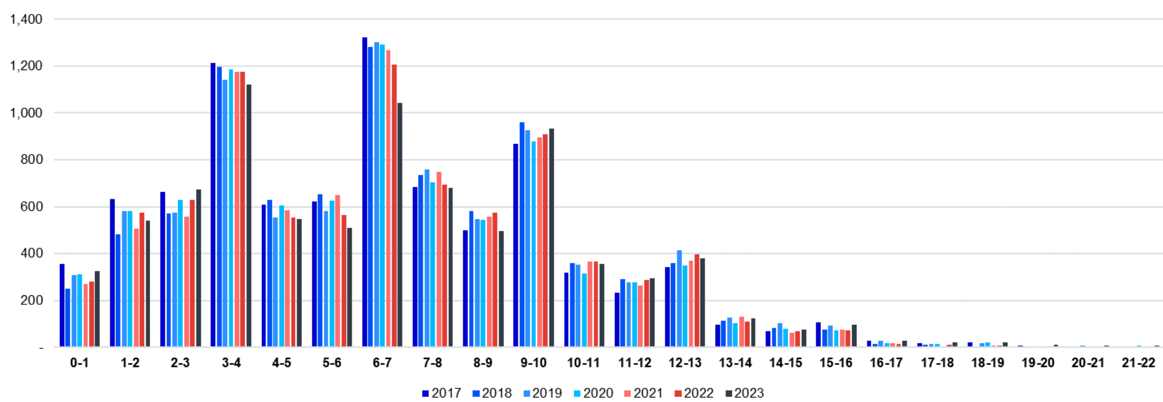


Figure 54: Adjusted wind data frequency distribution

On the previous figure, the vertical axis shows the amount of hours in a year in which the wind speed is between a certain range specified in the horizontal axis. The results are consistent through the years and there is a clear trend in which the most recurrent wind speed ranges are 3-4 m/s, 6-7 m/s, and 9-10 m/s. The next step is to develop a statistical model with this data so that it can be utilized to determine the probability of having a certain wind speed or another at a random point in time in a year. This statistical model is hence needed to determine the energy that can be extracted from the wind farm. In order to develop the mentioned statistical model, the data of a single year must be utilized. With the purpose of ensuring the higher validity possible of data, the year 2019 has been selected as the one which wind speed frequency will be utilized to develop the statistical model:

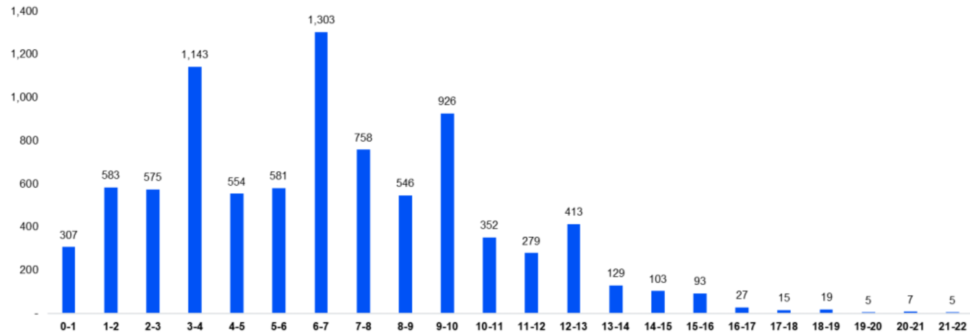


Figure 55: Adjusted wind data frequency (2019)

Hence, the next step is to build with 2019's data the mentioned statistical model. In the industry, it is a standard to utilize Weibull's distribution as the statistical way to model the frequency at which the different wind speeds take place at a certain examined location, in this case Burgos. Weibull's distribution is a continuous probability model which follows the following structure on its probability density function (PDF):

$$f(x) = \left(\frac{k}{C}\right) \cdot (\frac{x}{C})^{k-1} \cdot e^{-(\frac{x}{C})^k}$$

On the PDF, it is assumed that x, k and C are all above 0. The cumulative distribution function (CDF) is expressed in the following form (x>0, k>0, C>0):

$$F(x) = 1 - e^{-(\frac{x}{C})^k}$$

As it can be imagined, in the Weibull function x corresponds to the wind speed, which is the variable term of the statistical function. Terms k and C correspond to the shape and scale parameters respectively of Weibull's function. These constants must be calculated from the wind selected data as from them Weibull's function will be able to be plotted and hence the probability of having a certain wind speed in Burgos location at a certain point in time to calculate the energy potential of the farm. In order to calculate Weibull parameters, the CDF is reorganized in the following way utilizing the logarithm properties:

$$e^{-(\frac{x}{C})^k} = 1 - F(x)$$

$$-(\frac{x}{C})^k = \ln(1 - F(x))$$

$$k \cdot (\ln(x) - \ln(C)) = \ln(-\ln(1 - F(x)))$$

As *x* and *F(x)* are known from Burgos' analysed data, this final term can be expressed as a linear equation in the following form:

$$y = \mathrm{k}x' + \mathrm{a}$$

In which:

$$y = \ln(-\ln(1 - F(x)))$$

$$x' = \ln(x)$$

$$a = -\mathrm{k} \cdot \ln(\mathrm{C})$$

As *y* and *x'* are known for all the data points, *k* and *a* can be estimated utilizing the least square method by calculating the slope and intercept of the regression line:

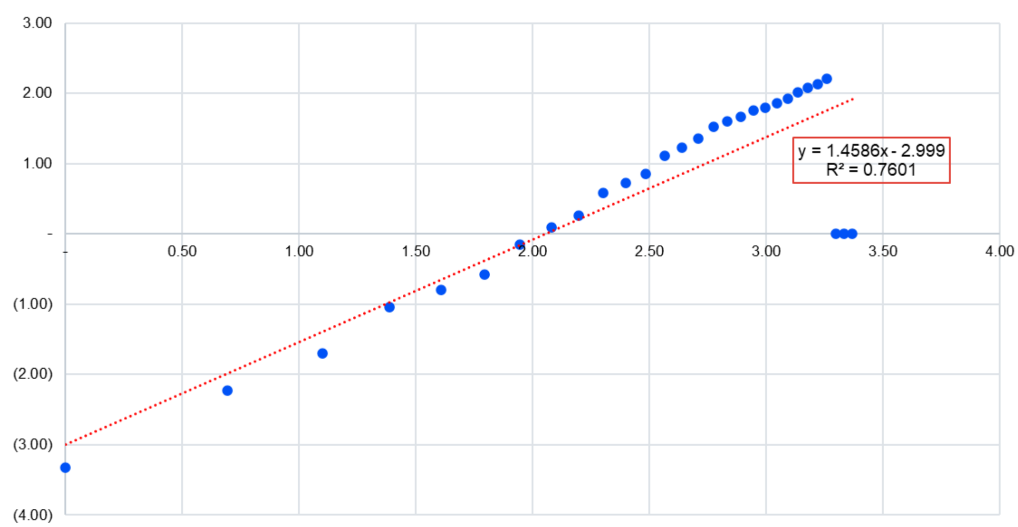


Figure 56: Least square method for Weibull's parameters

Once the regression line is plotted, the parameters k and C can be estimated. Parameter k directly comes from the estimated regression line and is equal to k = 1.4586. However, to calculate C the last formula is applied once parameters a and k are known (-2.9999 and 1.4586 respectively). In this way, C = 7.8153 and the Weibull distribution applicable to this case study's wind farm can be plotted:

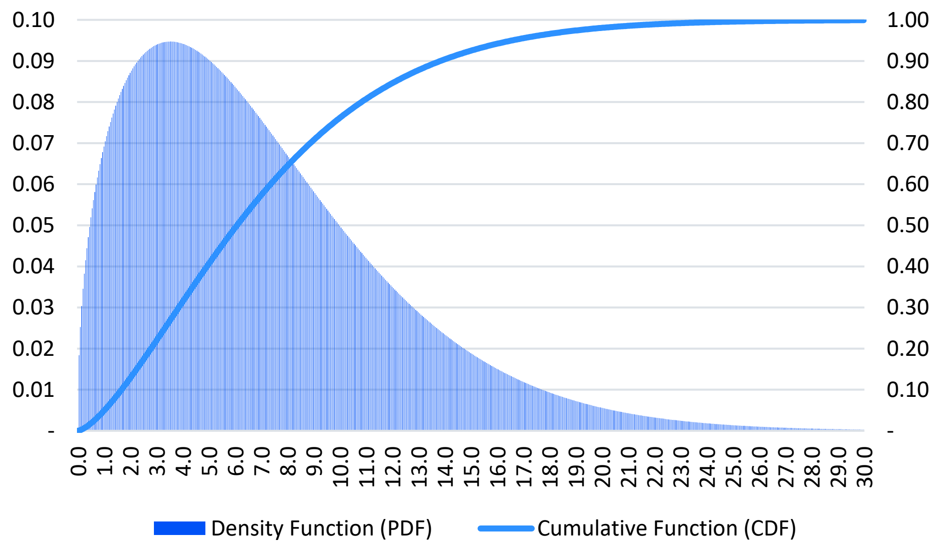


Figure 57: Wind farm's Weibull function

As expected, the most probable wind speed values in the density function are those that are around the adjusted average wind speed in the turbine's hub, that is the wind speeds around 5-6 m/s. As can be seen in the figure, the higher the wind speed the lower the probability of actually occurring. In terms of the cumulative function, the value increases with the wind speeds until it reaches the unit at c. 30 m/s.

Once the actual statistical model that describes the probability of the different wind speeds in the chosen location is ready, it is time to keep working on the assessment of the potential energy that can be produced by the wind turbine in such wind conditions. As explained above, energy is the multiplication of power and time, and currently with the statistical model it is possible to know how much time in a year there is a certain wind speed or another. Hence, the next step is to estimate the power that a wind turbine can produce at the wind speed range.

As explained in the deep dive in wind technology section, the power of a wind turbine varies with the wind speed. Every turbine has its own operational curve that describes the variation of power with the wind speed. For this case study, three different wind turbine types are going to be analysed so that finally the one that is able to produce the highest amount of electrical energy is going to be the one utilized in the wind farm. The three chosen turbines correspond to three of the main turbines brands with higher footprint in the market: Siemens-Gamesa (SG 2.1-114 model), Vestas (V150/40000-4200 model) and General Electric (GE 5.3-158 model). The nominal capacity of each of the turbines is 2.1 MW, 4.0 MW, and 5.3 MW respectively. Clearly, the performance of each of the models will be normalized in order to compare them in equal conditions. The wind turbine power curves are as follows:

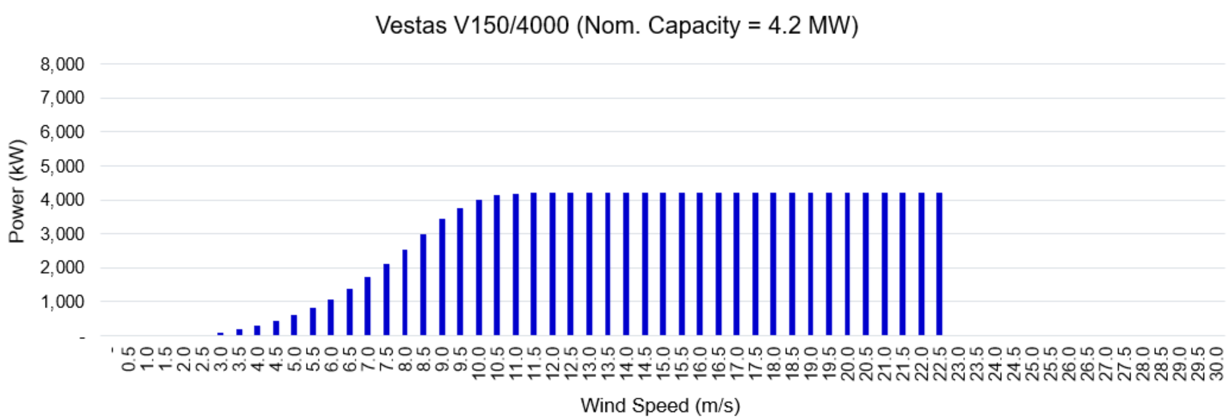


Figure 58: Vestas V150/4000 Wind-Power Curve

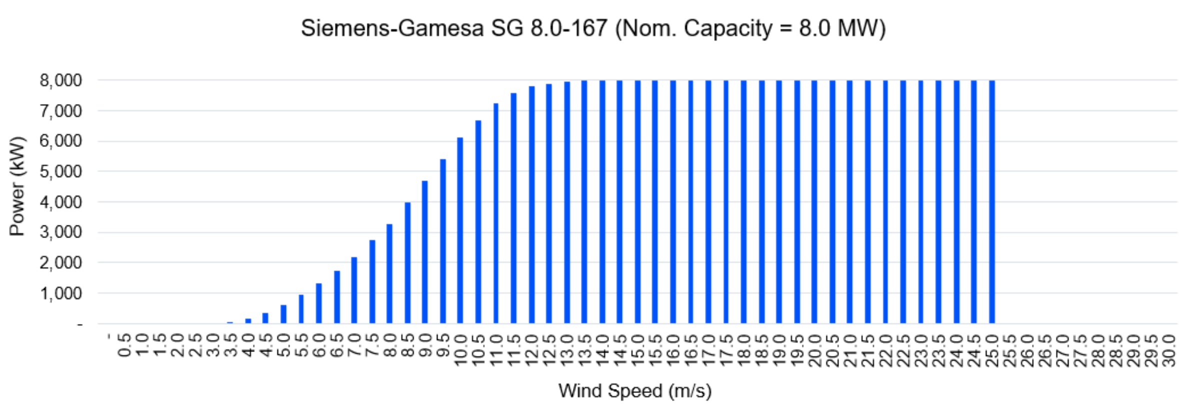


Figure 59: Siemens-Gamesa SG 2.1-114 WInd-Power Curve

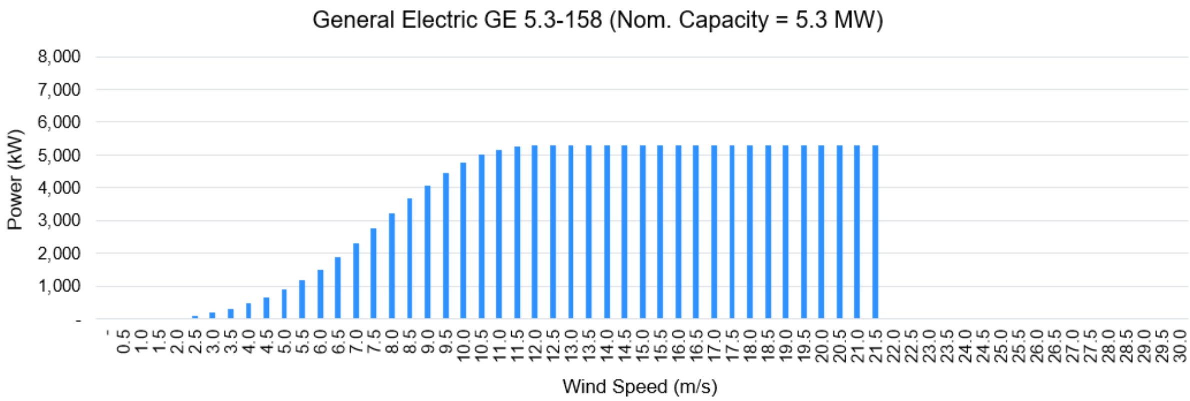


Figure 60: General Electric GE 5.3-158 Wind-Power Curve

Once the wind turbines' power production curves are known, it is the time to calculate the energy output that these turbines can produce in a year in order to decide for one of the models or another. For this calculation, the definition of energy is applied: time (Weibull's PDF) multiplied by power (wind turbine curve) for each of the different wind speeds in the analysed location and adding up the results of energy at the end. This is complicated as it is not only multiplying the rounded wind speeds (those that end up in .0 or .5 m/s), but also multiplying for every single possible wind speed considered. In a mathematical way, this is done with an integral function with the possible wind speed boundaries as the integral limits (0-30 m/s). If the integral of the multiplication of the wind turbine power curve (P(v)) and Weibull's function (f(v)) is performed between the 0-30 m/s speed limits, the average power in a year is obtained:

$$\bar{P} = \int_{v_{min}}^{v_{max}} P(v) \cdot f(v)\, dv = \int_{0}^{30} P(v) \cdot f(v)\, dv$$

If the average power in a year is multiplied by the total time in a year (8760 hours), the average energy output of a wind turbine in a year in the given location is obtained:

$$\bar{E} = \bar{P} \cdot t = \bar{P} \cdot 8760$$

Now, in order to normalize the wind turbine's results and avoid considering the fact that the different analysed turbines have different nominal capacities, the average energy of each wind turbine is normalized dividing it by the corresponding nominal capacity. With this, the equivalent hours of electrical energy production in a year of each wind turbine at its nominal capacity are obtained:

$$Equivalent\ Hours = \frac{\bar{E}}{Turbine\ Nominal\ Capacity}$$

In order to perform the first mathematical step, which is the integral, the wind turbine power curves must have a continuous form and not the current discrete shapes that turbine companies release in the operational characteristics of their products. This is the reason why, in order to transform the discrete power curves into a continuous shape, the MATLAB program is utilized. This tool is able to transform the discrete points of the wind turbine power curves into a polynomial proxy of a continuous power curve which is later plugged into the integral. The polynomial proxy curves, together with Weibull's statistical time function, obtained through MATLAB and which have a degree of 9, are as follows:

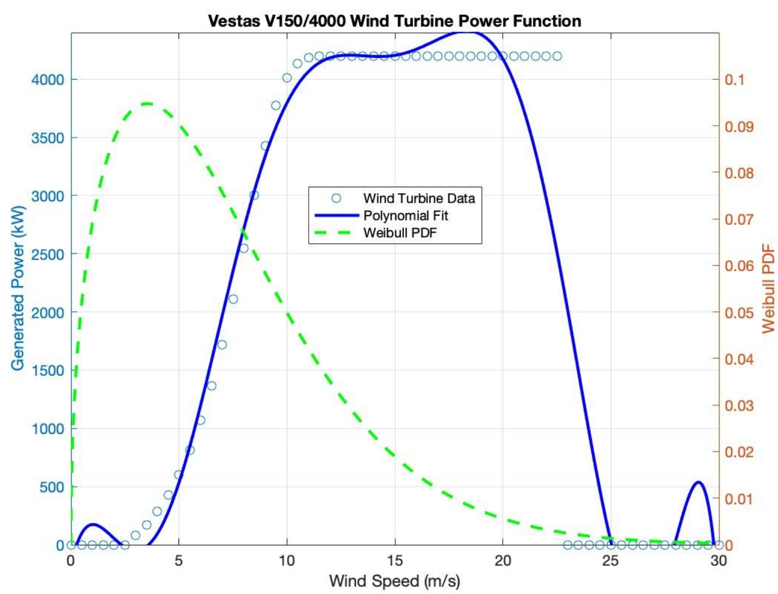


Figure 61: Polynomial proxy to Vestas V150/4000 Wind-Power Curve (MATLAB)

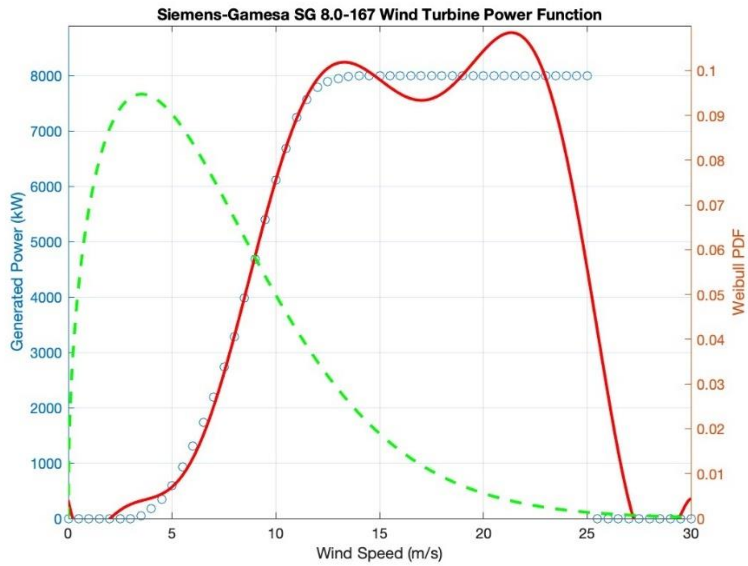


Figure 62: Polynomial proxy to Siemens-Gamesa SG 8.0-167 Wind-Power Curve (MATLAB)

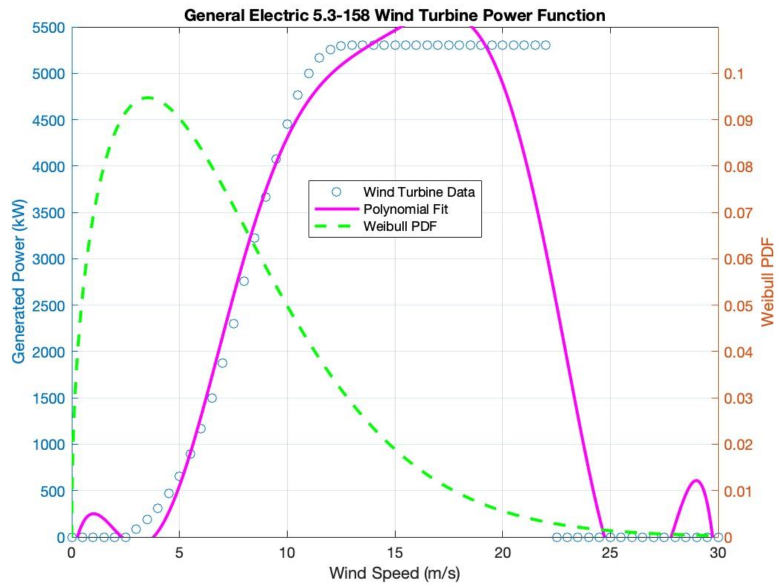


Figure 63: Polynomial proxy to General Electric 5.3-158 Wind-Power Curve (MATLAB)

Now, combining the three curves in a single graph:

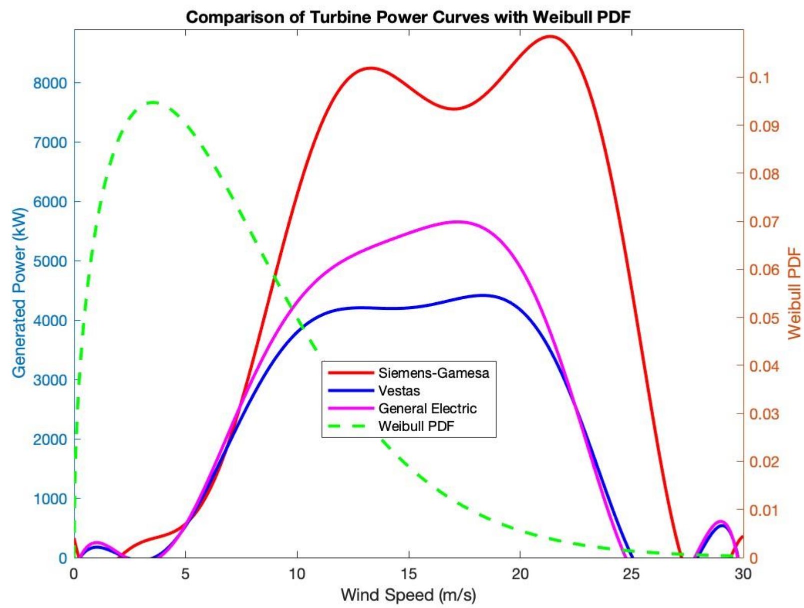


Figure 64: Comparison of polynomial proxies Wind-Power Curves

Once the polynomial proxies of the wind turbine power curves are known, it is the time to perform the mathematical analysis in order to decide which wind turbine to use. For this purpose, a code in the MATLAB tool has been developed that can be found in the appendix A, and which allows to perform the average yearly power calculation needed to calculate the average yearly energy and the equivalent hours for each turbine model. The following table summarizes the obtained results:

Turbine Brand	*Unit*	**Siemens-Gamesa**	**Vestas**	**General Electric**
Model	*Name*	SG 8.0-167	V150/4000	5.3-158
Nominal Capacity	***MW***	**8.0**	**4.2**	**5.3**
Energy Produced (1h)	*kWh*	2,782	1,744	2,030
(x) Yearly hours	*h*	*8,760*	*8,760*	*8,760*
Energy Produced (1y)	*MWh*	24,369	15,276	1,778
Net Equivalent Hours	***h***	**3,046**	**3,637**	**3,354**

Table 11: Wind resource gross results for the different turbine models

However, as the yearly amount of hours producing energy at full capacity is the input that is going to be plugged into the financial model in order to calculate the potential revenues of the wind farm, it is important to understand that not all the electrical energy produced by the turbine is finally plugged into the electrical system as there are losses during this process. According to the wind platform *Efecto Estela*, these losses are:

- **Electrical losses:** Occur as electricity generated in each turbine passes through its transformer, wiring, and the park's substation before entering the distribution grid. These losses, typically 7%, vary based on transformer type, wiring, and distance.
- **Availability losses:** These losses happen when turbines are out of service for maintenance or grid requirements, accounting for around 5% of energy loss.
- **Hysteresis:** High-wind hysteresis causes turbines to stop for safety reasons when wind speeds exceed a certain threshold, typically around 22-23 m/s. This interruption, approximately 3% of energy loss, occurs until wind speeds decrease.
- **Blade contamination:** Exposure to dust, insects, or ice reduces aerodynamic efficiency, resulting in losses of approximately 2%.
- **Wind power curve performance:** Manufacturers' power curve warranties often present optimistic estimates compared to real-world performance. To adjust for this, analysts typically apply a 8% energy production penalty in their estimates.

Hence, in order to be conservative in the assumptions, 25% loss is applied to the equivalent hours of each turbine obtaining the following net equivalent hours:

Turbine Brand	*Unit*	**Siemens-Gamesa**	**Vestas**	**General Electric**
NEH (pre-losses)	*h*	3,046	3,637	3,354
(-) 25% Losses	*h*	*(762)*	*(909)*	*(839)*
NEH (post-losses)	***h***	**2,285**	**2,728**	**2,516**

Table 12: Wind resource net results for the different turbine models

In this way, after having performed all the wind resource calculations regarding the entrepreneur project of developing a wind farm, the chosen turbine brand is *Vestas*. Concretely, the chosen turbine model is the *V150/4000*. Although the main technical and operational characteristics of the wind turbine are included in the appendix B, the main feature is that it has a nominal capacity of

4.2 MW (per turbine) and, in the chosen location, each turbine is able to produce c. 2,700h of net energy (after all possible losses being considered).

5.2 Operational Assumptions

Once the investment firm or the wind farm developer has undertaken its deep study on the wind resource and has made the decision on where the wind farm will operate and with which wind turbines, it is the time to decide on which operational hypothesis can be assumed in order to later plug them in a financial model to assess the viability of the investment and the expected returns.

To do so, it is important that the developers undertake a deep research in order to ensure that the operational assumptions that are later plugged in the model are realistic and according to the industry standards.

The operational assumptions that have been researched and considered for this case study can be classified in two main groups and are the following:

- **Time Assumptions**: This type of assumption has the characteristic of being variable across the different years of operation of the wind farm. Hence, a different input must be set in the financial model for every year. The assumptions that have been researched and considered are:
    - CPI: Known as the Consumer Price Index, it reflects the inflation of the country in which the wind farm will be operating, in this case Spain. It is an important input to adjust future real figures into nominal figures, which are those in which inflation must be considered to reflect the actual market conditions in which the wind farm will be operating in the future. In the industry, the CPI is typically extracted from the projections that the IMF (International Monetary Fund) releases every April and November of every year. In this case study, the last available IMF inflation curve utilized in the model is from April 2024. The figures that are adjusted to inflation over time are: Pool Price, PPA price, GdO's price, land lease price, operational

expenditures prices (Opex), development expenditures (Devex) prices, and capital expenditure prices (Capex).

  - Pool price: As explained in previous chapters, the price at which electricity is sold in the Spanish pool varies for every single hour of the day reflecting the balance of offer and demand. In this sense, the pool price curve reflect the price of electricity in future years. For this case study, the latest available power curve corresponds to the energy consultant Afry from Q1 2024. Between the three available curves (low, central, high), the central one has been utilized. As these market reports are confidential, the utilized curve will not be publicly reflected in this case study.
  - Wind capture price coefficient: As reflected in previous chapters, this figure quantifies the volume-weighted average price that wind production assets can secure compared to the overall average electricity price over a specific timeframe. As with the pool price, the utilized curve is the central Afry Q1 2024 case.
  - Guarantees of Origin: The GdO's prices for the following years is also a varying input. For this case study, the prices from the energy researcher *FutureEnergy* have been considered.
  - Generation tax rate: It reflects the varying percentage of total revenues that the Spanish government imposes as generation tax. As the Spanish political context is very volatile, the most conservative scenario has been assumed in which the tax rate is 7% during the operational life of the plant.

- **General Assumptions**: This type of assumption has the characteristic of being constant across the different years of operation of the wind farm. Hence, a single input must be set in the financial model for the year in which the input will be utilized. The assumptions that have been researched and considered are:
  - Development duration: It is an input that reflects the amount of time that the development of a wind farm will cost. Its unit is years and the assumption considered has been of 3 years.
  - Construction duration: After the development, the construction takes place. As with the development, the construction duration is the time spent during the construction

of the wind farm. The unit is years and the assumption considered for the case study has been of 2 years.

- Turbine: This input reflects the brand, model and capacity of the wind turbine that will be utilized in the wind farm. Although it is an input in the financial model, it is actually an output of the wind resource study undertaken in the previous section. The wind turbines utilized are from the brand Vestas, model V150/4000 and of capacity 4.2 MW.
- Number of turbines: This input reflects the number of turbines that will be reflected in the financial model and it is actually the input that decides the total capacity of the wind farm in MW. The decided number of turbines is 12 leading to a total wind farm installed capacity of 4.2 MW.
- Turbines operating life: This figure reflects the number of years for which the wind turbine will be operating. Clearly, its unit is years and the assumption considered for the case study is according to industry standards of 25 years.
- P50: This corresponds to the net equivalent hours calculated in the wind resource section. It reflects the yearly net amount of hours that with a total probability of 50% will be reached every year in the chosen location for the wind farm. Similarly to the P50, the P90 is a more conservative assumption that reflects the net equivalent hours that will be reached with a total probability of 90%. Together with the wind farm installed capacity, these two inputs will decide the total energy produced per year. Its unit is hours per year and the assumption extracted as output from the wind resource section is of 2,700 hours.
- Degradation of turbines: Unfortunately for the wind farm developer or investment firm, the turbines do not operate at their 100% level during their whole operating life. In this way, certain degradation must be assumed. In order to reflect it in the financial model, the following inputs must be considered: (i) Number of years without turbines' degradation, and (ii) Degradation factor of the wind turbines. In this way, the assumptions for this case study have been according to standards: (i) 10 years without degradation and (ii) degradation factor of 0.5% per year.

- Production sold to pool: This figure reflects the amount of energy being sold to the pool out of the total energy production. Its unit is percentage out of the total production (%). If there is no PPA in place, the assumption is of 100%. However, if there is PPA in place the assumption is of 60% of total production.
- PPA: As explained in previous chapters, the inputs associated to the PPA reflect the existence and conditions of a potential purchase price agreement reached by the wind farm owners and other parties. The inputs associated to the PPA plugged into the model are: (i) Existence or not of a PPA, (ii) PPA activation date, (iii) Duration of the PPA, (iv) Percentage of energy sold to the PPA (it is complementary of the percentage of production sold to pool), and (v) PPA price. For this case study, the assumption has been that it exists a PPA in place since the year 2032 and for a total duration of 12 years at a price of 50€/MWh and selling 40% of the total energy produced.
- Opex – Operation and Maintenance: This figure reflects the cost of operating and maintaining the wind farm at an optimal technical stage. As it can be imagined, the cost of it is not constant during the whole operating life of the wind farm. In the industry, the cost of operating and maintaining a wind farm is low in the first operating years and gets higher as the wind farm gains years of operation. In order to reflect this in the financial model, the O&M costs are divided into tranches different tranches (for this case study 5), all of them reflecting a increasing O&M cost and duration. For this case study, in order to reflect the industry standards, the following tranches costs and durations have been considered: (i) Tranche A: Duration of 1 year and cost of 8,000€/MW per year, (ii) Tranche B: Duration of 3 years and cost of 12,000€/MW per year, (iii) Tranche C: Duration of 5 years and cost of 15,000€/MW per year, (iv) Tranche D: Duration of 6 years and cost of 18,000€/MW per year, and (v) Tranche E: Duration of 10 years and cost of 21,000€/MW per year. All the figures in real terms.
- Rest of Opex: As explained in the operation chapter, other operating expenditures include the land lease, the insurance, the supply cost, the SG&A, the grid access

cost and others. In real terms, the assumptions considered for this case study are according to standards: 3,000€/MW in land lease (incurred since the Ready-to-Build date), 2,000€/MW in insurance, 1,300€/MW in supply cost, 4,600€/MW in SG&A, 220€/MWh as grid access cost, and 4,800€/MW as other costs. Additionally, considering operating taxes as Opex, the following assumptions have been undertaken: (i) 2,000€/MW as IBI, (ii) 2,600€/MW as IAE, and (iii) 1,000€/turbine as potential environmental taxes.

- <u>Development Expenditures (Devex)</u>: This assumption corresponds to the total cost of developing the wind farm until it reaches the ready-to-built status. The unit utilized to measure the cost is € per MW of installed capacity. In this case study, the assumption has been according to standards in the industry of 50,000€/MW following this cost split: (i) Sites assessment: 5,000€/MW, (ii) Permits and approvals: 15,000€/MW, (iii) Environmental studies: 15,000€/MW, and (iv) Interconnection studies: 15,000€/MW.
- <u>Capital Expenditures – Construction</u>: These costs correspond to the expenses incurred during the construction of the wind farm, since the ready-to-build status until the wind farm reaches COD. As with the Devex, the total construction cost is calculated per MW. In this case study, again following industry standards, the total construction cost is of 900,000€/MW with the following split: (i) Engineering design and construction: 300,000€/MW, (ii) Procurement of wind generators: 200,000€/MW, (iii) Infrastructure and civil works: 200,000€/MW, (iv) Interconnection costs: 100,000€/MW, (v) Project management: 50,000€/MW, and (vi) Contingencies: 50,000€/MW.
- <u>Capital Expenditures – Recurring</u>: In every wind farm, every certain amount of years there is a recurring investment considered as capital expenditures in order to replace the materials that could have been damaged by the normal operation of the renewable plant. In this case study, the assumption has been that every 4 years since the plant's operation there is a recurring capex of 12,000€/MW.
- <u>Depreciation</u>: It has been assumed to be linear during the whole life of the asset.

- Corporate income tax: According to Spanish regulation, it has been assumed to be 25% of the total earnings before taxes.

5.3 Financial Assumptions

Once the operational assumptions have been determined, the financial assumptions to be plugged in the financial model must be specified. As with the operational assumptions, there are two main types of financial assumptions:

- **Time Assumptions**: As explained above, these assumptions are variable across the years and hence a yearly input must be considered. The only time assumption needed in the financing assumptions is:
    - EURIBOR: Known as the Euro Interbank Offered Rate, it is the interest rate at which financial institutions lend money to each other. It is an important financial input as it reflects the base of the interest rate at which the bank will lend money to the wind farm. The total interest rate will be EURIBOR plus a certain margin reflected in the established debt contract. For this case study, the EURIBOR curve considered is as of March 2024.
- **General Assumptions**: As explained above, these assumptions are not variable across the years and hence an only input for all the years must be considered. The general assumptions researched and established in this case study are:
    - Pool – Receivables days: This figure is part of the working capital assumptions and it reflects the amount of days that it takes for a wind farm to be paid the accrued revenues coming from the pool. According to industry standards, it has been assumed to be 30 days.
    - PPA – Receivables days: Also part of the working capital assumptions, it has the same meaning as above but with the PPA revenues. This figure is reflected in the PPA contract and it has also been assumed to be 30 days.

- Payables days: Also part of the working capital assumptions, this figure reflects the amount of days that it takes for a wind farm to actually pay the already incurred expenses. According to industry standards, it has been assumed to be 60 days.

Before explaining the rest of financial assumptions, the financing of the wind farm must be explained. Since its development phase, certain capital drawdowns take place that must be financed whether with equity or with debt. In the development and construction years, as the wind farm is not in operation, it does not generate positive cash flows that can be utilized to meet debt obligations or finance part of the expenditures. For this reason, debt during the development and construction phases is typically more expensive than during the operation phase. Additionally, banks typically ask for certain part of the total expenditures to be financed with equity in order for the business owners to prove that they believe in the project. The debt financing of the wind farm follows a project finance structure in which there are two consecutive debts:

- **Capex facility**: This debt aims to cover the financing needed to perform the development and construction of the wind farm. During these two phases, it has been assumed that 30% of the capital needs will be drown from equity sources while the rest (70%) will be drown from debt financing. The interest rate of the debt will be EURIBOR plus a fixed 3% margin. As during development and construction there will not be positive cash flows to pay for the interests, these will be capitalized, hence paid in kind, and added to the principal of the debt.
- **Refinancing facility**: Once the development and construction phases end up, there will be positive cash flows for the wind farm and hence it will be able to meet its debt obligations. In this way, the debt should be less expensive and hence a refinancing takes place. The whole principal of the capex facility is paid back to the bank utilizing debt financing to fund it. This is the principal of the new refinancing facility. In regards to the interest rate, this keeps being EURIBOR plus a margin that is lowered to 2% to reflect the lower risk profile. To meet debt obligations, a target Debt Service Coverage Ratio (DSCR) is established at 1.40x following industry standards. The DSCR is the result of the following operation:

$$DSCR = \frac{Cash\ Flow\ Available\ for\ Debt\ Service}{Debt\ Service} = \frac{CFADS}{Principal\ Repayment + Interest}$$

Hence, once calculated the CFADS for every single year, the debt repayment is sculpted to meet a target DSCR of 1.40x.

CHAPTER 6. ANALYSIS OF RESULTS

6.1 Model Circularities

When building the financial model of the entrepreneurship project resulting from the development and operation of a wind farm, the developer must take into account that in the excel where the model is built some circularities may be encountered. In Microsoft Excel, a circularity is reached when the result of a cell depends on its own result. Hence, when the circularity appears it must be resolved. There are two main ways of tackling a circularity in excel: (i) Enabling the program to iterate indefinitely (typically 100 times), and (ii) Programming a macro typically known in the industry as “Copy/Paste Macro”. The first method has the issue that it can lead to inconsistent results if the circularity is non-convergent and the program won’t flag this issue. This is why the second method, a copy/paste macro, has been utilized for this case study’s thesis.

In the project, the following two circularities have been encountered:

- **<u>Circularity 1 - Debt Circularity</u>**: This circularity occurs due to that the interest to be paid from the refinancing facility is calculated as (BoP: Beginning of Period, EoP: End of Period):

$$Refi\ Interest = \ MEAN(Refi\ Principal\ BoP, Refi\ Principal\ EoP)\ x\ Interest\ Rate$$

  Hence, the interest to be paid depends on the principal of debt outstanding from the refinancing facility at the end of the period. Likewise, the refinancing debt outstanding at the end of the period depends on the amount of the refinancing facility that has been repaid during the period diminishing the principal of debt. In turn, the amount of debt that can be repaid in the period depends on the amount of cash available for debt repayment after the paid interests have been deducted of the Cash Flow Available for Debt Service (CFADS). This is where the circularity appears. Graphically, the circularity can be explained as follows:

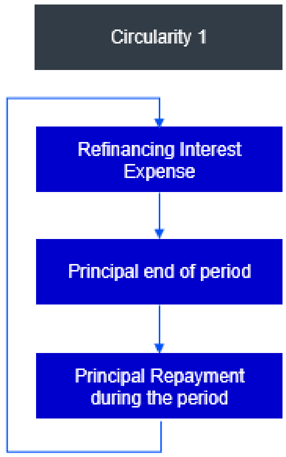


Figure 65: Graphical description of Circularity 1

- **<u>Circularity 2 - Taxes Circularity</u>**: Similarly to Circularity 1, this circularity occurs due to that the taxes to be paid during the period are calculated as:

$$Taxes = \ EBT\ x\ Corporate\ Tax\ Rate$$

Hence, the taxes to be paid depend on the Earnings Before Taxes (EBT) which is calculated as EBIT minus the interest paid during the period. As explained in the previous circularity, the interest to be paid directly depend on the principal of debt at the end of the period which depends at turn on the amount of debt repaid during the period. The amount repaid in the period depends on the CFADS. Likewise, the CFADS depend on taxes and hence the circularity appears as CFADS is calculated as:

$$CFADS = \ EBITDA - Capex - Incr.NWC - Taxes$$

Graphically, the circularity can be described as follows:

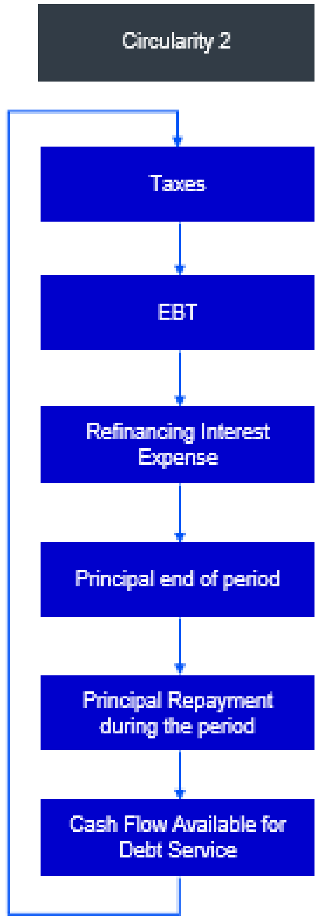


Figure 66: Graphical description of Circularity 2

As mentioned above, in order to break the circularities and make the model functional, a copy/paste macro has been programmed that is explained below in the macros section.

6.2 Financial Statements

As commonly known in the entrepreneurship industry, the financial statements are key to understand the project and assess its viability. These statements not only are the main results of the development and operation of the wind farm project, but also they are where the wind farm developer will see whether the project will be viable and will make the developer have a return or whether the project locations, wind resource, assumptions, sources of revenues and costs will need to be revisited until reaching the required entrepreneur returns.

The financial statements resulting from the wind resource study and the operational and financial assumptions taken into consideration for the case study are:

Income Statement 2024 - 2033

Calendar Year		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Revenue	***€k***	**-**	**-**	**-**	**-**	**-**	**6,664**	**8,487**	**9,029**	**8,305**	**8,259**
o/w Pool	*€k*	-	-	-	-	-	6,290	8,132	8,706	5,280	5,180
o/w PPA	*€k*	-	-	-	-	-	-	-	-	2,771	2,820
o/w GdO's	*€k*	-	-	-	-	-	374	355	323	255	259
Opex	***€k***	**-**	**-**	**-**	**-**	**-**	**(1,957)**	**(2,320)**	**(2,389)**	**(2,370)**	**(2,564)**
o/w O&M	*€k*	-	-	-	-	-	(410)	(627)	(638)	(650)	(827)
o/w Other Opex	*€k*	-	-	-	-	-	(843)	(858)	(873)	(889)	(905)
o/w Tax Opex	*€k*	-	-	-	-	-	(704)	(835)	(878)	(831)	(833)
EBITDA	***€k***	**-**	**-**	**-**	**-**	**-**	**4,708**	**6,167**	**6,640**	**5,935**	**5,695**
% EBITDA margin	*%*	-	-	-	-	-	*71%*	*73%*	*74%*	*71%*	*69%*
D&A	*€k*	-	-	-	-	-	(2,226)	(2,226)	(2,226)	(2,226)	(2,258)
EBIT	***€k***	**-**	**-**	**-**	**-**	**-**	**2,481**	**3,941**	**4,414**	**3,709**	**3,438**
% EBIT margin	*%*	-	-	-	-	-	*37%*	*46%*	*49%*	*45%*	*42%*
Interest	*€k*	-	(57)	(253)	(348)	(1,238)	(1,769)	(1,700)	(1,615)	(1,517)	(1,440)
EBT	***€k***	**-**	**(57)**	**(253)**	**(348)**	**(1,238)**	**713**	**2,242**	**2,799**	**2,192**	**1,997**
Corporate Income Tax	*€k*	-	-	-	-	-	(178)	(560)	(700)	(548)	(499)
Net income	***€k***	**-**	**(57)**	**(253)**	**(348)**	**(1,238)**	**534**	**1,681**	**2,099**	**1,644**	**1,498**

Income Statement 2034 – 2043

Calendar Year		2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Revenue	*€k*	**8,094**	**8,195**	**8,569**	**8,253**	**8,311**	**8,396**	**8,515**	**8,790**	**8,731**	**8,804**
o/w Pool	*€k*	4,975	5,020	5,345	4,980	4,980	5,022	5,115	5,345	5,243	5,279
o/w PPA	*€k*	2,871	2,923	2,976	3,029	3,084	3,123	3,164	3,205	3,246	3,288
o/w GdO's	*€k*	247	252	248	244	248	251	237	240	243	237
Opex	*€k*	**(2,588)**	**(2,632)**	**(2,695)**	**(2,711)**	**(2,934)**	**(2,982)**	**(3,033)**	**(3,096)**	**(3,137)**	**(3,187)**
o/w O&M	*€k*	(841)	(857)	(872)	(888)	(1,084)	(1,104)	(1,124)	(1,144)	(1,165)	(1,186)
o/w Other Opex	*€k*	(921)	(938)	(955)	(972)	(989)	(1,007)	(1,025)	(1,043)	(1,062)	(1,081)
o/w Tax Opex	*€k*	(826)	(837)	(868)	(851)	(860)	(871)	(884)	(909)	(910)	(921)
EBITDA	*€k*	**5,505**	**5,563**	**5,874**	**5,542**	**5,377**	**5,414**	**5,482**	**5,693**	**5,595**	**5,617**
% EBITDA margin	*%*	*68%*	*68%*	*69%*	*67%*	*65%*	*64%*	*64%*	*65%*	*64%*	*64%*
D&A	*€k*	(2,258)	(2,258)	(2,299)	(2,299)	(2,299)	(2,299)	(2,358)	(2,358)	(2,358)	(2,358)
EBIT	*€k*	**3,248**	**3,306**	**3,616**	**3,243**	**3,078**	**3,115**	**3,183**	**3,335**	**3,237**	**3,259**
% EBIT margin	*%*	*40%*	*40%*	*42%*	*39%*	*37%*	*37%*	*37%*	*38%*	*37%*	*37%*
Interest	*€k*	(1,362)	(1,273)	(1,166)	(1,060)	(946)	(818)	(680)	(541)	(407)	(270)
EBT	*€k*	**1,886**	**2,033**	**2,450**	**2,183**	**2,132**	**2,297**	**2,503**	**2,794**	**2,830**	**2,989**
Corporate Income Tax	*€k*	(472)	(508)	(613)	(546)	(533)	(574)	(626)	(699)	(708)	(747)
Net income	*€k*	**1,415**	**1,415**	**1,524**	**1,838**	**1,637**	**1,599**	**1,723**	**1,877**	**2,096**	**2,123**

Income Statement 2044 – 2053

Calendar Year		2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
Revenue	**€k**	**9,114**	**9,163**	**9,212**	**9,275**	**9,359**	**9,443**	**9,493**	**9,579**	**9,663**	**9,598**
o/w Pool	€k	8,861	8,923	8,985	9,045	9,126	9,207	9,289	9,371	9,453	9,385
o/w PPA	€k	-	-	-	-	-	-	-	-	-	-
o/w GdO's	€k	253	240	227	230	233	236	205	208	210	213
Opex	**€k**	**(3,456)**	**(3,510)**	**(3,565)**	**(3,621)**	**(3,681)**	**(3,741)**	**(3,799)**	**(3,862)**	**(3,925)**	**(3,978)**
o/w O&M	€k	(1,408)	(1,433)	(1,459)	(1,485)	(1,512)	(1,539)	(1,567)	(1,595)	(1,624)	(1,653)
o/w Other Opex	€k	(1,100)	(1,120)	(1,140)	(1,160)	(1,181)	(1,202)	(1,223)	(1,245)	(1,267)	(1,290)
o/w Tax Opex	€k	(948)	(957)	(966)	(976)	(988)	(1,000)	(1,009)	(1,021)	(1,034)	(1,036)
EBITDA	**€k**	**5,658**	**5,653**	**5,647**	**5,654**	**5,678**	**5,703**	**5,694**	**5,717**	**5,738**	**5,619**
% EBITDA margin	*%*	*68%*	*62%*	*62%*	*61%*	*61%*	*61%*	*60%*	*60%*	*60%*	*59%*
D&A	€k	(2,358)	(2,449)	(2,449)	(2,449)	(2,449)	(2,625)	(2,625)	(2,625)	(2,625)	(3,570)
EBIT	**€k**	**3,300**	**3,204**	**3,198**	**3,205**	**3,229**	**3,078**	**3,069**	**3,092**	**3,113**	**2,050**
% EBIT margin	*%*	*36%*	*35%*	*35%*	*35%*	*35%*	*33%*	*32%*	*32%*	*32%*	*21%*
Interest	€k	(126)	(27)	-	-	-	-	-	-	-	-
EBT	**€k**	**3,174**	**3,177**	**3,198**	**3,205**	**3,229**	**3,078**	**3,069**	**3,092**	**3,113**	**2,050**
Corporate Income Tax	€k	(472)	(794)	(794)	(800)	(801)	(807)	(769)	(767)	(773)	(778)
Net income	**€k**	**2,381**	**2,383**	**2,399**	**2,403**	**2,422**	**2,308**	**2,302**	**2,319**	**2,335**	**1,537**

Cash Flow Statement 2024 – 2033

Calendar Year		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
EBITDA	*€k*	-	-	-	-	-	4,708	6,167	6,640	5,935	5,695
Tax	*€k*	-	-	-	-	-	(178)	(560)	(700)	(548)	(499)
Change in WC	*€k*	-	-	-	-	-	(226)	(90)	(33)	57	35
Operating Cash Flow	***€k***	**-**	**-**	**-**	**-**	**-**	**4,303**	**5,517**	**5,907**	**5,444**	**5,231**
Capex	*€k*	(2,729)	(2,822)	(2,898)	(23,379)	(23,823)	-	-	-	-	(661)
CF Available for Debt Service	***€k***	**(2,729)**	**(2,822)**	**(2,898)**	**(23,379)**	**(23,823)**	**4,303**	**5,517**	**5,907**	**5,444**	**4,569**
Capex Facility Drawdown	*€k*	1,910	1,975	2,029	16,365	16,676	-	-	-	-	-
Capex Faclity Repayment	*€k*	-	-	-	-	(40,852)	-	-	-	-	-
Capex Facility PIK	*€k*	-	57	253	348	1,238	-	-	-	-	-
Refinancing Drawdown	*€k*	-	-	-	-	40,852	-	-	-	-	-
Refinancing Repayment	*€k*	-	-	-	-	-	(1,305)	(2,241)	(2,605)	(2,372)	(1,824)
Refinancing Interests	*€k*	-	-	-	-	-	(1,769)	(1,700)	(1,615)	(1,517)	(1,440)
CF Available for Shareholders	***€k***	**(819)**	**(789)**	**(617)**	**(6,666)**	**(5,909)**	**1,230**	**1,576**	**1,688**	**1,556**	**1,306**
Distributions	*€k*	-	-	-	-	-	(1,230)	(1,576)	(1,688)	(1,556)	(1,306)
Equity Injections	*€k*	919	789	617	6,666	5,909	-	-	-	-	-
Cash Flow After Distributions	***€k***	**100**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Cash BoP	***€k***	**-**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Cash Variation	*€k*	100	-	-	-	-	-	-	-	-	-
Cash EoP	***€k***	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Net Debt EoP	***€k***	**1,810**	**3,843**	**6,124**	**22,838**	**40,752**	**39,448**	**37,207**	**34,602**	**32,230**	**30,407**
Leverage Ratio (ND/EBITDA)	*x*	-	-	-	-	-	8.4x	6.0x	5.2x	5.4x	5.3x

Cash Flow Statement 2034 – 2043

Calendar Year		2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
EBITDA	€k	5,505	5,563	5,874	5,542	5,377	5,414	5,482	5,693	5,595	5,617
Tax	€k	(472)	(508)	(613)	(546)	(533)	(574)	(626)	(699)	(708)	(747)
Change in WC	€k	18	(1)	(20)	28	32	1	(1)	(13)	11	2
Operating Cash Flow	**€k**	**5,051**	**5,054**	**5,242**	**5,024**	**4,876**	**4,841**	**4,856**	**4,982**	**4,899**	**4,872**
Capex	€k	-	-	-	(710)	-	-	-	(763)	-	-
CF Available for Debt Service	**€k**	**5,051**	**5,054**	**5,242**	**4,314**	**4,876**	**4,841**	**4,856**	**4,219**	**4,899**	**4,872**
Capex Facility Drawdown	€k	-	-	-	-	-	-	-	-	-	-
Capex Faclity Repayment	€k	-	-	-	-	-	-	-	-	-	-
Capex Facility PIK	€k	-	-	-	-	-	-	-	-	-	-
Refinancing Drawdown	€k	-	-	-	-	-	-	-	-	-	-
Refinancing Repayment	€k	(2,247)	(2,337)	(2,578)	(2,022)	(2,537)	(2,640)	(2,788)	(2,473)	(3,092)	(3,210)
Refinancing Interests	€k	(1,362)	(1,273)	(1,166)	(1,060)	(946)	(818)	(680)	(541)	(407)	(270)
CF Available for Shareholders	**€k**	**1,443**	**1,444**	**1,498**	**1,233**	**1,393**	**1,383**	**1,387**	**1,206**	**1,400**	**1,392**
Distributions	€k	(1,443)	(1,444)	(1,498)	(1,233)	(1,393)	(1,383)	(1,387)	(1,206)	(1,400)	(1,392)
Equity Injections	€k	-	-	-	-	-	-	-	-	-	-
Cash Flow After Distributions	**€k**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Cash BoP	**€k**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Cash Variation	€k	-	-	-	-	-	-	-	-	-	-
Cash EoP	**€k**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Net Debt EoP	**€k**	**28,160**	**25,823**	**23,245**	**21,224**	**18,687**	**16,047**	**13,258**	**10,786**	**7,693**	**4,483**
Leverage Ratio (ND/EBITDA)	*x*	5.1x	4.6x	4.0x	3.8x	3.5x	3.0x	2.4x	1.9x	1.4x	0.8x

Cash Flow Statement 2044 – 2053

Calendar Year		2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
EBITDA	€k	5,658	5,653	5,647	5,654	5,678	5,703	5,694	5,717	5,738	5,619
Tax	€k	(794)	(794)	(800)	(801)	(807)	(769)	(767)	(773)	(778)	(512)
Change in WC	€k	19	4	5	4	3	2	6	3	4	14
Operating Cash Flow	**€k**	**4,884**	**4,863**	**4,853**	**4,857**	**4,874**	**4,936**	**4,932**	**4,947**	**4,964**	**5,121**
Capex	€k	-	(819)	-	-	-	(880)	-	-	-	(945)
CF Available for Debt Service	**€k**	**4,884**	**4,044**	**4,853**	**4,857**	**4,874**	**4,056**	**4,932**	**4,947**	**4,964**	**4,176**
Capex Facility Drawdown	€k	-	-	-	-	-	-	-	-	-	-
Capex Faclity Repayment	€k	-	-	-	-	-	-	-	-	-	-
Capex Facility PIK	€k	-	-	-	-	-	-	-	-	-	-
Refinancing Drawdown	€k	-	-	-	-	-	-	-	-	-	-
Refinancing Repayment	€k	(3,362)	(1,221)	-	-	-	-	-	-	-	-
Refinancing Interests	€k	(126)	(27)	-	-	-	-	-	-	-	-
CF Available for Shareholders	**€k**	**1,395**	**2,797**	**4,853**	**4,857**	**4,874**	**4,056**	**4,932**	**4,947**	**4,964**	**4,176**
Distributions	€k	(1,395)	(2,797)	(4,853)	(4,857)	(4,874)	(4,056)	(4,932)	(4,947)	(4,964)	(4,176)
Equity Injections	€k	-	-	-	-	-	-	-	-	-	-
Cash Flow After Distributions	**€k**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Cash BoP	**€k**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Cash Variation	€k	-	-	-	-	-	-	-	-	-	-
Cash EoP	**€k**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Net Debt EoP	**€k**	**1,121**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**	**(100)**
Leverage Ratio (ND/EBITDA)	x	0.2x	(0.0x)	(0.0x)	(0.0x)	(0.0x)	(0.0x)	(0.0x)	(0.0x)	(0.0x)	(0.0x)

Balance Sheet 2024 – 2033

Calendar Year		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Cash & Cash Equivalents	*€k*	100	100	100	100	100	100	100	100	100	100
Receivables	*€k*	-	-	-	-	-	548	698	742	681	679
PP&E	*€k*	2,729	5,551	8,449	31,828	55,652	53,426	51,200	48,974	46,747	45,151
Total Assets	***€k***	**2,829**	**5,651**	**8,549**	**31,928**	**55,752**	**54,073**	**51,997**	**49,816**	**47,528**	**45,930**
Payables	*€k*	-	-	-	-	-	322	381	393	389	422
LT Debt - Capex facility	*€k*	1,910	3,943	6,224	22,938	-	-	-	-	-	-
LT Debt - Refinancing facility	*€k*	-	-	-	-	40,852	39,548	37,307	34,702	32,330	30,507
Total Liabilities	***€k***	**1,910**	**3,943**	**6,224**	**22,938**	**40,852**	**39,869**	**37,688**	**35,095**	**32,719**	**30,928**
Reserves	*€k*	-	-	-	-	-	-	105	517	605	798
Share Capital	*€k*	919	1,708	2,325	8,991	14,899	14,204	14,204	14,204	14,204	14,204
Total Equity	***€k***	**919**	**1,708**	**2,325**	**8,991**	**14,899**	**14,204**	**14,309**	**14,721**	**14,809**	**15,002**
Total Liabilities + Equity	***€k***	**2,829**	**5,651**	**8,549**	**31,928**	**55,752**	**54,073**	**51,997**	**49,816**	**47,528**	**45,930**
BS Check	***€k***	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Balance Sheet 2034 – 2043

Calendar Year		2034	2035	2036	2037	2038	2039	2040	2041	2042	2043
Cash & Cash Equivalents	€k	100	100	100	100	100	100	100	100	100	100
Receivables	€k	665	674	702	678	683	690	698	722	718	724
PP&E	€k	42,894	40,636	38,378	36,789	34,490	32,191	29,891	28,296	25,938	23,580
Total Assets	**€k**	**43,659**	**41,410**	**39,181**	**37,568**	**35,273**	**32,981**	**30,689**	**29,118**	**26,756**	**24,404**
Payables	€k	425	433	442	446	482	490	497	509	516	524
LT Debt - Capex facility	€k	-	-	-	-	-	-	-	-	-	-
LT Debt - Refinancing facility	€k	28,260	25,923	23,345	21,324	18,787	16,147	13,358	10,886	7,793	4,583
Total Liabilities	**€k**	**28,686**	**26,356**	**23,787**	**21,769**	**19,269**	**16,637**	**13,856**	**11,395**	**8,309**	**5,107**
Reserves	€k	769	850	1,190	1,594	1,800	2,140	2,630	3,520	4,243	5,093
Share Capital	€k	14,204	14,204	14,204	14,204	14,204	14,204	14,204	14,204	14,204	14,204
Total Equity	**€k**	**14,973**	**15,054**	**15,394**	**15,798**	**16,004**	**16,344**	**16,834**	**17,724**	**18,447**	**19,297**
Total Liabilities + Equity	**€k**	**43,659**	**41,410**	**39,181**	**37,568**	**35,273**	**32,981**	**30,689**	**29,118**	**26,756**	**24,404**
BS Check	***€k***	-	-	-	-	-	-	-	-	-	-

Balance Sheet 2044 – 2053

Calendar Year		2044	2045	2046	2047	2048	2049	2050	2051	2052	2053
Cash & Cash Equivalents	*€k*	100	100	100	100	100	100	100	100	100	100
Receivables	*€k*	747	753	757	762	767	776	780	787	792	789
PP&E	*€k*	21,222	19,592	17,143	14,694	12,245	10,500	7,875	5,250	2,625	0
Total Assets	***€k***	**22,069**	**20,445**	**18,000**	**15,556**	**13,112**	**11,376**	**8,755**	**6,137**	**3,517**	**889**
Payables	*€k*	567	577	586	595	603	615	625	635	643	654
LT Debt - Capex facility	*€k*	-	-	-	-	-	-	-	-	-	-
LT Debt - Refinancing facility	*€k*	1,221	-	-	-	-	-	-	-	-	-
Total Liabilities	***€k***	**1,787**	**577**	**586**	**595**	**603**	**615**	**625**	**635**	**643**	**654**
Reserves	*€k*	6,078	5,664	3,210	757	-	-	-	-	-	-
Share Capital	*€k*	14,204	14,204	14,204	14,204	12,509	10,761	8,131	5,502	2,874	235
Total Equity	***€k***	**20,282**	**19,868**	**17,414**	**14,961**	**12,509**	**10,761**	**8,131**	**5,502**	**2,874**	**235**
Total Liabilities + Equity	***€k***	**22,069**	**20,445**	**18,000**	**15,556**	**13,112**	**11,376**	**8,755**	**6,137**	**3,517**	**889**
BS Check	***€k***	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

From the financial statements, the following main conclusions can be extracted:

- As explained in the previous chapter in the operational assumptions section, the project is not operational until 2029 as the first four years (2024-2028) correspond to the development and construction phases with three and two years of respective duration each of the phases.
- In terms of revenue, the wind farm starts generating revenue once it is operational, hence in 2029 mainly through two main sources covered in previous chapters: (i) Pool revenue, and (ii) GdO's (Guarantees of Origin). The difference between the pool revenues among the different years is explained by the difference in pool price and wind capture coefficient estimated by the chosen energy consultant (Afry) in their Q1 2024 estimations. It is also relevant to see the effect that the PPA has over the total revenues. As anticipated in the assumptions, a PPA is ongoing between 2032-2043. This results in a revenue stabilization of +8m€ during the period.
- Operating expenditures are also stable during the years. However, as it can be seen above, not only the inflation causes a higher expenditure during the period, but also the fact that the O&M is higher as the plant gets older.
- Stable revenues and opex lead to an EBITDA that varies between €5-6m every year. In turn, EBITDA margin remains at constant levels between 60-70%.
- In terms of D&A, the slight growth is explained through the recurring capex that the plant experiences during its operational years. This leads to a higher depreciation and hence higher D&A among the years.
- Debt interests begin to be accrued since the first year in which there is debt outstanding and show a peak in 2029. In that year, after financing the construction of the plant, the debt is at maximum levels and hence the interest as well. From then on, as debt is consistently repaid through the years, the principal is lowered and hence the amount of interest accrued. Interest stop being accrued in 2045, first year in which the debt is finally fully repaid.
- Finally, as it can be seen in the CF Statement, the plant is able to generate cash to be distributed to shareholders since its first operational year, in 2029.

6.3 Valuation

Once the financial statements have been completely analyzed and understood, another way to assess the viability of the project is to value it. This step is key in order to understand whether developing and constructing a wind farm in Burgos with the obtained wind resource results is a worth entrepreneurship project in which the renewable energy developer would be properly investing its money or if the chosen location (Burgos) is not suitable to make the project worth it.

Valuing the project is not difficult as the wind farm developer only needs to compute the required investment and the distributions that it would obtain if the project went forward. In the section above (financial statements), the equity injections and the distributions of the wind farm developer have been computed in the Cash Flow Statement.

With the computed injections and distributions, there are several ways to understand whether the project is financially viable or not. For this case study, what makes sense is understanding what price would a 3rd party investor pay if it wanted to buy the wind farm once it is operational, that is in year 2029. For this reason, in order to calculate the value of the wind farm in 2029 a valuation method must be utilized. In the industry, there are typically two main methodologies: (i) Discounted Cash Flow (DCF), and (ii) Multiple valuation (relative valuation).

Utilizing the first method to compute the equity value (that is the actual money perceived by the wind farm developer), the distributions from 2029 on are discounted at a chosen discount rate. In order to calculate this discount rate industry standards have been followed reaching a result of 7.5%. This means that an investor would expect a return of 7.5% if it invested in a wind farm which has no development and construction risks as it is already fully operational. In the industry, this return is according to standard as the only risk of the asset relies on the volatility of the electricity price. Discounting the distributions a equity value of €21.9m is reached. This added to the €39.4m of net debt expected for the year leads to an enterprise value of €61.4m meaning an implied multiple €m/MW of €1.2/MW. Depending on the 3rd party buyer nature, this implied multiple can be seen as a little bit high according to industry standards. To solve it, sensitivities to the exit will be applied in the following section to better understand this.

Now, knowing the exit value of the asset for the wind farm developer, the IRR and TVPI of the investment can be calculated. This will tell the wind farm developer if it is worth to take the risk and invest time and money on this entrepreneurship project or not. The concepts of IRR and TVPI are related as they try to solve whether the investment is worth or not, however they are not the same:

- **IRR**: Known as Internal Rate of Return, is the discount rate at which the cash inflows and outflows of the investors must be discounted in order to make the net present value of all cash flows equal to zero. It is a useful metric for the wind farm developer in order to understand the potential return of this concrete investment. With the previously developed exit conditions, in 2029 at a resulting price equal to the future cash flows discounted at a rate of 7.5%, the resulting IRR of investing in the development and construction and later exiting when the farm is operational would give the developer an IRR of 23.6%. Two main conclusions must be highlighted:
    - In an infrastructure class asset such as a wind farm, it would be seen by the investor as a worth IRR as it is well above +15%. The reason why the IRR seems high is that the actual amount invested by the wind farm developer during the development and construction is very much reduced by leveraging bank debt during these periods.
    - Additionally, the IRR is reasonable as the asset is riskier during the development and construction phases, which is the wind farm developer's holding period. Once the asset is operational, although still risky as any investment, it should be considered as a more de-risked asset and that is where the return is lower (7.5%).
- **TVPI**: Known as the Total Value to Paid-in Capital (or MOIC, MoM, CoC), it corresponds to the total cash inflows perceived by the developer divided into the total cash outflows. Hence, it is distributions divided to investment. Again, with the previously developed exit conditions, in 2029 at a resulting price equal to the future cash flows discounted at a rate

of 7.5%, the resulting TVPI of investing in the development and construction and later exiting when the farm is operational would give the developer TVPI of 1.55x. This means that for every 1€ invested in 2024, 1.55€ will be given back in 2029. The result is reasonable for this kind of asset. In the next section, sensitivities will be applied to this result in order to see what could be done to improve it.

6.4 Sensitivities

The reason why a wind farm developer builds a financial model in order to assess the viability of its entrepreneurship project is to be able to know the impact on valuation and returns of the investment if some key assumptions change during the development and construction. In the finance industry, this type of analysis is known as sensitivities as they try to check how sensitive a certain output is to the change of one or two key inputs.

Additionally, this type of analysis helps the entrepreneurs to better understand some key results of the project. For this reason, for this case study four different sensitivities have been run in order to understand some key results obtained in the valuation and viability assessment of the project. The sensis have been run on the following inputs:

1. **Exit year & Discount rate:** This sensitivity tries to measure the impact on exit IRR, exit TVPI, implicit €m/MW multiple when changing the exit year from 2029 (valuation assumption) to 2033. This is important in order for the developer to know when it makes sense for the entrepreneur to exit the investment maximizing the returns. Additionally, a sensi on the discount rate is also run in order to assess the impact it has to have assumed a discount rate of 7.5% in the valuation case of the previous section. The discount rate sensi flows between 7.00% and 8.00% in steps of 0.25%.

2. **Target DSCR & Refinancing margin:** This sensi measures the impact on exit IRR, exit TVPI, and LT IRR (assuming no exit) of changing the hypothesis of the target DSCR

(between 1.3x and 1.5x in steps of 0.05x) and the margin of the refinancing facility (between 1.00% and 3.00% in steps of 0.50%). This sensi is important as these are two assumptions very much influenced by market conditions and the bank lenders of the facilities. As when the refinancing occurs (2029) market conditions may have varied, it is important to have assessed the impact on the project viability in case the market is pessimistic on renewable greenfield projects.

3. **Net Equivalent Hours and # of Turbines:** This sensi measures the impact on exit IRR, exit TVPI, and LT IRR (assuming no exit) of changing the hypothesis of the net equivalent hours (between 2,400 and 3,000 in steps of 150) and the number of turbines (between 8 and 16 in steps of 2). Firstly, this sensi is important as the net equivalent hours are the result of the section of the wind resource study previously developed which relies on statistical methods and the pessimistic case of a resulting wind resource lower than expected must be checked. Additionally, the number of turbines have been chosen so that it makes sense, however, it is interesting to check if with a higher or lower capacity of the wind farm, the project delivers higher or lower returns.

4. **Percentage of Energy sold to Pool and PPA Price:** This sensi measures the impact on exit IRR, exit TVPI and LT IRR (assuming no exit) of changing the PPA hypothesis during the years in which the PPA is activated as developed in the previous chapter. The hypothesis that change are the split percentage of energy sold to pool and to PPA when it is activated: Percentage sold to pool varies from 40% to 80% in steps of 10%. Secondly, the other changing hypothesis is the PPA price that varies from 40 to 60€/MWh in steps of 10€/MWh. The aim of this sensitivity is analyzing whether the PPA is useful for the returns of the wind farm.

The results of the sensitivities explained above are the following:

1. **Exit year & Discount rate:**

Exit IRR	2029	2030	2031	2032	2033
7.00%	26.7%	21.0%	17.9%	15.8%	14.4%
7.25%	25.1%	20.0%	17.2%	15.3%	14.0%
7.50%	23.6%	19.1%	16.5%	14.8%	13.6%
7.75%	22.1%	18.1%	15.9%	14.3%	13.3%
8.00%	20.6%	17.2%	15.2%	13.9%	12.9%

Table 13: Sensitivity Exit year & Discount rate on Exit IRR

Exit TVPI	2029	2030	2031	2032	2033
7.00%	1.64x	1.78x	1.89x	2.00x	2.09x
7.25%	1.60x	1.73x	1.85x	1.95x	2.05x
7.50%	1.55x	1.69x	1.81x	1.91x	2.01x
7.75%	1.51x	1.65x	1.77x	1.87x	1.97x
8.00%	1.47x	1.61x	1.73x	1.83x	1.93x

Table 14: Sensitivity Exit year & Discount rate on Exit TVPI

Implicit €m/MW @ exit	2029	2030	2031	2032	2033
7.00%	1.24x	1.21x	1.16x	1.11x	1.08x
7.25%	1.23x	1.19x	1.14x	1.10x	1.06x
7.50%	1.22x	1.18x	1.13x	1.08x	1.05x
7.75%	1.21x	1.17x	1.12x	1.07x	1.04x
8.00%	1.19x	1.16x	1.11x	1.06x	1.03x

Table 15: Table 14: Sensitivity Exit year & Discount rate on Implicit €m/MW multiple

From the results, the following conclusions can be extracted:

- On exit IRR, the lower the discount rate of the future CF at the sale of the plant the higher the exit IRR as the paid amount by the rebuyer would be higher and hence the return. Additionally, it is interesting to see that the year of exit of the asset significantly changes the return. If the asset is exited in the first operational year (2029), the return is higher that if the asset is exited in the following years. The reason for this is the time value of money.
- On exit TVPI, again, the lower the discount rate the higher the TVPI as the exit price perceived by the seller is higher. However, it is also interesting to see that oppositely to what happened with the exit IRR, the exit TVPI is higher if the asset is later exited. The reason for this is that when the asset is operational it is able to distribute dividends that increase TVPI. At this stage it is important to highlight that TVPI is a metric that does not take into account the time value of money.

- On the implicit €m/MW, what must be highlighted is that the higher multiple results when the asset is exited earlier as there are more years in which the CF can be discounted as the plant would be operational more years from then on.

2. Target DSCR & Refinancing margin:

Exit IRR	1.30x	1.35x	1.40x	1.45x	1.50x
1.00%	23.7%	24.9%	26.0%	27.0%	28.1%
1.50%	22.5%	23.7%	24.8%	25.9%	27.0%
2.00%	21.3%	22.5%	23.6%	24.7%	25.8%
2.50%	19.9%	21.1%	22.3%	23.4%	24.5%
3.00%	18.4%	19.6%	20.8%	22.0%	23.1%

Table 16:Sensitivity Target DSCR & Refinancing margin on Exit IRR

Exit TVPI	1.30x	1.35x	1.40x	1.45x	1.50x
1.00%	1.56x	1.59x	1.62x	1.65x	1.68x
1.50%	1.52x	1.56x	1.59x	1.62x	1.65x
2.00%	1.49x	1.52x	1.55x	1.59x	1.62x
2.50%	1.45x	1.48x	1.52x	1.55x	1.58x
3.00%	1.41x	1.45x	1.48x	1.51x	1.54x

Table 17:Sensitivity Target DSCR & Refinancing margin on Exit TVPI

LT IRR	1.30x	1.35x	1.40x	1.45x	1.50x
1.00%	10.0%	10.3%	10.5%	10.8%	11.0%
1.50%	9.9%	10.1%	10.4%	10.6%	10.9%
2.00%	9.7%	9.9%	10.2%	10.4%	10.7%
2.50%	9.5%	9.7%	10.0%	10.2%	10.5%
3.00%	9.3%	9.5%	9.8%	10.0%	10.3%

Table 18: Sensitivity Target DSCR & Refinancing margin on LT IRR

From the results, the following conclusions can be extracted:

- On exit IRR, the higher the target DSCR the higher is the IRR at exit. Additionally, as it is obvious, the higher the margin on the debt the lower is the return made by the developer. It is interesting however to check that even if the margin is at a high level (3%) the investment keeps holding a worth return (18% in the worst case).
- On exit TVPI, the same conclusions explained above apply. Again, even in the worst case scenario of financing the returns are worth for this type of investment.

- On LT IRR, it is interesting to check that the financing conditions do not change it significantly as there is only a difference of 170 bps between the worst and best case scenario.

3. Net Equivalent Hours and # of Turbines:

Exit IRR	2,400	2,550	2,700	2,850	3,000
8	7.4%	15.7%	23.3%	30.2%	36.6%
10	7.6%	15.9%	23.5%	30.4%	36.8%
12	7.7%	16.0%	23.6%	30.6%	37.0%
14	7.7%	16.1%	23.7%	30.7%	37.2%
16	7.8%	16.1%	23.8%	30.8%	37.3%

Table 19: Sensitivity NEH & # of Turbines on Exit IRR

Exit TVPI	2,400	2,550	2,700	2,850	3,000
8	1.15x	1.35x	1.55x	1.76x	1.97x
10	1.16x	1.35x	1.55x	1.76x	1.97x
12	1.16x	1.35x	1.55x	1.76x	1.98x
14	1.16x	1.35x	1.56x	1.76x	1.98x
16	1.16x	1.35x	1.56x	1.77x	1.98x

Table 20: Sensitivity NEH & # of Turbines on Exit TVPI

LT IRR	2,400	2,550	2,700	2,850	3,000
8	7.5%	8.9%	10.1%	11.2%	12.3%
10	7.6%	8.9%	10.2%	11.3%	12.3%
12	7.6%	9.0%	10.2%	11.3%	12.3%
14	7.6%	9.0%	10.2%	11.3%	12.3%
16	7.6%	9.0%	10.2%	11.3%	12.3%

Table 21:Sensitivity NEH & # of Turbines on LT IRR

From the results, the following conclusions can be extracted:

- On exit IRR, there is a very significant delta in returns in the wind resource variable. If the net equivalent hours vary the returns change significantly. This is not surprising as the project is a wind farm and the most important variable to consider is the wind resource. This is the reason why a very detailed wind resource study has been done at the beginning of the case study. Additionally, it is interesting to see that the scale of the project in MW does not change the returns picture as doubling the number of turbines does not increase the returns significantly.

- On exit TVPI, the same conclusions explained above apply.
- On LT IRR, the wind resource does not affect as much as in the exit IRR but still changes the picture of the return significantly. Again, the scale of the plant does not change the returns expectations.

4. Percentage of Energy sold to Pool and PPA Price:

Exit IRR	40%	50%	60%	70%	80%
40.0	13.8%	16.2%	18.5%	20.7%	23.0%
45.0	17.9%	19.5%	21.1%	22.6%	24.2%
50.0	21.7%	22.7%	23.6%	24.5%	25.4%
55.0	25.5%	25.8%	26.1%	26.4%	26.7%
60.0	29.1%	28.8%	28.5%	28.2%	27.9%

Table 22: Sensitivity % Pool & PPA price on Exit IRR

Exit TVPI	40%	50%	60%	70%	80%
40.0	1.30x	1.36x	1.42x	1.48x	1.54x
45.0	1.40x	1.44x	1.48x	1.53x	1.57x
50.0	1.50x	1.53x	1.55x	1.58x	1.61x
55.0	1.61x	1.62x	1.63x	1.63x	1.64x
60.0	1.72x	1.71x	1.70x	1.69x	1.68x

Table 23: Sensitivity % Pool & PPA price on Exit TVPI

LT IRR	40%	50%	60%	70%	80%
40.0	8.6%	9.0%	9.3%	9.7%	10.1%
45.0	9.2%	9.5%	9.8%	10.0%	10.3%
50.0	9.9%	10.0%	10.2%	10.3%	10.5%
55.0	10.5%	10.5%	10.6%	10.6%	10.7%
60.0	11.1%	11.0%	11.0%	10.9%	10.9%

Table 24: Sensitivity % Pool & PPA price on LT IRR

From the results, the following conclusions can be extracted:

- On exit IRR, with the applied power prices there is difference in returns depending on the PPA price applied. As it is clear, the higher the PPA price the higher the return keeping constant the percentage sold to pool. Additionally, it is interesting to see that with the applied power price curve the minimum PPA price in which it is worth to have more energy sold to PPA is 60€/MWh.

- On exit TVPI, the same conclusions explained above apply.
- On LT IRR, the same conclusions explained for the exit IRR apply.

6.5 Macros

As explained above, in the financial model built with Microsoft Excel, several macros have been programmed in order to (i) solve the circularities, and (ii) automatically be able to calculate the sensitivities.

The macro built to solve the circularity is called "TFM_COPY_PASTE" and the code is as follows:

```
Sub TFM_COPY_PASTE()
    ' TFM_COPY_PASTE Macro
    ' This macro will perform the copy paste needed for the circular calculations: (i) Tax and (ii)
Refinancing interest expense
    ' Keyboard Shortcut: Ctrl+Shift+P

    Dim check As Double
    Dim sourceRange As Range
    Dim destRange As Range
    Dim macroSheet As Worksheet

    ' Set the worksheet and ranges
    Set macroSheet = Worksheets("Macro")
    Set sourceRange = macroSheet.Range("O16:BK17")
    Set destRange = macroSheet.Range("O20:BK21")
```

```
    ' Get the initial value of the check cell
    check = Round(macroSheet.Range("K26").Value, 0)

    ' Loop until the check value is zero
    Do While check <> 0
        ' Copy values directly to the destination range
        destRange.Value = sourceRange.Value

        ' Recalculate the check value
        check = Round(macroSheet.Range("K26").Value, 0)
    Loop

    ' Clear the clipboard
    Application.CutCopyMode = False
End Sub
```

On the other hand, although there is a macro for every sensitivity table, the following code describes the followed logic:

```
Sub Sensi_Pool_and_PPAPrice_onExitIRR()
    ' Declare variables for input and output ranges
    Dim input1 As Range
    Dim input2 As Range
    Dim output As Range

    ' Declare variables to store input values
    Dim input1Values As Variant
    Dim input2Values As Variant
```

```
' Declare an array to store the results
Dim results(1 To 5, 1 To 5) As Double
Dim i As Integer, j As Integer

' Set cells in the "Gen_Inputs" tab to be equal to the input cells in the "Sensitivities" tab
Worksheets("Gen_Inputs").Range("L58").Formula = "=" &
Worksheets("Sensitivities").Range("K95").Address(External:=True)
Worksheets("Gen_Inputs").Range("L69").Formula = "=" &
Worksheets("Sensitivities").Range("K96").Address(External:=True)

' Define the cells containing the inputs and the output
Set input1 = Worksheets("Sensitivities").Range("K95") ' Adjusts the worksheet as needed
Set input2 = Worksheets("Sensitivities").Range("K96") ' Adjusts the worksheet as needed
Set output = Worksheets("Sensitivities").Range("K97") ' Adjusts the worksheet as needed

' Define the sets of values for the inputs (5 options each)
input1Values = Array(0.4, 0.5, 0.6, 0.7, 0.8)
input2Values = Array(40, 45, 50, 55, 60)

' Loop through all combinations of input values
For i = 1 To 5
  For j = 1 To 5
    ' Assign input values
    input1.Value = input1Values(i - 1)
    input2.Value = input2Values(j - 1)

    ' Update the corresponding cells in "Gen_Inputs"
    Worksheets("Gen_Inputs").Range("L58").Value = input1.Value
    Worksheets("Gen_Inputs").Range("L69").Value = input2.Value
```

```
        ' Run the TFM_COPY_PASTE macro
        Application.Run "TFM_COPY_PASTE"

        ' Store the result in the array
        results(i, j) = output.Value
    Next j
Next i

' Create a new worksheet for the results
Dim ws As Worksheet
Set ws = Worksheets.Add
ws.Name = "PoolPPAPrice_ExitIRR"

' Write the headers
ws.Cells(1, 2).Value = "Pool (%)"
ws.Cells(2, 1).Value = "PPA Price (€/MWh)"

' Write the input values and results to the worksheet
For i = 1 To 5
    ws.Cells(1, i + 2).Value = input1Values(i - 1)
Next i

For j = 1 To 5
    ws.Cells(j + 2, 1).Value = input2Values(j - 1)
Next j

For i = 1 To 5
    For j = 1 To 5
```

```
            ws.Cells(j + 2, i + 2).Value = results(i, j)
        Next j
    Next i

    ' Set the inputs back to the middle range values
    input1.Value = input1Values(2) ' Middle value of input1
    input2.Value = input2Values(2) ' Middle value of input2


    ' Clear the formulas in cells L196 and L197 of the "Gen_Inputs" tab
    Worksheets("Gen_Inputs").Range("L58").ClearContents
    Worksheets("Gen_Inputs").Range("L69").ClearContents

    Application.Run "TFM_COPY_PASTE"
End Sub
```

CHAPTER 7. SDG's

Figure 67: Sustainable Development Goals logo

The Sustainable Development Goals (SDGs) are a collection of 17 interlinked global goals that are thought to be a "blueprint to achieve a better and more sustainable future for all". These were instituted by the United Nations General Assembly in 2015 and they are meant to be achieved in 2030.

7.1 Alignment with Sustainable Development Goals (SDGs)

The development and operation of a wind farm in Spain aligns with the following SDGs:

- **Goal #7: Affordable and Clean Energy.** *Ensure access to affordable, reliable, sustainable and modern energy for all.* The expansion of renewable energy sources is crucial in addressing the challenges posed by climate change and ensuring a sustainable future. Wind energy, in particular, has emerged as one of the most promising solutions for achieving this goal. By harnessing the power of wind, we can generate electricity without the harmful emissions associated with fossil fuels. This thesis focuses on the development and operation of a wind farm in Spain, a country with significant wind resources and a strong commitment to renewable energy. The project involves careful planning and implementation, from wind resource assessment to choosing turbine technology, ensuring that the wind farm operates efficiently and effectively. The project aims to showcase how an entrepreneur project based on wind energy would be executed and what it is needed to know to perform it. Ultimately, this initiative not only contributes to Spain's renewable energy targets but also supports the global pursuit of affordable, clean, and sustainable energy for all, in alignment with the objectives of SDG #7.

- **Goal #9: Industry, Innovation and Infrastructure.** *Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.* This wind farm project aligns with the objectives of Goal #9 by contributing to the development of resilient and sustainable energy infrastructure. By leveraging wind turbine technology and operational practices, the project not only boosts the efficiency of renewable energy production but also exemplifies how sustainable industrialization would work. The construction and operation of the wind farm involves innovative approaches which contribute to the advancement of infrastructure that is both durable and environmentally jobs and fostering technological expertise in Burgos, which aligns with the broader aim of inclusive and sustainable industrial growth. By providing a reliable and clean energy source, the wind farm also lays the workforce for future innovation and infrastructure development in the renewable energy sector, particularly in regions where sustainable solutions are most needed.

- **Goal #11: Sustainable cities and communities.** *Make cities and human settlements inclusive, safe, resilient and sustainable.* The development and operation of a wind farm contributes significantly to creating more sustainable and resilient communities, especially in Spain and concretely in Burgos. By generating clean energy locally, the project reduces dependence on fossil fuels and lowers greenhouse gas emissions, directly supporting the sustainability of nearby urban and rural areas. Moreover, the wind farm promotes responsible energy consumption by providing a reliable and renewable power source that meets the energy needs of communities without depleting natural resources. This shift to renewable energy is essential in reducing pollution and mitigating the environmental impacts associated with conventional power generation. Additionally, by reducing the region's carbon footprint and contributing to a cleaner environment, the project helps create healthier, safer, and more resilient communities.

- **Goal #13: Climate action.** *Take urgent action to combat climate change and its impacts.* Addressing climate change requires a rapid and comprehensive shift from fossil fuels to renewable energy sources. Wind energy plays a crucial role in this transition by providing a clean, sustainable, and abundant alternative to traditional power generation methods. The development and operation of the wind farm in Spain directly contributes to the reduction of greenhouse gas emissions by harnessing wind power to generate electricity without producing CO2. This project is a vital step toward achieving climate goals, as it helps to decarbonize the energy sector, which is one of the largest contributors to global warming. By replacing fossil fuel-based energy with wind power, the project not only mitigates the impacts of climate change but also sets a precedent for further renewable energy initiatives. In doing so, it supports the global effort to limit temperature rise and protect ecosystems, ultimately ensuring a more sustainable and climate-resilient future.

Figure 68: Detail of the Sustainable Development Goals involved in the projectt

CHAPTER 8. CONCLUSIONS

Throughout the project, in the different chapters the conclusions have been extracted accordingly. However, this chapter is useful to reflect on the key takeaways that an entrepreneur must have on mind when aiming to develop and operate a greenfield wind farm in Spain:

- **Global and National Renewable Energy Trends**: Spain's renewable energy sector is well ahead of the global curve, with renewable sources accounting for over 50% of electricity production compared to the global average of 30%. This provides a favourable environment for the development of new renewable energy projects, such as wind farms. Entrepreneurs should capitalize on Spain’s advanced renewable infrastructure and regulatory framework to further increase the country’s wind energy capacity.
- **Wind Energy Leadership**: Wind energy is Spain’s leading renewable energy source, representing over 21.5% of the country’s electricity generation. The significant wind resource available in Spain makes it an ideal market for developing wind farms. Entrepreneurs must consider the competitive advantages that Spain’s established wind energy infrastructure offers, including strong governmental support and a mature supply chain that supports rapid project development and operation.
- **Solar Energy Complementarity**: Solar energy has grown exponentially in Spain, reaching over 11.5% of total electricity production. While the focus of this project is on wind energy, entrepreneurs should be aware of the potential for hybrid renewable energy projects that combine wind and solar technologies. This complementary approach could enhance energy production efficiency, reduce downtime, and increase profitability by maximizing renewable resource utilization.
- **Regulatory and Policy Support**: Spain’s renewable energy market benefits from strong regulatory backing, particularly from European Union policies that incentivize renewable energy development. The Spanish government has set ambitious goals to further increase renewable energy penetration, aiming for 80% of electricity generation from renewables

by 2030. Entrepreneurs must navigate and leverage these regulatory frameworks, which offer favourable conditions for the development and expansion of wind farms.

- **Market Opportunities in Energy Storage**: As renewable energy sources like wind and solar grow, grid integration challenges will increase. Entrepreneurs should consider incorporating energy storage solutions, such as battery energy storage systems (BESS), into their wind farm projects. These technologies can mitigate the intermittency of renewable energy, stabilize output, and optimize profitability by storing energy during peak production periods and selling it when demand is high.
- **Understanding Wind Technology**: Entrepreneurs must grasp the basics of wind turbine operation, from converting kinetic wind energy into mechanical energy and then into electrical energy. Key turbine components such as blades, hub, nacelle, and gearbox are critical to efficiency. Proper understanding of these components and their specifications (such as blade length and tower height) will directly influence energy production and overall project profitability.
- **Turbine Placement and Land Selection**: The choice of site for a wind farm is crucial as it directly impacts wind resource availability, environmental concerns, and logistical feasibility. Entrepreneurs must consider both the macro (wind resource, topography) and micro (turbine placement on-site) factors to maximize efficiency. Conducting comprehensive land and wind studies helps in optimizing turbine placement, reducing wake effects, and ensuring long-term operational success.
- **Access and Grid Connection**: Gaining access and securing a connection to Spain's electrical grid is a complex but essential step in the development process. Entrepreneurs must navigate regulatory frameworks and work with Red Eléctrica de España (REE) to obtain access and connection (A&C) permits. Proper planning for grid connection early in the process is vital to avoid delays, and proximity to transmission lines can significantly reduce construction costs.
- **Permitting Challenges**: Securing the necessary permits is one of the most time-consuming and risk-prone phases of wind farm development. Entrepreneurs must be aware of the regulatory hurdles, including environmental impact assessments, administrative permits,

and land-use approvals. Efficiently managing these processes while engaging with local communities and regulatory bodies will help mitigate risks and keep the project on track.

- **Optimizing Construction and Operational Phases**: Once the permitting phase is complete, entrepreneurs must ensure seamless coordination between turbine manufacturers and contractors. Decisions such as choosing between separate contracts or an EPC contract for turbine supply and balance of plant work will affect cost and risk exposure. Managing the construction timeline effectively is key to transitioning smoothly into the operational phase, where the focus shifts to optimizing energy production and maintenance.
- **Understanding Electricity Flow and Liberalization**: Entrepreneurs must have a solid grasp of how electricity flows from generation to end consumers. In Spain, the generation phase is liberalized, meaning that any individual or company can generate electricity. However, the transmission and distribution phases are regulated, and access is controlled by entities like Red Eléctrica de España (REE). For a wind farm developer, understanding this liberalized framework, as well as the roles of regulated entities in transmitting and distributing electricity, is essential for integrating into the grid and ensuring successful operations.
- **Revenue Streams and Market Participation**: A wind farm can generate revenue through various channels, including the national pool (merchant revenues), bilateral contracts (PPAs), and specific remuneration regimes. Each source has a different risk profile, with merchant revenues being subject to market volatility and PPAs offering price stability. Entrepreneurs need to understand the Spanish electricity market dynamics, including the day-ahead and intraday markets, and how wind farms can maximize revenues by participating in these markets or securing long-term agreements.
- **Operational Cost Management**: Operating a wind farm involves managing several key cost components, such as maintenance, land leases, and insurance. Maintenance, in particular, plays a significant role in minimizing downtime and maximizing turbine efficiency. Entrepreneurs should implement preventive maintenance strategies to ensure that the turbines continue to operate at peak performance throughout their lifespan. This will help keep Opex under control while ensuring stable and efficient operations.

- **Regulatory Incentives for Renewable Energy**: Spain offers two main regulated remuneration regimes for renewable energy: the Specific Remuneration Regime and the Economic Regime for Renewable Energy (REER). These schemes provide additional revenue on top of market-based earnings, helping wind farms reach a reasonable return on investment. Entrepreneurs must understand these regulatory frameworks and participate in competitive auctions to benefit from such incentives. These mechanisms reduce market risks and improve financial stability.
- **The Importance of Power Purchase Agreements (PPAs)**: PPAs are becoming increasingly important for renewable energy projects, particularly wind farms. By securing long-term agreements with energy buyers, wind farm developers can ensure stable revenue streams, reducing exposure to market volatility. Entrepreneurs should consider PPAs as part of their revenue strategy, negotiating favourable terms with consumers or commercialization companies to create predictable cash flows. This is especially critical in an environment where wholesale electricity prices can fluctuate significantly.
- **Wind Resource Assessment is Critical**: One of the most important steps in determining the viability of a wind farm is the detailed wind resource assessment. In this project case study, data was gathered and analysed from Burgos, an ideal location with a robust wind history. Entrepreneurs must prioritize this analysis to ensure that the selected site has sufficient wind speeds to justify the investment. A comprehensive assessment not only validates the potential energy output but also helps optimize turbine selection and placement.
- **Importance of Data Accuracy and Validation**: The accuracy and reliability of wind data are paramount. In this case study, historical data from atmospheric stations was carefully validated, showing a data validity rate above 97%. Entrepreneurs must ensure that the data they use is accurate and complete, as unreliable data can lead to flawed conclusions and jeopardize the entire project. Validating the data allows for a more precise wind resource analysis, which is critical for making informed investment decisions.
- **Wind Speed Adjustments for Turbine Height**: Wind speed increases with height, which is why it's crucial to adjust wind data to reflect the height of wind turbine hubs. This case

study demonstrated how wind speed data at lower altitudes was adjusted to the 150-meter hub height of the turbines. Entrepreneurs must perform similar calculations to ensure that the wind data they use accurately reflects the expected wind speeds at the height of the turbines, which directly impacts energy generation forecasts.

- **Selecting the Right Turbine Model**: Choosing the right turbine model is essential for maximizing energy output. In the case study, three different turbines from leading manufacturers were analysed. Each turbine's power curve was compared to the wind resource data to determine the most efficient model. Entrepreneurs should carefully analyse turbine options to find the best fit for their site, considering factors like capacity, efficiency, and compatibility with the wind profile of the selected location.
- **Considering Operational and Energy Losses**: After selecting the turbines, it's important to account for potential energy losses during operation, including electrical, availability, hysteresis, blade contamination, and power curve performance losses. In this case study, a 25% energy loss was applied to account for these factors. Entrepreneurs must conservatively estimate such losses when calculating energy output to ensure that the financial model accurately reflects the realistic performance of the wind farm.
- **Financial Stability through Revenue and EBITDA**: The project's financial statements show stable revenue generation beginning in 2029, with annual revenues ranging from €8 million to €9m. This revenue is primarily driven by participation in the Spanish electricity market and a PPA starting in 2032. The project also demonstrates strong operational efficiency, maintaining EBITDA margins between 60% and 70% throughout its operational life. Entrepreneurs should focus on ensuring stable revenue streams, particularly through long-term contracts like PPAs, to reduce exposure to market volatility.
- **Debt Management and Interest Costs**: Debt plays a critical role in financing the project, particularly during the construction phase. In the case study, interest payments peak in 2029, when debt is at its highest, but they decrease significantly as the debt is repaid over time. By 2045, the project will have fully repaid its debt, leading to increased cash flow available for distribution to shareholders. Entrepreneurs should consider a structured debt

repayment strategy to manage interest costs effectively and ensure the project remains financially viable over its lifespan.

- **Valuation and Investor Returns**: The valuation of the wind farm in 2029, based on Discounted Cash Flow (DCF) analysis, estimates an equity value of €21.9m and an enterprise value of €61.4m. These figures are based on a 7.5% discount rate, which reflects industry standards (slightly below) for fully operational wind assets with limited risk. The project's internal rate of return (IRR) is projected to be 23.6%, a strong return for infrastructure investments, driven by the leveraged financing used during the construction phase. Entrepreneurs should ensure their projects are structured to attract investors by demonstrating strong financial returns through sound valuation methods.
- **Sensitivity to Key Assumptions**: Sensitivity analyses reveal that changes in key variables, such as the discount rate, exit year, and refinancing terms, can significantly impact the project's returns. For example, delaying the exit year from 2029 to 2033 reduces the IRR but increases the total value to paid-in capital (TVPI), as more dividends are distributed over time. Similarly, increasing the target debt service coverage ratio (DSCR) improves returns, while higher refinancing margins reduce profitability. Entrepreneurs must conduct thorough sensitivity analyses to understand how changes in financial and operational assumptions affect the overall viability of their projects.
- **Wind Resource and Operational Factors**: The most critical factor influencing the project's financial performance is the wind resource, with net equivalent hours (NEH) ranging from 2,400 to 3,000 having a significant impact on returns. The sensitivity analysis shows that higher NEH results in a substantial increase in both IRR and TVPI. Conversely, changes in the number of turbines have a more modest effect on financial outcomes, indicating that the site's wind resource is the primary driver of success. Entrepreneurs should prioritize accurate wind resource assessments and optimize turbine placement to maximize energy production and financial returns.
- **SDGs**: The development and operation of the wind farm project is highly aligned with several Sustainable Development Goals (SDGs), particularly Goals #7 (Affordable and Clean Energy), #9 (Industry, Innovation and Infrastructure), #11 (Sustainable Cities and

Communities), and #13 (Climate Action). This alignment showcases how the project not only addresses Spain's renewable energy targets but also contributes to global efforts in sustainability. By generating clean, renewable energy and promoting technological innovation, the project advances the creation of sustainable infrastructure, fosters inclusive growth, reduces dependence on fossil fuels, and combats climate change. Entrepreneurs engaging in similar ventures should aim to integrate these SDGs into their projects to ensure they contribute to both local and global sustainability efforts.

CHAPTER 9. REFERENCES

[1] Repsol. (n.d.). *Energy Yearbook*. Repsol. Retrieved from https://www.repsol.com/en/technology-and-digitalization/energy-yearbook/index.cshtml

[2] Repsol. (2023). *Annual Energy Statistics 2023*. Repsol.

[3] Red Eléctrica de España. (2023, December). *Renewable energy breaks records and accounts for more than 50% of electricity generation in Spain*. REE. Retrieved from https://www.ree.es/en/press-office/press-release/news/press-release/2023/12/Renewable-energy-breaks-records-and-accounts-for-more-than-50-per-cent-of-electricity-generation-Spain-2023

[4] Red Eléctrica de España. (n.d.). *Generación: Potencia instalada*. REE. Retrieved from https://www.sistemaelectrico-ree.es/informe-del-sistema-electrico/generacion/potencia-instalada

[5] Asociación Empresarial Eólica (AEE). (n.d.). *Wind energy in Spain*. AEE. Retrieved from https://aeeolica.org/en/about-wind-energy/wind-energy-in-spain/

[6] IFEMA Global Mobility Call. (n.d.). *The potential of solar energy in Spain*. IFEMA. Retrieved from https://www.ifema.es/en/global-mobility-call/sector-news/the-potential-of-solar-energy-in-spain

[7] Invest in Spain. (n.d.). *Renewable energy*. ICEX. Retrieved from https://www.investinspain.org/en/industries/renewable-energy

[8] Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO). (2021). *Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030*. MITECO. Retrieved from https://www.miteco.gob.es/content/dam/miteco/images/es/pnieccompleto_tcm30-508410.pdf

[9] Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO). (2023). *Borrador para la actualización del PNIEC 2023-2030*. MITECO. Retrieved from https://www.miteco.gob.es/content/dam/miteco/es/energia/files-1/Borrador%20para%20la%20actualizaci%C3%B3n%20del%20PNIEC%202023-2030-64347.pdf

[10] King & Wood Mallesons. (2023). *Renewable energy in Spain: 2023 overview*. KWM. Retrieved from https://www.kwm.com/es/es/insights/latest-thinking/renewable-energy-spain-2023.html

[11] Iberdrola. (n.d.). *Main operational data*. Iberdrola. Retrieved from https://www.iberdrola.com/about-us/figures/main-operational-data

[12] Endesa. (n.d.). *Renewable energies: A commitment to the energy transition*. Endesa. Retrieved from https://www.endesa.com/en/our-commitment/energy-transition/renewable-energies

[13] Naturgy. (n.d.). *Spain: International presence*. Naturgy. Retrieved from https://www.naturgy.com/en/about-us-naturgy/international-presence/spain/

[14] The Roundup. (n.d.). *Wind turbine power curve*. The Roundup. Retrieved from https://theroundup.org/wind-turbine-power-curve/

[15] MDPI. (2023). *Wind turbine dynamics and efficiencies*. *Energies, 16*(1), 180. Retrieved from https://www.mdpi.com/1996-1073/16/1/180

[16] EDP. (2023). *EDP Renewables connects Spain's first wind-solar hybrid project to the grid*. EDP. Retrieved from https://www.edp.com/en/news/edp-renewables-connects-spains-first-wind-solar-hybrid-project-grid#:~:text=Spain%20continues%20to%20be%20a,are%20developing%20green%20hydrogen%20projects

[17] Saeta Yield. (n.d.). *Portfolio of renewable assets*. Saeta Yield. Retrieved from https://www.saetayield.com/activos/

[18] FRV. (n.d.). *Renewable energy projects*. FRV. Retrieved from https://frv.com/projects/

[19] Opdenergy. (2023). *Investor report: H1 2023*. Opdenergy. Retrieved from https://opdenergy.com/wp-content/uploads/2023/10/OPDE-P-1S23-vdef.pdf

[20] Enerside. (2023). *Investor presentation*. Enerside. Retrieved from https://enerside.com/wp-content/uploads/2023/03/PresentacionInversores.pdf

[21] Ignis. (n.d.). *IPP energy generator*. Ignis. Retrieved from https://ignis.es/generador-de-energia-ipp/

[22] TotalEnergies. (n.d.). *Renewable energy development in Spain*. TotalEnergies. Retrieved from https://totalenergies.com/spain

[23] Repsol. (n.d.). *Developing renewable energies*. Repsol. Retrieved from https://www.repsol.com/en/about-us/what-we-do/developing-renewable-energies/index.cshtml

[24] Galp. (n.d.). *Renewable energy projects*. Galp. Retrieved from https://www.galp.com/corp/en/about-us/what-we-do/renewables-new-businesses/renewables

[25] Siemens Gamesa. (n.d.). *Wind energy solutions*. Siemens Gamesa. Retrieved from https://www.siemensgamesa.com/es-es

[26] Funcas. (2023). *Renewable energy developments in Spain*. Funcas. Retrieved from https://www.funcas.es/wp-content/uploads/Migracion/Articulos/FUNCAS_CIE/252art07.pdf

[27] EDP. (n.d.). *Renewable energy auctions in Spain*. EDP. Retrieved from https://www.edpenergia.es/es/blog/electricidad-y-gas-para-empresas/subastas-energia-renovable/

[28] Energía y Sociedad. (n.d.). *Manual de la energía: Regulación española de las energías renovables*. Energía y Sociedad. Retrieved from https://www.energiaysociedad.es/manual-de-la-energia/3-5-regulacion-espanola-de-las-energias-renovables/

[29] Lupicinio International Law Firm. (n.d.). *Evolución del sistema retributivo de la energía renovable en España*. Lupicinio. Retrieved from https://lupicinio.com/evolucion-del-sistema-retributivo-de-la-energia-renovable-en-espana/

[30] Cuatrecasas. (2020). *Regulación sobre energías renovables en España*. Cuatrecasas. Retrieved from https://www.cuatrecasas.com/resources/1609766096es-600872e3bbf43648796874.pdf?v1.65.0.20231214

[31] Garrigues. (2022). *Real Decreto-ley 6/2022: Principales medidas en el sector eléctrico y generación de energía eléctrica*. Garrigues. Retrieved from https://www.garrigues.com/es_ES/noticia/real-decreto-ley-62022-principales-medidas-sector-electrico-generacion-energia-electrica

[32] Iberdrola. (n.d.). *Wind turbines and blades*. Iberdrola. Retrieved from https://www.iberdrola.com/sustainability/wind-turbines-blades

[33] Enel Green Power. (n.d.). *Wind energy: How it works*. Enel. Retrieved from https://www.enelgreenpower.com/learning-hub/renewable-energies/wind-energy/wind-turbine

[34] Windmills Tech. (n.d.). *Wind turbine blade forces*. Windmills Tech. Retrieved from https://windmillstech.com/wind-turbine-blade-forces/

[35] Windmills Tech. (n.d.). *Wind turbine components*. Windmills Tech. Retrieved from https://windmillstech.com/wind-turbine-components/

[36] Tutorials Point. (n.d.). *Difference between horizontal-axis and vertical-axis wind turbines*. Tutorials Point. Retrieved from https://www.tutorialspoint.com/difference-between-horizontal-axis-and-vertical-axis-wind-turbines

[37] U.S. Department of Energy. (n.d.). *Wind turbines: Bigger and better*. DOE. Retrieved from https://www.energy.gov/eere/articles/wind-turbines-bigger-better

[38] Reoltec. (n.d.). *La industria eólica española*. Reoltec. Retrieved from https://reoltec.net/la-industria-eolica-espanola/

[39] Energética21. (2021). *España está a la cabeza en la fabricación de aerogeneradores*. Energética21. Retrieved from https://energetica21.com/noticia/espana-esta-a-la-cabeza-en-la-fabricacion-de-aerogeneradores

[40] Asociación Empresarial Eólica (AEE). (n.d.). *La eólica en España*. AEE. Retrieved from https://aeeolica.org/sobre-la-eolica/la-eolica-en-espana/

[41] Eólica Vertical. (2019). *Eólica onshore vs offshore*. Eólica Vertical. Retrieved from http://www.eolivertical.es/2019/08/28/eolica-onshore-vs-offshore/

[42] Stevens Engineering. (n.d.). *Difference between offshore and onshore wind energy*. Stevens Engineering.

[43] Ideas Medioambientales. (n.d.). *Distancias entre aerogeneradores*. Ideas Medioambientales. Retrieved from https://ideasmedioambientales.com/distancias-entre-aerogeneradores/

[44] Iberdrola. (n.d.). *How onshore wind farms work*. Iberdrola. Retrieved from https://www.iberdrola.com/sustainability/how-onshore-wind-farms-work

[45] Transect. (n.d.). *Steps to secure a wind farm development site*. Transect. Retrieved from https://www.transect.com/blog/steps-to-secure-a-wind-farm-development-site

[46] Agricultural Marketing Resource Center (AgMRC). (n.d.). *Steps to wind farm development*. AgMRC.

[47] Seguro Renovables. (n.d.). *Permisos de acceso y conexión a la red eléctrica*. Seguro Renovables. Retrieved from https://www.segurorenovables.com/punto-conexion-fotovoltaica/permisos-acceso-y-conexion-red/#Caducidad_de_permisos_de_acceso_y_conexion

[48] Red Eléctrica de España (REE). (n.d.). *Normativa, guías, formularios y otra documentación*. REE. Retrieved from https://www.ree.es/es/clientes/generador/acceso-conexion/normativa-guias-formularios-y-otra-documentacion

[49] Red Eléctrica de España (REE). (n.d.). *FAQs sobre el acceso y conexión a la red*. REE. Retrieved from https://www.ree.es/es/clientes/generador/acceso-conexion/te-ayudamos-con-unas-faqs

[50] Red Eléctrica de España (REE). (n.d.). *Conoce la capacidad de acceso a la red eléctrica*. REE. Retrieved from https://www.ree.es/es/clientes/generador/acceso-conexion/conoce-la-capacidad-de-acceso

[51] Cambio Energético. (n.d.). *Acceso y conexión a la red eléctrica en 2021*. Cambio Energético. Retrieved from https://www.cambioenergetico.com/blog/acceso-conexion-red-electrica-2021/

[52] Fundación Naturgy. (2022). *La promoción de generación renovable en España*. Fundación Naturgy.

[53] Seguro Renovables. (n.d.). *Declaración de impacto ambiental para proyectos renovables*. Seguro Renovables. Retrieved from https://www.segurorenovables.com/punto-conexion-fotovoltaica/declaracion-de-impacto-ambiental/

[54] Comisión Nacional de los Mercados y la Competencia (CNMC). (n.d.). *Informe de renovables y autoconsumo en España*. CNMC.

[55] Sfera Proyecto Ambiental. (n.d.). *Estudio de impacto ambiental para proyectos renovables*. Sfera Proyecto Ambiental. Retrieved from https://www.sferaproyectoambiental.com/estudio-renovables

[56] Wind Farm Balance of Plant (BoP). (n.d.). *What is BoP in wind farms?*. Wind Farm BoP. Retrieved from https://www.windfarmbop.com/what-is-this-bop/

[57] Wind Farm Balance of Plant (BoP). (n.d.). *Construction contracts for wind farms*. Wind Farm BoP. Retrieved from https://www.windfarmbop.com/wind-farms-construction-contracts/

[58] Heavy Goods. (n.d.). *Wind farm construction logistics*. Heavy Goods. Retrieved from https://heavygoods.net/

[59] Long International. (n.d.). *Onshore wind farm construction overview*. Long International. Retrieved from https://www.long-intl.com/blog/onshore-wind-farm-construction/

[60] Adurcal. (n.d.). *Viabilidad de proyectos eólicos*. Adurcal. Retrieved from https://www.adurcal.com/enlaces/mancomunidad/viabilidad/57.htm

[61] BloombergNEF. (2023). *Corporate clean power buying grew 12% to new record in 2023*. BloombergNEF. Retrieved from https://about.bnef.com/blog/corporate-clean-power-buying-grew-12-to-new-record-in-2023-according-to-bloombergnef/

[62] Pexapark. (2024). *European PPA Market Outlook 2024*. Pexapark.

[63] Iberdrola. (n.d.). *Energy contracts: Power Purchase Agreements (PPA)*. Iberdrola. Retrieved from https://www.iberdrola.com/about-us/contracts-ppa-energy

[64] Seguro Renovables. (n.d.). *PPA de energía renovable: Tipos de contratos*. Seguro Renovables. Retrieved from https://www.segurorenovables.com/punto-conexion-fotovoltaica/ppa-de-energia-renovable/#PPA_Virtual_o_Sintetico

[65] Comisión Nacional de los Mercados y la Competencia (CNMC). (n.d.). *Procedimientos asociados a garantías de origen para renovables y cogeneración*. CNMC. Retrieved from https://sede.cnmc.gob.es/tramites/energia-electricidad/procedimientos-asociados-garantias-de-origen-renovables-cogeneracion

[66] OMIE. (n.d.). *Mercado diario de electricidad: Informe técnico*. OMIE.

[67] OMIE. (n.d.). *Mercados intradiarios y continuos: Informe de operación*. OMIE. Retrieved from https://www.omie.es/sites/default/files/inline-files/mercados_intradiario_y_continuo.pdf

[68] Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO). (2022). *Preguntas frecuentes sobre renovables*. MITECO. Retrieved from https://www.miteco.gob.es/content/dam/miteco/es/energia/files-1/renovables/preguntas-frecuentes/preguntasfrecuentes/20220606_FAQS%20-%20Descargable.pdf

[69] Villafranca, A. (2022). *Renewable energy remuneration in Spain*. In *Renewable Energy Policy in Spain* (pp. 155-175).

[70] BOE. (2022). *Real Decreto-ley 23/2022: Energías renovables*. Boletín Oficial del Estado (BOE). Retrieved from https://www.boe.es/diario_boe/txt.php?id=BOE-A-2022-21138

[71] Magnus CMD. (n.d.). *Nuevo régimen económico de energías renovables en España*. Magnus CMD. Retrieved from https://magnuscmd.com/es/el-nuevo-regimen-economico-de-la-energia-renovable-en-espana/

[72] International Energy Agency (IEA) & Nuclear Energy Agency (NEA). (2020). *Projected Costs of Generating Electricity: 2020 Edition*. Paris: OECD Publishing.

[73] Lazard. (2023). *Lazard's Levelized Cost of Energy Plus (LCOE+) - April 2023*.

[74] NOAA - National Centers for Environmental Information, & US Air Force - 14th Weather Squadron. (2018). *Federal Climate Complex Data Documentation for Integrated Surface Data (ISD)*. Asheville, NC: NOAA National Centers for Environmental Information.

[75] Universidad del País Vasco (UPV/EHU). (n.d.). *Estadísticas del viento*. Retrieved from http://www.sc.ehu.es/sbweb/fisica3/datos/viento/estadistica.html

[76] NOAA - National Centers for Environmental Information. (n.d.). *Hourly weather observations*.

[77] Renewable Energy. (n.d.). *Wind power*. Retrieved from http://students.aiu.edu/submissions/profiles/resources/onlineBook/q7P4s5_renewable-energy-Wind-Power.pdf

[78] The Wind Power. (n.d.). *GE Energy 5.3-158 turbine specifications*. Retrieved from https://www.thewindpower.net/turbine_es_1645_ge-energy_5.3-158.php

[79] The Wind Power. (n.d.). *Siemens Gamesa SG-2.1-114 turbine specifications*. Retrieved from https://www.thewindpower.net/turbine_es_1661_siemens-gamesa_sg-2.1-114.php

[80] The Wind Power. (n.d.). *Vestas V150-4000/4200 turbine specifications*. Retrieved from https://www.thewindpower.net/turbine_es_1490_vestas_v150-4000-4200.php

[81] Revista de Ingeniería, Diseño y Empresa. (2022). *Evaluación del diseño de turbinas eólicas*.

[82] Schaffarczyk, A. (2014). *Understanding Wind Power Technology: Theory, Deployment and Optimisation*.

[83] Ramírez González, P. (2006). *Modelado estadístico de las características del viento para su evaluación energética: Aplicación a las Islas Canarias* (Tesis doctoral). Universidad de Las Palmas de Gran Canaria, Departamento de Ingeniería Mecánica.

[84] United Nations. (n.d.). *Sustainable Development Goals (SDGs)*. United Nations.

APPENDIX A

```
clc
clear all

% Data of the wind turbine power curve (wind speed and generated power)
data_SG = [0, 0; 0.5, 0; 1.0, 0; 1.5, 0; 2.0, 0; 2.5, 0; 3.0, 0; 3.5, 48;
4.0, 169; 4.5, 350; 5.0, 593; 5.5, 930; 6.0, 1307; 6.5, 1737; 7.0, 2186;
7.5, 2730; 8.0, 3278; 8.5, 3980; 9.0, 4687; 9.5, 5400; 10.0, 6112; 10.5,
6690; 11.0, 7249; 11.5, 7570; 12.0, 7795; 12.5, 7895; 13.0, 7947; 13.5,
7990; 14.0, 8000; 14.5, 8000; 15.0, 8000; 15.5, 8000; 16.0, 8000; 16.5,
8000; 17.0, 8000; 17.5, 8000; 18.0, 8000; 18.5, 8000; 19.0, 8000; 19.5,
8000; 20.0, 8000; 20.5, 8000; 21.0, 8000; 21.5, 8000; 22.0, 8000; 22.5,
8000; 23.0, 8000; 23.5, 8000; 24.0, 8000; 24.5, 8000; 25.0, 8000; 25.5, 0;
26.0, 0; 26.5, 0; 27.0, 0; 27.5, 0; 28.0, 0; 28.5, 0; 29.0, 0; 29.5, 0;
30.0, 0];

data_V = [0 0; 0.5 0; 1.0 0; 1.5 0; 2.0 0; 2.5 0; 3.0 78; 3.5 172; 4.0
287; 4.5 426; 5.0 601; 5.5 814; 6.0 1069; 6.5 1367; 7.0 1717; 7.5 2110;
8.0 2546; 8.5 3002; 9.0 3428; 9.5 3773; 10.0 4012; 10.5 4131; 11.0 4186;
11.5 4198; 12.0 4200; 12.5 4200; 13.0 4200; 13.5 4200; 14.0 4200; 14.5
4200; 15.0 4200; 15.5 4200; 16.0 4200; 16.5 4200; 17.0 4200; 17.5 4200;
18.0 4200; 18.5 4200; 19.0 4200; 19.5 4200; 20.0 4200; 20.5 4200; 21.0
4200; 21.5 4200; 22.0 4200; 22.5 4200; 23.0 0; 23.5 0; 24.0 0; 24.5 0;
25.0 0; 25.5 0; 26.0 0; 26.5 0; 27.0 0; 27.5 0; 28.0 0; 28.5 0; 29.0 0;
29.5 0; 30.0 0];

data_GE = [0 0; 0.5 0; 1.0 0; 1.5 0; 2.0 0; 2.5 0; 3.0 88; 3.5 186; 4.0
310; 4.5 466; 5.0 657; 5.5 892; 6.0 1168; 6.5 1496; 7.0 1876; 7.5 2303;
8.0 2761; 8.5 3227; 9.0 3668; 9.5 4075; 10.0 4452; 10.5 4762; 11.0 4998;
11.5 5165; 12.0 5253; 12.5 5298; 13.0 5300; 13.5 5300; 14.0 5300; 14.5
5300; 15.0 5300; 15.5 5300; 16.0 5300; 16.5 5300; 17.0 5300; 17.5 5300;
18.0 5300; 18.5 5300; 19.0 5300; 19.5 5300; 20.0 5300; 20.5 5300; 21.0
5300; 21.5 5300; 22.0 5300; 22.5 0; 23.0 0; 23.5 0; 24.0 0; 24.5 0; 25.0
0; 25.5 0; 26.0 0; 26.5 0; 27.0 0; 27.5 0; 28.0 0; 28.5 0; 29.0 0; 29.5 0;
30.0 0];

ins_cap_SG=8.0;
ins_cap_V=4.2;
ins_cap_GE=5.3;

% Extract wind speed and power data
wind_speed = data_SG(:, 1);

power_SG = data_SG(:, 2);
power_V = data_V(:, 2);
power_GE = data_GE(:, 2);

% Fit a function to the data
```

```
fitting_SG = fit(wind_speed, power_SG, 'poly9'); % Fit to a polynomial of
degree 9
fitting_V = fit(wind_speed, power_V, 'poly9'); % Fit to a polynomial of
degree 9
fitting_GE = fit(wind_speed, power_GE, 'poly9'); % Fit to a polynomial of
degree 9


% Evaluate the fitted function over a range of wind speeds from 0 to 30
m/s
evaluated_wind_speed = linspace(0, 30, 1000); % Evaluation points of wind
speed

fitted_power_SG = feval(fitting_SG, evaluated_wind_speed); % Evaluate the
fitted function
fitted_power_V = feval(fitting_V, evaluated_wind_speed); % Evaluate the
fitted function
fitted_power_GE = feval(fitting_GE, evaluated_wind_speed); % Evaluate the
fitted function

% Graph the fitted function and the data
figure;
plot(wind_speed, power_SG, 'o', 'DisplayName', 'Wind Turbine Data'); %
Graph the data
hold on;
plot(evaluated_wind_speed, fitted_power_SG, 'r-', 'LineWidth', 2,
'DisplayName', 'Polynomial Fit'); % Graph the fitted function
xlabel('Wind Speed (m/s)');
ylabel('Generated Power (kW)');
title('Siemens-Gamesa SG 8.0-167 Wind Turbine Power Function');
legend('Location', 'best');
grid on;

figure;
plot(wind_speed, power_V, 'o', 'DisplayName', 'Wind Turbine Data'); %
Graph the data
hold on;
plot(evaluated_wind_speed, fitted_power_V, 'b-', 'LineWidth', 2,
'DisplayName', 'Polynomial Fit'); % Graph the fitted function
xlabel('Wind Speed (m/s)');
ylabel('Generated Power (kW)');
title('Vestas V150/4000 Wind Turbine Power Function');
legend('Location', 'best');
grid on;

figure;
plot(wind_speed, power_GE, 'o', 'DisplayName', 'Wind Turbine Data'); %
Graph the data
hold on;
```

```
plot(evaluated_wind_speed, fitted_power_GE, 'm-', 'LineWidth', 2,
'DisplayName', 'Polynomial Fit'); % Graph the fitted function
xlabel('Wind Speed (m/s)');
ylabel('Generated Power (kW)');
title('General Electric 5.3-158 Wind Turbine Power Function');
legend('Location', 'best');
grid on;

% Weibull distribution parameters
k = 1.4586; % Shape parameter
c = 7.8153; % Scale parameter

% Define the Weibull probability density function (PDF)
weibull_pdf = @(x) (k / c) * (x / c).^(k - 1) .* exp(-(x / c).^k);

% Evaluate the Weibull PDF over the same range of wind speeds
weibull_evaluated = weibull_pdf(evaluated_wind_speed);

% Create a new figure
figure;

% Create the first y-axis for wind turbine data
yyaxis left;
plot(wind_speed, power_SG, 'o', 'DisplayName', 'Wind Turbine Data'); %
Graph the data
hold on;
plot(evaluated_wind_speed, fitted_power_SG, 'r-', 'LineWidth', 2,
'DisplayName', 'Polynomial Fit'); % Graph the fitted function
xlabel('Wind Speed (m/s)');
ylabel('Generated Power (kW)');
ylim([0, 8900]); % Set limits for the y-axis
title('Siemens-Gamesa SG 8.0-167 Wind Turbine Power Function');

% Create the second y-axis for the Weibull PDF
yyaxis right;
plot(evaluated_wind_speed, weibull_evaluated, 'g--', 'LineWidth', 2,
'DisplayName', 'Weibull PDF'); % Graph the Weibull PDF
ylabel('Weibull PDF');
ylim([0, 0.11]); % Set limits for the y-axis
grid on;

% Create a new figure
figure;

% Create the first y-axis for wind turbine data
yyaxis left;
plot(wind_speed, power_V, 'o', 'DisplayName', 'Wind Turbine Data'); %
Graph the data
hold on;
```

```
plot(evaluated_wind_speed, fitted_power_V, 'b-', 'LineWidth', 2,
'DisplayName', 'Polynomial Fit'); % Graph the fitted function
xlabel('Wind Speed (m/s)');
ylabel('Generated Power (kW)');
ylim([0, 4400]); % Set limits for the y-axis
title('Vestas V150/4000 Wind Turbine Power Function');

% Create the second y-axis for the Weibull PDF
yyaxis right;
plot(evaluated_wind_speed, weibull_evaluated, 'g--', 'LineWidth', 2,
'DisplayName', 'Weibull PDF'); % Graph the Weibull PDF
ylabel('Weibull PDF');
ylim([0, 0.11]); % Set limits for the y-axis
grid on;

% Show the legend
legend('Location', 'best');

figure;
yyaxis left;
plot(wind_speed, power_GE, 'o', 'DisplayName', 'Wind Turbine Data'); %
Graph the data
hold on;
plot(evaluated_wind_speed, fitted_power_GE, 'm-', 'LineWidth', 2,
'DisplayName', 'Polynomial Fit'); % Graph the fitted function
xlabel('Wind Speed (m/s)');
ylabel('Generated Power (kW)');
ylim([0, 5500]); % Set limits for the y-axis
title('General Electric 5.3-158 Wind Turbine Power Function');
yyaxis right;
plot(evaluated_wind_speed, weibull_evaluated, 'g--', 'LineWidth', 2,
'DisplayName', 'Weibull PDF'); % Graph the Weibull PDF
ylabel('Weibull PDF');
ylim([0, 0.11]); % Set limits for the y-axis
grid on;
legend('Location', 'best');

% Integrate the product
produced_energy_SG = integral(@(x) fitting_SG(x) * weibull_pdf(x), 0, 30,
'ArrayValued', true)
produced_energy_V = integral(@(x) fitting_V(x) * weibull_pdf(x), 0, 30,
'ArrayValued', true)
produced_energy_GE = integral(@(x) fitting_GE(x) * weibull_pdf(x), 0, 30,
'ArrayValued', true)

MWh_year_SG = produced_energy_SG * 8760/1000
MWh_year_V = produced_energy_V * 8760/1000
MWh_year_GE = produced_energy_GE * 8760/1000

Net_Equivalent_Hours_SG = MWh_year_SG/ins_cap_SG
```

```
Net_Equivalent_Hours_V = MWh_year_V/ins_cap_V
Net_Equivalent_Hours_GE = MWh_year_GE/ins_cap_GE

figure;
yyaxis left;
plot(evaluated_wind_speed, fitted_power_SG, 'r-', 'LineWidth', 2,
'DisplayName', 'Siemens-Gamesa');
hold on;
plot(evaluated_wind_speed, fitted_power_V, 'b-', 'LineWidth', 2,
'DisplayName', 'Vestas');
plot(evaluated_wind_speed, fitted_power_GE, 'm-', 'LineWidth', 2,
'DisplayName', 'General Electric');
ylabel('Generated Power (kW)');
ylim([0, 8900]); % Adjust the y-axis limits
yyaxis right;
plot(evaluated_wind_speed, weibull_evaluated, 'g--', 'LineWidth', 2,
'DisplayName', 'Weibull PDF');
ylabel('Weibull PDF');
ylim([0, 0.11]); % Adjust the y-axis limits
xlabel('Wind Speed (m/s)');
title('Comparison of Turbine Power Curves with Weibull PDF');
legend('Location', 'best');
```

APPENDIX B

V150-4.2 MW™ IEC IIIB/IEC S

Power regulation	Pitch regulated with variable speed

Operating data

Rated power	4,000kW/4,200kW
Cut-in wind speed	3m/s
Cut-out wind speed	24.5m/s
Re cut-in wind speed	22.5m/s
Wind class	IEC IIIB/IEC S

Standard operating temperature range from -30°C* to +45°C with de-rating above 30°C (4,000kW)

* Subject to different temperature options

Sound power

Maximum	104.9dB(A)*

*Sound Optimised Modes dependent on site and country

Rotor

Rotor diameter	150m
Swept area	17,671m²
Air brake	full blade feathering with 3 pitch cylinders

Electrical

Frequency	50/60Hz
Converter	full scale

Gearbox

Type	two planetary stages and one helical stage

Tower

Hub heights	105m (IEC) 123m (DIBt) 145m (DIBt) 155m (IEC) 166m (DIBt)

Nacelle dimensions

Height for transport	3.5m
Height installed (incl. CoolerTop®)	8.4m
Length	12.96m
Width	3.98m

Hub dimensions

Max. transport height	3.5m
Max. transport width	3.7m
Max. transport length	5.5m

Blade dimensions

Length	73.7m
Max. chord	4.2m

Max. weight per unit for transportation	70 metric tonnes

Turbine options

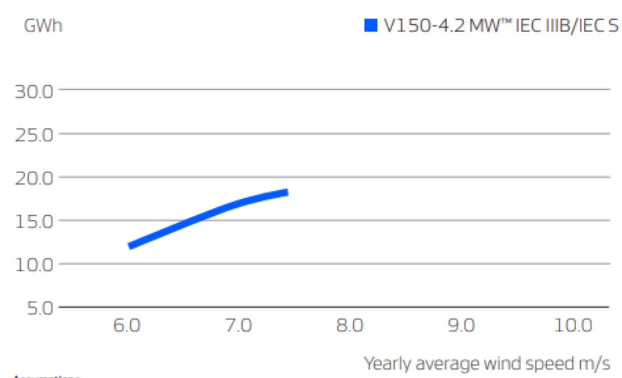
- 4.2 MW and 4.5 MW Power Optimised Modes (site specific)
- Load Optimised Modes down to 3.6 MW
- Condition Monitoring System
- Service Personnel Lift
- Vestas Anti-Icing System™
- Vestas Ice Detection
- Low Temperature Operation to -30°C
- Fire Suppression
- Shadow detection
- Vestas Bat Protection System
- Aviation Lights
- Aviation Markings on the Blades
- Vestas InteliLight®
- Nacelle Hatch for Air Inlet

Sustainability

Carbon Footprint	7.3g CO_2e/kWh
Return on energy break-even	7.6 months
Lifetime return on energy	21 times
Recyclability rate	88.1%

Configuration: 155m hub height and wind class IECIIIB. Depending on site-specific conditions. Metrics are based on an externally reviewed Life Cycle Assessment available on vestas.com

Annual energy production



Assumptions
One wind turbine, 100% availability, 0% losses, k factor = 2
Standard air density = 1.225, wind speed at hub height