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Trabajo Fin de Máster

Estudio detallado del potencial e integración efectiva de las energías renovables en España
Resumen

An in-depth analysis of the renewable energy potential and its effective integration in Spain
Summary

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Abstract

Pese a que la contaminación está cambiando el balance energético que se ha ido imponiendo a lo largo de millones de años, la mayor parte de la energía que se genera actualmente proviene de combustibles fósiles tales como el carbón, petróleo y gas natural. La característica principal de estas fuentes de energía es que no son capaces de regenerarse a un ratio suficiente para poder sostener una extracción rentable, en los aspectos económico y ecológico, en términos de tiempo a escala humana. Es decir, una vez que se consumen no pueden ser reemplazados.

Asimismo, una gran cantidad de países han notificado una notable reducción en las cantidades de estos recursos y sufren las consecuencias que ello acarrea. No sólo tienen un efecto medioambiental negativo sino que, también, pueden provocar daños muy perjudiciales a la economía del país en cuestión.

Sin embargo, las fuentes no renovables todavía son la base de la energía actualmente. A pesar de lo cual, la sociedad comienza a ser cada vez más consciente de los efectos perjudiciales que está clase de recursos condicionan y una nueva tendencia vienen creciendo desde los últimos años: las fuentes renovables de energía. A diferencia de las fuentes no renovables, éstas pueden regenerarse a ratios más rápidos que a los que son consumidas. El sol, el viento, el agua y la biomasa, por ejemplo, son fuentes renovables muy comunes que pueden aprovecharse fácilmente.

A lo largo de este resumen, se muestra y explica, en menor detalle que en la memoria en inglés, un estudio de como las energías renovables van ganando terreno tanto en el territorio peninsular como en los archipiélagos asociados, Islas Canarias y Archipiélago Balear.

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Índice

1. Introducción

1.1. Motivación

El sector energético a escala global está sufriendo una transformación gradual debido a la actual concienciación sobre la sostenibilidad y el cambio climático. La Unión Europea se ha mostrado como un referente en esta área, que otros países toman como ejemplo. España se encuentra entre uno de los mayores países de la Unión y por tanto juega un rol de sustancial importancia en referencia a la definición de la economía de la misma. En el sector energético, sin embargo, España se ha considerado de alguna manera “aislada” debido a la escasez de intercambio energético con sus países vecinos. España cuenta con gran cantidad de horas de sol, lo cual se puede traducir en un gran potencial para la energía solar, junto con otros potenciales destacables en eólica, hidroeléctrica y biomasa. En este trabajo de fin de máster se realiza un esfuerzo para poder entender la situación energética actual del país, hacer un análisis del potencial disponible e identificar los desafíos que el país debe afrontar para conseguir una integración efectiva y adecuada del potencial renovable dentro del mix energético español. Se exploran algunos proyectos interesantes como la energía de las olas y zonas en desarrollo y, además, se destaca al final del trabajo la importancia de la red eléctrica española para poder garantizar la estabilidad de la totalidad de la red europea.

1.2 Problemas abordados

- ¿Qué desafíos representan un obstáculo para el desarrollo de un sector energético renovable y sostenible en España?
- ¿Puede el país seguir los objetivos energéticos y climáticos establecidos por la Unión Europea?
- ¿Cómo de importante es el mejorar la capacidad de intercambio internacional para España?
- ¿Qué métodos son efectivos para la promoción de fuentes renovables en España?
- ¿Es posible la consecución efectiva de los objetivos renovables con las políticas energéticas y subsidios actuales?

1.3 Metodología

Recolección de información para un primer entendimiento sobre la situación de la energía primaria en España.

Análisis general sobre la demanda, consumo y generación de electricidad en España.

Análisis del potencial disponible actualmente en el país de las energías hidroeléctrica, eólica (marina y terrestre), fotovoltaica, solar termoeléctrica, biomasa y undimotriz.

Los objetivos energéticos y climáticos de la UE y la situación de España en cuanto a su consecución.

Entendimiento de cómo España está considerada “aislada” de la red eléctrica Europea y las posibles implicaciones del aumento del intercambio internacional. Identificación de los futuros proyectos de intercambio más relevantes y sus consecuencias.

Breve perspectiva sobre el sector eléctrico español.

2. Situación energética global y renovable actual

Como primera impresión de España, cualquiera puede imaginar que una región periférica como ésta podría registrar un gran potencial renovable debido a sus características climatológicas y geográficas. Sin embargo, las impresiones no siempre concuerdan con la realidad. A lo largo de este apartado se explicará como las energías primaria y final son obtenidas y consumidas para obtener una idea global de la situación en España.

Como una gran mayoría de países europeos, España se encuentra en una transición gradual hacia las energías renovables, lo cual se ve reflejado en un aumento acorde en la contribución registrada de las mismas. Sin embargo, este incremento renovable no significa que España pueda considerarse un país 100% renovable, todo lo contrario, a pesar de los esfuerzos que se realizan todavía es un país fuertemente dependiente de los combustibles fósiles. Por ejemplo, en 2015, un 50% de la energía final consumida tuvo como origen estas fuentes. [4]

De cara a la energía primaria, cabe destacar la considerable diferencia que existe entre la producida y la consumida. Como puede apreciarse en la figura 2.1, que muestra en azul la energía producida y en rojo la consumida, España depende significativamente de los combustibles fósiles lo que provoca que el país se posicione en una situación muy desfavorable, ya que depende casi completamente de importaciones de países diversos debido a la ausencia de productos energéticos autóctonos en cantidad suficiente.

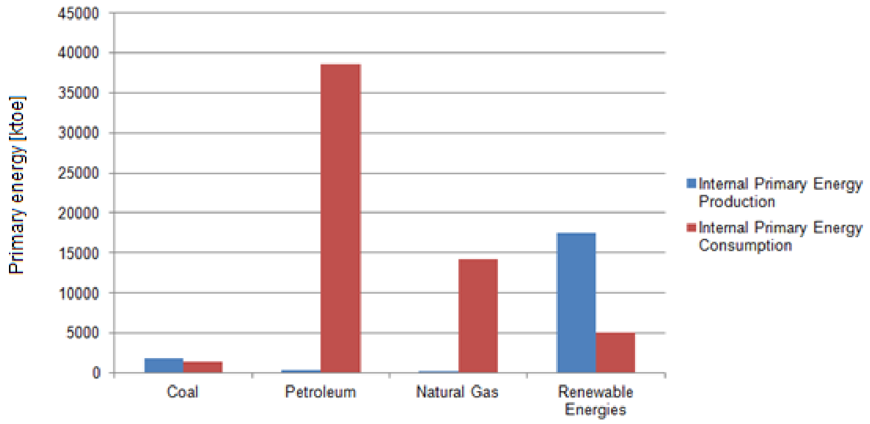


Figure 2.1. Producción de energía primaria en comparación al consumo (2015), SEE/IDAE/MINETUR.

[ktep]	Producción de energía primaria	Consumo de energía primaria
Carbón	1.762,00	1.332,00
Petroleo	375,00	33.642,00
Gas Natural	50,00	14.293,00
Energías renovables	17.450,00	5.102,00

Table 1. Energía primaria producida y consumida, *SEE/IDEA/MINETUR*.

Puede imaginarse que la producción de energía primaria ha mostrado un escaso ratio de auto-suficiencia, debido esencialmente a la gran cantidad de importaciones de productos petrolíferos. Sin embargo, el aumento de contribución renovable contribuye paulatinamente a un aumento de dicho ratio. Esto puede observarse en la siguiente figura 2.2.

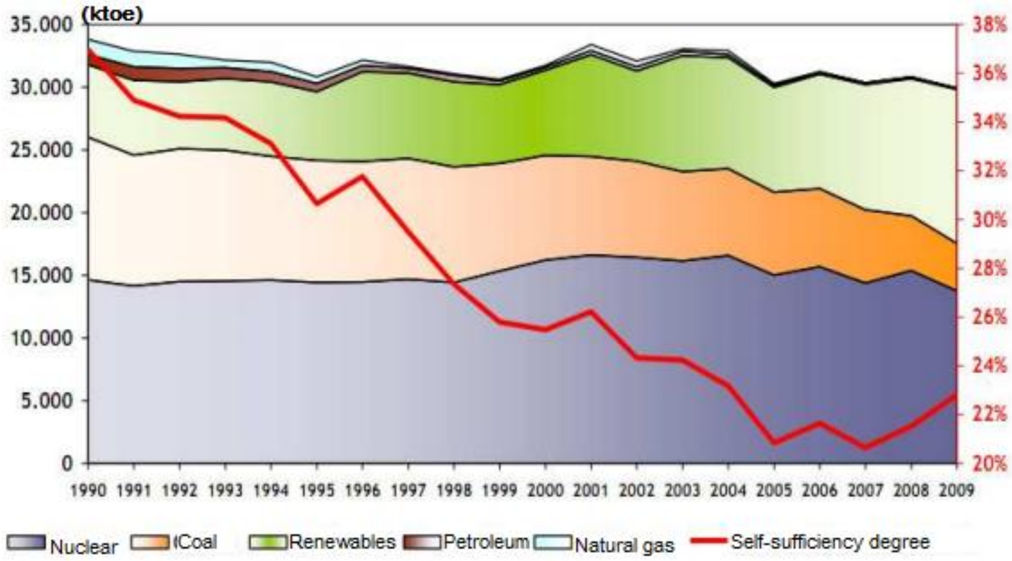


Figure 2.2. Producción de energía primaria y ratio de auto-suficiencia 1990-2009,*[29],MINETUR,IDAE*.

De cara a la energía final consumida en el país, puede verse en la siguiente figura 2.3 como todavía en los sectores de industria y transporte, generalmente los sectores de mayor peso, se basan todavía en combustibles fósiles. [5] [6]

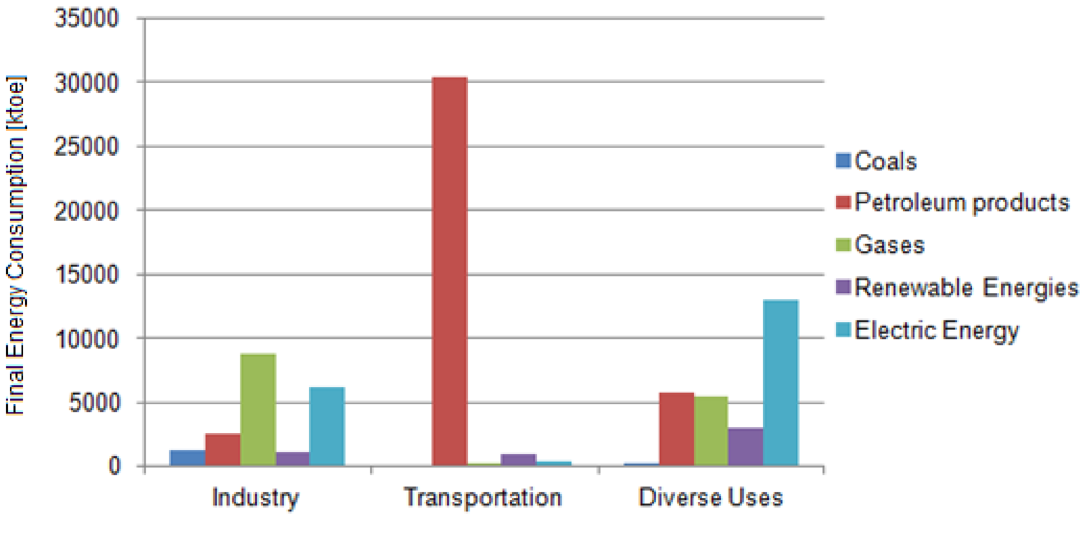


Figura 2.3. Consumo de energía final por sectores y orígenes [ktep], *IDEA/MINETUR*.

Para obtener una idea más detallada tanto de la energía primaria como de la energía final consumidas en España, se muestran a continuación los datos recogidos por el Instituto para la Diversificación y Ahorro de la Energía, IDAE, en el año 2015. Se recogen en las figuras 2.4 y 2.5 a continuación. También, para información más detallada, referirse al Apéndice III.

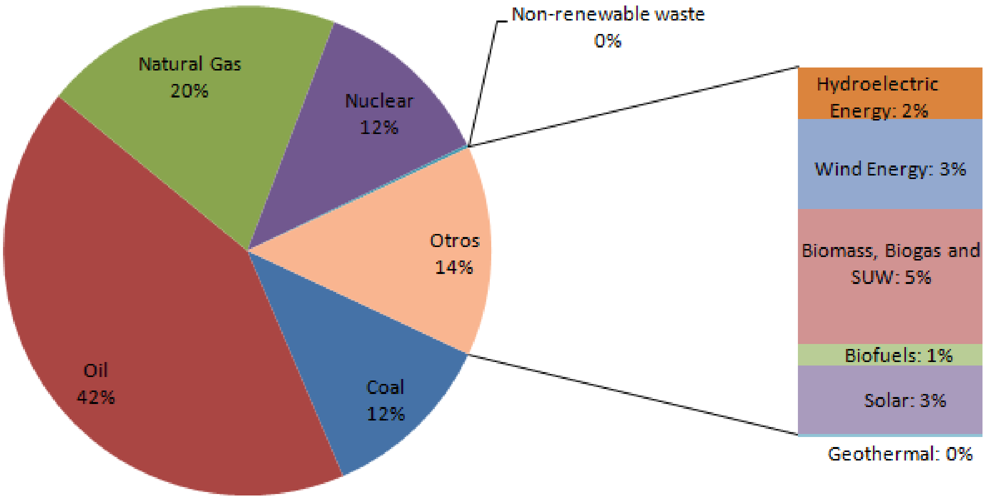


Figura 2.4. Energía primaria consumida y fuentes correspondientes, *IDAE.*

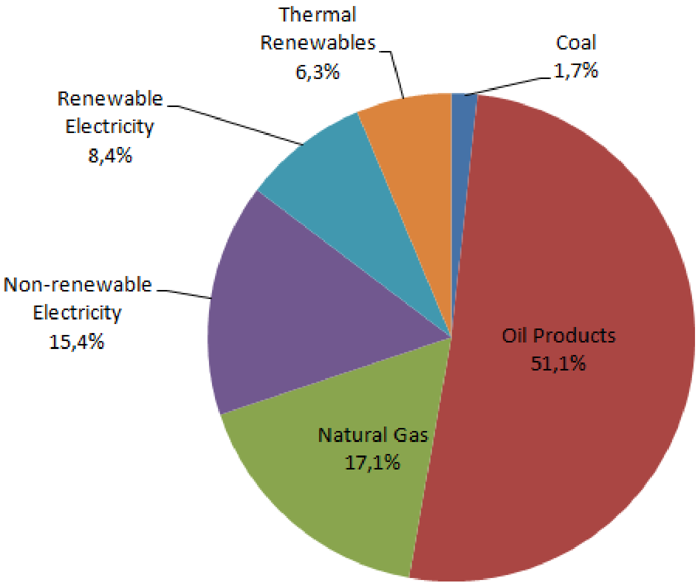


Figura 2.5. Energía final consumida y fuentes correspondientes, *IDAE.*

Puede consultarse también como es la división de los diferentes productos energéticos en los diferentes sectores en el Apéndice IV. Destacan como datos de mayor relevancia: una fuerte dependencia del sector industria especialmente en gas natural y carbón; una práctica totalidad de productos petrolíferos en el sector transporte; y como característica positiva, en el sector doméstico destaca el uso de energías renovables. La electricidad se divide en partes prácticamente equivalentes entre los sectores industria, doméstico y terciario.

Entrando ahora en contexto de las propiamente fuentes renovables, una vez explicada la situación global del país, puede decirse que España se ha puesto a la altura con la tendencia renovable que crece en Europa. De acuerdo al informe anual de REN21, España es uno de los 20 países líderes en generación renovable.

Alrededor de un tercio de la energía eléctrica producida en 2015 tuvo origen renovable y, concretamente, el 51% de dicha cantidad lo proporcionó la energía eólica, que registró cuotas de generación mayores que las de gas natural o carbón y con el 29% aparece seguidamente la energía hidroeléctrica (sin incluir el bombeo). El resto del “pool” eléctrico se generó con un 8,5% de energía fotovoltaica, un 5,9% de solar termoeléctrica y un último 6% mediante un mix de biomasa, biogás y residuos sólidos urbanos.

En el ámbito térmico de las energías renovables, un tercio del mismo fue producido solamente por biomasa – lo que equivale a una producción de 3.936 kilo toneladas equivalentes de petróleo que fueron en su mayoría destinadas al sector doméstico. Los biocombustibles también registraron una gran participación, con una contribución de 1.018 kilo toneladas equivalentes de petróleo (80% biodiesel y 20% biogasolina) y la energía solar térmica, a pesar de lo que podría imaginarse, participa con solo un 6% de la producción. Finalmente, biogás con un 1% y la energía geotérmica, con un 0,5%, cierran el mix térmico de las renovables.

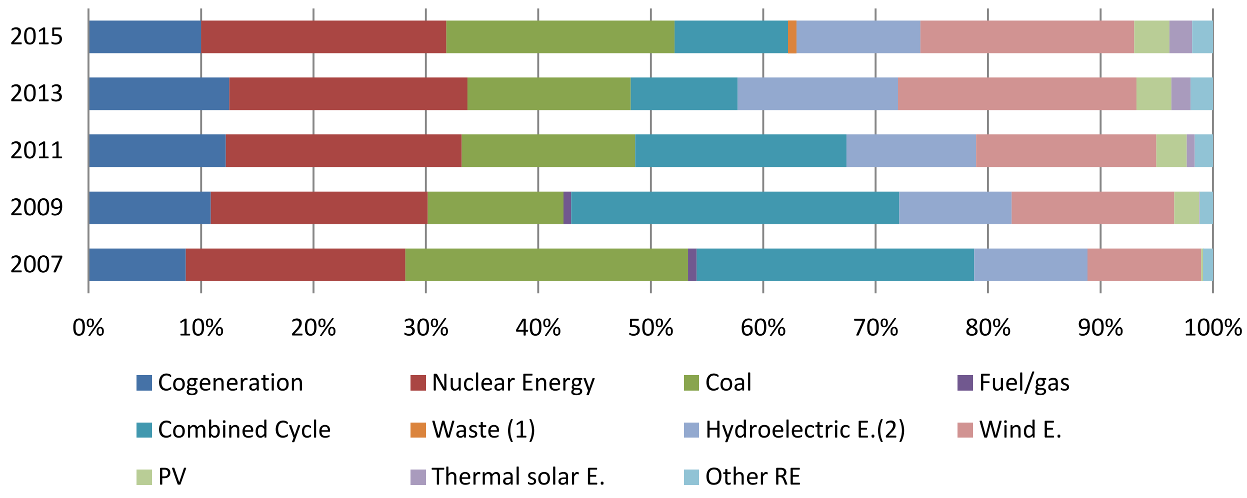
Para información más detallada de la producción renovable durante los años 2014 y 2015, referirse al Apéndice I.

3. El sector eléctrico

En este contexto de la situación energética de España, es muy importante conocer también el estado actual del sector eléctrico y como las energías renovables están, o no, integradas en el mismo. El desarrollo de este sector influye significativamente en el desarrollo de las fuentes renovables.

Nuestro sector eléctrico comenzó su proceso de liberación en el año 1997 que provocó una apertura del mercado a terceras partes y una nueva organización del mismo en la cual toda actividad relacionada con la electricidad deberá llevarse a cabo de manera libre. En él aparecen cuatro participantes principales: generación, transporte, distribución y comercialización de la energía eléctrica. Destacan entre estos las denominadas comercializadoras de referencia, o las cinco grandes eléctricas que acumulan el 90% de las ventas a consumidores directos y el 60% del mercado mayorista. Estas compañías son: Endesa, Iberdrola, Gas Natural, EDP España y Viesgo. El listado de comercializadores y distribuidores puede consultarse en el CD-Rom anexo.

La demanda nacional de electricidad en 2015 alcanzó los 280.481 gigavatios-hora, finalmente mostrando un incremento tras la tendencia negativa que la acompañaba desde el comienzo de la crisis en 2008, con un 36,9% de generación eléctrica. A pesar de que la evolución en la generación renovable puede apreciarse gráficamente en la figura 3.1, cabe destacar que en el año 2015, se registró una menor contribución renovable debido a condiciones climáticas no favorables para el agua y viento, lo que significó una disminución en la generación hidroeléctrica y eólico, por lo que dichas pérdidas fueron suplidas con ciclo combinado y carbón. Además, en la figura 3.2 se muestran las fuentes principales utilizadas. Para más información sobre generación eléctrica en 2015, se encuentran datos más detallados en el apéndice VII.



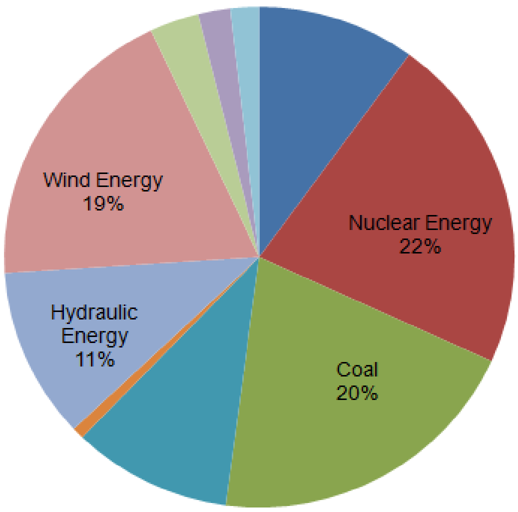


Figure 3.1 & 3.2. Generación eléctrica según su origen, *REE.*

No puede olvidarse en este ámbito, como la gran extensión del país provoca una gran diferencia entre las demandas regionales. Así como, por ejemplo, el pasado año 2015 la Comunidad de Madrid registró una demanda de 28.842 gigavatios-hora cuando Aragón, con una extensión muy superior, registró solamente 10.253 gigavatios-hora.

Con relación a las curvas de demanda, en España se distinguen dos períodos de horas pico y un período de horas valle, que equivaldría a las horas nocturnas. La disparidad que existe entre valle y pico es muy pronunciada en el caso español, al cesar en dicho período las actividades terciarias y residenciales. Son únicamente las industrias y algunos hospitales o alumbrados los que continúan en funcionamiento a altas horas de la madrugada. Debido a lo cual se han establecido en España las denominadas “tarifas con discriminación horaria” que establecen un precio diferente para la electricidad en función de la franja horaria en la que es consumida – menor en horas valle y mayor en horas pico. Mediante esta manera España aboga por una curva de demanda menos pronunciada, es decir una demanda de energía más estable y, por tanto, más sencilla de prever optimizando así la eficiencia del sector eléctrico.

Estas compra-ventas de energías que se producen para que la electricidad pueda llegar finalmente hasta nuestras casas, se producen en el mercado eléctrico. En el caso de la Península, se realizan todas las actividades pertinentes llevadas a cabo por España y Portugal conjuntamente. Se incluyen tres sub-mercados (mercado diario, mercado intradiario y mercado de servicios complementarios) en los que se negocia y establece diariamente el precio de la electricidad para las 24 horas del día siguiente. Los operadores son diferentes en cada uno de los países y, en el caso de España, se encuentran dos operadores diferenciados: OMIE, Operador del Mercado Ibérico – Polo español, encargado de los aspectos económicos; y Red Eléctrica de España, que se encarga de los aspectos técnicos.

El precio final de la electricidad depende de las fuentes que la proporcionan. Es decir, cuando la energía es proporcionada por fuentes renovables como, por ejemplo, la energía eólica los gastos producidos por compra de material se reducen a cero y, por tanto, el precio a pagar por dicha energía será menor. Por ejemplo, en el año 2015 la producción eólica alcanzó un efecto reductor contra energías convencionales de 15 euros, es decir, si no hubiera existido esta tecnología el precio anual de la electricidad hubiera aumentado en un 23,8%. Se destaca así de nuevo la importancia de la integración de las energías renovables en el sistema para optimizar este comportamiento. En la memoria en inglés de este trabajo puede consultarse el ejercicio del mercado español en enero de 2017 como ejemplo. Para mostrar una idea general de la situación actual, en la siguiente tabla 2, se muestra la distribución de fuentes energéticas que generaron la energía en dicho mes en el mercado diario.

Tecnologías	**Mercado diario en Enero**	
	[GWh]	**%**
Carbón	5.368	22,1%
Ciclo Combinado	1.653	6,8%
Energía Nuclear	5.271	21,7%
Energía hidroeléctrica	2.165	8,9%
Importaciones (PT+FR+AD+MA)	1.030	4,3%
Energía eólica	4.889	20,2%
Cogeneración/Residuos/Mini hidroeléctrica	3.869	16,0%
TOTAL	**24.245**	**100,0%**

Table 2. Generación por tecnologías Enero 2017 – Mercado diario, *OMIE.*

Por último, para poder obtener una versión global total del sector eléctrico español y, más aún, entender el propio desarrollo de las energías renovables, es necesario explicar el denominado “déficit de tarifa”, que se puede definir como una deuda reconocida que existía entre las compañías generadoras de electricidad y los consumidores y que es debida a una incorrecta gestión de las tarifas eléctricas. Debido a que los precios establecidos en las facturas no se correspondían con los precios reales que deberían haberse pagado para cargar con los gastos producidos por las actividades de generación, empieza a aparecer una deuda en el año 2000 que se desencadena en 2008 hasta unos 6.300 millones de euros. Desde entonces, se han ido tomando diversas medidas para poder recuperar el valor de la deuda y es aquí donde se afecta en gran medida a la integración de las energías renovables.

El pasado 2013, y para poder acabar con el déficit de tarifa, el gobierno aprueba una nueva reforma para la gestión del mercado eléctrico con la intención acabar con los 4.500 millones de déficit de tarifa que se alcanzaban en el momento. Para ello, establece una nueva reorganización de las empresas generadoras por la que las generadoras de energías renovables pierden su status de "régimen especial" y por el que pasan a ser consideradas al mismo nivel que tecnologías convencionales. Lo cual significa que las renovables pierden sus apoyos y subvenciones y lo único que obtienen "a cambio" es la denominada "rentabilidad razonable". Como es imaginable, en el ámbito renovable, esta medida solo dificultó la integración de las tecnologías en el sector. Más detalles son añadidos en la memoria inglesa de este mismo documento.

Para más información sobre las políticas energéticas, referirse a la memoria inglesa, capítulo 11 y al apéndice VI para los subsidios regionales.

4. La red eléctrica de España

Este complejo intrincado de personalidades, organizaciones y subsistemas se organizan a su vez alrededor de la red eléctrica española. Ésta cuenta con más de 42.000 kilómetros de líneas de alto voltaje, más de 5.000 subestaciones y más de 80.000 mega voltio-amperios de capacidad de transformación.

Cuenta con un único operador, Red Eléctrica de España, encargado tanto de asegurar la continuidad, seguridad y la correcta coordinación entre productores y red de transporte; como de consolidar el equilibrio del sistema, estimando la demanda eléctrica y estableciendo las medidas pertinentes a cada momento; y, además, la tarea de desarrollar y extender la red con su correspondiente mantenimiento. En la siguiente figura 4.1, se muestra el estado de la red en el año 2014.

Figure 4.1. Red eléctrica española a 2014, *REE*.

Además de ser requisito indispensable para el transporte de energía, una correcta expansión de la red favorece a la integración de las fuentes renovables. Los intercambios internacionales con otros sistemas eléctricos aseguran un mejor y más seguro abastecimiento de electricidad, mejoran la eficiencia y competitividad de la red y proporcionan la estabilidad necesaria para poder gestionar de manera eficaz y momentánea la generación renovable, disminuyendo a su vez el precio de la electricidad gracias al aprovechamiento de las tecnologías “verdes”.

Uno de los objetivos europeos establecidos para el año 2020 establece que todos los países pertenecientes a la unión deben de llegar a un ratio de intercambio internacional de al menos 10% con sus países vecinos. España, debido a su situación geográfica con escasez de países vecinos (Francia, Portugal, Andorra y Marruecos), ha sido comúnmente denominada como una “isla energética” y se sitúa actualmente en un ratio del 4% de intercambio internacional. Las capacidades de intercambio comercial actuales se muestran en la siguiente tabla 3.

Conexión	Mínimo [MW]	Máximo [MW]
Francia-España	2.600	3.450
España-Francia	2.100	2.600
Portugal-España	2.700	3.100
España-Portugal	1.900	2.000
Marruecos-España	600	600
España-Marruecos	900	900

Table 3. Commercial exchange capacities from 4th to 17th of Februar 2017, *REE*.

De acuerdo a este objetivo se han establecido en España tres proyectos de mayor importancia, denominados Proyectos de Interés Común, respaldados por la Comisión Europea. Están enfocados al norte peninsular para reforzar las conexiones de alto voltaje con Francia – y a su vez conectarse con el resto de los países de la Unión Europea. Las tres líneas pueden observarse en la siguiente figura 4.2.

Figure 4.2. Conexiones Francia – España planeadas en PCIs, *PCI EU comisión.*

Todos ellos proyectan la instalación de nuevas líneas de corriente continua hasta 2.000 mega vatios de capacidad conectando el norte de España con la región francesa de Aquitania. Con ello se pretenden acercar a España al objetivo europeo aunque las previsiones esperan aumentar el ratio solamente hasta el 8% para 2020. A pesar de lo cual, España podría alejarse de su consideración de "isla energética" para pasar a conseguir una influencia mayor en la red europea y reducir las limitaciones que pueden aparecer cuando aparecen altos ratios de producción renovable.

5. Integración de las energías renovables

A lo largo del siguiente apartado se muestran las diferentes tecnologías y sus principales características que se encuentra en el estado español. Como se ha mencionado anteriormente, España se considera uno de los mayores productores renovables a escala internacional y en 2015 registró el cuarto puesto en la lista de mayor capacidad renovable instalada per cápita. En concreto, España cuenta con cerca de 50.000 mega vatios de potencia renovable instalada y en funcionamiento, la cual se divide de la siguiente manera, tabla 4.

Tecnología	Potencia instalada [MW]	% del total	Número de centrales
Eólica	22.953	46,3%	1.014,0
Hidroeléctrica	18.492	37,3%	283+
Solar fotovoltaica	4.672	9,4%	47,0
Solar térmica	2.254	4,5%	44,0
Biomasa	711	1,4%	44,0
Biogás	214	0,4%	118,0
Residuos sólidos urbanos	305	0,6%	

Tabla 4. Capacidad instalada y número de centrales por tecnología, *elaboración propia*.

No fue hasta los años 80 cuando el gobierno decidió tomar parte activa en este campo. Fue entonces cuando las primeras regulaciones renovables fueron aprobadas y las primeras tecnologías aparecían con cierta importancia dentro del sector eléctrico español. Además, en 1985, se instalaron las primeras plantas mini-hidroeléctricas respaldas por el gobierno y desde entonces más y más capacidad ha ido instalándose como se explica a continuación. Para información más detallada referirse al Apéndice II y Archivo de Excel "Capacity installed".

5.1. Energía hidroeléctrica

La energía hidroeléctrica comenzó a desarrollarse en España hace ya más de un siglo, gracias a lo cual, esta tecnología ha conseguido una importancia significante dentro del mix energético español. Estas centrales presentan una buena eficiencia operativa, una respuesta buena a cambios bruscos de demanda y se han desarrollado de manera por la cual sus efectos medioambientales pueden considerarse lo suficientemente bajos. En el año 2015, la energía hidroeléctrica cubrió el 11,1% de la demanda eléctrica del país y contribuyó un 2% del total de la energía primaria consumida.

Aparecen dos tipos de centrales en España. Por un lado, las centrales de agua fluyente, generalmente no mayores de 5 mega vatios, las cuales representan un 75% del mercado español e incluyen las denominadas centrales micro-centrales hidroeléctricas (aproximada un 5% del mercado); y por el otro, las centrales a pie de presa, con ratios de potencia instalada entre 5 y más de 1.000 mega vatios, que representan el 20% del mercado español. La mayor ventaja de este tipo de centrales es la posibilidad de combinación del “modo turbina” y el modo “bombeo” por el cual a horas de baja demanda energética, la energía producida se emplea en el bombeo de grandes cantidades de agua a alturas elevadas para su almacenamiento.

Entre los más de 1.500 lagos y embalses repartidos por todo el territorio se encuentran más de 800 centrales entre las que destacan:

- Central hidroeléctrica La Muela-Cortes: cuenta con 1.750 mega vatios de generación y 1.280 para bombeo. Produce anualmente 1.625 giga vatios-hora y atiende la demanda anual de 400.000 hogares.
- CH Aguayo I+II: 932 mega vatios de generación y 1.182 de bombeo.
- Aldeadávila I+II: con 1.243 mega vatios instalados, produce anualmente 2.400 giga vatios-hora.

5.2. Energía eólica

La energía eólica se ha consolidado como la mayor fuente renovable en generación eléctrica, gracias a sus casi 23.000 mega vatios de potencia instalada. Su desarrollo comienza alrededor del 2006, con la instalación de las primeras turbinas eólicas. Es interesante destacar aquí como la energía eólica ha acaparado mayor potencial de generación en solo 10 años, que la hidroeléctrica en más de un siglo. El sector eólico en España emplea a 22.468 trabajadores, exporta tecnologías con valor de 2.925 millones de euros y contribuye con 2.731 millones de euros al producto interior bruto del país anualmente. Concretamente, en 2016, la energía eólica produjo 47.319 giga vatios-hora y cubrió el 19,3% de la demanda eléctrica.

De acuerdo a los informes ministeriales, España plantea llegar a los 29.479 mega vatios de potencia instalada en 2020 para convertir a la energía eólica en la tecnología de mayor generación eléctrica, superando así a otras convencionales como el carbón o el ciclo combinado, y llegando a cubrir entre el 21 y el 25% de la demanda total del país.

Entre los parques eólicos más destacables en territorio español se encuentran:

- Dólar III, en Andalucía, del promotor Iberdrola. Alcanza una potencia de 49,5 mega vatios y 25 molinos.
- Tardienta I y su expansión, Tardienta II, que juntos consolidan una potencia de 103,7 mega vatios y 132 turbinas eólicas.
- Muela Cubillo, tiene 50 mega vatios instalados con solo 50 turbinas y se encuentra en Castilla – La Mancha.
- Sil y sus dos consiguientes expansiones. En total, 90 mega vatios con 96 turbinas de diferentes tipos instaladas por Iberdrola.

5.2.1. Tecnologías terrestres y marinas

Cabe destacar en este apartado la notable diferencia que existe entre estos dos tipos de tecnologías actualmente en España. Mientras que en eólica terrestre España se sitúa como uno de los principales países en potencia instalada y generación eléctrica, la eólica marítima tiene una aparición casi mínima. Se ha instalado únicamente un parque eólico marino “Arinaga Off-shore”, con 4 mega vatios de potencia, en las Islas Canarias y se encuentra prácticamente en fase prototipo.

A pesar de que la potencia unitaria de las turbinas marítimas es considerablemente mayor que la de las terrestres y la gran cantidad de litoral español, todavía no es posible aprovechar todo su potencial. La razón simple. Las limitaciones de las tecnologías actuales no concuerdan con las características de profundidad de las costas españolas y, por tanto, hace imposible la instalación de parques eólicos “off-shore”. No sólo eso, la ausencia de infraestructura eléctrica en la costa y la de red eléctrica submarina también ha retrasado su posible desarrollo.

A través de un estudio de viabilidad realizado en 2009 por el Ministerio de medioambiente en conjunto con el Ministerio de industria, turismo y comercio se definen 72 zonas de posible viabilidad de las cuales, únicamente 31 kilómetros cuadrados cumplirían con las especificaciones medioambientales, técnicas y económicas requeridas para una posible inversión en este tipo de tecnologías.

5.3. Energía solar fotovoltaica

Esta tecnología ha sufrido en el ámbito español un desarrollo muy particular. Actualmente se encuentran 4.672 mega vatios instalados a lo largo de la península pero, sin embargo, nada comparable con el desarrollo que se esperaba tras el “boom” fotovoltaico que experimentó el país en el año 2008 y que, debido a sucesivas y restrictivas normativas como el denominado “impuesto solar”, ha sido de alguna manera “olvidado”. España ha pasado de encontrarse como país líder a uno la cola europea en este tipo de tecnología. El desarrollo de la potencia instalada puede verse en la siguiente figura 5.1, desde el “boom” hasta el 2015.

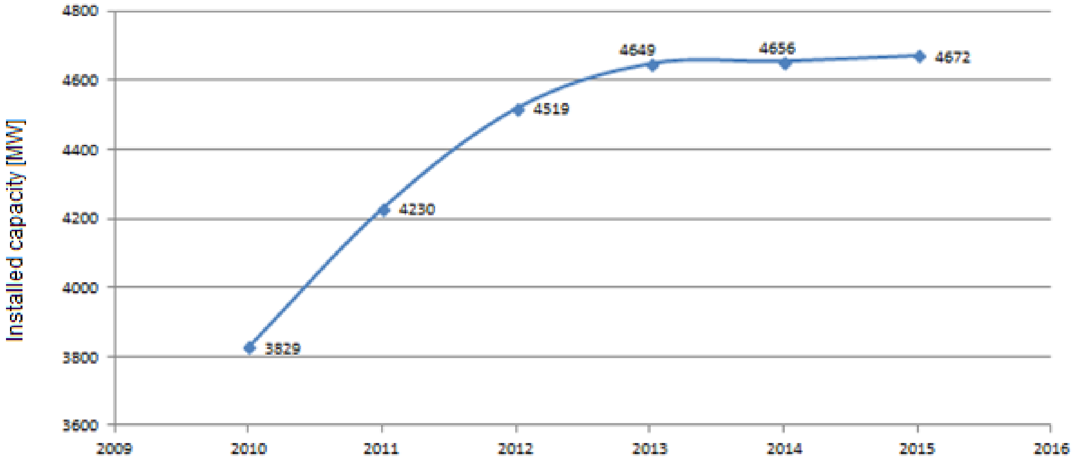


Figure 5.1. Desarrollo de la potencia installada después del “boom”, *UNEF*.

En 2015, la energía fotovoltaica cubrió el 3,1% de la demanda nacional y aporto el 0,57% a la energía primaria total consumida. Además, y de acuerdo con UNEF (la Unión Española Fotovoltaica), solo se instalaron 49 nuevos mega vatios en ese año, lo que representa un escaso 0,09% de los 51.000 mega vatios instalados a nivel mundial.

Sin embargo, no toda perspectiva es negativa. Compañías, tanto locales como extranjeras, son conocedoras el potencial solar que ofrece el país y comienza a plantearse el recuperar la tendencia que crecía en el pasado. Nombres como Hive Energy, X-Elio o SAG Solar-Shunfeng diseñan y plantean la construcción de nuevas plantas fotovoltaicas en la península. En concreto, la revitalización de esta tecnología es imprescindible si España quiere llegar a cumplir los objetivos renovables establecidos para el año 2020.

Como parques fotovoltaicos destacados, se encuentran:

- Solarpark Cáceres, instalado por Wirsol Solar, que cuenta con 10,7 mega watios instalados en 391.645 metros cuadrados y genera anualmente 18.786 mega vatios-hora.
- Elduayen, en Badajoz y gestionado por Tsolar, cuenta con 59.079 paneles que alcanzan los 11,45 mega vatios.
- Parque fotovoltaico Puertollano, Ciudad Real, con más de 50 hectáreas y 70 mega vatios de potencia.
- Parque fotovoltaico Olmedilla de Alarcón, Cuenca, con 60 mega vatios y operado por Nobesol. Se inauguró en 2008 y genera anualmente 87.500 mega vatios-hora.

5.4. Energía solar termoeléctrica

En relación con la energía fotovoltaica, la solar termoeléctrica también muestra un desarrollo irregular. Después de una ausencia de instalación durante dos años, finalmente en 2015 alcanzó los 2.253,9 mega vatios, una cobertura de demanda del 2,1% y una aportación al consumo de energía primaria del 1,8%. Más en detalle, generó 5.113 giga vatios-hora de electricidad en ese mismo año.

La mayor diferencia de esta tecnología es que ha experimentado en los últimos años una gran mejora en eficiencia y expansión del parque termoeléctrico. La mayor ventaja de esta tecnología, reside en el hecho de que puede ser almacenada. Es decir, puede aportar electricidad al sistema incluso en horas sin radiación solar y puede entonces aportar una estabilidad tan necesaria dentro de la red eléctrica. Puede observarse en la siguiente figura 5.2, como la generación de esta tecnología se adapta perfectamente a la curva agregada de la demanda diaria.

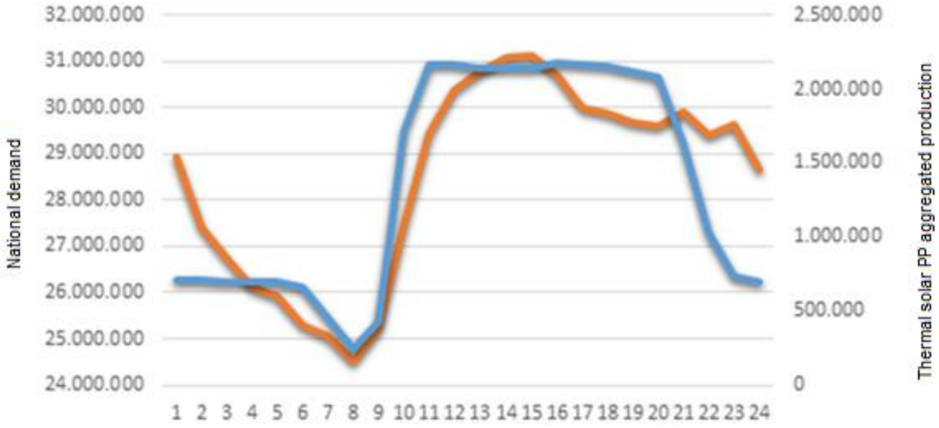


Figure 5.2. Producción agregada termoeléctrica frente a la demanda diaria nacional, *PROTERMOSOLAR*.

España ha conseguido en los últimos años una posición líder en esta tecnología y compañías locales comienzan a expandir proyectos a países extranjeros tales como Estados Unidos, Oriente Medio, China o India entre otros. No sólo eso, de acuerdo con el potencial solar de España, el país confía en la posibilidad de convertirse en un exportador “verde” y así, quizás, ayudar a países colindantes al cumplimiento de sus objetivos 2020. Esta medida sería también de gran importancia de cara a la mejora de la situación económica actual del país.

Pueden destacarse, entre otros parques solares, los siguientes:

- Abantia/Comsa EMTE en Lérida, con 22,5 mega vatios instalados. Destaca por su hibridación de cilindro en C parabólico con una planta de biomasa.
- Abengoa Solar, en Sevilla, cuenta con 30 mega vatios y es una de las pocas centrales con torre y vapor saturado.
- Alvarado. Es una planta solar con cilindro en C parabólico que alcanza los 50 mega vatios de potencia. Fue instalada por Acciona y genera electricidad para 28.000 hogares.

5.5. Energía de las olas

La primera planta comercial undimotriz de Europa fue conectada a la red en julio de 2011, en la pequeña localidad de Mutriku. El proyecto comenzó en el año 2002, cuando se planteó el incorporar la central al nuevo dique que se necesitaba construir. La inversión total ha sido de 6,4 millones de euros y, a día de hoy, ha inyectado a la red un total de 1 giga vatio-hora, cumulativo, y proporciona energía a 100 hogares.

La planta se basa en la utilización de una tecnología pionera, la denominada columna de agua oscilante, por la cual el movimiento de las olas genera un flujo de aire que al fluir a través de las turbinas produce la electricidad. La gran novedad de esta tecnología es que el flujo que recorre las turbinas es aire, y no agua, por lo que la corrosión producida tiene un efecto mucho menor. Además, las turbinas son simétricas, por lo que el aire puede fluir en ambos sentido produciendo electricidad. En su conjunto, Mutriku cuenta con 16 pares turbina-CAO que alcanzan los 296 kilo vatios de potencia intalada.

Como ha sido mencionado previamente, Mutriku consiguió el pasado año 2016 la inyección de 1,3 giga vatios-hora, lo que coloca a esta central como productora record de este tipo de energía a nivel mundial. En la siguiente figura 5.3, proporcionada por el Ente Vasco de la Energía, puede verse la generación desde su puesta en marcha.

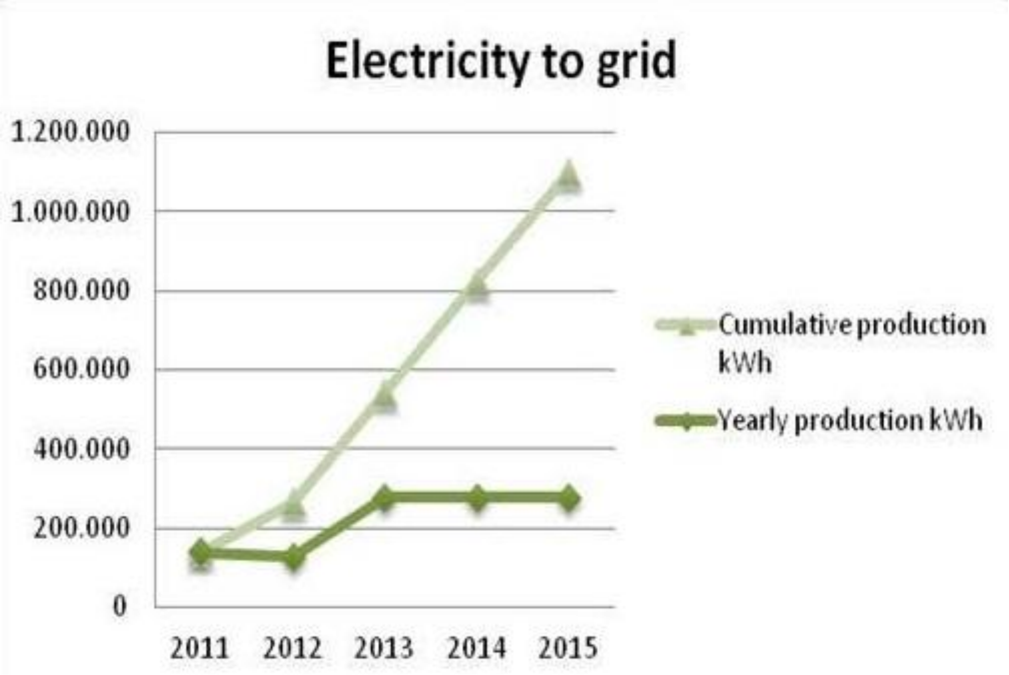


Figure 5.3. Energía generada e inyectada por la planta undimotriz de Mutriku, EVE.

A pesar de registrar una generación mucho más "humilde" que otras tecnologías más comunes, la instalación de esta planta supone un gran paso hacia delante para el país. La central undimotriz de Mutriku supone el primer paso para el aprovechamiento del potencial energético de las costas españolas. Es más, a raíz del pensamiento Mutriku se han ido desarrollando diferentes ideas y centros de investigación, como Bimep, para poder aprovechar el litoral español.

5.6. Biomasa

En relación a la generación eléctrica por medio de biomasa, se encuentran 712 mega vatios de potencia instalados, especialmente concentrados en Andalucía, Aragón y Asturias, y consiguieron una cobertura de demanda del 1,4%. España se sitúa como sexto país en generación eléctrica a partir de biomasa sólida dentro de la UE, detrás de Alemania, Francia, Suecia, Finlandia y Polonia. Aunque, sin embargo, al calcular la generación per cápita, las cifras cambian significantemente.

De acuerdo a los datos de AVEBIOM, Asociación Española de Valorización de la Biomasa, la generación eléctrica mediante biomasa creció en más de un 20% entre los años 2014 y 2015. No obstante, si se remonta hasta el año 2008, el crecimiento de la potencia instalada ha sido casi del 400%. A lo largo del 2015, generó más de 12.000 giga vatios-hora. Cabe destacar que, además de la producción eléctrica, muchas de las centrales aprovechan el calor residual producido durante el proceso, convirtiéndose así en centrales de cogeneración.

Destacan, entre otras, las siguientes centrales de biomasa:

- Ence Huelva, que incluye Ence I, Ence II y Ence Biomasa, que acumulan juntas 118 mega vatios. Ence I y Ence II son plantas de cogeneración a base de cultivos energéticos y restos industrial y forestal. Ence Biomasa, por su parte, funciona con biomasa forestal.
- CB Monzón, CB Erla o CB Zuera. Que juntas acumulan 148,5 mega vatios y queman biomasa forestal.
- Ence Navía, en Asturias, que junto con su expansión cuenta con 77 mega vatios de potencia. Funcionan a base de biomasa forestal y la expansión incorpora, además, cogeneración.

En relación al lado térmico de la biomasa, aparece esta fuente de energía desde hace algunos años en la instalación de nuevas redes de district heating. Para obtener una idea cuantitativa, en 2015, suministró 3.936 kilo toneladas equivalentes de petróleo para fines térmicos, es decir, casi tres cuartos del total de energía consumida en este sector. De este total, 548 kilo toneladas se derivaron a central de biomasa para consumo de calor útil y el resto fueron directamente enviadas a sistemas de calefacción.

5.7. Biogás y residuos sólidos urbanos (RSU)

Estas dos fuentes de energía, incluso combinadas, todavía representan una cuota de mercado mucho menor que las tecnologías previamente explicadas. Se encuentran 214 mega vatios de potencia instalados en centrales de biogás y 305 en centrales a base de residuos sólidos urbanos. Juntos obtuvieron una cobertura de demanda alrededor de 0,7% - 0,31% residuos sólidos urbanos y 0,42% biogás.

Las primeras plantas de biogás se instalaron en España en los años 80, pero a causa de reducidas ayudas y retribuciones no se han desarrollado mucho desde entonces. En el territorio español, la mayoría fueron instalados cerca de vertederos o almacenes de materia orgánica con los que a través de la biometanización, se consigue el biogás. La mayoría de las plantas instaladas es concentran en zonas con gran actividad industrial o agrícola – Cataluña, Madrid o Andalucía. Así puede comprenderse por qué el biogás de vertedero es el más comúnmente utilizado en las centrales españolas.

Por su parte, los residuos sólidos urbanos, se encuentran en zonas industriales como Madrid (29,8 megavatios) o Cataluña (51,5 megavatios). Destaca su importancia en las Islas Baleares, en el que además de tratarse una gestión más eficiente de residuos les proporciona cierta independencia energética con respecto a la península. 74,8 megavatios del total de 305 megavatios se encuentran en Palma de Mallorca.

5.8. Integración renovable en la red eléctrica

Para conseguir una integración eficiente de todas las tecnologías previamente explicadas, Red Eléctrica de España ha desarrollado un organismo denominado Cecreo, Centro de Control de Energías Renovables, cuya única función es el promover la integración de las energías verdes en el sistema.

Se trata, básicamente, de una herramienta tecnológica con la intención de integrar tecnologías con altos grados de variabilidad, reducida adaptación a cambios de demanda y poca predictibilidad. Cada 12 segundos, la herramienta recibe información a tiempo real de los puntos de control. De acuerdo a los datos recogidos, Cecre realiza un análisis a escenario real con el que gestiona las operaciones de mantenimiento necesarias y manda las ordenes correspondientes a las plantas renovables en caso de necesidad. Todo en ello en un intervalo menor a 15 minutos. Gracias a iniciativas como esta puede observarse, como en la siguiente figura 5.4, el crecimiento de las renovables en cuanto a la demanda total de energía del país.

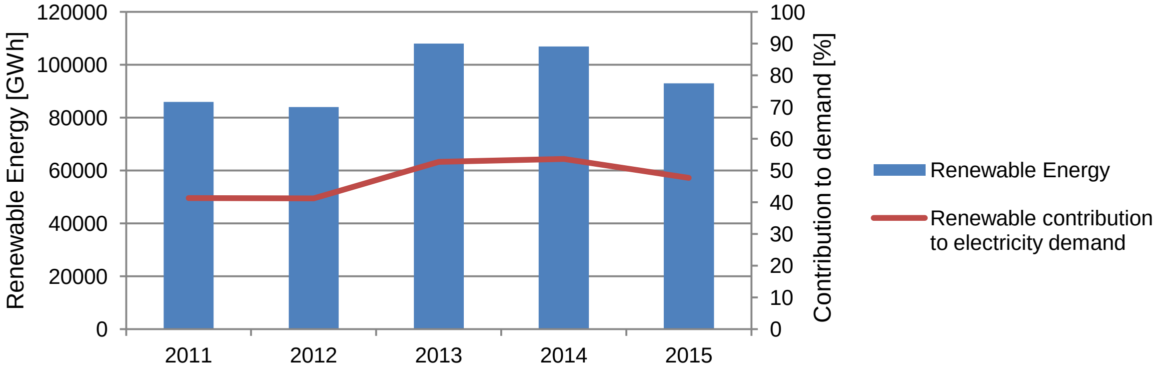


Figure 5.4. Cuota de generación renovable y contribución a la demanda total, *REE*.

5.9. Análisis del potencial renovable

Una vez mostrada la capacidad instalada disponible en el país, es interesante observar además el potencial de las tecnologías que podría contribuir más significativamente a la transición “verde” de España. Para ello, diversos factores han de tenerse en cuenta ya que pueden condicionar de diferente manera en el desarrollo a las diferentes tecnologías. Además de esto, hay que tener en cuenta que las diferentes tecnologías comenzaron su trayectoria hacia la competitividad en diferentes momentos y a diversas velocidades.

De acuerdo a lo cual, el Plan Renovable 2011-2020 llevado a cabo por el Instituto de Diversificación y Ahorro de la Energía, señala los siguientes factores:

- La posibilidad de colaborar a la creación de un “mix” energético diferenciado.
- Explotación eficiente de fuentes renovables.
- Facilidad de integración a la red eléctrica.
- Posibles efectos medioambientales de la tecnología.
- Potencial disponible.
- Potencial mejorable.
- Generación de empleo.
- Apoyo público.
- Otros beneficios sociales.

Con lo que se llega a una clasificación de potenciales estimados para el año 2020 como se muestra en la siguiente tabla 5:

Tecnologías	Potencial [GW]
Energía Solar	>1000
Eólica (marina y terrestre)	340
Undimotriz	20
Hidroeléctrica	33
Bombeo	13
Biomasa eléctrica	8
Residuos	2
Biogás	1

Table 5. Análisis del potencial de las diferentes tecnologías en generación electrica, *PER 2011-2020*.

De acuerdo a lo explicado anteriormente y estos datos proporcionados por el Instituto para la Diversificación y Ahorro de la Energía, IDAE, el estudio del potencial se centrará en energía solar, eólica y biomasa – teniendo en cuenta también su posible potencial térmico.

5.9.1. Energía eólica

Para conocer el potencial que puede ofrecer esta tecnología, nos referimos a un estudio llevado a cabo por el IDAE en colaboración con la consultora Meteosim Truewind S.L. en el que se combinan un software de predicción del viento a largo plazo junto con las características topográficas del país.

Junto al software se establecen una serie de limitaciones tecnológicas, económicas y medioambientales que definen las zonas aptas finales. Como limitación tecnológica para turbinas terrestres se establece una velocidad media anual de viento mayor o igual a 6 metros por segundo a una altura de 80 metros sobre el nivel del mar, la cual se considera la velocidad óptima para las turbinas comerciales actuales de media y alta potencia. Los resultados se muestran en la siguiente figura 5.5.

Figure 5.5, Velocidad media annual de viento [m/s], *IDAE*.

Los resultados son agrupados, además, en las siguientes tablas 6 y 7, en la primera se muestran las cinco regiones con mayor potencial de acuerdo a la velocidad media anual, mostrando los kilómetros cuadrados y el porcentaje de la región que podría ser apto para nuevas turbinas. En la tabla 7, se muestran los resultados semejantes pero en función de la densidad de potencia del viento.

Vmedia > 6m/s [km2 basis]			**Vmedia > 6m/s [% basis]**		
Región	**km2**	**(%)**	**Región**	**km2**	**(%)**
Andalucía	20.981	24	**Islas Canarias**	2.854	52
Castilla y León	16.907	18	**Galicia**	14.199	48
Castilla - La Mancha	16.640	21	**Navarra**	4.947	48
Aragón	14.614	31	**Aragón**	14.614	31
Galicia	14.199	48	**Cantabria**	1.513	28

Table 6. Regiones de mayor potencial de acuerdo a la velocidad media de viento anual, *IDAE*.

Densidad de potencia > 250 W/m2 [km2 basis]			**Densidad de potencia > 250 W/m2 [% basis]**		
Región	**km2**	**(%)**	**Región**	**km2**	**(%)**
Andalucía	24.332	28	**Galicia**	16.498	56
Galicia	16.498	56	**Islas Canarias**	2.363	43
Aragón	14.278	30	**Cantabria**	2.136	40
Castilla y León	12.536	13	**Asturias**	4.208	40
Castilla - La Mancha	11.547	15	**Navarra**	4.016	39

Table 7. Regiones de mayor potencial de acuerdo a la densidad de potencia. *IDAE.*

Se puede obtener información más detallada sobre las diferentes regiones en el Apéndice V y en el archivo de Excel anexo “Potential Analysis”.

Como puede observarse, todavía hay una gran cantidad de territorio disponible para la instalación de nuevos parques eólicos a pesar de que ya existen una gran cantidad de megavatios instalados. Puede observarse, como se indica en la siguiente tabla 8, las regiones con mayor potencia instalada se encuentran además entre las regiones con mayor territorio adecuado para nuevas instalaciones. Este hecho indica que España, es conocedor de su potencial y ha comenzado a explotarlo. Lo que ahora es necesario continuar estudiando y buscando tecnologías más eficientes a la vez que se conciencia a la población de la importancia de estas tecnologías.

Top 5 – Energía Eólica	
Región	**Potencia [MW]**
Castilla y León	5.560,0
Castilla - La Mancha	3.806,5
Andalucía	3.337,7
Galicia	3.314,1
Aragón	1.893,3

Table 8. Las 5 regiones con mayor potencia instalada, *elaboración propia*.

El potencial eólico ha sido brevemente mencionado previamente por lo que, en este apartado, se muestran los resultados del informe gráficamente (figuras 5.6, 5.7 y 5.8), para dar una idea de la falta de tecnologías aptas para ser instaladas en el litoral Español. Tras un primer filtrado basado en las características de las tecnologías actuales, solo un 21% de toda la superficie del litoral sería adecuada para la instalación de turbinas marítimas. Tras aplicar los filtrados de viabilidad económica y medioambiental, ese 21% se reduce en 31 kilómetros cuadrados con viabilidad completa.

Figuras 5.6 Litoral Cantábrico (arriba izquierda), 5.7 litoral Mediterráneo (arriba derecha) y 5.8 litoral Canario (abajo), *IDAE*.

5.9.2. Energía solar

El potencial solar se mide en función de la cantidad de radiación solar directa que recibe un terreno determinado durante un tiempo determinado. Esta radiación solar directa es la base de funcionamiento tanto como para la energía solar fotovoltaica como para la energía termoeléctrica. Ambas, como se ha comentado a lo largo de este resumen, no han sido desarrolladas para poder explotar todo su potencial.

Conocida la radiación solar directa de las diferentes regiones españolas, puede calcularse fácilmente la cantidad de energía que eso significa. Así, puede estimarse la eficiencia y la capacidad teórica de estas tecnologías de acuerdo a las horas de sol recibidas. Se muestran a continuación los mapas térmicos de la península y el archipiélago Canario de acuerdo a la radiación media anual recibida en el año 2015 (figuras 5.9 y 5.10).

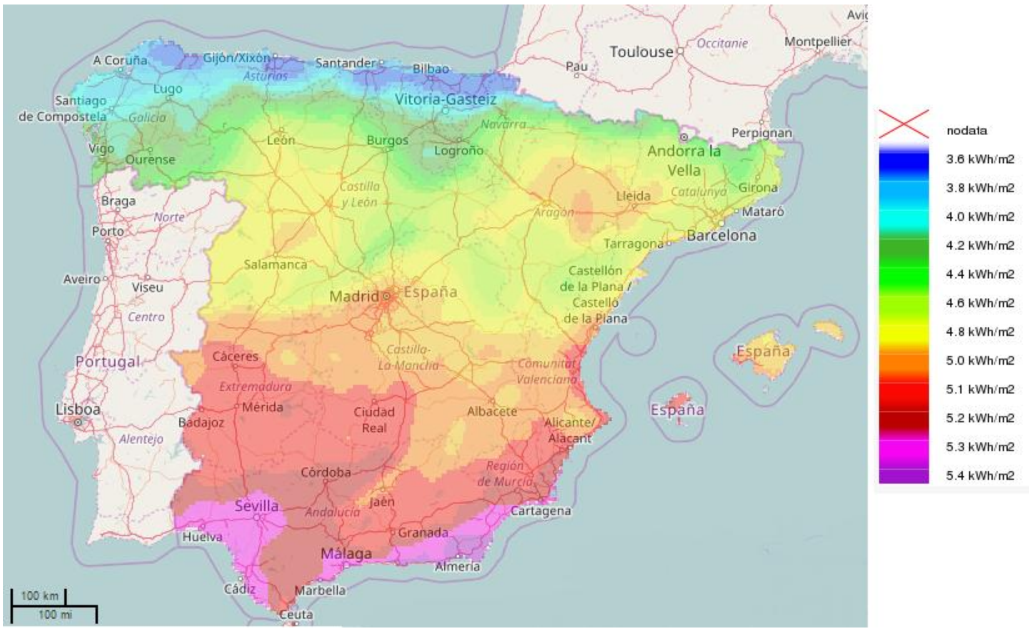


Figura 5.9. Mapa térmico anual en la península y Baleares [kWh/m^2], *ADRASE*.

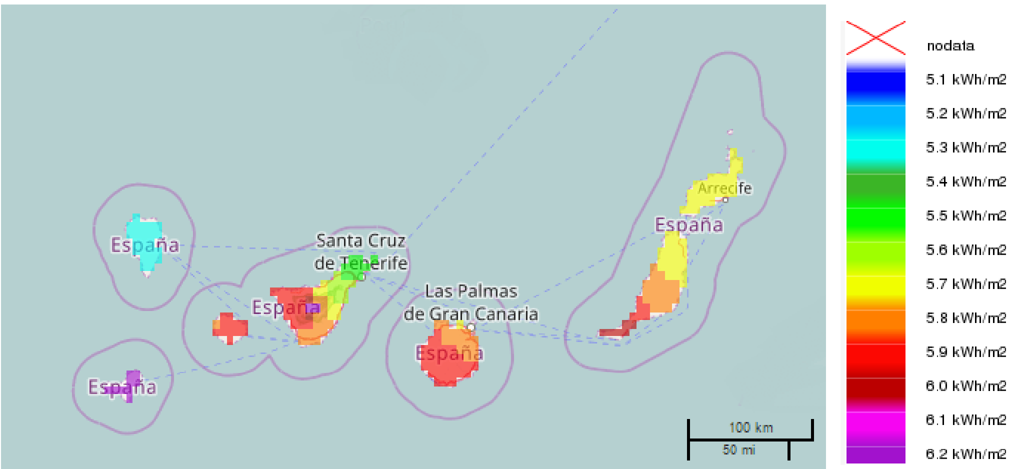


Figura 5.10. Mapa térmico anual en el archipiélago Canario [kWh/m^2], *ADRASE*.

Como información complementaria, en las siguientes tablas 9 y 10, se muestran las regiones que más horas de sol reciben en las estaciones de verano e invierno.

	Media horas/día	Media invierno [kWh/mes]
Castilla y León	4,7	1.409,3
Andalucía	6,1	1.272,7
Castilla - La Mancha	5,2	786,3
Cataluña	5,3	638,5
C. Valenciana	6,0	539,2

	Media horas/día	Media verano [kWh/mes]
Castilla y León	9,5	2.567,2
Andalucía	10,1	2.158,6
Castilla - La Mancha	9,7	1.493,7
Cataluña	8,8	1.029,0
Aragón	9,5	859,2

Tables 9 & 10. Regions with more sun hours, *leonesa solar*.

Para información más detallada sobre la radiación solar en España, consultar el apéndice V y el archivo anexo en el CD “Potential Analysis”.

Puede observarse a simple vista como la cantidad de horas de sol que recibe el país es considerablemente elevada, especialmente observando en los mapas la parte sur de la península. La instalación de nuevas plantas solares es completamente rentable desde el punto de vista del potencial solar, solamente hace falta que este recurso sea utilizado adecuadamente y con el respaldo de las políticas españolas. Una gran de cantidad de promotores y asociaciones españolas luchan cada día por recobrar el estado que la energía solar "prometía" a finales del 2008 y junto con la concienciación ciudadana se espera que la situación cambie radicalmente para completar los objetivos renovables 2020.

5.9.3. Biomasa

La biomasa es un objeto interesante de estudio debido a su amplio abanico de posibilidades. No solo puede usarse en el sector eléctrico y en el térmico, sino que supone además una manera más sostenible de tratar los residuos orgánicos de la industria, agricultura y los bosques. Además, bajo condiciones específicas, puede ser convertida en biogás y biocombustibles. De acuerdo con estas características, el potencial español en relación a la biomasa se expresará en la cantidad de biomasa disponible en el país.

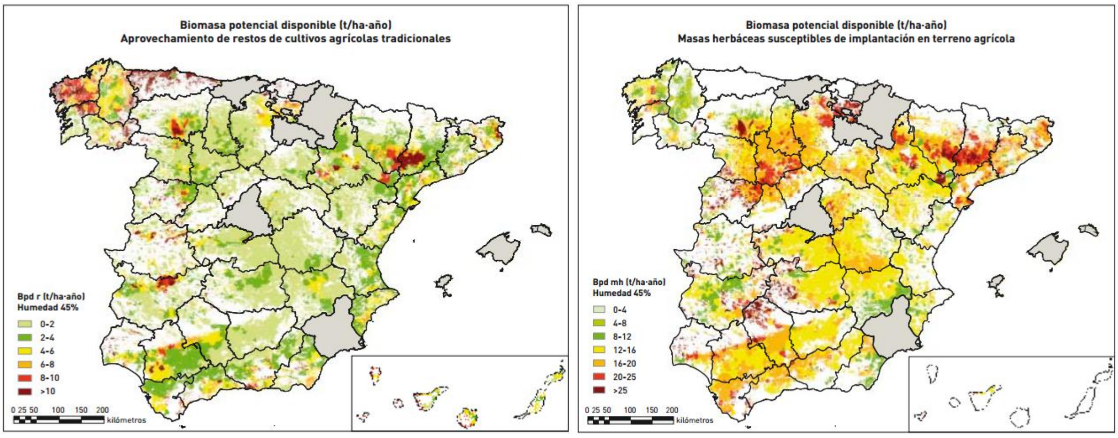
En España se encuentra varios tipos diferenciados de biomasa, que puede clasificarse en los siguientes grupos:

- Biomasa procedente masas forestales y agrícolas existentes:
    - Masas forestales existentes.
        - Restos de aprovechamientos madereros.
        - Aprovechamiento del árbol completo. La biomasa es recolectada de masas forestales antiguas y naturales o implantadas cuyo uso se desviaba del energético pero que ahora se dedican plenamente a ello.
    - Biomasa de residuos agrícolas.
        - Leñosos. Residuos de la poda de olivares, frutales y viñedos.
        - Herbáceos. Principalmente engloban pajas y maizales.
- Biomasa procedente de masas susceptibles de implantación con fines energéticos. La biomasa procede en gran medida de masas forestales naturales abandonadas que se encuentran en la parte baja de las montañas o que han sido establecidas con este propósito en terreno forestal o agrícola.
    - Masas leñosas susceptibles de implantación en terreno forestal o agrícola. Los más comunes son chopos, sauces, eucaliptos y quercus. Dependiendo de los propósitos y las zonas de implementación también se distingue:
    - Masas herbáceas susceptibles de implantación en terreno agrícola. Casi todos los cultivos tradicionales puede utilizarse para la producción de biomasa, se pueden usar cereales (maíz, cebada, centeno, avena, etc.) y oleaginosas (colza o girasol).

En la siguiente tabla 11, se representan los potenciales estimados por el Instituto de Diversificación y Ahorro de la Energía, IDAE, para el año 2020. Se añaden además los precios por tonelada de biomasa. Las distribuciónes de los dos tipos de biomasa más comunes se puede apreciar en las figuras a continuación, figuras 5.11 y 5.12.

Source		**Biomass [t/year]**	**Biomass [toe/year]**	**Average costs [€/t]**
Existing forest masses	**Waste of wood treatment plants**	29.854.243	636.273	26,59
	Utilization of the whole tree	15.731.116	3.414.158	43,16
Agricultural waste	**Herbaceous**	14.434.566	6.392.631	20,97
	Woods	16.118.220		
Herbaceous masses subjected to implementation in agricultural lands		17.737.868	3.593.148	53,39
Wood masses subjected to implementation in agricultural lands		6.598.861	1.468	36,26
Wood masses subjected to implementation in forest lands		15.072.320	1.782.467	42,14
TOTAL SPANISH BIOMASS POTENTIAL		**88.677.193**	**17.286.851**	

Table 11. Spanish prospective biomass potential, *IDAE*.



Figuras 5.11 y 5.12. Cultivos agrícolas tradicionales (izda) y masas herbáceas susceptibles de implementación en terreno agrícola (dcha), *IDAE*.

Como puede observarse, la cantidad de biomasa que puede llegar a colectarse se acerca a más de 88.000.000 toneladas por año, que traducido a términos energéticos son unas 17.200.000 toneladas equivalentes de petróleo. Si España comienza a sacar realmente provecho de su sector agrícola, que cuenta con una gran importancia en muchas zonas del país, la biomasa se transformará en una de las fuentes renovables con mayor solidez y peso.

Para información más detallada, referirse al apéndice V.

6. Sector de calefacción urbana

Es importante destacar, para obtener la imagen completa de la transición verde en la que España se encuentra en este momento, la evolución de las redes de calor y frío que comienzan a verse en diferentes localidades españolas.

Su instalación comenzó muy recientemente, en el 2011, cuando la Asociación de Empresas de Redes de Calor y Frío (ADHAC) y el IDAE comenzaron un acuerdo común de promoción e instalación de las primeras redes. Lo destacable de esta iniciativa, además de ser sistemas más eficientes capaces de utilizar el calor residual que de otra manera podría perderse, es que se ha basado casi por completo en la integración de fuentes renovables.

En el censo del 2016 de redes se han registrado un total de 330, de las cuales un 74% (es decir 225 redes) funcionan a base de renovables. Más concretamente: 218 a partir de biomasa, 2 con biogás, 2 con energía geotérmica, 2 con calor residual y una última que consiste en una hibridación de paneles fotovoltaicos con biomasa. Su distribución puede observarse en la siguiente figura 6.1.

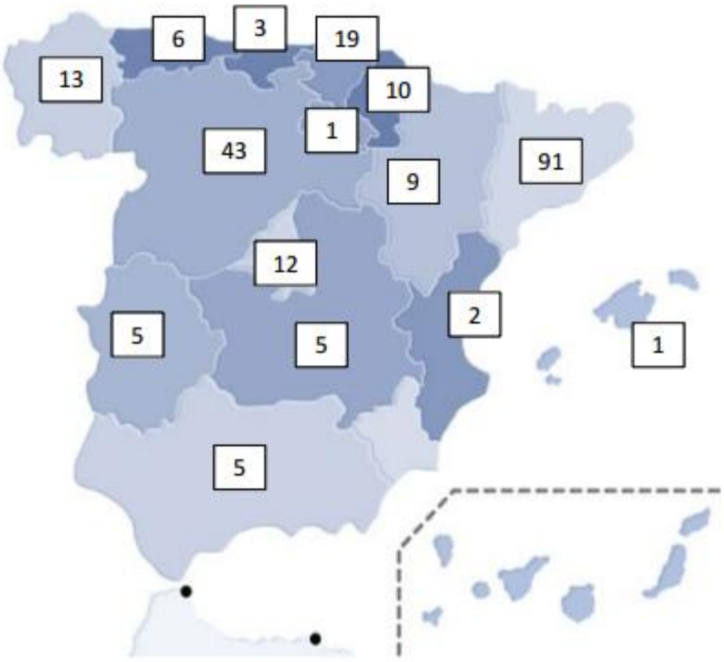


Figure 6.1. Redes de frío y calor basadas en fuentes renovables, *ADHAC*.

7. Aspectos futuros del sector eléctrico en España

A modo de introducción a la conclusión, se reflejan aquí las causas y las posibles soluciones que condicionan la llegada de una España 100% renovable para el 2050. El país tiene el potencial para obtener una producción renovable y a su vez obtener su independencia energética, al no tener que importar los combustibles de países externos. Pero debido a numerosos factores el desarrollo no ha alcanzado el nivel al que podría haber llegado.

Por otro lado, la fuerte crisis a la que el país se vio sometido tampoco ha favorecido en ningún caso a la integración de las renovables, las cuales en este período han perdido cualquier tipo de subsidio o ayuda que el estado previamente les concedía. No sólo eso, las mayores bazas renovables en las que el país confía son el viento y el sol. Ambas fluctúan constantemente y por tanto son mucho más difíciles de gestionar que otros combustibles convencionales. En último lugar, se encuentra la escasez de intercambio internacional con la que cuenta el país lo que es requisito indispensable si se desea conseguir una integración completa de la electricidad generada por estas tecnologías.

Debido a todo ello y, a pesar de todas las ventajas que supondría una generación puramente renovable, este tipo de energías siguen añadiendo un coste añadido al sistema eléctrico. Su desarrollo continúa en una fase de aprendizaje que no puede competir con las energías tradicionales, a pesar de todos los esfuerzos realizados en los últimos años. Por ejemplo, un parque eólico funciona efectivamente 3.000 hora es un año cuando una planta de ciclo combinado o carbón podría hacerlo durante 24 horas los 365 días del año.

Por ello, ¿cuáles son los retos que debe afrontar España para sobreponerse a estos inconvenientes?

Como se ha visto en el análisis del potencial español, España tiene la oportunidad de aprovechar mucho más de lo que se aprovecha actualmente. Por ejemplo, el mayor desafío que se presenta es el poder conseguir utilizar la energía almacenada en las costas españolas, tanto en términos de eólica como mareomotriz o undimotriz.

De cara al territorio interior, una recuperación del status solar es, también, imprescindible. Al ser uno de los países con mayor radiación solar recibida, la instalación de nuevas plantas en la península y en las islas, además de favorecer la generación renovable, fortalecería el estado económico del país dotándolo de una independencia de la que ahora mismo carece.

Por supuesto, ambas medidas, además de unidas a la mayor instalación de potencia renovable de las demás tecnologías, jamás podrá tener una integración efectiva si la red eléctrica no evoluciona de manera paralela. Es imperativa una mejora de gestión en las redes unida a sus nuevas ampliaciones, instalación de smart grids y, sobretodo, un aumento de la capacidad de intercambio internacional que acerque a España a la totalidad de la Unión Europea. España necesita ser uno más de los “grandes” en capacidad de intercambio si confía en una generación plenamente renovable.

Por último, y no por ello menos importante, las normativas de respaldo a las renovables no pueden continuar como están implantadas en el momento. La denominada “rentabilidad razonable” ha sido una medida correctora al déficit de tarifa, pero la promoción de renovables no es suficiente en este camino.

7. Conclusión

En conclusión, una generación renovable si es posible, pero no consiste solo en la instalación de las denominadas centrales “verdes”. Se ha demostrado a lo largo de todo este trabajo que el país presenta un gran potencial renovable, tanto actual como posible, el cual representa unas perspectivas muy favorables de cara a un futuro más sostenible. Sin embargo, para una correcta integración de las fuentes renovables en España se requiere una coordinación total y sincronizada de todos los participantes involucrados en el sector eléctrico tanto a nivel nacional como internacional. Todo ello unido a una concienciación social que promueva el uso de estas fuentes frente a la comodidad y hábito de las fuentes convencionales a las que tanto estamos acostumbrados. Los objetivos 2020 no están a una distancia inalcanzable, pero sí lejana. Es imperativa una reconsideración seria sobre la situación actual para por fin abandonar la fuerte dependencia que tenemos, todavía hoy en día, sobre los combustibles fósiles.

Trabajo Fin de Máster

Estudio detallado del potencial e integración efectiva de las energías renovables en España

An in-depth analysis of the renewable energy potential and its effective integration in Spain

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Abstract

Despite the fact that contamination and pollution are changing the energy balance which has been imposed for millions of years, most of the energy in which mankind relies on originates from fossil fuels, such as coal, oil and natural gas. The main characteristic of this kind of energy resources is that they do not renew themselves at a sufficient rate for sustainable economic extraction in meaningful human time-frames. Which means in a more ordinary way to say it: once they are consumed, they cannot be replaced.

Not only that, many countries have recorded significant reduction of these sources and are currently suffering from the side effects which accompany them. These sources have also the highest environmental impact and might have also a considerable damaging economic impact.

However, non-renewable sources still mean the most important energy source nowadays. However, mankind is getting more and more conscious regarding the damaging effects of these sources and a new tendency has been arising the past years: Renewable energy sources. These sources are naturally replenished at a faster rate than they are consumed. Solar, wind, geothermal, hydro, and some forms of biomass are common sources of renewable energy.

Along this report, it will be shown and explained a detailed research about this arising tendency in the Peninsula Ibérica and the associated territories of Canary and Balearic Islands.

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1. Introduction

1.1. Motivation

The global energy sector is gradually going through a major transition, due to increasing concern over sustainability and climate change. The EU has already proved to be a benchmark in this area for other countries to follow. Spain is one of the major countries of the European Union, and plays a substantial role in defining the economy of the EU. In the energy sector, however, Spain is said to be 'isolated' considering the low transfer capacity between Spain and its neighboring countries. Spain has a lot of sun-hours, i.e., large potential for solar power, not neglecting other potentials like wind, hydro and biomass. In this thesis an effort has to be made to understand the present energy situation in Spain, make an analysis of the available potential and identify the challenges for a successful and effective integration of the renewable potential into the Spanish energy mix. Interesting aspects and ventures like 'Wave' energy and 'development' zones are explored, and the importance of the Spanish grid in maintaining the stability of the complete European grid is to be highlighted at the end of this thesis.

1.2. Addressed Problems

- What challenges pose an obstacle for a sustainable but renewable energy sector in Spain?
- Can the country keep up with the EU energy and climate goals?
- How important is improving the cross border transfer capacity for Spain?
- What methods are effective in the promotion of the renewable energy generation in Spain?
- Is it possible to effectively reach the renewable targets with the current support schemes?

1.3. Methodology

- Data collection for an initial understanding of the present situation for the primary energy in Spain
- Overall country based analysis on demand, consumption and generation of electricity in Spain
- Analysis of the available potential for Hydro electricity, Solar PV, Solar Thermal, Wind On and Off shore, biomass and wave energy in Spain
- The EU energy and climate goals and the status of Spain in reaching them
- Understanding how Spain is considered to be 'isolated' from the European grid and the implications of increasing the cross border transfer capacity
- Identifying cross border transmission line projects and their importance to the Spanish electricity sector
- Providing a brief outlook for the future of the Spanish electricity sector

2. Spain: brief introduction

Spain is one of the 28EU country members, which is located in the south west of the European continent. It has a total geographical extension of 504.645 km^2, including the two island systems of Canary and Balearic Islands. As a country mostly surrounded by water, the Pyrenees are the only junction with the European mainland, in where it makes frontier with France and Andorra. Spain has close to 46.500.000 inhabitants, according to the National Institute of Statistics (INE in Spanish), which are allocated around the territory with an average density of 92,2 inhabitants/km^2. However, most of the population is concentrated around large population centre and thus a major part of the territory remains empty.

The climate changes notably depending on the region, despite the fact that Mediterranean climate predominates in most of the territory. The climate which is found in the coast gets more extreme as you travel inwards within the Peninsula. In addition, Oceanic climate is founded on the northern regions and Mountain climate is found in the many Spanish mountain ranges. In a minor range, a Subtropical climate predominates over the Canary Islands and Arid and Semi-arid climates can be also registered in certain regions from the South-East.

The combination of all these factors makes Spain privileged territory when taking into account natural resources such as sun, wind, water currents, etc. [1]

3. Primary and final energy production and consumption

One’s first thoughts about Spain can see it as a peripheral country that could have a great renewable potential due to its geographic characteristics and extension. Nevertheless, impressions usually do not fit reality. As a first introduction, it is explained here the primary and final energy production and consumption in order to get a current overall view of the country.

Spain, as other European countries, is investing and promoting renewable sources in order to produce the required energy. In accordance to which, more renewable contribution is gradually appreciated on the country’s data. A huge amount of energy is provided by sources such as wind or hydroelectric energy. However, this “so-called” leading position in renewable production does not mean that countries can be considered as completely renewable, in fact, that situation is still years ahead from us now. Spain is not different from the case and despite the fact that it has been increasing the production and improving and installing diverse renewable-based power plants, it is still a strongly fossil-fuels-dependent country. As it was published last year by MINETUR (Ministry of Industry, Energy and Tourism)’s 2015 Energy Report, more than **50%** of the final energy consumption is still obtained through these methods. It can be seen in the figure 3.1 below how still coal, petroleum and gases lead the different sectors. [4]

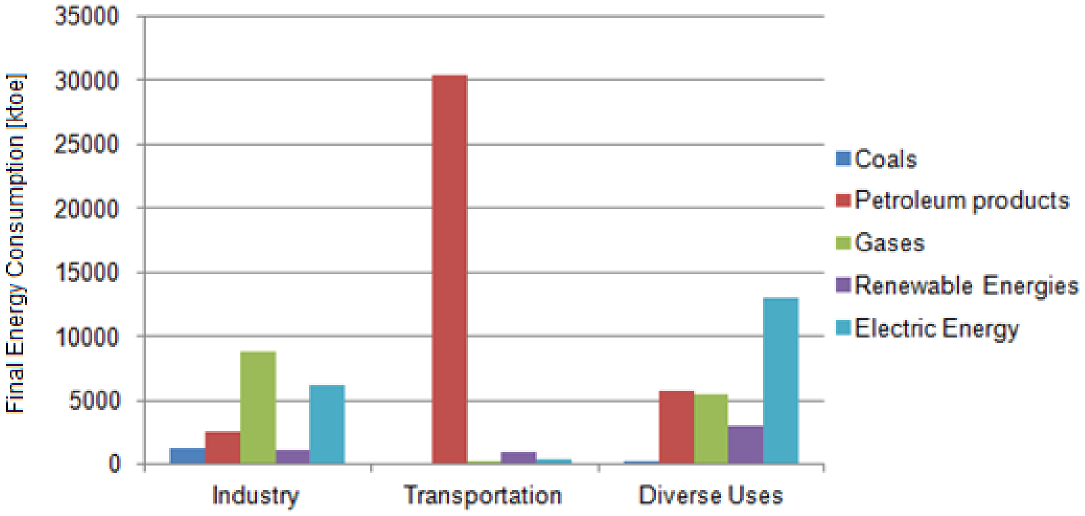
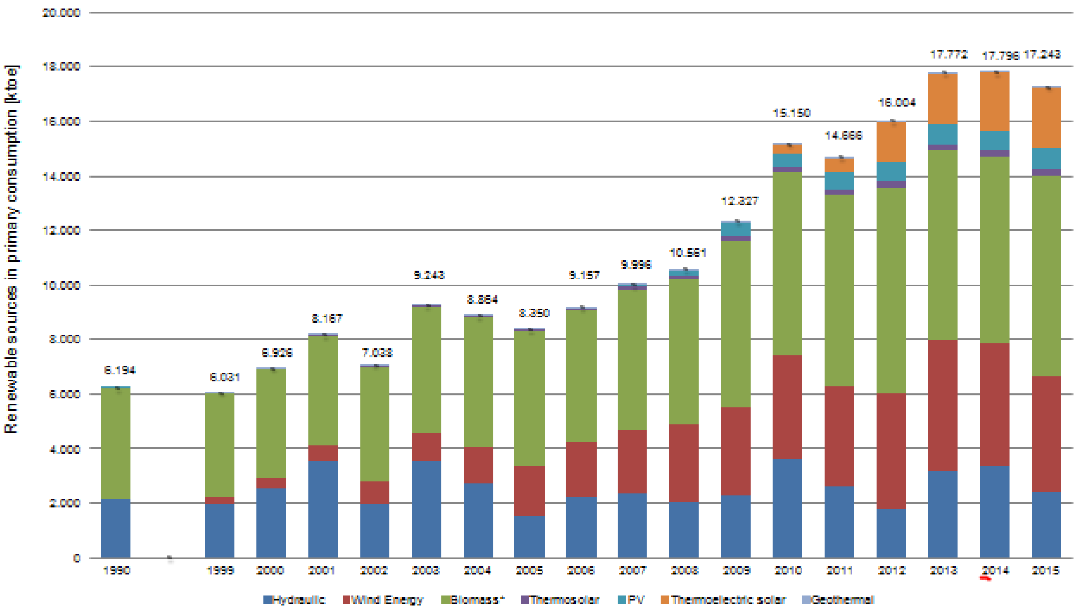


Figure 3.1. Final energy consumption by sectors and sources [ktoe], *IDEA/MINETUR*.

Regarding total numbers, the final energy consumption in Spain that year 2015 was **79.145 ktoe**, from which **5.294 ktoe** where consumed from renewable energies.

Nevertheless, as mentioned earlier, the renewable sources exploitation has been under development during the last years. Here in the graph below, figure 3.2, it is possible to see the renewable sources in primary consumption’ evolution since the 1990 until 2015, by different sources.



*Including biomass, biogas, biofuels and SUW.

Figure 3.2. Evolution of RES primary energy consumption [ktoe], *MINETUR,IDAE*.

It is also interesting to take a look on the production per year (figure 3.3 and table 3.1), also in ktoe, to be aware of the imbalance which appears when comparing primary energy production to primary energy consumption.

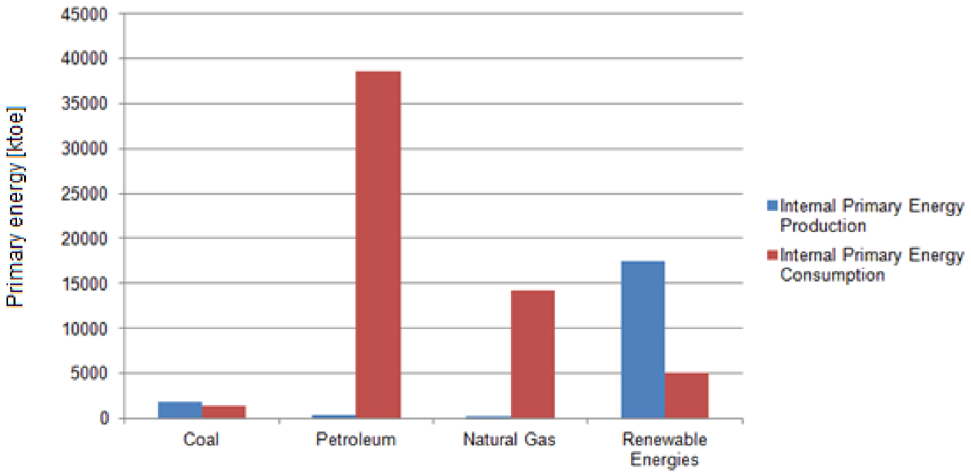


Figure 3.3. Primary energy production vs primary energy consumption (2015), *SEE/IDAE/MINETUR*.

[ktoe]	Primary Energy Production	Primary Energy Consumption
Coal	1.762,00	1.332,00
Petroleum	375,00	33.642,00
Natural Gas	50,00	14.293,00
Renewable Energies	17.450,00	5.102,00

Table 3.1. Primary energy consumed and produced, *SEE/IDEA/MINETUR*.

In order to break this imbalanced equilibrium, a lot of effort is invested in order to promote renewable energies. Currently, the Spanish geographical situation is better suited than other countries in the European context. In Spain it is effortless to come upon an almost unique amount of sun effective hours, different climatic conditions along the Peninsula and adequate geographical conditions (such as wind, oceans and water flows).

Regarding the primary energy production, Spain has been characterized by a limited availability, due to the absence of indigenous resources and a high energetic dependence from other countries – easily appreciable on the country imports. In addition with an upraised consumption of imported petroleum products, this resulted in a scant rate of self-sufficiency. However, along the past decades, renewable energies have been gathering more and more weight in the country's energy profile. In the following figure 3.4, it is shown the evolution on primary energy production and the self-sufficiency rate development along the past years. [5] [6]

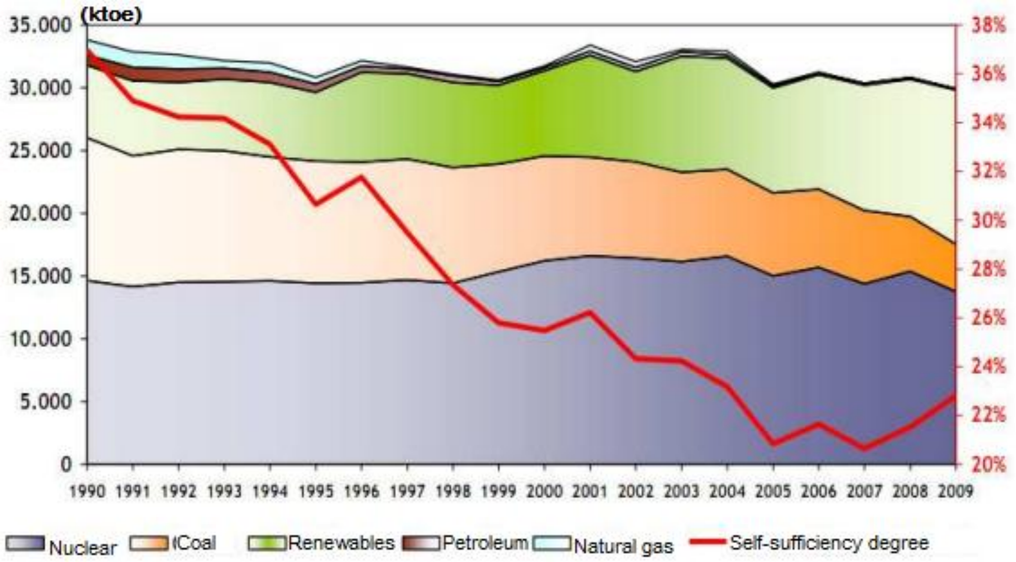


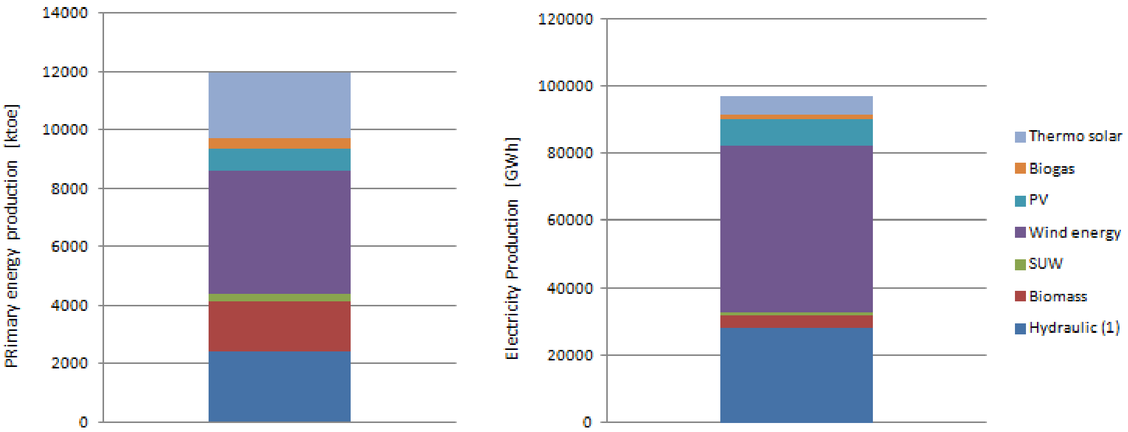
Figure 3.4. Primary energy production and self-sufficiency development 1990-2009,*[29],MINETUR,IDAE.*

4. Renewable energy sources present situation

Regarding renewable energy resources, it can be said that Spain has caught up in accordance with the renewable trend that has been implemented in the last decade. The last year's global status report REN21 has pointed Spain as one of the 20 leader countries in renewable energies production. And currently, the renewable energy resources can be seen as follows – also alluding to MINETUR's 2015 Energy Report. [4]

Despite the fact that the final electricity demand grew a **2,5%** on 2015, the gross electricity production increased only in a **0,6%**, the fact was complemented by a **97%** increment on French imports. Less availability of wind and hydroelectric energies due to non-adequate climate conditions resulted in just a **90 TWh** of this renewable production – in comparison to the **280 TWh** gross produced. This is translated as a shrinkage in renewable production with respect to gross electricity production, from **14,5%** in 2014 to **12,1%** in 2015. [9]

Around a third of the electricity generation was provided by renewable sources, and from that, concretely a **51%**, was provided only by wind energy. This technology has reached the second position on the list of generation systems and has contributed with higher shares than natural gas or carbon in the Spanish energetic mix. Then, comes hydroelectric energy with a **29%** of the renewable market share (not including pumped storage energy). Both energy sources have performed significantly despite the decrements registered for both of them during 2015. The rest of the pool is provided by **8,5%** photovoltaic, **5,9%** thermoelectric solar energy, the remaining **6%** was provided by biomass, biogas and renewable waste. This is represented graphically in the following figure 4.1. [9] [10]



(1) Pumped storage energy is not included.

Figure 4.1. Renewable energies in 2015, *MINETUR/IDAE.*

Discussions about thermal supply of renewable sources, most of it (around three quarters) was provided by biomass. This percentage represents **3.936 kilo-tonnes of oil equivalent** (ktoe) divided in:

- **548 ktoe** belong to useful heat consumption in biomass power plants.
- **3.338 ktoe** belong to heating systems, stoves and boilers along the different sectors – industry, households and tertiary.

The biofuels also represent an important part within the thermal supply and they reach a second position. It was registered a contribution of **1.018 ktoe** from which a vast majority, around 80%, was provided by biodiesel and the rest by biogasoline. In contrast to what could be expected, thermal solar energy represents roughly **6%** of the consumption – even though there are more than 3,6 million square meters installed nowadays. Biogas provided with **1%** and geothermal energy appears shyly with a **0,5%** share.

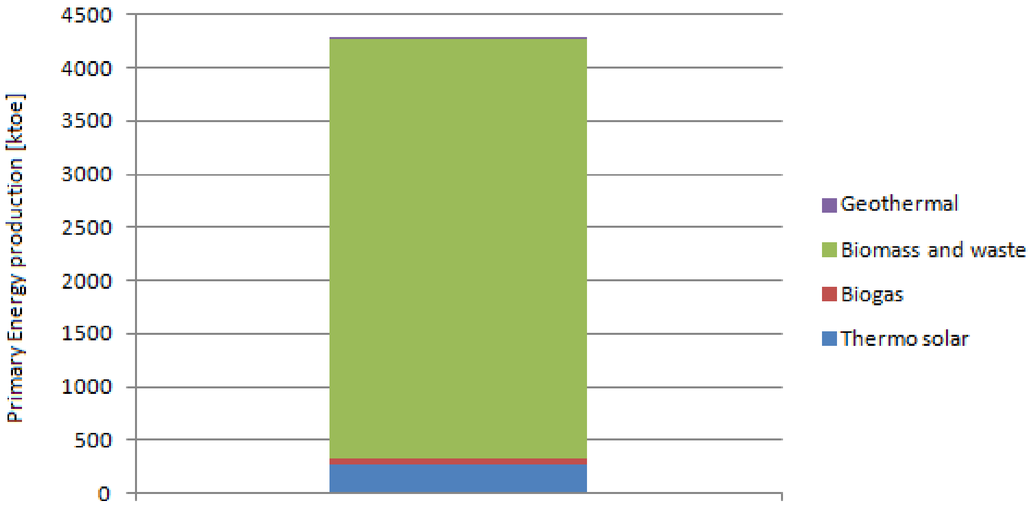


Figure 4.2. Differentiation in cooling and heating sector, *MINETUR/IDAE*.

The renewable energies primary consumption has shown an impressive growth since 2000, from **7 ktoe** to **17 ktoe** in 2014 - almost a **250% growth rate**. This growth was concurrently followed with a significant change on the used renewable sources. While in 2000 were mostly hydroelectric and biofuels the top renewable suppliers, with 57% and 37% of the market share respectively, now it is found a more balanced share of technologies. [3] [8] [10]

Detailed information about the current renewable situation has been described in Appendix I.

5. Installed power plant capacity and power plant map

Regarding renewable energy, different sorts of renewable energies exploitation facilities are positioned all over the Spanish territory and are basically differentiated with respect to the specific geographical conditions in which they are installed. As a quick first draft, it is shown here a map of the country with the different main power plants drawn on it up to 2013 – along with the reference of the installed capacity attached further in this report.

Primarily, there are found technologies such as hydroelectric or thermal energy which have been exploited for longer time, others which are being currently appropriately developed and improved such as wind energy or PV and last, but not least, the new developments such as mini-wind or wave energy.

Figure 5.1. Main power plants installed in the Peninsula, *REE*.

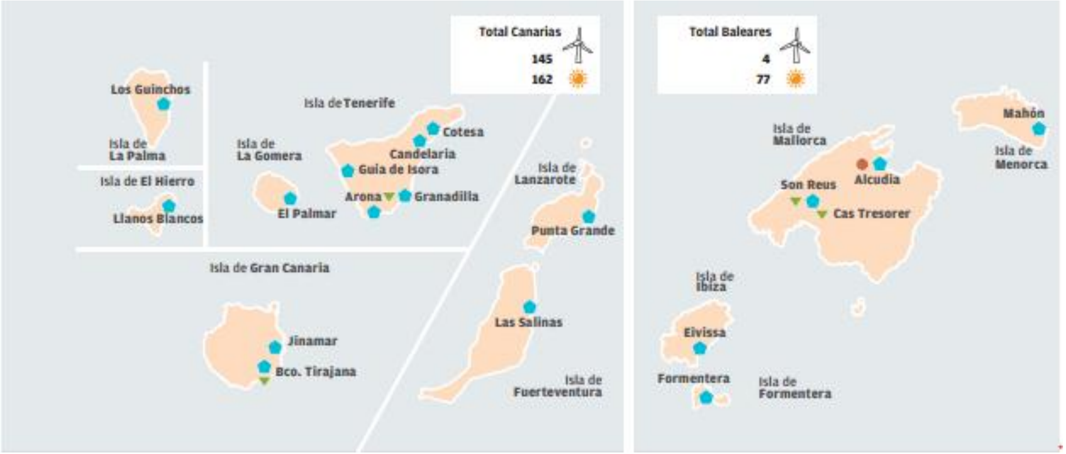


Figure 5.2. Main power plants installed in island territories, *REE*.

Getting into detail, until now, more than **49.500 MW** of renewable capacity have been installed along the Spanish territory. As major participants, wind and hydroelectric energies are found with a **46%** and a **37%** of the total capacity installed. Nevertheless, a wide difference between them is observed. While hydroelectric power plants were initially built around a century ago, the Spanish wind parks started to be noticeable along the past two decades. Wind energy has been consolidated as the major representative of renewable energies on the Spanish energetic mix since then.

Subsequently solar energy is found, in both technologies: photovoltaic with a **9,5%** and thermal solar energy with close to **4,5%** of the total. Despite the fact that Spain is one of the countries with greater amount of hours of solar irradiation, an appropriate development of such capacity installations cannot be observed, at least not yet.

Last, but not least, natural resources are also used within the electricity generation procedures. There are several power plants based on biomass, biogas or solid urban waste burning in order to produce electricity. Most of them, simultaneously, used the residual heat and hence are transformed into cogeneration power plants. [10]

More information on the distribution of power plants by region and source can be found in Appendix II.

6. Energy by source and sector

During 2015, the Spanish electric grid finally registered an increment on the demanded electric energy, which experienced a diminishing trend during the last years. According to the data and the results collected, this was taken as a positive indicator of economic recovery. However, a similar and meaningful increment in the renewable share is still missing. The balance of energy sources shows that a third of the electric energy demanded in 2015 was covered by renewable energies. However in 2016, the participation of renewable on electric energy production decreased due to notable falls in hydroelectric and wind energy, even though they still show a significant share.

This situation has been observed on the consumption profiles for both primary and final forms of energy. This economic recovery leaded into larger energy consumptions but no significant supply changes.

The consumption of primary energy reached **123.867 ktoe** in 2015. This implies a great increment in comparison to the previous year 2014, concretely a **4,6%**. In a first sight, a substantial difference can be noticed between non-renewable sources and the renewable ones. They only reached around **14%** of the total gross (**17.423 ktoe**). The values are shown in the following table 6.1 and the corresponding figure 6.1.

Energy source	[ktoe]
Coal	14.426
Oil	52.434
Natural Gas	24.590
Nuclear	14.927
Non-renewable waste	260
Hydroelectric Energy	2.397
Wind Energy	4.243
Biomass, Biogas and SUW	6.353
Biofuels	1.018
Solar	3.213
Geothermal	20
TOTAL	**123.867**

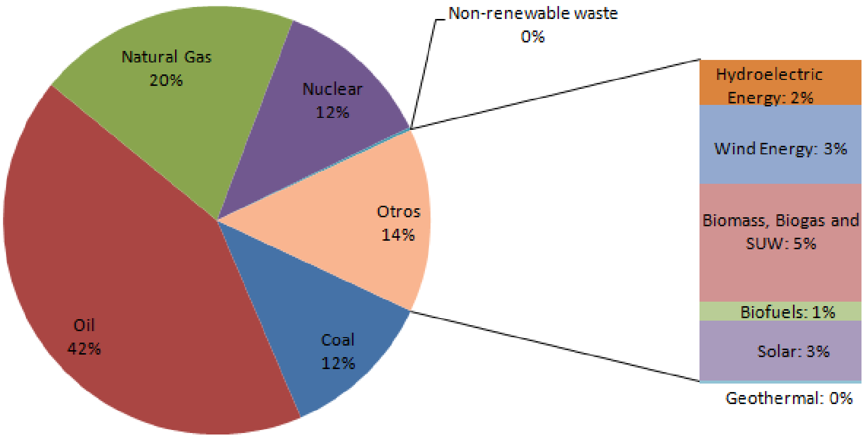


Table 6.1. Primary Energy consumption by sources 2015, *IDAE*, and Figure 6.1. Graph representation, *IDAE*.

The fossil fuels such as oil, coal and natural gas are still the most consumed energy resources in Spain and among them, coal gets the greatest share. Regarding the renewable energy sources, they register a decrement of **3,1%** in terms of primary energy consumption in comparison to the previous year.

Regarding the final energy consumption, it has increased **1,5%** points with respect to the values registered in 2014. The presence and distribution of the different energy sources remain basically steady and only changes of minor importance can be found. This sparse change is considered to be caused by the economic growth through which the Spanish inhabitants are going currently.

In accordance to which was previously explained, the final energy consumption registers around **80 ktoe** (not taking into account the non energetic usages). A slightly higher amount is reached when those usages come into picture. In the following table 6.2 and figure 6.2, there are shown the values divided in sources and the comparison with the previous year.

	2014		**2015**		**2015/2014**
	[ktoe]	**Structure [%]**	**[ktoe]**	**Structure [%]**	**Variation [%]**
COAL	1.367	1,6	1.400	1,7	2,4
OIL PRODUCTS	38.642	46,5	39.511	47,1	2,2
GAS	14.293	17,2	13.896	16,5	-2,8
ELECTRICITY	19.513	23,5	19.999	23,8	2,5
ENERGÍAS RENOVABLES	5.109	6,2	5.301	6,3	3,8
Biomass	3.762	4,5	3.936	4,7	4,6
Thermal Biomass	3.362	4,0	3.388	4,0	0,8
Useful Heat from Cogeneration	400	0,5	548	0,7	37,1
Biogas	101	0,1	51	0,1	-49,9
Thermal Biomass	23	0,0	23	0,0	0
Useful Heat from Cogeneration	78	0,1	28	0,0	-64,6
Biofuels	969	1,2	1.018	1,2	5
Thermo Solar Energy	259	0,3	277	0,3	7,2
Geothermal Energy	19	0,0	20	0,0	4,9
FINAL ENERGETIC CONSUMPTION	**78.925**	**95,1**	**80.107**	**95,4**	**1,5**
Non Energetic usages					
Coal	0	0,0	43	0,1	
Oil Products	3.622	4,4	3.368	4,0	-7
Gas	485	0,6	448	0,5	-7,5
NON ENERGETIC CONSUMPTION	**4.107**	**5,3**	**3.859**	**5,3**	**-6**
TOTAL	**83.031**	**100**	**83.966**	**100**	**1,1**

Table 6.2. Final energy consumption by sources 2014/2015, *IDAE*.

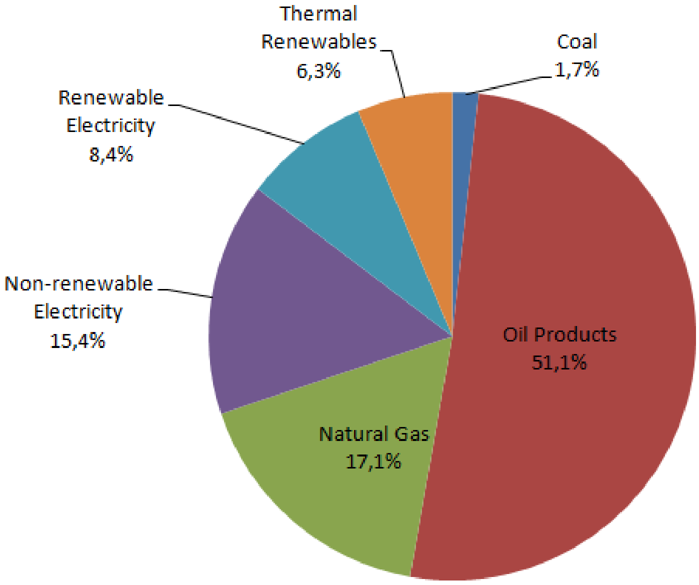


Figure 6.2. Final energy consumption by sources (2015), *IDAE.*

More information in relation to the recent final and primary energy consumption is collected in Appendix III. [5] [12]

Along with the primary partition of energy consumption by sources, it is important to observe which activities are the huge consumers of energetic products. Information on the sectoral dis-aggregation of demand is provided by the IDAE.

After a humble recovery in the year 2010, the industry sector showed a continuous downward trend in energetic demand. This can be explained easily since the industrial registers since 2010 showed an according lower activity. Unfortunately, the values which belong to the year 2015 are still not available but, instead, the idea can be approximated from the previous year data. The variation in between years has not been registered as significant by the Institute of Energy Diversity and Saving.

The values registered are shown on the table 6.3, as it is shown here below.

	COAL				**GASES**	**ELECTRICITY**
SECTOR	**Hard coal, Anthracite and Aggregates**	**Coke**	**Coke oven and Blast furnace gases**	**Coal Tras**	**Natural Gas**	**Electric Energy**
Measure Unit	**[kt]**	**[kt]**	**[kt]**	**[kt]**	**[GWh]**	**[GWh]**
Industry	919	545	519	0	101.731	71.657
Transportation	0	0	0	0	982	4.159
Diverse Usages	194	8	0	0	63.399	151.081
Households	*147*	*0*	--	--	*35.956*	*70.710*
Tertiary	*0*	*0*	--	--	*16.851*	*70.309*
Agriculture	*0*	*0*	--	--	*7.291*	*5.167*
Non especified	*46*	*8*	--	--	*3.301*	*4.895*
TOTAL CONSUMPTION	**1.112**	**554**	**519**	**0**	**166.111**	**226.897**

	OIL PRODUCTS					
SECTOR	**LPG**	**Gasoline**	**Kerosene**	**Gasoil**	**Fueloil**	**Petroleum Coke**
Measure Unit	**[kt]**	**[Ml]**	**[Ml]**	**Ml**	**[kt]**	**[kt]**
Industry	128	--	--	982	447	1.403
Transportation	35	5.681	6.425	22.509	87	0
Diverse Usages	1.124	45	135	4.582	86	0
Households	*970*	*0*	*0*	*1.756*	*22*	*0*
Tertiary	*118*	*15*	*0*	*1.120*	*43*	*0*
Agriculture	*37*	*30*	*0*	*1.702*	*4*	*0*
Non especified	*0*	*0*	*135*	*3*	*17*	*0*
TOTAL CONSUMPTION	**1.287**	**5.726**	**6.559**	**28.073**	**620**	**1.403**

	RENEWABLE ENERGY					
SECTOR	**Thermal Solar Energy**	**Geothermal Energy**	**Biomass**	**Biogas**	**Biofuels**	
					Biodiesel	**Bioetanol**
Measure Unit	**[GWh]**	**[GWh]**	**[kt]**	**[GWh]**	**[kt]**	**[kt]**
Industry	27	1	3.193	581	8	0
Transportation	1	0	0	0	863	291
Diverse Usages	2.978	218	7.928	593	4	3
Households	*2.363*	*124*	*7.502*	*0*	*1*	*0*
Tertiary	*598*	*44*	*219*	*131*	*2*	*1*
Agriculture	*17*	*51*	*193*	*89*	*1*	*2*
Non especified	*0*	*0*	*13*	*372*	*0*	*0*
TOTAL CONSUMPTION	**3.006**	**219**	**11.121**	**1.174**	**875**	**294**

(1) Non energetic usages excluded.

Table 6.3. Energetic consumption: global and by sectors 2015, *MINETUR, IDAE*.

As conclusion from the tables, it is observed how the major consumer sectors, industry and transportation, are still mainly based on fossil fuels. On one side, transportation runs mostly with oil products (such as gasoil, gasoline and kerosene) and, on the other side, industry needs a huge amount of natural gas. Nevertheless, it is worthy to note how renewable energies represent the basis for the household sector, especially solar thermal energy and biomass. Both renewable sources start to be common within the heating and cooling systems in the Spanish neighborhoods. Finally, tertiary and agriculture sectors consume a minor amount of energetic products. [13]

For more detailed information, please refer to Appendix IV, in which every sector is subdivided in different categories.

The current situation of the energetic situation in Spain during the past few years has been described so far. Through this, it is easy to conceive a general scheme about how the circumstances develop and accordingly accustom the energy market.

7. Electricity sector: Description and participants

As it is known, the electricity sector always captures major importance wherever it is involved, as the economic development of a country is closely related to its energy use. In Spain, the Law 54/1997's approval on the 27th of November 1997 meant for the Electric Sector a first stage of a progressive liberalization process. This started the grid opening to third parties and the establishment of an organized market for energy negotiation. It basically establishes that every electric activity must be carried out freely.

Currently, the available Law 24/2013, approved on the 26th of December, is the one which regulates the sector's structure and performamce. According to that, the electricity supply involves four main activities that can be read as follow:

- **Generation:** Those individuals or entities in charge of electric energy production, as well as building, operation and maintenance of the production installations. The generation can be divided as well in two main groups: facilities in Ordinary Regime (which includes those producers based in common fossil fuels and reaches a number of 1.241 facilities) and the previously so-called "Special Regime" (slightly modified in economic terms in 2012), which includes the ones which produce energy from residual energies (cogeneration and waste) or non-fossil fuels**.**

- **Transportation:** Transportation of electric energy through the Spanish transmission grid. The grid can be divided in two subgroups, primary lines (lines equal or greater than 380kV) and secondary lines (lines up to 220 kV).

- **Distribution:** Transportation of the energy from the transmission lines to the consumption points or other distribution lines in order to finally supply the energy to consumers. Every line, transformation elements and other electric elements with voltage inferior to 220kV are considered as distribution installations. In the Islands, the lines with equal or major voltage of 66kV are considered, however, transmission lines. A detailed list of the 333 registered distributors is available at the annex CD.

- **Commercialization:** This activity is performed by companies, which having access to the distribution and transmission lines, have the function of selling this energy to the consumers or other individuals of the system and of carrying out international trading operations. A detailed list of the 415 registered commercialization companies is available at the annex CD.

The relationship among these participants is shownvbg schematically in the following figure 7.1. [15] [16] [17]

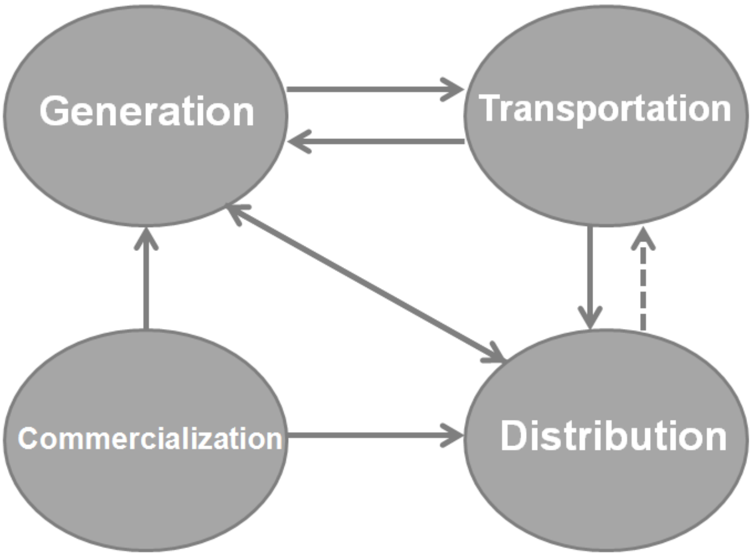


Figure 7.1. Interactions among the grid participants, *visualized personally for the sake of this study*.

Nevertheless, and according to the policies and trends which currently rise up, a new activity has appeared worth to be taken into account within the system. This minor group, recognized through the Real Decreto 647/2001, is named as Load Balancers – or “Gestores de cargas” in Spanish. The guidelines regarding how to regulate this activity were gathered within this ordinance and it establishes that this Load Balancers of the system are those trading companies which perform their activity with the main goal of electric energy supplying for electric vehicles recharging. [15]

These participants are divided in different sub-groups for a more accurate classification. Two main groups are found.

According to their extension:

- Individual standards: contractual nature related with each consumer.
- Zone standards: related with a determinate geographic zone, which is supplied by a unique distributor.

According to the types of area:

- U (Urban area): municipality with more than 20.000 supplies, or province capital.
- S (Semi-urban area): municipalities with a number of supplies between 2.000 and 20.000, excluding province capitals.
- RC (Concentrated Rural area): municipalities in within 200 and 2.000 supplies.
- RD (Dispersed Rural area): municipalities with less than 200 supplies, as well as supplies located outside of population centers. [18]

Yet among these four participants, there are five major companies which highlight and have a cumulative of **90%** of sales of commercialization to final consumers and around **60%** of the sales on the wholesale market. As to be named, they are Endesa, Iberdrola, Gas Natural, EDP España and Viesgo. They are also commonly referred as reference commercialization companies. [19]

8. The Spanish electricity market and its tariff deficit

The Spanish electricity market is defined as the set of markets in where is negotiated the purchase and sale of electric energy which is delivered in the Spanish grid. It was first established after the Spanish electricity sector liberalization in 1997 and, since then, the producer companies report daily the conditions of amount and price at which they are willing to sell the generated electricity in their installations.

The set of markets involve the Daily Market, Intra-day Market and Complementary Services Market. These can be explained as follows:

- **Daily Market.** It gathers all the energy purchase-sale transactions which correspond to following day's production and supply. First, the distribution, commercialization and consumption parts present their purchase-sale offers corresponding to the 24 hours of the following day. Once these offers have been received, the matching is carried out starting from the cheapest offer, until it reaches the demand.
- **Intra-day Market.** It works following the same criteria as the Daily Market but it works only when some adjustment needs to be done, once the Daily Market's agenda is established. A Final Agenda is then set up with these assessments agreed in the Intra-day Market and the previous ones from the Daily Market. The Intra-Day Market is structured in six different sessions, which each one includes: opening, closure, matching, reception of breakdowns and publishing. The sessions take place at 17.00h, 21.00h, 01.00h, 04.00h, 08.00h and 12.00h.
- **Complementary Services Market.** This market is made up of the procedures which are used to solve the misbalances between generation and demand. They aim to assure the security and quality of the electricity supply.

There are two main organizations which operates the Spanish electricity market. On one hand, OMIE (Operador del Mercado Ibérico – Polo Español that can be translated as Operating Company of the Spanish Electricity Market – Spanish side) manages the economic side of generation and Red Eléctrica de España, REE, manages the technical aspects – this organism will be detailed explained in the following chapter "Grid and cross border exchange capacity". [22] [23]

In order to properly understand it, let's show an example. Here it is provided the data registered in January 2017 by OMIE in its monthly report. With that, it is possible to observe how the production of different technologies is matched to certain prices and, with that, a final price for energy is established.

With regard to the Daily Market evolution, electricity reached an average value of **71,49 €/MWh** during last January and the average range of values which have been registered goes from **51,09** to **91,88 €/MWh**. On off-peak hours the prices oscillated between **40,80** and **97,70 €/MWh** and between **44,22** to **101,99 €/MWh** the rest of the day.

The following figures 8.1 and 8.2 show the aggregate curves of offer and demand of the hours with the highest price (8.1) and the lowest price (8.2).

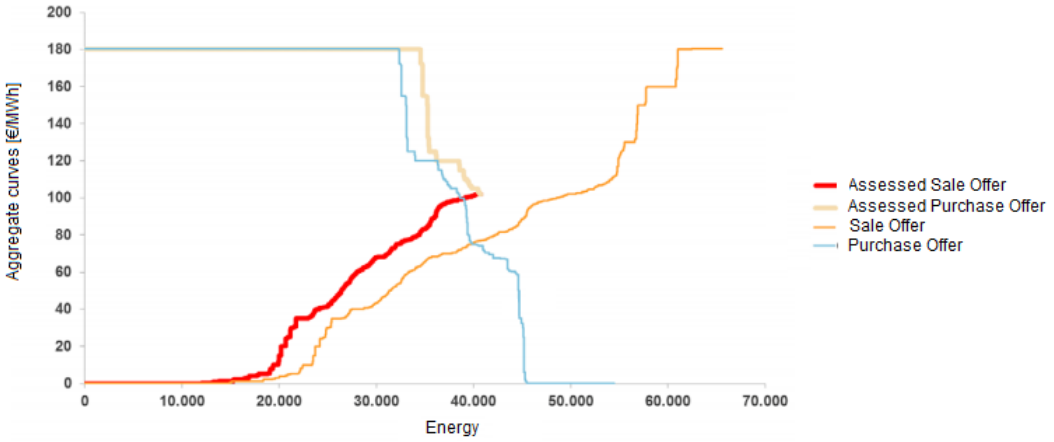


Figure 8.1. Aggregate curves for offer and demand of 25.01.2017 - hour: 21, *OMIE*.

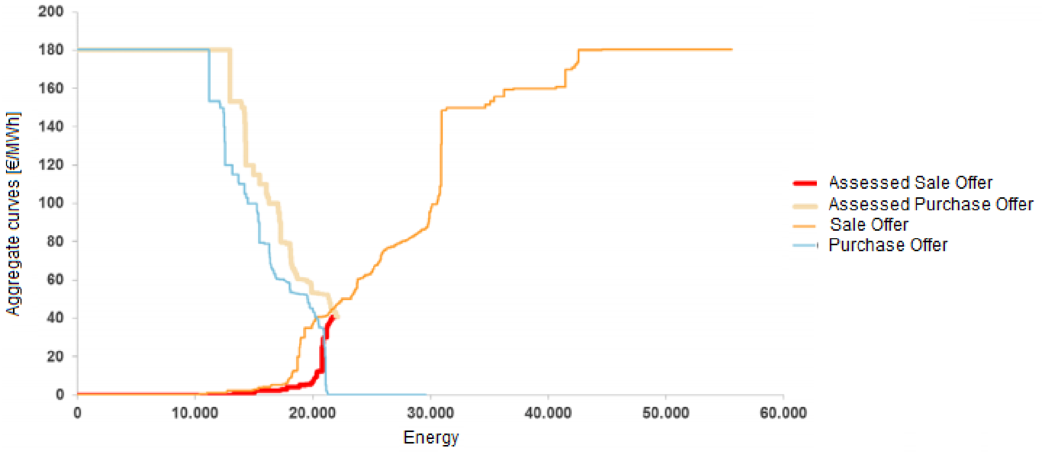


Figure 8.2. Aggregate curves for offer and demand on 28.01.2017 - hour: 5, *OMIE*.

It was previously explained that the final price per megawatt-hour in the Daily Market depends on the offer prices of the different electricity producers. In the figures it is not shown exactly which technology provides which percentage of the final price but in the following table 8.1, it is shown the amount of total electricity, in GWh, which was supplied by different technologies within January's Daily Market.

Technologies	**Daily Market January**	
	[GWh]	**[%]**
Coal	5.368	22,1%
Combined Cycle	1.653	6,8%
Nuclear Energy	5.271	21,7%
Hydroelectric Energy	2.165	8,9%
Importations (PT+FR+AD+MA)	1.030	4,3%
Wind Energy	4.889	20,2%
Cogeneration/Waste/Mini Hydroelectric Energy	3.869	16,0%
TOTAL	**24.245**	**100,0%**

Table 8.1. Production by technologies in the Spanish electric system in January 2017 – Daily Market, *[20].*

In addition, in the following figure 8.3, the behavior of different technologies in relation to the demand in January is as shown.

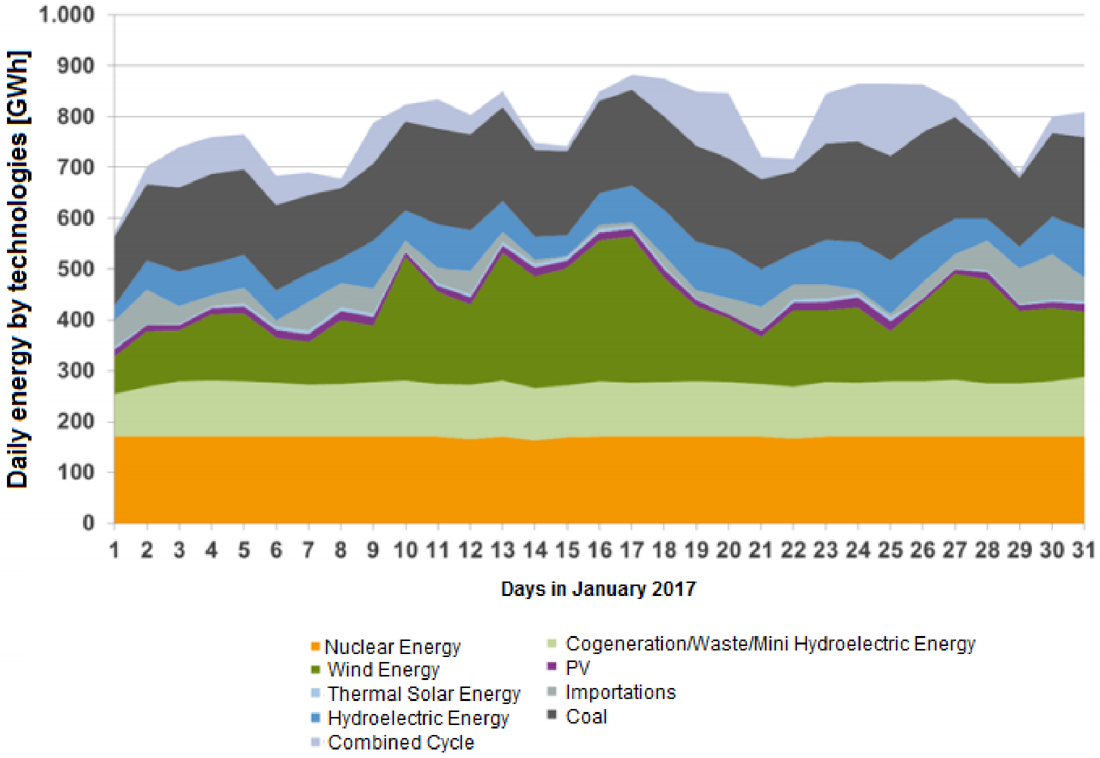


Figure 8.3. Energy by source during January 2017 within the Daily Market, *[20].*

As example, it can be perfectly seen that on the 28th of January, wind energy provided a considerable amount of energy while other sources as combined cycle or coal were present in minor percentage. As it was said, referring to figure 8.3, the lowest price of electricity was achieved. During this day the green source (wind energy) showed a major generation rate that conventional energy sources.

Secondly, it appears the Intra-Day Market. The contracting of energy in the Iberian Peninsula (taking account also the Portuguese Polo) reached **2.764 GWh** along the six sessions, which represents a **12,7%** of the energy of the contracting made in the Daily Market. The average volume of contracting in each session accumulates **89.148 MWh**.

According to the purchase-selling deals made in both markets, the Final Agenda is established and reads: “The total production of electricity was **25.648 GWh**; the total demand of reference commercialization companies (Endesa, Iberdrola, EDP España, Gas Natural and Viesgo) was **3.506 GWh**, and the total demand of the rest of commercialization companies and direct consumers was **22.674 GWh**”.

Nevertheless, the price is not conditioned only by these two processes. In the following table 8.2, it is shown a short resume about the different conditioners which exists and modify the final price for the different companies. [20] [21]

	Reference commercialization companies		Other commercialization companies Direct consumers		National Demand	
	[€/MWh]	[%]	[€/MWh]	[%]	[€/MWh]	[%]
Diary Market	74	89	74	90	74	90
Intra-Day Market	0	0	0	0	0	0
Restrictions	2	2	2	2	2	2
Power reserve (to put up)	0	0	0	0	0	0
Seconday allocation	1	1	1	1	1	1
Other procedures	0	0	0	0	0	0
Capacity payment	4	5	3	4	3	4
Interrumptibility service	2	2	2	2	2	2
TOTAL	**83**	**100**	**81**	**100**	**82**	**100**

Table 8.2. Final price in detail in the Spanish electricity market, January 2017, *OMIE/[20].*

After this explanation about the Spanish electricity market behavior and characteristics, it is worthy to mention a relevant characteristic of the current Spanish electricity sector, the Tariff Deficit. This issue is of major importance since it has been conditioning the whole system for more than 15 years.

The tariff deficit is an acknowledged debt that exists in Spain among the consumers and the electric companies which arose as consequence of an inefficient management of the Spanish electric tariffs. As a result, the regulated revenues of the electric system (access tolls and charges which consumers pay in order to get access to the system) were not high enough to bear the real costs associated to the regulated activities (such as transportation, distribution, energy subsidies, etc). This means that the recognized electricity price in the Spanish electricity bills did not correspond with the real electricity generation price invested.

This deficit mechanism first started with the Law 54/1997, which regulated the Electric Sector by then. The first large misbalance was given in 2005, even though the deficit was registered every year since 2000. Later, in 2008, the deficit “faced” the exponential entrance of renewable energies in the system and a demand fall caused by the economic recession. Those facts finally caused its shoot up and increased the debt until **6.300 million Euros** – compared to the **70 million Euros** in 2003.

Nevertheless, this situation has been reversed with the 2013’s reform. This reform was basically implemented in order to stop this economic hole from keep growing. It is in here when renewable energies’ matter appears in relation with this tariff deficit, since they were not precisely benefited by the new energetic policies.

The government implemented through this reform a new regulatory system in order to cover the **4.500 million Euros** debt and thus stop its growing. The Industry Ministry approves:

- **Immediate light price increment**, which covers around 900 million Euros.
- **Subsidies for traditional electric companies** are cut – which saves around 1.350 million Euros.
- **Subsidies for renewable energies** are erased and new supports schemes are adopted – saves also 1.350 million Euros.
- **General State Budgets** cover the remaining 900 million Euros.

These new support schemes for renewable energies, which derive from the last 2013's Electric Reform, will be extensively explained in the following section "Support Schemes".

Apparently in the upcoming year 2017, and following the positive trend which started in 2013, is not expected a register of tariff deficit. According to this, the achievement of no tariff deficit would assure that the situation is fully recovered. Hence more favorable regimes for renewable energies are expected to be adopted in the near future. [24] [25]

9. The transmission grid and cross border transfer capacity

This complex accumulation of subsystems and participants reorganize themselves within the Grid. The Spanish grid consists of more than **42.000km** of high voltage transmission lines, with more than **5.000 substations** and more than **80.000MVA** of transformation capacity. Current data, accumulated until the end of 2015 are shown in the following tables 9.1, 9.2 and 9.3.

Peninsular and island territories grid					
km of line	**2011**	**2012**	**2013**	**2014**	**2015**
400kV	19.671	20.109	20.639	21.094	21.179
220kV	18.410	18.779	19.053	19.192	19.387
150-132-110kV	272	272	272	272	398
<110kV	2.011	2.014	2.014	2.014	2.022
TOTAL	**40.364**	**41.174**	**41.978**	**42.572**	**42.986**

Substations positions peninsular and island territories					
Number of positions	**2011**	**2012**	**2013**	**2014**	**2015**
400kV	1.253	1.319	1.374	1.394	1.441
220kV	2.813	2.936	3.026	3.077	3.124
150-132-110kV	52	52	52	52	84
<110kV	743	743	745	769	779
TOTAL	**4.861**	**5.050**	**5.197**	**5.292**	**5.428**

Transformation capacity peninsular and island territories					
Capacity [MVA]	**2011**	**2012**	**2013**	**2014**	**2015**
Total	72.869	78.629	81.289	83.939	84.544

Tables 9.1, 9.2 and 9.3. Spanish grid data, *REE*.

In the following figure 9.1, a geographical representation of the Spanish transmission grid is shown on the map. Nevertheless, more detailed current grid geographic situation, updated to January 2016, can be also consulted on the reference [108] “Mapas de la red”. [26]

Figure 9.1. Spanish transmission grid, *REE*.

As a main characteristic of the grid, there is only one organism called Red Eléctrica de España, REE, on which the supply system relies. It is the only operator of the Spanish electric network since the Law 17/2007 was approved on the 4th of July, and it also manages the Canary and Balearic Islands and the autonomous cities of Ceuta and Melilla. Since then, Red Eléctrica de España has managed the transportation within the grid in an exclusive regime. [26]

REE is in charge of the necessary activities in order to guarantee continuity, security and an adequate coordination in between production system and transportation network, also assuring that the energy produced is transmitted from the generators to the distribution lines according the current legislations. This means, it is the major entity in which the quality and assurance of the service rely on.

Secondly, REE must guarantee the equilibrium in the system. Therefore, it estimates the demand of electric energy and manages simultaneously both generation installations and the electricity transportation at every moment. When the situation is different, it also sends the appropriate orders to the power plants in order to avoid possible future losses. Also, inside the Peninsula, REE operates the adjustment services of the system which involve technical constrain solving (bottleneck solutions), complementary services allocation and deviations handling.

Finally, it is also in charge of the development and enlargement of the grid, parallel to its maintenance, transit management with the outside systems and guarantees the access to the grid by third parties under quality conditions. [28]

In terms of international cross-border connections, a larger electricity exchange capacity with neighboring countries provides more supply security, improvements in efficiency and competitiveness with those countries and also facilitates the integration for renewable energies.

Commercial electricity exchanges take place daily with the lines' spare capacity which is not intended to supply security, taking advantage of the energy price differences among the connected electric systems. Thereby the electricity generation is achieved with more efficient technologies thanks to the flow from cheaper to more expensive regions/technologies.

The commercial capacity, in MW, gives an indication of the most probable forecast of exchange capacity among the systems. For example, in the following table 9.4 and the figure 9.2 the commercial capacity exchange at the beginning of 2017 are shown.

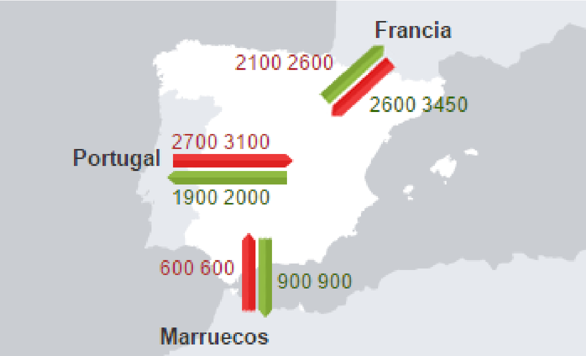


Figure 9.2. Commercial exchange capacity among neighboring countires [MW], *REE*.

Connection	Minimum [MW]	Maximum [MW]
France-Spain	2.600	3.450
Spain-France	2.100	2.600
Portugal-Spain	2.700	3.100
Spain-Portugal	1.900	2.000
Morocco-Spain	600	600
Spain-Morocco	900	900

Table 9.4. Commercial exchange capacities from 4th to 17th of Februar 2017, *REE*.

As to have a numerical idea, during 2015 the export balance of Spain reached **467 GWh** – **15.119 GWh** of exports minus the **14.652 GWh** of imports.

These connections have achieved a great importance. Especially for Spain, since it has limited opportunities to exchange energy due to its small number of neighboring countries – moreover, it has been usually referred as an "energetic island" (isolated energetic system). As shown in figure 9.2, Spain only counts with connections to Morocco, Portugal and France. [31]

Within the European Union, at least a 10% rate of energy exchange with neighboring countries has been established as common goal for 2020. According to that, several Projects of Common Interests, PCI, has been developed and supported by the European Commission in order to increase the Spanish exchange rate and fulfill the European objectives. These are mainly focused on the North of the peninsula, reinforcing the high voltage lines in connection to France – which leads, at the same time, to a connection with the rest of the countries of the EU. Nevertheless, Spain will not be able to fulfill the objectives 2020 but these projects push it closer to it. In the following figure 9.3, the expected projects are shown but they are planned to be finished after 2020.

Figure 9.3. France – Spain connections planned through PCI, *PCI EU commission*.

The most ambitious project is named “Biscay Gulf project”, which connects the French region of Aquitaine with the Basque Country. The project includes an underwater connection of DC, **2 x 1000 MW**, which is drawn as the left blue line on the figure 9.3. The other two lines also connect Aquitaine with Spanish territories, Navarra and Aragón, and reach a capacity of **2.000 MW** through high voltage DC. These lines also give an opportunity for electricity flows from as far east as Poland to as far north as Great Britain. [30]

With the acquisition of these lines, it is expected to reach an exchange rate of 8%. Spain remains confident that it will finally fulfill the European objectives and abandon its current “energetic island” status. And not only that, the placing into service of such transmission lines will smooth the limitations that normally appear when high production of renewable-based energy is registered.

The horizon 20-20-20 is likewise running through the Spanish grid’s future planned actuations – apart from the international interconnections which have been already mentioned. The 2015-2020 Planning was developed by the Ministry of Industry, Energy and Tourism and aims to assure the electricity supply, while assuring simultaneously an environmental respect to minimum cost.

It is expected an investment of **4.554 million Euros** in the following actuations:

- **Supply assurance.**
    - New network meshes in order to improve the supply in wide zones from Spain.
    - 155 new support actuations from transportation line to distribution line and big consumers in order to improve the local quality.
- **Technical constrains.**
    - Grid reinforcements in order to reduce those constrains costs.
- **Demand.**
    - 13 new substations and other 11 enlargements for the new High Speed Train lines.
    - New local developments of transportation grid in order to support the industrial demand.
- **Interconnections.**
    - Reinforcements on the connections among the islands and in between Ceuta and the Peninsula.
    - International connection reinforcement – one in the North of Cataluña connecting with France and another one in the South connecting with Africa.
- **Generation evacuation.**
    - Projects which are adjusted to the demand forecasts. [27]

10. Integration of Renewable Energy in Spain

As mentioned before, the Spanish territory is fortunate to receive such availability of renewable sources with such a high potential that can be applied in the industrial field. According to REN21, Spain is placed in the top 5 countries when talking about total capacity by the end of 2015. Specifically Spain is placed 4th in renewable power capacity per capita, 1st place in concentrating solar thermal power (CSP) and 5th in wind power capacity. [2]

In the 80's the Spanish government decided to actively take part in this field. In this moment, first energy efficiency regulations were approved and they finally developed in the first implementation of renewable energies inside the Spanish electric sector. In 1985, the first mini-hydroelectric power plants were installed, completely supported by government regulations. Since then, the Spanish territory has been studying and developing different technologies which are discussed in the following chapter.

10.1. Hydroelectric energy

Spain has incremented its electric supply fundamentally with wind and solar energies but, on the contrary to hydroelectric energy, they do not have yet the reliability which is required by the electric system. In this matter the hydroelectric potential is proven. These power plants show high operation reliability, a good response to demand changes and their environmental effects are sufficiently developed in order to be considered low.

Hydroelectric energy has been developed for more than a century in Spain. Consequently the hydroelectric generation system is considered stable and highly efficient and has collected significant importance within the electricity sector. A good example of this is the hydroelectric power plant located in Bolarque, which has worked for more than 100 years and is still efficiently working.

There are two types of hydroelectric power plants in Spain:

- **Run-of-river power stations.** They capture a portion of the river flow and lead it to the power station for turbinate and subsequently return it to the river. They use low power ranges (typically **less than 5 MW**) and represent a 75% of the market share. They include "irrigation channel stations", which use the water drop in irrigation canals to produce electricity. The power range of these is between 1 and 5 MW and can account a 5% of the market share in Spain and they are known as micro-hydroelectric power plants.

- **Reservoir power station.** They usually have levels **greater than 5 MW** and represent approximately 20% market share in Spain. Among them, "Pumped storage or reversible power" power stations are found. These ones generate energy (turbine mode), and have the ability to raise water to a reservoir or deposit consuming power (pumped storage mode).

Both of these types are included in a major characterization, which is divided in mini-hydroelectric or big scale hydroelectric power plants. The differentiation is quite easy, mini-hydroelectric power plants can reach a maximum of 10 MW of installed capacity, unlike the big scale ones which can reach more than of 1000 MW, as it is the case in Spain. [44]

Different technologies are used depending on the characteristics of the power plant. Since the design of these power plants has been developed during a long period, starting around the end of the 19th century, there are currently a huge variety of designs which allows taking advantage of every type of water height.

- For water heads up to 70 meters, Kaplan wheels are used. They work efficiently with large flow and short height, keeping its efficiency around 90%. This technology allows taking advantage over low riverbeds with gentle slope.
- In the zones in which steeper slopes, it changes to Francis turbines, which admit a range in between 50 to 300 meters high. They also offer a large regulation range, including heights and flows truly diverse, which makes it the optimum ones when it comes to real-time-regulations.
- On the upper parts of the rivers, with shorter flows and higher heads, Pelton turbines are used. The jump range goes from 200 to 1500 meters high with also a wide regulation range which keeps the efficiency around 90% for every possible case. [47]

Nowadays, hydroelectric energy represents an important percentage of the energetic situation in Spain, which is reflected in the amount of installed capacity: **18.492 MW**. Thanks to which, it managed to cover **11,1%** of the Spanish electric demand in 2015 and provided close to a **2%** to primary energy consumption. [35]

Along their rivers' distribution there are found around **1.500 reservoirs** in which more than 800 power plants have been installed. They include ranges from less than 1 to several hundreds of megawatts – Mini- and Big scale hydroelectric as it was above explained. Among others, some of them can be outpointed due to their importance and dimensions:

- **Hydro power plant La Muela** – Cortes: **1.750 MW** for generation and **1.280 MW** for pumped storage energy. It is able to produce **1.625 GWh** and attend the annual demand of 400.000 households.
- **Hydro power plant Aguayo II**: **932 MW** for generation and **1.182 MW** for pumped storage energy.
- **Aldeadávila I + II**: **1.243 MW** installed for generation. It produces annually **2.400 GWh**.

As conclusion, hydroelectric energy has stability and a mature degree which is lacking in the rest of renewable energies. Thanks to that, a major contribution of renewable energies is provided by these power plants – it will be further developed in the chapter "Electricity generation".

10.2. Wind energy

Wind energy has consolidated itself as the renewable resource with the largest share in electricity generation at the moment. Spain has taken advantage of their numerous wind zones and has installed turbines all over the territory. Currently are found **22.953 MW** of capacity installed which have been accumulated since the technology began to be installed around 2006. It is interesting to highlight that it is a major amount than hydroelectric power plants, which had a history of up to a century. This huge investment in wind energy makes Spain the 5th country with the largest wind installed capacity in the World and at Spanish context it employs **22.468 workers**, exports technology with value of **2.925 million Euros** every year and provides **2.731 million Euros** to the country's GDP (**0,25%**), among others.

La Asociación Empresarial Eólica (AEE), or Wind Energy Business Association as could be translated in English, is the representative of wind energy in Spain. AEE involves 200 associate enterprises and represents more than the 90% of this sector. It includes promoters, turbine and components manufacturers, national and regional associations, consultants, layers, etc. AEE is also in charge of wind energy's R&D and serves the different associates according to their own needs.

In relation to the electric sector, wind energy produced **47.319 GWh** in 2016 and covered the **19,3%** of the whole total electric demand of the country. In accordance with MINETUR's energetic planning for the period 2016-2020, a total of **29.479 MW** of installed wind energy capacity are planned to be installed. If so, they are expected to provide in between **21** and **25%** of the whole electric demand. In this case, if Spain reaches this 2020 goal, wind energy will become the principal generation technology in the country.

As mentioned before in the "Electricity Market" chapter, the more "green" power plants provide energy to system, the cheaper the final price is. As one of the greatest "green" producers, here it is shown an example about how wind energy affects the final energy price.

The energy price is fixed everyday on a competitive pool, in where the different energy sources offer the electricity in order to satisfy next day's foreseen demand. As wind cost is zero, wind energy producers can offer the electricity at lower price than others and hence displace conventional energy sources with higher prices. The windier the day is, the lower will be electricity price.

For instance, let's account the wind energy performance in 2015. Its reducer effect against conventional sources was **15 €/MWh**. If wind energy would have not existed, the annual average price on the electric market would have reached **62,32 €/MWh** - a 23,8% higher. If this is reflected into numbers, the price that would have been paid to supply the demand would have increased in **2.952 million Euros**.

Currently there are 4 main wind big scale turbine producers in Spain which accumulate around 50 GW around the world: Acciona Windpower can be found in 18 countries of the 5 continents; General Electric Wind (acquired in 2015 by Alstom Wind) reaches around 6.500 MW installed; Gamesa has installed around 33.000 MW in 54 diverse countries; and Mtorres, which started their own turbine manufacturing in 2000. [49]

As relevant wind power parks in Spain, it can be mentioned:

- **Dólar III**, in Andalucía, Wind Park promoted by Iberdrola. It reaches **49,5 MW** and 25 wind turbines.
- **Tardienta I** and its enlargement, Tardienta II, together they sum **103,7 MW** of installed capacity and 132 wind turbines.
- **Muela Cubillo**, reaches **50 MW** with only 25 high power turbines. It is located in Castilla – La Mancha.
- **Sil** plus two further enlargements. In total, **90 MW** are accumulated. Iberdrola installed 96 turbines of different types.

Off-shore versus on-shore technologies

There is a noticeable difference between off-shore and on-shore wind energy in Spain. Nowadays, Spain is one of the leader countries on on-shore installed capacity but not many off-shore wind turbines have been installed yet. Furthermore, only a few have been installed on the Canary Islands and are considered as prototyping phase. The 4-MW-capacity installation was carried out by Gamesa Energía and was called “Arinaga Off-shore”.

The unitary power of an off-shore wind turbine is proved to be larger than that of on-shore’s one and, in consequence, it is considered the projection of 4-MW-off-shore turbines construction during the next decade which will provide a better exploitation of the Spanish nearby coasts. Some organizations believe that up to 25.000 MW of off-shore capacity can be installed in strategic points such as the Canary Islands, the Strait of Gibraltar, The Ebro Delta area, the Galician coast or the Creus cape, with adapted solutions. [54]

In order to get to know a realistic perspective about the possibility of off-shore wind parks installation along the Spanish littoral, an analysis is made based on the report “Estudio estratégico ambiental del litoral español para la instalación de parques eólicos marinos”, or “*Environmental and strategic report of the Spanish littoral regarding the installation of off-shore wind parks”* translated to English, which was published on 2009 by the Ministries of Environment and Rural and Maritime Affairs, and the one in charge of Industry, Tourism and Trading. It establishes a zoning in which the different nearby coasts of Spain are divided and it is indispensable in order to understand the potential of currently off-shore technologies in the country.

Besides this zoning that can be considered as a first filter step according to environmental considerations, also technical and economic restrictions participate in the study. These last two are explained as follows:

- **Technical considerations.** Adequate maritime depth, which is coherent with the current maritime technologies.
- **Technical-economic considerations.** A sufficient availability of the resources is imperative in order to consider future wind parks installations.

The zoning was carried out through Geographic Information Systems (GIS). This tool allows generating an objective and realistic cartography over the Spanish territories in accordance with the strategic considerations for more suitable off-shore technologies. As a result, 72 zones have being defined as wind off-shore areas as it is shown in the following figure 10.1.

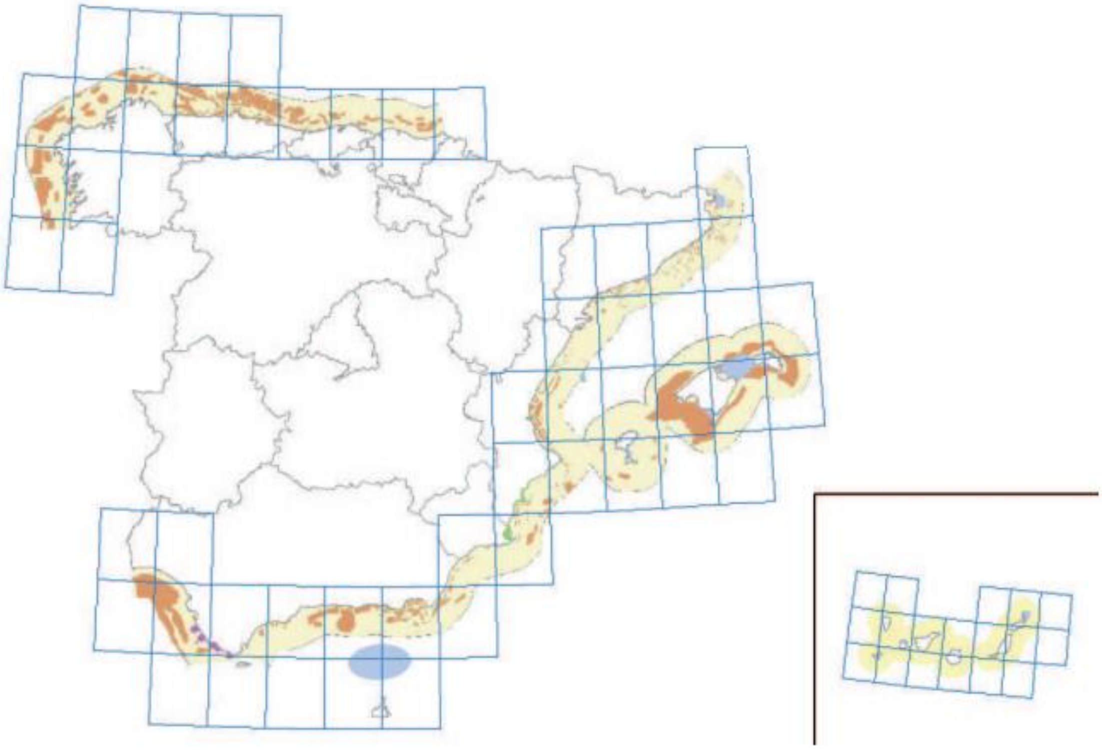


Figure 10.1. Off-shore zoning in the Spanish litoral, *[56].*

Following the criteria established and considering the compatibility between off-shore wind parks and their expected environmental effects, three different zones are defined:

- **Exclusion zones**, represented in red color. Zones which are not suitable for off-shore wind park installation because the identified potential environmental effects has been declared as non-compatible or because conflict generation with other maritime uses which are considered paramount. These zones represent 55.889 km^2 of the usable Spanish area.

- **Suitable zones with environmental conditioning**, represented in yellow. In here, various negative environmental effects are likely to appear while installing an off-shore wind park and thus a more exhaustive analysis will required to be conducted in order to measure the possible impact on the corresponding project. These zones represent **89.759km^2** of usable surface.
- **Suitable zones**, in green color. These zones are free of any expected environmental affection, according to the available information during the Study. Finally, these zones involve **84.666km^2** of usable surface.

It is shown in figure 10.2, the results obtained from the zoning according to environmental constrains.

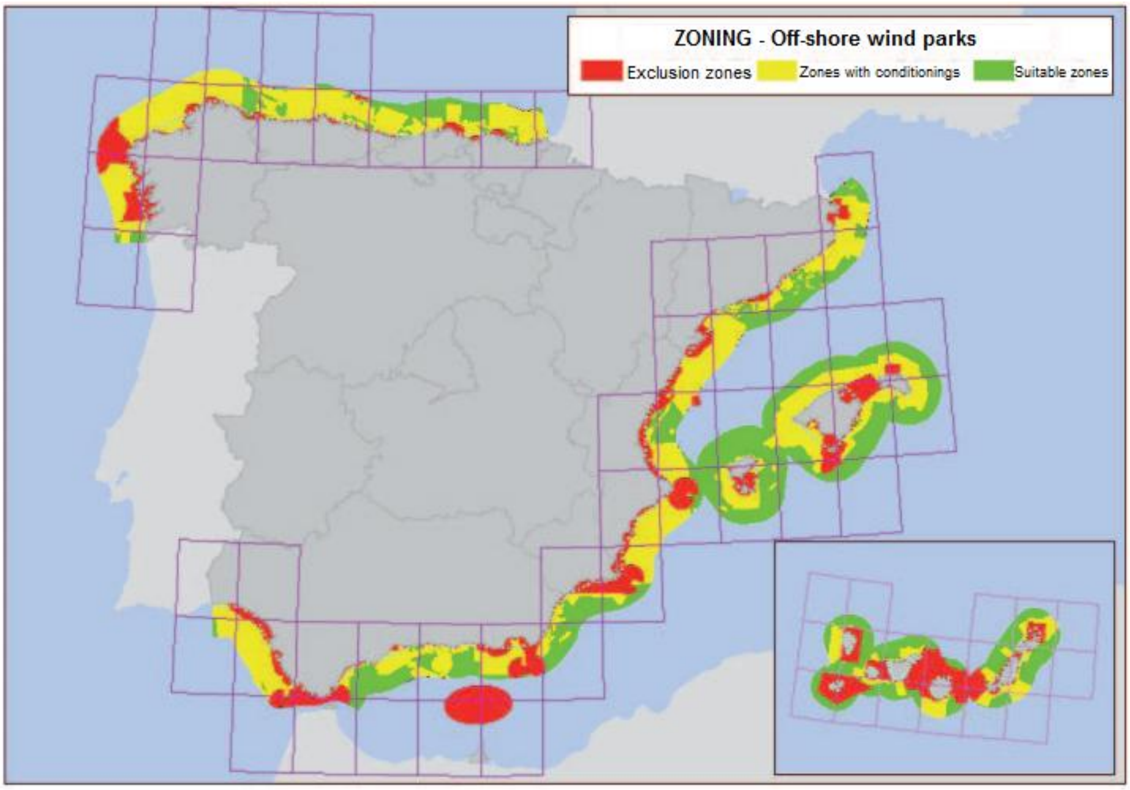


Figure 10.2. Zoning according environmental effects, *[56].*

As second place, a technical filtration must be applied. The average depth of a European off-shore wind park is shorter than 20 meters. As exceptional cases, some parks have reached almost 50 meters – considering this depth as limit for the current technologies developed and for the future-expected-to-be turbines until 2020. The depth of Spanish nearby coast generally exceeds this value and thus the current technologies are not still enough developed in order to be profitable on the Spanish littoral.

Not only that, a technical-economic viability must be assured prior to the consideration of installing a new wind turbine. Factors such as investment ratios per power unit, maintenance and utility costs and the retributions allocated for the produced energy are measured in order to set up an according minimum annual average wind speed. Thereby an annual average wind speed smaller to 7,5m/s up to 80m high will nullify any feasible project due to technical and economic invalidity.

After the data gathering and subjection to the different constrains, the initial zoning is significantly reduced and achieves the following values:

- Suitable zones: 31 km^2.
- Suitable with environmental conditionings: 1.381 km^2.
- Exclusion zones: 2.116 km^2.

As shown, in spite of having a wide coast lines only a minor part of it is suitable for off-shore installation. The primary problem relies in the substantial sea depth in the nearby of the Spanish coasts, which commonly exceeds the current technologies established limits. Not only that, the lack of electric infrastructure in the coast and underwater grid, larger investment required and the construction's technologies specifications have postponed the development of such wind parks in the country.

The off-shore development possibilities rely mostly on a further development of the technologies in order to be admissible according to the geographic characteristics of Spain. Another chance is given to depth-water floating platforms which are currently in development phase. [55] [56] [57]

10.3. Photovoltaic energy

The solar photovoltaic energy has experienced a particular development in the Spanish territory and history. Currently, **4.672 MW** are installed all along the Spanish territory, but that expected growth that came along with the Spanish boom, which appeared a decade ago, was somehow “forgotten” and the successive energetic normative curtailed its prospective path. The installed capacity development is shown on the figure 10.3.

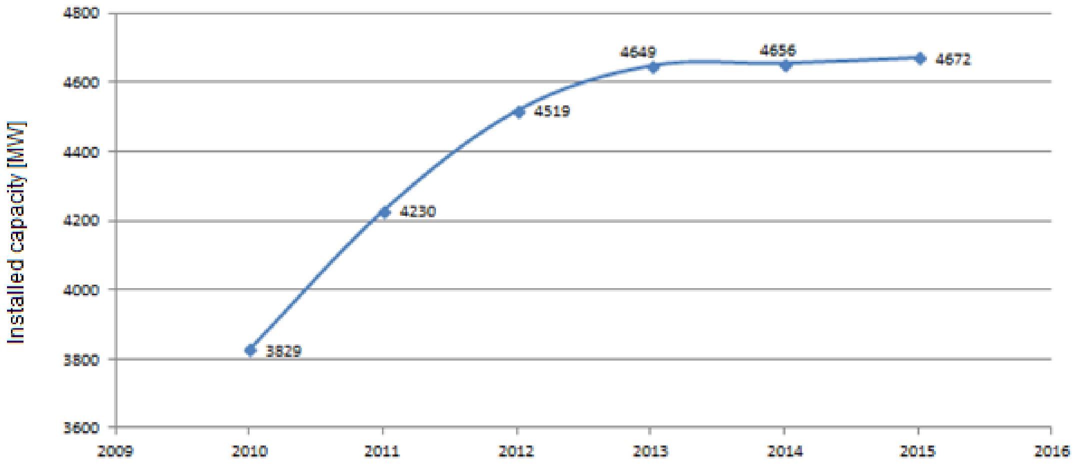


Figure 10.3. Capacity installed development after the “boom”, *UNEF*.

A great percentage of the capacity installed is distributed among Andalucía (**870 MW**), Comunidad Valenciana (**350 MW**), Castilla - La Mancha (**923 MW**), Castilla y León (**494 MW**), Extremadura (**561 MW**) and Murcia (**440 MW**). These regions are located on the southern half of the Peninsula and receive, as daily average, more than **140 W/m^2** or as it can be translated into terms of direct normal irradiation, it means more than 3 kWh/m^2 in a day.

In 2015, photovoltaic energy supplied a **0,57%** of the primary energy consumption and covered a **3,1%** of the electric demand. Also, according to the information provided by UNEF, the Spanish Photovoltaic Business Association, only **49 MW** were newly installed during that year, which represents a **0,09%** of the **51.000 MW** installed around the world. Not only that, in the last legislature only **700 MW** of wind energy and biomass were auctioned, leaving the photovoltaic energy aside of the auctioning. [35] [58]

Nevertheless, not every perspective is negative. Photovoltaic energy brings up good points for developing and foreign companies start to take a chance on the possibility that Spain, being the country with the largest solar radiation in Europe, will recover the previous trend. Such names as Hive Energy, X-Elio (the previous Gestamp Solar) or SAG Solar-Shunfeng are on their way of designing and building new PV power plants all over the Spanish territory. Some examples are the Lorca Solar power plant in Murcia – currently in operation; or another one to be built in Calzadilla de los Barros (Extremadura). Each one of them accumulates around **400 MW** of capacity installed. [60] [61]

A different point of view has been adopted by the different Spanish promoters due to their experience. Despite such things as the “Solar Tax” implemented back in 2013 or the subsidies removal which promoted a recessive behavior, the PV promoters sum 50.000 MW in access-to-the-grid requests according to the REE data. It is imperative an appropriate boost in this technology in order to reach the Spanish renewable goals for 2020.

On the other hand, regarding to self-consumption photovoltaic panels, the past 9th of October 2015 the new Royal Decree 900/2015 was approved. This normative regulates the self-consumption photovoltaic installations but, instead of promoting them, it establishes new obstacles to their installation through a series of charges and impediments which diminish significantly their profitability. However, as positive fact, the photovoltaic technology continues increasing within the agricultural and livestock sectors providing the required energy for pumping, irrigation and heating systems, among others. [58]

As relevant photovoltaic power plants the following ones are found:

- **Solarpark Cáceres**, installed by Wirsol Solar, has **10,7 MW** installed and generates annually **18.786 MWh**. It accounts **391.645 square meters**.
- **Elduayen**, in Badajoz and installed by Tsolar, reaches **11,45 MW** with **59.079 panels**.
- **Parque fotovoltaico Puertollano (Ciudad Real)**, which reaches **70 MW** and more than **150 ha**. Developed by Renovalia.
- **Parque Fotovoltaico Olmedilla de Alarcón (Cuenca)**, with **60 MW** of installed capacity and operated by Nobesol. It started in 2008 and produces **87.500 MWh** annually.

10.4. Thermal solar energy

As observed with photovoltaic energy, this technology also shows an irregular development. After two years where no capacity was installed, thermal solar energy has reached **2.253,9 MW** installed by the end of 2015. Through this it represented a **1,8%** of the primary energy consumption and contributed with a **2,1%** on the electricity gross demand. Concretely, it produced **5.113 GWh** in the same year. [35]

As it can be seen in the following figure 10.4, the thermal solar production has been increasing accordingly to the generation park boost and mostly due to an efficiency increment in the different power plants.

Figure 10.4. Generation profiles from Thermal solar energy, *PROTERMOSOLAR*.

The biggest advantage of thermoelectric solar energy is that it is easily manageable and it can be stored. It is an energetic source able to provided energy to the system, even with absence of the solar irradiation. This is a major advantage of thermoelectric solar energy, since it can provide stability to the electric system. In accordance with this characteristic, the curve of aggregate production of thermal solar power plants mates perfectly the daily national electric demand curve. It is shown in the following figure 10.5.

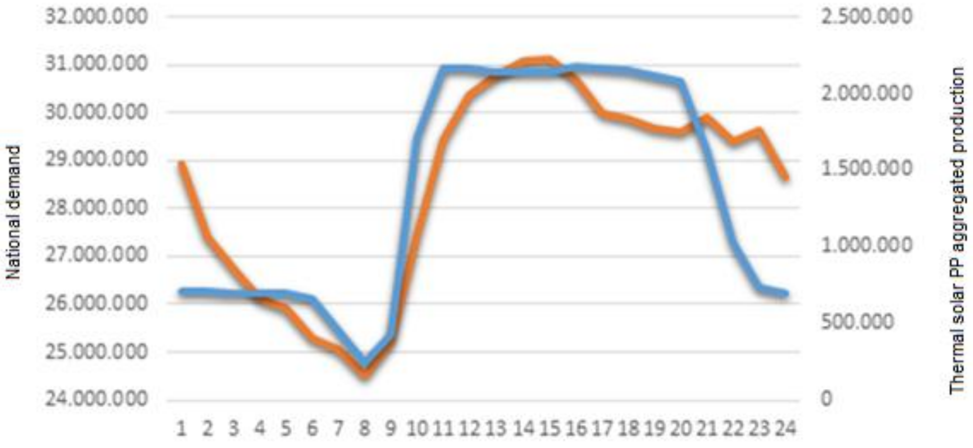


Figure 10.5, Aggregate production curve vs. diary electric national demand, *PROTERMOSOLAR*.

Spain represents a major role in both installed capacity and technological capability of this technology. Therefore, some Spanish companies start to develop new projects all over the world – in places such as USA, Middle East, China or India among others. In addition, thanks to the huge amount of solar irradiation which is received in the territory, especially on the southern half, in the future Spain aims to be a great "green" energy exporter and thus maybe help other countries in order to fulfill their 2020 green goals. This measure could be also really interesting and strategic in order to improve the economic situation of the country.

It is also appropriate to mention PROTERMOSOLAR, the Spanish Association of the Thermoelectric Solar Energy Businesses. It was founded in 2004 with the aim of promoting and developing the thermoelectric solar industry in Spain. Nowadays, it counts with 50 members, among whom almost every part of the sector is involved such as promoters, builders, R&D centers, consultants, components manufacturers, etc. [63]

At last, as highlighted facilities in Spain, it is worthy to mention:

- **Abantia/Comsa EMTE** located in Lérida, with **22,5 MW** of installed capacity. Its especial feature is the fact that it hybridizes a C parabolic cylinder thermal solar facility with a biomass facility.
- **Abengoa Solar**, in Sevilla, with **30 MW**, One of the few facilities in Spain with tower with saturated stream.
- Thermal solar power plant with C parabolic cylinder of **Alvarado** with **50 MW**, installed by Acciona. It can provide the energy required by 28.000 households.

10.5. Wave energy

In July 2011, the world's first commercial wave power plant was opened in Mutriku, a small village located in the North of Spain. The project started in 2002 when they first thought about the possibility of installing a wave power plant on the breakwater that was planning to be built on Mutriku's harbor. The investment in order to build it up has reached 6,4 million Euros and the energy which it produces is enough to cover the needs of 100 households.

The Mutriku power plant consists in sixteen groups of pairs of Oscillating Water Columns, OWC, a new prototype technology, joined with sixteen Wells turbines, which are simple and strong. The whole assembly reaches a total capacity installed of 296 kW – each pair turbine-turbo generator has 18,5 kW. Moreover, the blades of this turbines are designed to be symmetrical, a fact that enables it to spin invariably in the same direction, completely independent of the direction in which the inner flow moves. In the following figure 10.6, it is shown a drawing of the turbine.

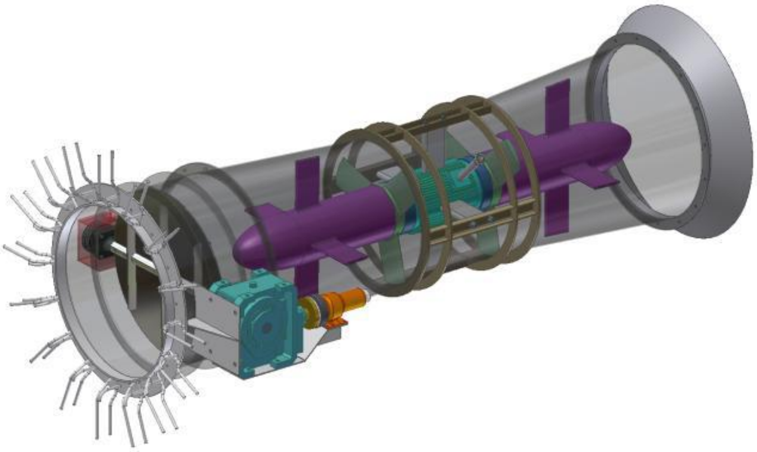


Figure 10.6. Wells turbine in Mutriku's power plant, *[64]*.

The installation was carried out by the Scottish company Wavegen, which was bought by Voith Group some time ago. Its branch, Voith Siemens Hydro Power Generation, developed this pioneer Oscillating Water Column technology which includes a special characteristic and that it is found in Mutriku's turbines. Unlike conventional turbines which are mainly activated by water, Mutriku's turbines run with air flows. It is the upside-down movement of the waves the one which produces an air flux inside the chambers and subsequently runs the turbines. Thanks to this innovation the turbines deteriorate way less than regular ones.

Last year 2016, Mutriku power plant managed to inject **1,3 GWh** (cumulative) of electricity into the Spanish grid, which is considered as a "world record" in production of this type of renewable energy. The evolution of its performance is shown in the following figure 10.7, provided by the EVE, Ente Vasco de la Energía.

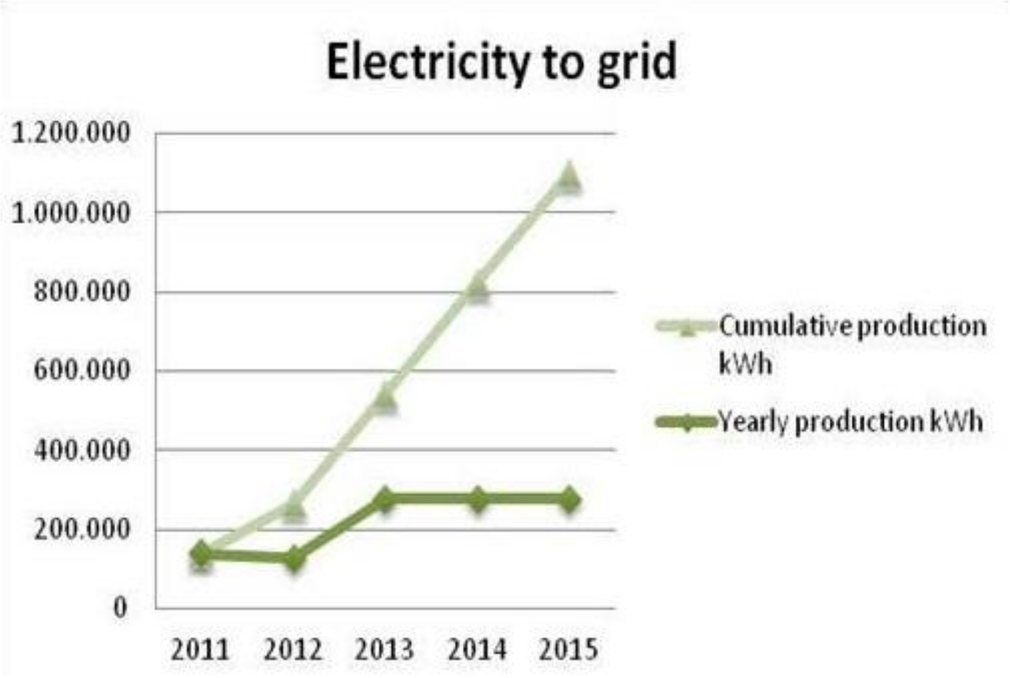


Figure 10.7. Mutriku's generated electricity injected to the grid, EVE.

Even though, this can be considered as a "humble" generation in comparison with other renewable energies already considered as "mature", it consolidates a great step when it comes the Spanish Seas' resources usage. Thanks to the efficient performance that this power plant has shown since its launch, other initiatives started to come up. Besides Mutriku's performance and technology are under continuous research and development other promoters and companies have also started to trust this source as a profitable one. One good example is the installation of the research facility Bimep, installed also in the Northern Seas of Spain, which is totally focused on sea technologies research. More information about this facility will be explained in the chapter "Futuristic aspects of the Spanish electricity sector". [64] [65] [66]

10.6. Biomass

Biomass is defined as "every kind of substance with biological origin excluding those which have been under geological formations and hence they have suffered a mineralization process" – Regulation 2003/87/CE of the European Parliament. Therefore, biomass can originate from multiple and diverse sources. According to those, four main groups can be established: [73]

- **Forest**: Biomass from the treatment and exploitation of vegetal masses. Directly related to forest sector and its activities in the mountains.
- **Forestry**: the biomass is here produced on crops, woody crops and arable crops – including both pruning processes and harvesting. Directly related with the agricultural sector and its activities
- **Agribusiness and forest business**: The biomass is produced by products, sub products and waste from industrial activities within the Forest and Agricultural sectors. Directly related to the mentioned industrial sectors.
- **Energy crops**: the biomass is produced in crops which are exclusively intended to energetic usage production. It can involve both forest and forestry business.

The obtained products can be divided into two types of usage:

- **Thermal biomass**: technical applications for heating, cooling and/or other industrial processes. Most common usage of forestry biomass (olive stones and nuts shells), forest biomass (logwood, woodchips...) and woody crops. These materials are normally transformed into pellets nowadays.
- **Electric biomass**: Used for electricity generation in both, exclusive and cogeneration methods.

In this chapter, the focus is on the biomass for electricity generation usage in Spain. There are currently installed **712 MW** of capacity and they concentrate themselves mostly in Andalucía, Aragón and Asturias. Thanks to these power plants it was covered approximately a **1,4%** of the Spanish electric demand. The country takes a 6th place on electricity generation through solid biomass in the EU, behind Germany, France, Sweden, Finland and Poland. However, when it is calculated production per capita, the obtained results are far away from the ones obtained as European average. [35] [68]

Biomass is gaining popularity in the production of electricity and this trend is expected to go on during the following years according to AVEBIOM (Asociación Española de Valorización de la Biomasa). This organization created in 2016 a so-called Biomass Observer website with the aim of collecting every kind of biomass-related information in a unique data base.

According to the data provided by this observer, the installed capacity of biomass for electricity generation increased in more than a **20%** from 2014 (around **600 MW**) to 2015 (around **712 MW**), but in comparison with 2008 it has increased around **400%**. During 2015 biomass produced more than **12.000 GWh** in their electric generation facilities. [67]

Some highlighted biomass-based power plants are:

- **Ence Huelva** (including Ence I, Ence II and Ence Biomasa) which accumulates a total of **118 MW**. Both Ence I and Ence II are cogeneration plants and use energy crop and industry and forest waste. Ence Biomasa, however, uses forestal biomass.
- **CB Monzón**, **CB Erla** or **CB Zuera**. All three of them accumulate **148,5 MW** and burn forest biomass.
- **ENCE Navia**, in Asturias, plus their enlargement has reached **77 MW** of installed capacity. They both work based on forest biomass and the expansion incorporates cogeneration too.

Thermal biomass will be only explained briefly since a major importance appears in biomass for district heating which will be subsequently discussed in detail. When classifying the thermal supply of renewable sources, biomass is greater spreaded rather than other technologies. In 2015, it provided **3.936 ktoe** to thermal supply which was approximately three quarters of the total Spanish thermal supply. From this amount **548 ktoe** were derived to biomass power plants for useful heat consumption and the rest were allocated to heating systems. [4]

10.7. Biogas and solid urban waste (SUW)

The usage of biogas and solid urban waste, or SUW, represents a minor percentage in comparison with the previous technologies that have been explained. There are found around **500 MW** installed of both technologies summed up together, **214 MW** for biogas and **305 MW** of solid urban waste. These technologies supply **0,7%** of the total Spanish electricity demand – **0,31%** SUW and **0,42%** biogas. [35]

Biogas power plants for electricity generation were installed in the 80s decade for the first time and they have registered an intermittent development since then, due to essentially minor retributions than other technologies. There are four major biogas sources: dumpsite biogas, biogas produced by agricultural waste, biogas from treatment plants and biogas produced by solid urban waste. All of them are obtained by the same process, the so-called "bio-methanation", which involves and anaerobic digestion of organic waste. [74]

The zones which cumulate a higher amount of biogas power plants are located most often around principal industrial or agricultural areas. Commonly they are installed in order to treat the industrial or agricultural waste located in the landfills to produce biogas, for that reason dumpsite biogas is the most common used type of biogas in Spain. There are found **49,8 MW** in Cataluña, followed closely by the **42,6 MW** installed in Madrid. As second position group, Andalucía has installed **21,4 MW** and finally there are **18,9 MW** in the Basque Country.

The largest biogas for electricity generation power plants that are found read as follows:

- **CLP Organogás SL** in Sevilla, Andalucía. It has been increased in size in eight occasions and has accumulated an installed capacity of **10,4 MW**. It runs mainly by dumpsite biogas.
- **Garraf's Dumpsite in Cataluña**. This landfill added a biogas facility of **12,4 MW** in order to take advantage of the residual waste which was there accumulated.
- **Gedesma** and **Valdemingomez 2000, SA**. Both are located in Madrid, and they reach **34,5 MW** of installed capacity. Biogas from dumpsite is the more common used fuel.
- **Cogeneration Pastguren**. In this case, the biogas is both used for electricity generation and useful heat generation simultaneously. This power plant was installed in 2001 in Vizcaya, in the Basque Country.

Regarding solid urban waste, it is also mainly located close to major industrial regions, such as Madrid (**29,8 MW**) or Cataluña (**51,5 MW**), but it also appears in more rural regions such as Galicia (**63,8 MW**) and Aragón (**49,9 MW**). It is noteworthy what a relevant role this technology plays in the Balearic Islands. Besides being an efficient and more sustainable way to manage residual waste it provides the Islands some energetic independence from the mainland – **74,8 MW** of the total solid urban waste installed capacity,**305 MW**, are found in Palma de Mallorca.

Four SUW big power plants are found:

- **Grupo Turbo-Generador Tirme-Son Reus**. This two-phase SUW power plant is located in Palma de Mallorca, in the Balearic Islands, as is the major electricity source which provides certain electric independency in the islands.
- **Planta de valorización energética de residuos industriales no peligrosos del reciclaje del papel**. This power plant was installed in Zaragoza in order to take energetic advantage of one of the largest industries located in the area, a paper industry. It has **49,9 MW** of installed capacity.
- **Tersa**. A power plant built in two phases which is located in Barcelona, Cataluña, and reaches **23,8 MW** installed.
- **Tirmadrid**. This power plant has **29,8 MW** of installed capacity and is located in Madrid.

10.8. Renewable energy integration in the grid

The path that current technologies are following in Spain gives confidence in order to keep promoting every possible way to reach green and sustainable generation. Nevertheless, even when the most innovative and competent power plants are installed; nothing will succeed without a proper integration of these technologies into the Spanish grid. This is currently one of the major challenges that renewable technologies must face.

As previously explained in this report, the electricity grid consists not only in the transportation of electricity from one point to the next one. There are many different factors that make it an extremely complex activity. Renewable electricity generation hinders even more a sustainable and correct grid performance. A more efficient grid management is required due to its usual fluctuating behavior. This competent handling is conditioned by the exchange capacity with neighboring countries, which is not high enough, and by the demand curves of the country, which again does not benefit Spain since it registers a significant difference in consumption between peak and off-peak hours. Therefore, more requirements and flexibility are also required by the manageable energy producers.

Red Eléctrica de España has developed an organization in order to face this challenge about renewable integration in the grid. Its name is CECRE, Centro de Control de Energías Renovables or Renewable Control Centre in English. It is basically a technological tool in order to incorporate these energies which have such a huge variability, smaller adaptation to the demand profiles and imprecise predictability.

Every 12 seconds, the tool receives real-time information from diverse control points. With all the data collected, Cecre carries out an analysis according to the real scenario, foreseen the operational and technical measures that assure a secure system and, if so, send the appropriate orders to the non-manageable renewable generation power plans that must be accomplished in less than 15 minutes.

Thanks of this control centre, it is possible to show how the renewable energies have developed their performance in this field. Despite the fact that the electricity demand has been diminishing until 2014 and finally showing a positive rate in 2015, the values reached by renewable sources present an opposite conduct. It can be seen in the following figure 10.8. [75] [76]

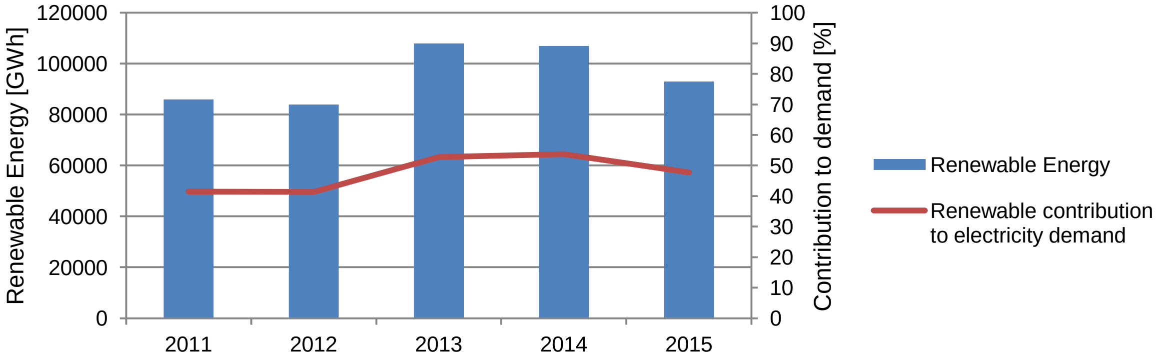


Figure 10.8. Renewable energy share and contribution to the gross demand, *REE*.

10.9. Potential analysis

Along this previous chapter, it has been explained the installed capacity and the current renewable energies' situation in the Spanish territory. Nevertheless, there are also several factors which have to be measured and taken into account when thinking about the future. This group of factors will condition the further development of certain types of technologies in order to reach the common goal of 20% share of renewable participation in the total final energy consumption in the country by 2020.

According to that, the different renewable sources which are found in Spain can be listed in order of larger to smaller potential. In the first place, it must be taken into account that the different technologies started their way to competitiveness through diverse development speeds and in different moments. This fact joined with the own characteristics that each technology possess and the energetic sources from which they come are the key factors in order to understand and classify them.

In accordance, several factors arise and allow classifying the technologies. Those are established on the government's renewable plan 2011-2020:

- The creation of an enough diversified "energetic mix".
- Efficient exploitation of renewable sources.
- Environmental effects of the technologies.
- Easy integration into the electricity grid.
- Available potential.
- Improving potential.
- Employment generation.
- Public support.
- Other social benefits.

Based on this renewable planning, a potential analysis was carried out by the Spanish government showing the expected potentials of the different renewable sources by the year 2020. The information is shown in the following table 10.1 and 10.2, and it involves both electricity and heat generation.

Technology	Potential [GW]
Solar Energy	>1000
Wind Energy (on-shore + off-shore)	340
Wave Energy	20
Hydroelectric Energy	33
Pumped Storage Energy	13
Electric Biomass	8
Waste	2
Biogas	1

Table 10.1. Potential analysis of technologies in electricity generation, *PER 2011-2020*.

Technology	Potential [ktoe]
Biofuels	4.775
Biogas	1.819
Biomass	20.425
Waste	4.045
Thermal Solar Energy	>15000

Tables 10.2. Potential analysis of different technologies in thermal generation, *PER 2011-2020*.

Taking into consideration all the information previously explained about the available capacity installed along the report merged with this information provided by the 2011-2020 renewable report, three main technologies will be further explained in this analysis: Wind Energy (both on-shore and off-shore), Solar Energy and Biomass. [77]

In the first place, Wind Energy already registers the largest capacity installed over the rest of technologies and, however, it still achieves a great potential. The situation is completely different while considering off-shore versus on-shore wind energy. A study has been carried out by the Spanish Instituto para el Ahorro y Diversificación de la Energía, IDAE, in collaboration with Meteosim Truewind S.L. consulting in order to measure the wind potential in the Spanish peninsular territories and as well as in the associated islands.

This study takes as basis weather simulation software focused on long-term wind potential prospective together with a parallel study where interacts with the Spanish topographic characteristics. It provides a huge amount of data about annual average wind speeds and from them, also converted into annual air power density data, which is easily calculated with the wind speed and air density values.

Firstly, let’s show the results collected from on-shore wind energy. As a first filter, and according to the 2020 wind energy potential requirements, it is established a condition of a minimum average wind speed of 6 m/s (or 250 W/m^2 in terms of air power density) at 80 meters above the sea level. This height is considered as an appropriate reference for currently commercialized medium and high power wind turbines. Together with this, some filters regarding technical and environmental restrictions are also taken into account.

In the figures 10.9 and 10.10, there are shown the collected data for wind speeds and power density at 80 meters above sea level. In the figures, the visual representation in colors pretends to give a first quick view about the wind potential in Spain:

- White: Zones which does not reach the minimum conditions.
- Blue: Low potential, low annual average wind speeds.
- Green: medium – low potential.
- Yellow and orange: medium – high potential.
- Pink and red: high potential.

Figure 10.9. Annual average wind speed in Spanish territories [m/s], *IDAE*.

Figure 10.10. Air power density in the Spanish territories, [W/m^2]. *IDAE*.

From the information provided by this report, several regions in Spain can be highlighted due to their calculated wind potentials. The results at 80 meters above sea level are shown in the following tables 10.3 and 10.4. In the table 10.3, the more optimum regions according annual average wind speed are shown, firstly according to the amount of square kilometers in which a wind turbine could be installed and, secondly, regarding the square kilometers as percentage of the region total expansion in which a wind turbine could be installed. In the table 10.4, the air power density is shown also following the same criteria.

Vavg > 6m/s [km^2 basis]			Vavg > 6m/s [% basis]		
Region	**[km^2]**	**[%]**	**Region**	**[km^2]**	**[%]**
Andalucía	20.981	24	**Canary Islands**	2.854	52
Castilla y León	16.907	18	**Galicia**	14.199	48
Castilla - La Mancha	16.640	21	**Navarra**	4.947	48
Aragón	14.614	31	**Aragón**	14.614	31
Galicia	14.199	48	**Cantabria**	1.513	28

Table 10.3. Regions with larger wind potential based on annual average wind speed, *IDAE*.

Power density > 250 W/m^2 [km^2 basis]			Power density > 250 W/m^2 [% basis]		
Region	**[km^2]**	**[%]**	**Region**	**[km^2]**	**[%]**
Andalucía	24.332	28	**Galicia**	16.498	56
Galicia	16.498	56	**Canary Islands**	2.363	43
Aragón	14.278	30	**Cantabria**	2.136	40
Castilla y León	12.536	13	**Asturias**	4.208	40
Castilla - La Mancha	11.547	15	**Navarra**	4.016	39

Table 10.4. Regions with larger wind potential based on air power density. *IDAE.*

In order to get more information regarding the wind potential, please refer to Appendix V, and for detailed information about the different regions please refer to Excel file "Potential Analysis" in the attached CD-Rom. [78]

A substantial area in Spain is completely suitable for new wind parks installation even though it is already the 5th country in the world when talking about installed capacity behind China, the USA, Germany and India. Here in the following table 10.5, there are shown the regions which accumulate the major share of installed capacity in the country.

Wind Energy	
Region	**Capacity [MW]**
Castilla y León	5.560,0
Castilla - La Mancha	3.806,5
Andalucía	3.337,7
Galicia	3.314,1
Aragón	1.893,3

Table 10.5. Top 5 regions in wind energy capacity installed, *visualized personally for the sake of this study*.

The top five regions in wind energy capacity installed are found as well among the regions in where most of the potential has been registered, which indicates that the wind potential was already discovered within these territories and it started to be exploited effectively. In this moment, as matter to transform Spain into a renewable country, it will be mandatory to keep studying and projecting new wind parks and, which is even more important, to increase the public awareness in relation to the importance of this kind of technologies.

The off-shore wind situation was already explained in this chapter. Therefore, no emphasis will be placed in explaining the reasons but in showing a graphical and intuitive summary of the viability report. The following table 10.6 shows the different annual average wind speed all over the Spanish littoral, at 80 meters above sea level, and their correspondent surfaces. The three following maps, figures 10.11, 10.12 and 10.13 represent the final suitable zones in which off-shore wind turbines could be installed – the actual current suitable zones are shown in green.

Speed [m/s]	**Surface [km^2]**	**Surface [%]**
6-6,5	1.071	16
6,5-7	1.232	19
7-7,5	841	13
7,5-8	583	9
8-8,5	303	5
8,5-9	176	3
9-9,5	168	3
9,5-10	130	2
>10	53	1
TOTAL	6.623	100
>7,5	**1.412**	**21,32**

Table 10.6. Annual average wind speed on the Spanish littoral zones, *IDAE.*

Figures 10.11 Cantabric littoral (up left), 10.12 Mediterranean littoral (up right) and 10.13 Canary Islands' littoral (down), *IDAE*.

As it was previously mentioned, the current situation of off-shore potential cannot be improved due to the depth characteristics of the Spanish coast. A further development of the current technologies must take place in order to really take advantage of the wind opportunities in the nearby coasts of Spain. [79]

Solar energy, in both forms of photovoltaic and thermal solar energy, is in everyone's lips when regarding further prospective renewable potential. Both energies have been developed along the past years but not as appropriate as it could have been in relation to Spain's capacity and potential. On one side, photovoltaic energy generated an enormous "energetic boom" in 2008, which finally leaded in a companies' exodus to foreign countries. On the other side, thermal solar energy started to be more intensively developed in the last few years and it is now when it starts to gain more considerable weight on the Spanish "energetic mix".

The potential of solar energy is measured according the so-called direct solar irradiation, DNI, which a region receives in a certain period of time. This is the irradiation which comes directly from the sun in contrast to diffuse radiation which is in major or minor grade scattered by the atmosphere prior to reach the surface. Both thermal solar energy and photovoltaic energy work with direct normal irradiation.

Collecting the data about the amount of solar irradiation that a certain device receives, it is possible to calculate the amount of energy in which it will be transformed. Therefore, it is possible to calculate the theoretical efficiency and capability of this kind of units according to the total collected hours of sun.

In the following table 10.7, the amount of hours that every Spanish region receives is shown, making a difference between winter and summer. According to that it is calculated the average amount of sun hours per day and the total kWh per month.

	Total winter sun hours	**Average hours/day**	**Winter Average [kWh/month]**	**Total summer sun hours**	**Average hours/day**	**Summer Average [kWh/month]**
Andalucía	7.649	6,1	1.272,7	12.694	10,1	2.159
Aragón	2.820	5,2	473,3	5.148	9,5	859
Asturias	595	5,3	99,1	1.042	5,8	174
Balearic Islands	1.032	5,7	171,9	1.763	9,7	294
Canary Islands	2.196	6,2	369,2	3.019	8,3	503
Cantabria	631	3,5	105,1	1.116	6,2	186
Castilla y León	7.710	4,7	1.409,3	15.415	9,5	2.567
Castilla-La Mancha	5.593	5,2	786,3	10.076	9,7	1.494
Cataluña	3.833	5,3	638,5	6.328	8,8	1.029
C. Valenciana	3.237	6,0	539,2	5.113	9,5	832
Extremadura	1.034	5,7	172,3	1.906	10,6	318
Galicia	2.067	3,8	344,3	3.741	7,6	659
Madrid	1.012	5,6	170,3	1.812	10,1	302
Murcia	1.114	6,2	184,6	1.814	10,1	302
Navarra	660	3,7	109,9	1.401	7,8	233
Basque Country	1.859	3,4	305,8	3.402	6,3	567
La Rioja	763	4,3	127,1	1.447	8,0	277

Table 10.7. Direct solar irradiation data in the Spanish regions, *leonesa solar*.

The outpointed regions are now collected in the following tables 10.8 and 10.9, in accordance to the information shown in the table above. [80]

	Average hours/day	Winter avg [kWh/month]
Castilla y León	4,7	1.409,3
Andalucía	6,1	1.272,7
Castilla - La Mancha	5,2	786,3
Cataluña	5,3	638,5
C. Valenciana	6,0	539,2

	Average hours/day	Summer avg [kWh/month]
Castilla y León	9,5	2.567,2
Andalucía	10,1	2.158,6
Castilla - La Mancha	9,7	1.493,7
Cataluña	8,8	1.029,0
Aragón	9,5	859,2

Tables 10.8 and 10.9. Regions with more sun hours, *leonesa solar*.

It should be noted here the fact that the expanse of the different regions affects significantly when speaking about total hours of sun. For example, both Castilla y León y Castilla-La Mancha fill nearly the whole centre of the Peninsula thus these data can be useful but not fully trustable, more detailed data is also required. That is why it is shown here, in addition, a thermal map in which the annual solar radiation is shown according also the different territories' dimensions. It is in W/m^2 and both the Peninsula and the island territories are shown in the figures 10.14 and 10.15.

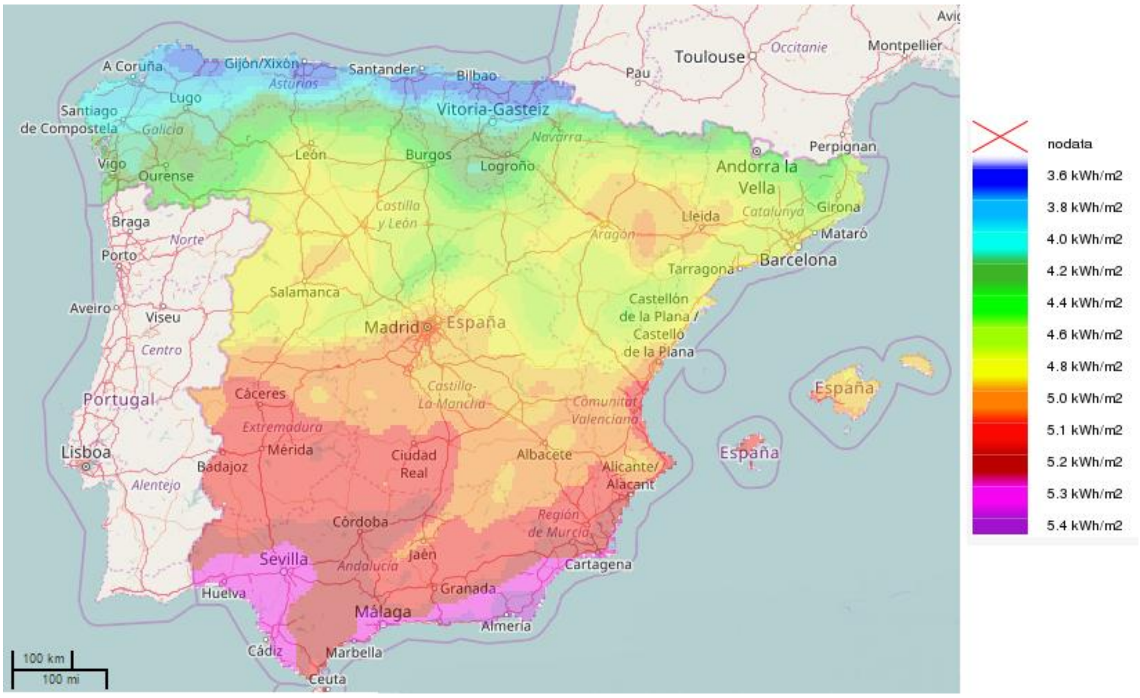


Figure 10.14. Annual thermal map in the Peninsula and Balearic Islands, [kWh/m^2], *ADRASE*.

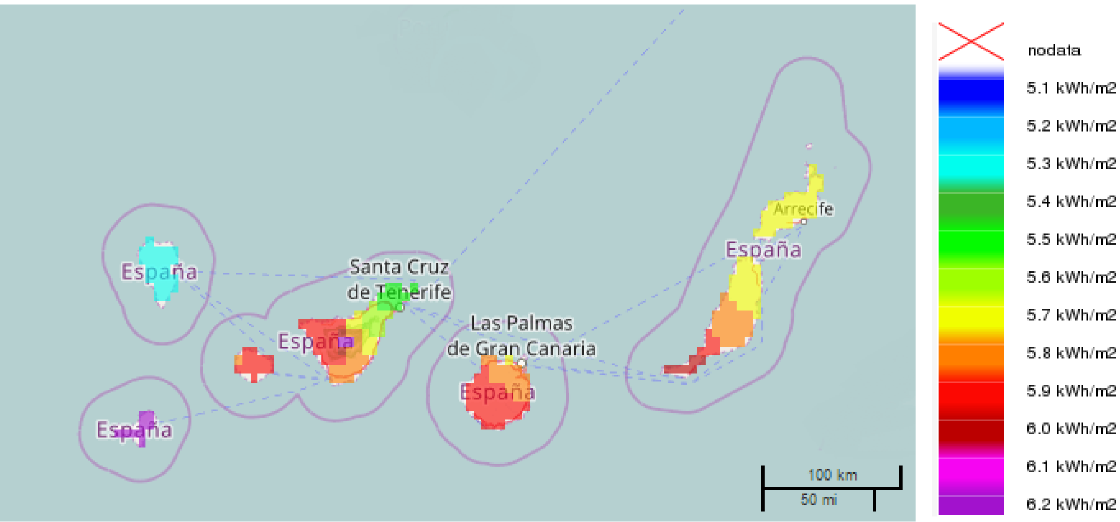


Figure 10.15. Annual thermal map in the Canary Islands, [kWh/m^2], *ADRASE*.

It can be easily observed that Spain, and especially the southern half, presents a significantly high solar potential. The amount of hours and the stability of those would show that the installation of new power plants is possible and profitable. To get an idea, with a **50 W** solar photovoltaic panel and 6,1 hours of solar irradiation per day, as Andalucía in winter, it is possible to generate **305 kWh** in a day. More detailed information can be consulted in Appendix V and Excel file “Potential Analysis”. [81]

Getting more into detail, photovoltaic energy is expected to provide a brilliant future for solar energy in the country. After the last decade, in which the prospective future of the brand new photovoltaic power plants was completely defeated, different promoters start to come up and they are confident that a recovery of photovoltaic is possible. In the table 10.10 it is possible to see the top five regions in photovoltaic installed capacity, most of those power plants were installed around 2008 and have been working since then.

PV	
Region	**Capacity [MW]**
Castilla - La Mancha	923,0
Andalucía	870,0
Extremadura	561,0
Castilla y León	494,0
Murcia	440,0

Table 10.10. Top 5 regions in PV installed capacity, *visualized personally for the sake of this study*.

As conclusion, it is appreciable how Spain is truly qualified in basis of the amount of solar irradiation, even though not enough power plants have been installed according to the solar potential. Within the European Union, Spain is leading the solar potential ranking and it is time now to start taking advantage of it.

With regard to the international solar energy perspective, several non-native companies have started to consider Spain as next energetic target for solar energy development in the future. However, in Spain, the solar promoters live and have lived a completely different situation. Due to recent past economic situation and policies, local promoters were impeded to invest in their own homeland, since there were too many the risks that they were forced to face. Only a few remained here while most of the companies migrated to foreign lands. Nevertheless, and thanks to the global awareness that has arisen, more and more organizations and companies are determinated to turn this situation upside-down. There are people confident that with the prospective renewable support and with the economic recession put finally behind, the solar energy will be finally considered as a reliable basis for a renewable transition in Spain.

At last, the biomass potential is also shown in the following fragment. It is chosen due to its broad range of possibilities since not only can it be used for electricity and useful heat generation but also represents a more sustainable way to manage the bio-waste from industry, agriculture and even forest industries. Moreover, when subjected to specific conditions, it is possible to be converted into biogas and biofuels. In accordance, the potential analysis of Spanish biomass is based in the available amount of different kinds of biomass that can be harvested in the country.

There are different types of biomass that can be found in Spain according to the geographical conditions of the country and the different industries which are settled down. Among all of them, a study was carried out by the IDAE in order to quantify the Spanish potential of this biomass. The biomass types which are taken into account read as follows:

- **Biomass from existing masses and crops.**
    - Existing forest biomass.
        - Waste of wood treatment facilities. Rests of treatment of actual forest masses.
        - Whole tree utilization. The biomass is collected from old natural or implanted masses which its prior usage deviated from energy and that currently are fully committed to it.
    - Biomass from agricultural waste.
        - Woods. Residual waste from olive and fruit trees and vineyards pruning.
        - Herbaceous. It mainly comprises wheat straw and corn.
- **Biomass from masses subjected to implementation for energy purposes**. They are provided mostly by currently abandoned natural forest masses located in the lower part of the mountain or especially established masses for these purposes, both in forest and agricultural lands.
    - Woods masses subjected to implementation in forest or agricultural lands. The most common implemented are poplar, willow, eucalyptus and quercus. Depending on the purposes and the implementation zones it comes also the distinction:
        - Wood masses subjected to implementation in forest lands. They combine the energetic purposes with an increment of the forest surfaces in the country.

        - Wood masses subjected to implementation in agricultural lands. They started due to the social need of biomass boosting as renewable source and thus they only have energetic purposes.
    - Herbaceous masses subjected to implementation in agricultural lands. Most of traditional crops can be used in biomass production. There are found both cereals (corn, barley, oat, rye, etc.) and oilseeds (rapeseed and sunflower).

Here in the following table 10.11, it is shown the prospected availability of the different biomass types, in both tons per year and toe per year, and the average costs per ton. More detailed information about the biomass potential according to the regions is shown in Appendix V.

Source		**Biomass [t/year]**	**Biomass [toe/year]**	**Average costs [€/t]**
Existing forest masses	**Waste of wood treatment plants**	29.854.243	636.273	26,59
	Utilization of the whole tree	15.731.116	3.414.158	43,16
Agricultural waste	**Herbaceous**	14.434.566	6.392.631	20,97
	Woods	16.118.220		
Herbaceous masses subjected to implementation in agricultural lands		17.737.868	3.593.148	53,39
Wood masses subjected to implementation in agricultural lands		6.598.861	1.468	36,26
Wood masses subjected to implementation in forest lands		15.072.320	1.782.467	42,14
TOTAL SPANISH BIOMASS POTENTIAL		**88.677.193**	**17.286.851**	

Table 10.11. Spanish prospective biomass potential, *IDAE*.

It must be mentioned that due to the wide extension of Spain, the biomass availability varies substantially from region to region. For example in regions such as Andalucía, Galicia and Castilla y León, the consumption of biomass registers the highest rates due to the establishment of a developed forest sectors. Also, the dissemination of population facilitates the usage of domestic biomass. [82]

Spain counts with a powerful agricultural sector which is turning, nowadays, into a potent source of biomass. With appropriate management systems and support from governmental normative, biomass can reach a significant status as renewable resource in Spain. The Spanish promoters have realized about it and a good example of adequate usage will be explained within the “Heating District sector” chapter.

11. Support schemes

In order to properly understand the current situation of renewable energies integration within the Spanish electricity sector, the current support schemes and procedures will be briefly explained in the following chapter.

Once the tariff deficit has been previously properly explained, let’s get an overview over how the current support schemes have developed during the last years. Until the beginning of the past year 2013, producers considered as Special Regime, were able to choose in between a Feed-in Tariff (FIT) or the market price plus a bonus (variable tariff).

This Special Regime was first consolidated on the 90’s through the Law 40/1994. This law first accepted as special regime facilities related with waste, cogeneration power plants, residual waste power plants and hydroelectric ones. In the following time, with the approval of the Law 54/1997, it was differentiated the production of Ordinary Regime (regarding traditional sources such as oil, carbon, etc) and the Special one (regarding RES), and also a specific remuneration for each one of this generation models was differentiated.

Logically, this Law has been evolving along the years and adapting to the conditions of the time. Consequently the normatives which were going successively adopted were closely related and intended to the RES developing and promoting. Thanks to the assurance and amount of future revenues that the remunerative system provided, the RES development was highly boosted until reaching a **42,8%** of total production in 2014. Nevertheless, due to the emergence of economic crisis and the growing tendency of the electricity sector tariff deficit caused by the cost increment added to the electric systems by the renewable energy sources development, most of the decisions which were taken were primarily oriented to the reduction of this added cost.

For this reason, the Ministry of Industry started in 2012 to implement certain measures to reduce the costs. Some of them affected directly to the RES remuneration, i.e. reduction in functioning hours for PV, elimination of the chance of energy selling a “pool” price plus bonus or suppression of subsidies for Special Regime power plants construction.

Later, in 2013, the new RD-L 2/2013 is approved and thus a strengthening of the current situation. At that moment it is possible to choose between a Feed-in Tariff and a variable tariff, but the bonuses are removed. Not only that, the remuneration of regulated activities are starting to be updated according to the underlying inflation (core inflation) and not according the IPC, as it was used to be done. Among all those actions, also in July 2013, a new Ordinance is established (RD-L 9/2013) and a new legal and economic Regime is agreed regarding RES generation plants. In here, it is the installed model from 54/1997 finally dropped out and so it is the previous Special Regime. From that moment on, all the facilities are regulated under the same normative and forced to assume the market obligations. [84] [85] [86]

The new accepted Regime is based in perception, when proceeds, of the derived revenues from the market participation, with an additional remuneration complement based on:

- A share based on the installed capacity (€/MW) which covers, when proceed, the investment costs of a type installation which cannot be retrieved through energy sale. Thanks to this remuneration, the installation will be able to reach a governmental developed concept, so-called as "rentabilidad razonable" or "reasonable profitability". A renewable, cogeneration or waste power plant will receive this remuneration if it did not reach the defined "reasonable profitability" value.
- A share based on performance (€/MWh) which covers the difference in between exploitation costs and the participation in the market revenues. The aim of this remuneration is to achieve a zero "Earnings Before Interest, Taxes, Depreciation and Amortization" index (EBITDA) and thus avoiding the operation losses within the electricity generation activity. A renewable, cogeneration or waste power plant will not receive this remuneration if their revenues derived from electricity sale are greater than its exploitation costs. This is designed mainly for those technologies with higher operational costs such as PV, thermal solar energy and cogeneration.
- Additional retribution (Island territories' systems). This new remunerative system can add, in exceptional cases, an extra incentive to the investment. These cases involve the situations in which a reduction in generation costs in isolated island territories' systems is achieved.

In this point, it is necessary to explain what exactly this "reasonable profitability" (currently around 7,5%) is. It is simply a concept developed by the government, and its value was calculated as the average of profitability of the Government Bonds along the last 10 years plus a differential (of 300 basis points). It can be rechecked in every six-year-long regulatory period in accordance to the profitability of the Government Bonds along the 24 months before the month May (the one prior to the start of the new regulatory period). [88]

This concept is applied over a theoretical "initial investment" and it is calculated since the moment that the power plant got into exploitation. A Regulatory Useful Life is assigned to each kind of technology; along the one they could receive a remunerative complement over the investment, additional from the achieved revenues due to energy sale at market price. This complement allows them to reach this "reasonable profitability". However, the facilities which have overcome their useful life or the ones which within their useful life period have already achieved this "reasonable profitability" will not receive this additional remuneration.

Continuing the trend, the Law 24/2013 settles the former principles and sets up the pointed out Remunerative Regime. The remunerations can be revised every three years (semi-regulatory period), according the estimations of revenues reached by energy sale evaluated over the average annual price of the diary and intraday market; according to the prices evolution within the market; and according to the operating hours estimation. The higher is the market price estimation, the smaller will be the remuneration for RES. This is because the higher market prices are, the smaller the part of investment which cannot be recovered by market sale is.

Roughly it can be said that, this new Remunerative System implies that the renewable participation in the market is now considered in a unique regime only with the addition of a complement remuneration intended to those properly and efficient facilities which are not able to retrieve their investment costs in the market. It cannot be considered as a support scheme but to a complementary compensation to allow renewable technologies to compete with traditional technologies within the current market. [83]

Particularly exceptions can rise, in which the government is able to validate a Specific Remunerative Regime based on competitive concurrence. This measurement is additional to the remuneration earlier explained and related and based in the same two principles (exploitation costs and investment costs). In order to calculate it, different values are taken into account from a type installation (regarding the technology, antiquity, installed capacity, electric system, etc.) along its life cycle and in relation to the activity performed by an efficient and good managed one. Such values are:

- Standard revenues earned by the generated energy measured according the production market.
- Standard exploitation costs.
- Standard value of the initial investment and the regulatory useful life, which both remain invariable.

As last matter regarding this “Specific Remunerative Regime” or Premium Tariff, the RD 947/2015 was approved with the aim of supporting new biomass plants located in the mainland electricity system and existing or new wind energy plants. It sets up the value of different compensation parameter for the references RES plants under this new Remunerative Regime.

The amount of this premium tariff for a plant is based on the values of compensation parameters for the standard (efficient and well managed) plants applied to mainland biomass and wind energy plants. These main parameters are:

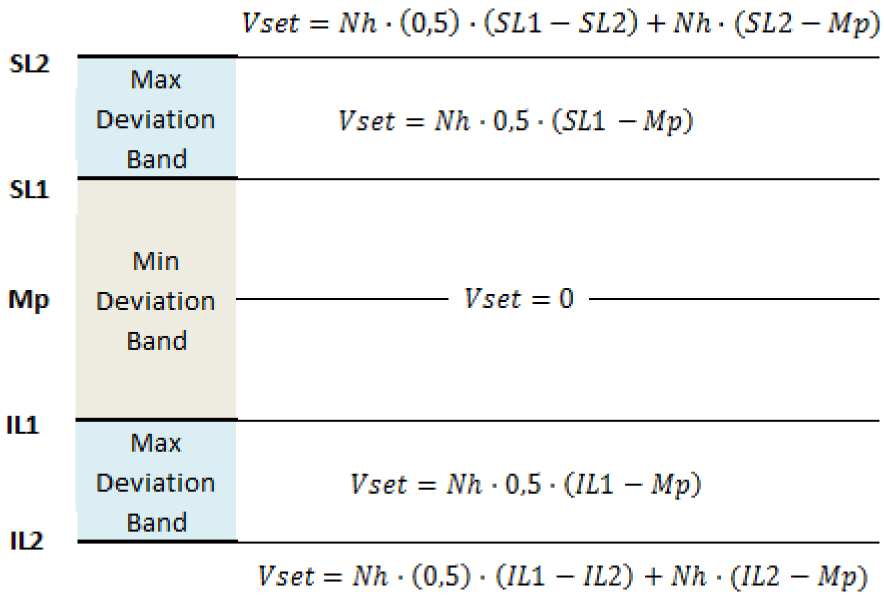
- Useful regulatory life.
- Standard value of the initial investment for the reference plant.
- Number of equivalent operation hours.
- Considered price to estimate the revenues from the sale of energy.
- Operating costs.
- Return on investment for the reference plant.
- Reasonable rate of return.
- If applicable, fuel costs. [85]

11.1. Deviation adjustment mechanism

According to RD 413/2014, the adjustment mechanism which will be applied by the end of each period is based in a definition of some maximum and minimum boundaries around the market price estimation.

The document determines for each years, two maximum limits (SL1 and SL2) and two minimum limits (IL1 y IL2) around the estimation made for the remuneration. These limits then compose one minimal deviation band, and two maximal deviation bands. The setting value (Vset) is calculated according when the final market price is located regarding those bands.

This Vset is calculated according to the formulas showed in the RD, reference [3], and which are shown schematically bellow in the figure 11.1:



*Nh = number of operational hours for each type installation

Figure 11.1. Schematic calculation of Vset,*[3].*

- If the final price is located on the minimal deviation band, the setting value is zero.
- If the final price is located on the maximal deviation bands, the setting value is the difference between the limits of the min deviation band and the final price (Mp) divided by 2.
- If the final price is located over the maximal deviation bands, Vset is calculated as the difference between the limits of max deviation band minus the final price divided by 2, plus the half of the sum of the max deviation band limits. [83]

11.2. Recent experience

According to Spanish Renewable Energies Enterprises Association (known as APPA in Spanish) this normative has not been exactly particular benefit for the renewable sector. Essentially, this was caused by a poor estimation of the Government about which will be the price of the diary electricity market.

At the beginning of the period, 2014, the Government estimation was **48,21€/MWh** while the real established price was **42,06€/MWh**, given by the National Commissions of Markets and Competence (CNMC in Spanish). In 2015, the estimated prices was **49,52€/MWh** with respect to the real one of **50,30€/MWh**. Finally in 2016, the estimation reached **49,75€/MWh** in contrast to the real one of **38,33€/MWh**.

The situation of 2014 will be graphically explained, which can provide an easier understanding of the situation. The following plot in figure 11.2 shows how the prices were located according to the boundaries early explained:

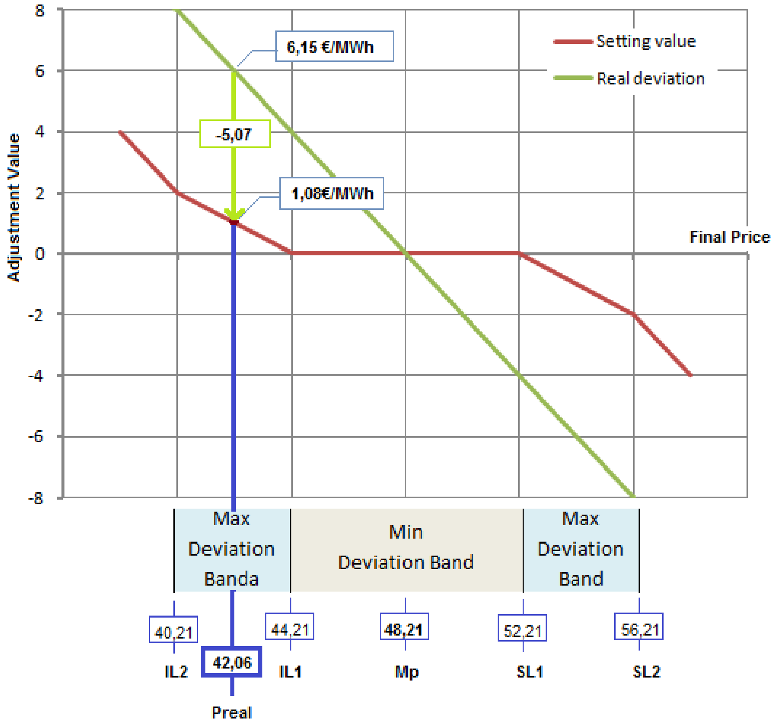


Figure 11.2. Adjustment mechanism in 2014*, [3], APPA*.

As it was mentioned above, the Government estimation was **48,21€/MWh** while the real established price (Preal) was **42,06€/MWh**, and thus the real deviation was **6,15€/MWh** between them. However, according to the adjustment mechanism the deviation only reaches **1,08€/MWh**. [93]

It means that according to this deviation adjustment, since the real price was inferior to the previously estimated one, the renewable facility is not able to get back those **5,07€/MWh,** which is the real difference. On the other way around, for example, the facility will not lose the achieved revenues. In addition, more information about the diverse regional subsidies is enlarged in the Appendix VI.

12. Electricity generation

The Spanish electricity generation park slightly increased at the end of the year 2015. It reached a total installed capacity of **106.247 MW**, the increment was mostly provided by the hydroelectric power plant La Muella II (**854 MW**) since the variations in other technologies were mostly absent or remained insignificant. It is shown more in detail in the following table 12.1.

	Peninsular system [MW]	Island territories' system [MW]	Total	% 15/14
Hydroelectric Energy	20.777	2	20.779	4,9
Nuclear Energy	7.866	-	7.866	0,0
Coal	10.972	510	11.482	0,0
Fuel/Gas	0	2.784	2.784	-15,8
Combined Cycle	25.348	1.851	27.199	0,0
Hydrowind Energy	-	12	12	0,0
Wind Energy	22.845	158	23.003	0,0
PV	4.423	244	4.667	0,5
Thermo Solar energy	2.300	-	2.300	0,0
Geothermal energy	984	5	989	0,0
Cogeneration and rest	7.098	121	7.219	0,0

Table 12.1. Installed capacity by the end of 2015 [MW], *REE*.

The national energy generation, including the peninsula and the island territories' systems, Baleares and Canary Islands and the cities of Ceuta and Melilla, was recorded as **280.481 GWh** by the end of 2015. It showed finally a positive value after two years in a row in a decreasing trend. This must be checked parallel to the demand during the same year, that also showed an increment after a similar decreasing tendency which was showed since 2010.

In accordance with the terms of the international agreement 20-20-20, Spain ventures for a gradual but a trustworthy sustainable transformation. Nevertheless, the changes in the Spanish generation exploited resources have yet not been identically focused. Even though renewable energies got a prominent role in generation with a **36.9%** share, they have shown a small decrement comparing to the year 2014, losing their almost **50%** weight then reached. The wind and hydroelectric production present significant drops, especially hydroelectric production which decreased in **27.5%**, caused by the hydrologic and wind characteristics during this period. In comparison with non-renewable sources which have reached a participation rate **of 63.1%**. This difference has been produced due to considerable additions made by coal production, **23,8%**, and combined cycle, **18,7%,** in order to catch up with the renewable lack. [4]

This is shown graphically in the following ring charts, figure 12.1. It involves both the renewable and non-renewable generation, in dark grey and light grey respectively, and the different kinds of resources which take part on it in comparison 2014 to 2015. More data is provided in Appendix VII.

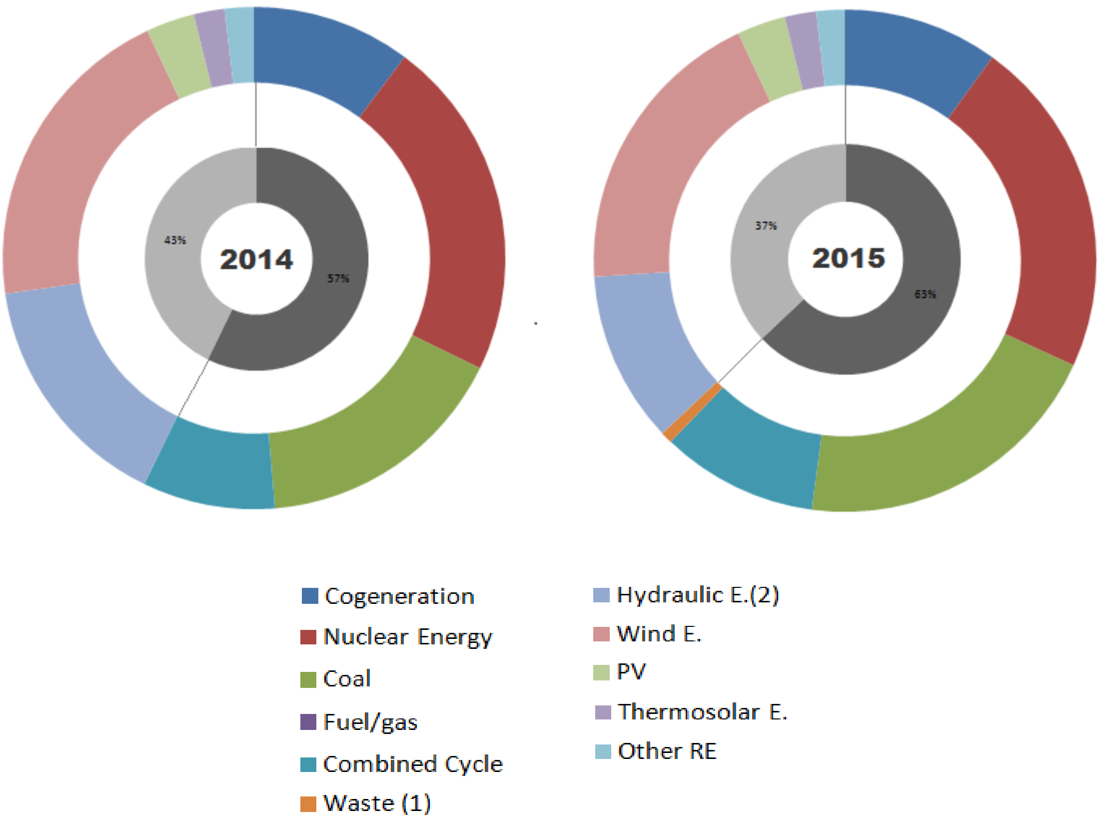


Figure 12.1.Generation comparison 2014 vs. 2015, main overview, *REE*.

Here in the following, figure 12.2, it is shown the energy production development provided for both non-renewable and renewable sources from 2006 until the end of 2015. In addition, in figure 12.3, different resources are further revealed.

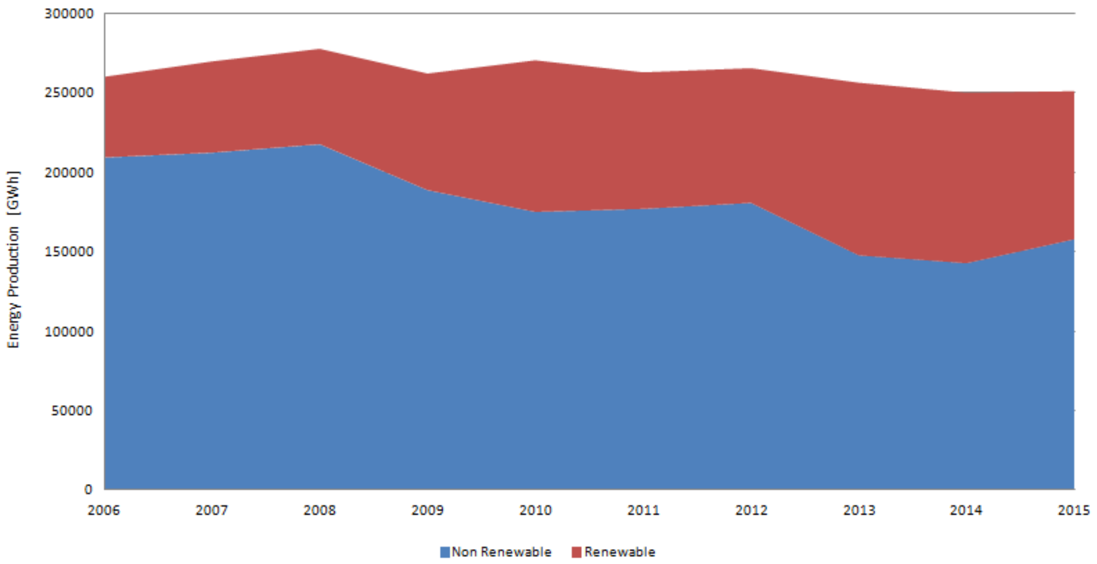
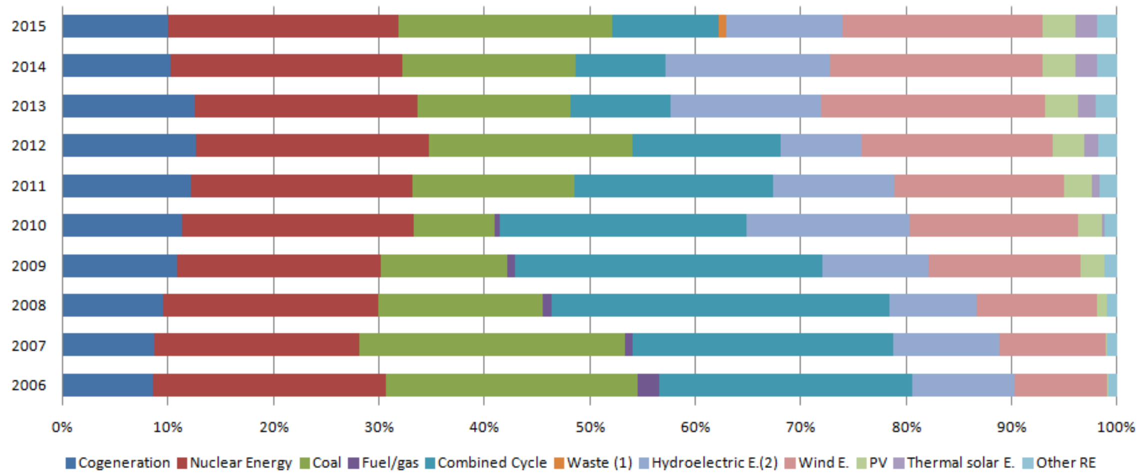


Figure 12.2. Energy production by renewable or non-renewable sources [GWh], *REE*.



(1) Generation included in Cogeneration and Other RE until 2014
(2) Pumped storage not included

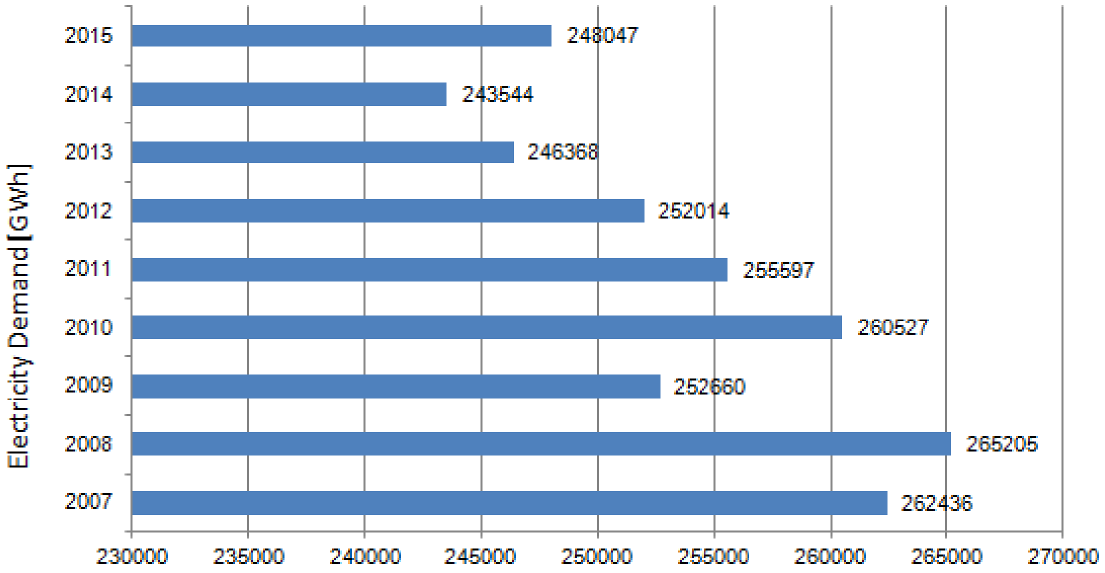
Figure 12.3. Resources in detail [%], *REE*.

From these figures it can be seen that the renewable production doubled in 2013 and 2014 the value which was reached in 2006. It was principally caused due to a strong consolidation of wind and hydroelectric energies. Even though and while parallel to that, the complete energy production slightly decreases every year. It may also be highlighted the quick growing of photovoltaic energy from 2008 to 2010, which basically remains stationary since then on – once again, it is worth to mention that solar "boom". On the other side, other types or renewable energies such as biomass, biogas and wave energy keep gaining weight as the time goes by. [94] [95]

13. Electricity demand and consumption

In order to properly understand the weight of renewable energy resources in the Spanish electric panorama, it is necessary to take a look also on the demand profiles, which are provided by Red Eléctrica de España, REE.

Here in the figure 13.1 below it is possible to take a look at the electricity demand evolution from 2007 to 2015.



*Demand (b.c.): injected energy in the net which is provided by power plants in ordinary regime, special regime and importations, and in where pumped storage consumption and exportations are deducted.

Figure 13.1. Electric demand evolution 2007-2015, *REE*.

It can be easily appreciated that the graphs suffers a considerable decrement from the values reached in 2008. As it is known, in this moment an economic recession arose all around the European continent, with especial negative outcomes in countries like Spain. In 2015 the Spanish electric consumption recovers a positive rate which was not registered since 2010. The electric demand reached **228.837 GWh**, which represents an increment of **1,2%** with respect to 2014. [94] [95]

Nevertheless, the huge extension of the country must be taken into account too. There are notorious differences in between regions. In the following figure 13.2, the different zones are drawn with the respective demand and percentage of change 2015/2014.

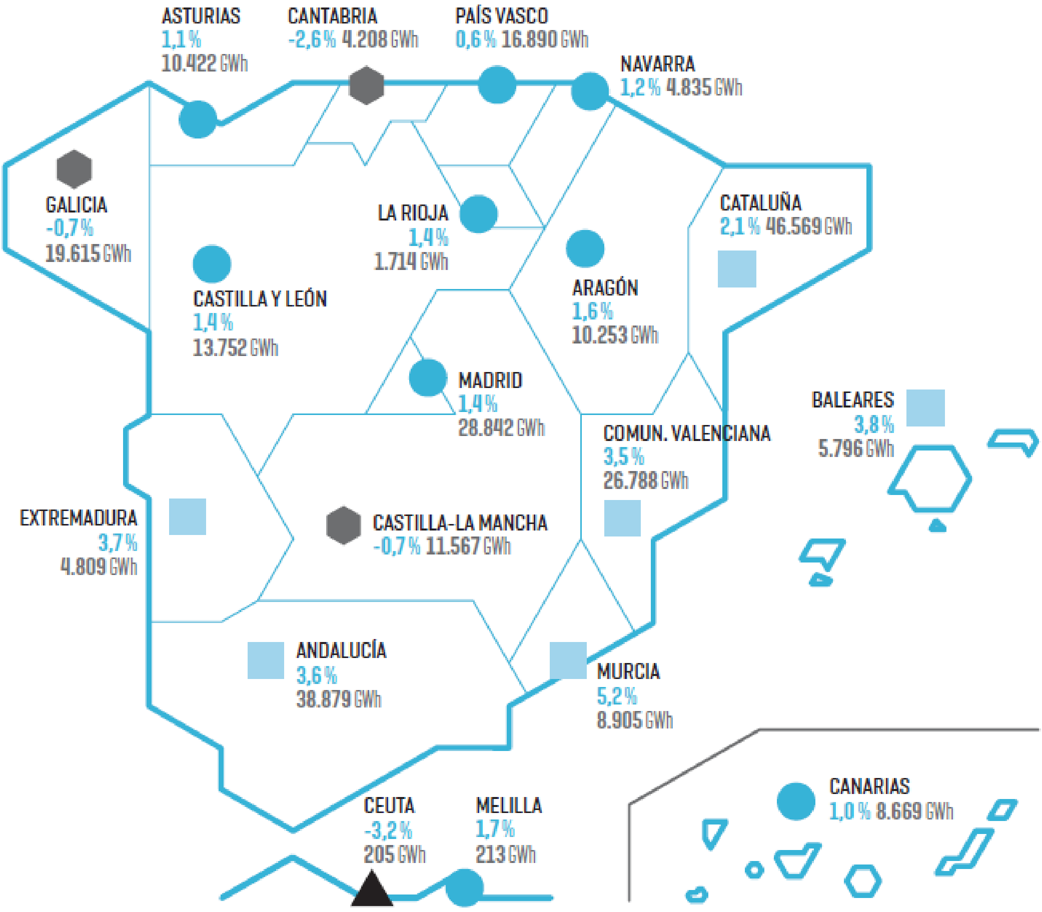


Figure 13.2. Demand by region [GWh] and comparison with previous year [%], *REE*.

Secondly, the climate restricts severely the demand curves. Let’s take, for example the demand curves provided by REE according the situation in both a day of summer, 27.07.2016, and one in winter, 05.20.2017. They are represented in the figures 13.3 and 13.4.

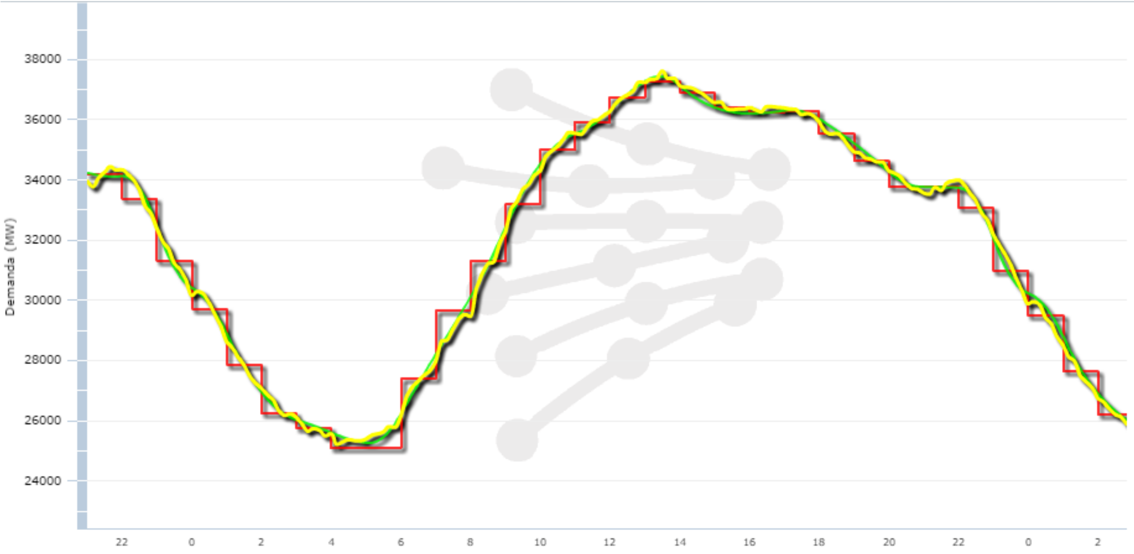


Figure 13.3. Demand curve in a summer day. Yellow = real; Green = Predicted, *REE*.

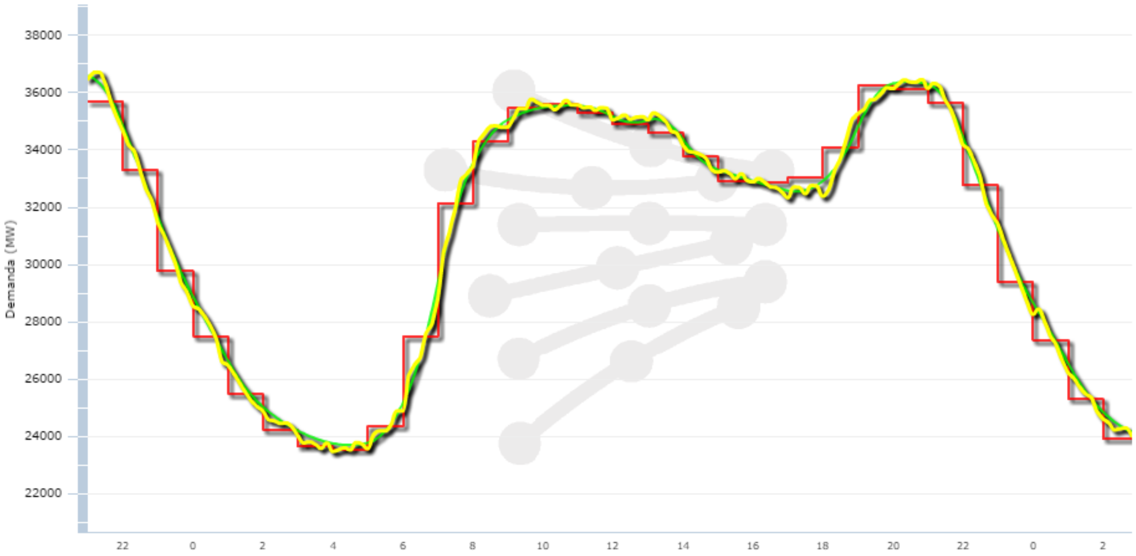


Figure 13.4. Demand curve in a winter day. Yellow = real; Green = Predicted, *REE*.

As observed, within the Spanish electricity market, there are three main zones that can be differentiated, even though in summer the behavior of the curves is smoother than in winter because of the different timetables and temperatures in between seasons. The disparity between the values reached respectively on peak and off-peak hours is highly significant.

Looking at the curves, it is appreciable that the minimum demand is reached during nocturnal hours. At this time are only the industries which keep a notable consumption and some tertiary services which must operate 24 hours per day such as hospitals, street lighting, etc contributes in a minor share. The differences in consumption by sectors can be noted on the following figure 13.5 provided by REE. [96] [97]

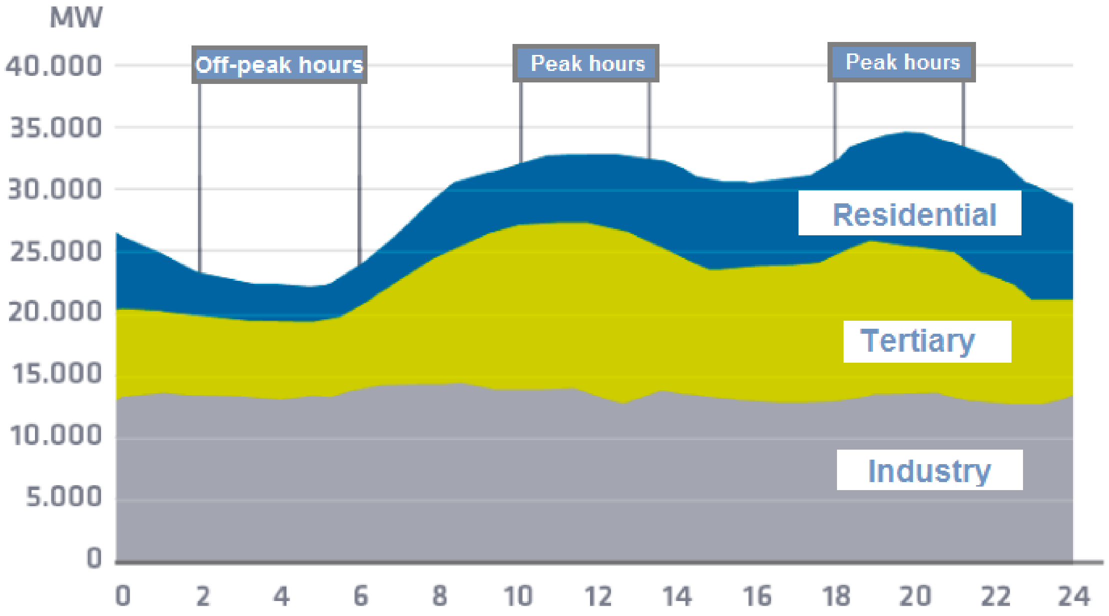


Figure 13.5. Demand curves by sectors, REE.

As corrective measure in order to reduce this difference along the daily demand the Spanish electricity market established in 2008 a “time discriminating” electric tariff, which applies a non identical price on electricity according to the time of the day in which the consumption is made. With this tariff is intended to diminish the peaks on electric demand, offering a lower price to the consumers which modify their consumption habits. The guidelines of the tariff are shown in the following table 13.1.

Hour period	No. Of hours	Discount (-) or Surcharge (+)	Application timetable
Off-peak hours	14h/day	-0,55	Winter: from 22h to 12h Summer: from 23h to 13h
Peak hours	10h/day	+0,2	Winter: from 12h to 22h Summer: from 13h to 23h

Table 13.1. Discriminating time tariff guidelines, *REE*.

In addition, in July 2011, and with the aim of promoting the electric car usage, it was also approved the so-called “Super off-peak tariff”, in which the off-peak period is divided again in two different subperiods, as follows in table 13.2.

Hour period	No. Of hours	Discount (-) or Surcharge (+)	Application timetable
Super off-peak hours	6h/day	-0,65	From 1h to 7h
Off-peak hours	8h/day	-0,45	From 23h to 1h and from 7h to 13h
Peak hours	10h/day	+0,2	From 13h to 23h

Table 13.2. Super off-peak tariff, *REE*.

Even though at first sight this corrective tariff does not seem as a real energetic saving, but only and economic one, a better distribution in the demand along the day can avoid and unnecessary over sizing among the power plant generation parks and the installation of new power plants. By doing so, the usage of particular installations in order to supply the consumption demand on peak hours is diminished and other power plants which are closer to the optimum point can be longer used. [100] [101]

The sum of all the influences previously explained, have conditioned the development of the Spanish electricity sector in parallel with the Spanish people social and cultural development. These same facts have also a meaningful impact on the price which a regular Spanish inhabitant should pay for the consumed electricity. Despite that the Spanish population has grown exponentially the last decades, after the year 2010 the demand has experimented a slight decline which recovers by 2015. All of that, together with the economic recession which took place in 2008, resulted in the following figure 13.6, in which it can be seen the demanded energy per year, in GWh, and the correspondent averaged price in a year, €/MWh.

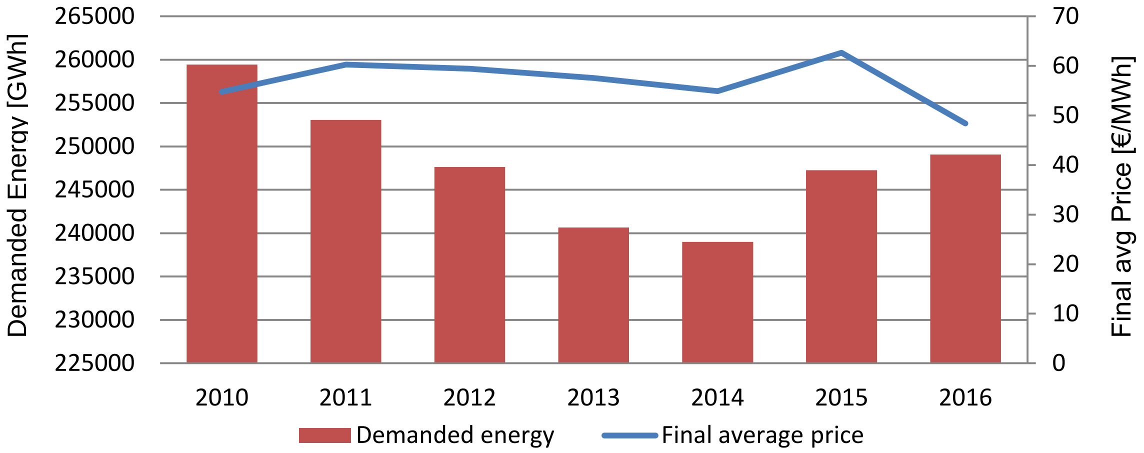


Figure 13.6. Demanded energy vs. Final average price - development, *OMIE*.

In addition, it is also shown below the situation during the year 2016, which gives more appropriate information about the current status – figure 13.7.

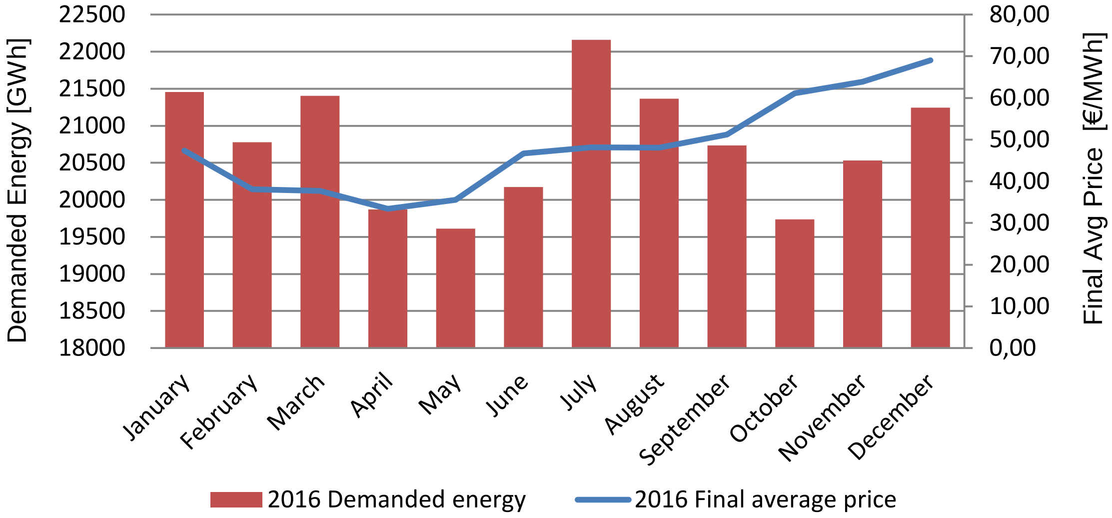


Figure 13.7. Demanded energy vs. Final average price in 2016, *OMIE*.

From the information, which is extracted from the graphs, it was calculated a energy price peak in 2015 of **62,66 €/MWh** which was not combined with a demand peak.

The final price of the electrical energy which a regular person is daily calculated according to the power plants which are providing the demanded energy at any moment of the day, always starting from the ones which offer the megawatt at the cheapest price. Following this principle, therefore, the more “green” power plants operate in the system, the cheaper the final price is. However, due to their fluctuating nature is not always possible to administrate as much energy as required by these kinds of power plants and more expensive energy sources such as gas or oil take action. That is exactly what happened in 2015, it was the year in which renewable energies only provided the **37,1%** of the gross electricity mix in the country. [99]

14. District heating sector

District heating and cooling networks development started not so long ago in Spain. In 2011 the ADHAC (explained below) and the IDAE started a mutual agreement in order to promote and start the installation of district heating and cooling networks. In Spain, besides it is a efficient technique that can gets back a huge amount of energy which is actually wasted through other procedures, it will help also in order to diminish our energetic dependence.

This fragment of the report is shown due to its close relation with the Spain's transition to renewable sources. District heating and cooling networks have gathered substantial importance along the last year and the aim is to install them based on renewable sources such as biomass, which appears to have a major role in their development.

Taking into account the energy efficiency goals for 2020, the district heating networks are established in the country as powerful basis. Therefore, the Spanish government has tried to adapt the legislations in order to provide adequate security and quality. Hence make the consumers feeling comfortable with this type of technology.

The regulation and registration for heating and cooling networks is carried out by la Asociación de Empresas de Redes de Calor y Frío (ADHAC), which in English means "Heating and Cooling Networks' Business Association". Since they started on 2011, they try to promote the usage of this kind of networks in urban areas as heating system, acclimatization and hot water for sanitary uses.

By 2016, there are registered **330 networks**, and 306 of them are registered in their annual census. They sum more than **550km** and supply more than **4.000 households**. These 306 networks registered can be divided by the type of consumed fuel:

- 225 by renewable energies.
- 3 by electricity.
- 41 by natural gas.
- 10 by gas-oil.
- 27 others.

So, **74%** of the heating and cooling networks installed in Spain run currently by renewable energies. Moreover, 218 of them run with biomass, 2 by biogas, 2 with geothermal energy, 2 with residual heating and the last one hybridizes photovoltaic energy with biomass. Those are distributed around the territory as it can be seen in the following figure 14.1.

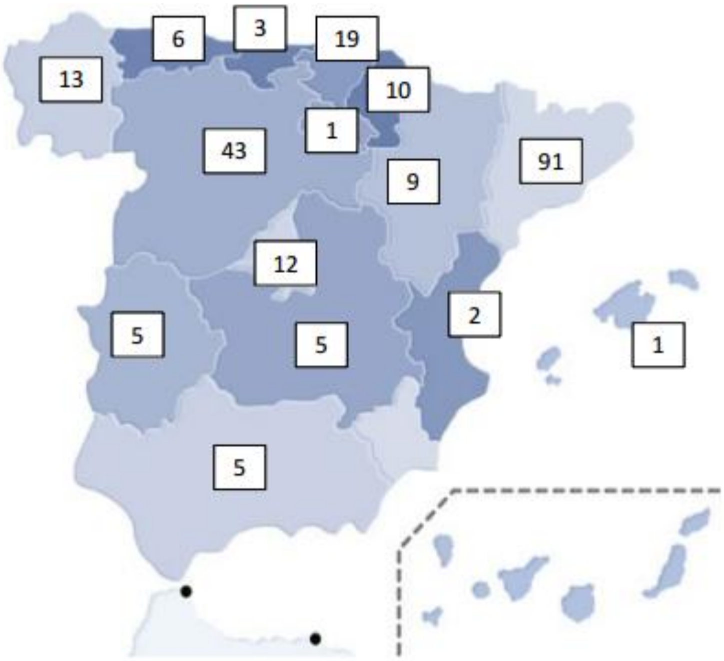


Figure 14.1. Renewable-based heating and cooling networks in Spain, *ADHAC*.

Spain is one of the major biomass producers in the European Union. Nevertheless, this sector has not evolved as expected even though it has not stalled. It is caused, mostly, by the economic situation and their consequent environmental laws that were established by the governments.

Regarding the growth in importance for biomass, let’s take Andalucía as an example, which is one of the regions with greater production of biomass. During 2015, a larger consumption of biomass for thermal usages was registered within the household sector than in the industry sector: **47%** was used in households, **38%** in industry, **11%** in the tertiary sector and finally a **4%** in the primary sector. Since February 2009 until May 2016, 20.039 proceedings for biomass energy exploitation were supported (which means an investment close to **118 million €**) and, from them, 19.979 are built for thermal biomass. Andalucía, counts with an estimated potential of **3.955 ktoe** annually but, unfortunately, not all of it is used. Until the moment, this is caused by the difficulty and high costs for logistics and the conditioning while transforming rough biomass to an efficient fuel. [102] [103] [104]

15. Futuristic aspects of the Spanish electricity sector

The suggested 100% renewable generation plan for 2050 seems far, far away from the current perspective. Nowadays, there is still a lack of technological development within the country in order to truly turn it into reality. This situation graves its roots on the fact that Spanish renewable energies rely principally on sun and wind, which are fluctuating and no manageable sources. In addition, the economical recession which started in 2008 strongly conditioned the Spanish successive governments to reduce the investment in energetic facilities, both conventional and renewable ones, and even to establish several restrictive taxes and regulations to the solar power auto consume panels and facilities.

Also, despite of all the advantages which are provided by renewable sources, these types of energy are still an added cost to the electric system. Their development survives on a learning phase and cannot compete with traditional energy sources, even though the situation has evolved satisfactorily during the last years. For instance, a wind energy park works efficiently around **3.000 hours in a year**, while a combined cycle or coal power plants could do it **24 hours** the **365 days of the year**.

So which are the challenges that Spain plan to overcome in order to become a fully renewable country? Which are the future opportunities?

In the first place, hydroelectric energy has achieved a brand new perspective. Nowadays, no dams are built but “green infrastructures” are instead. The future perspectives on hydroelectric energy are focused on achieving maximum efficiency, better performance and less environmental effects since it is already a mature and consolidated renewable source. All of these objectives are included within the Spanish 2020 goal of **20%** of renewable generation, in which hydroelectric energy plays a major role. It is expected an increment of **635 MW** of capacity installed in the period 2011-2020 in order to fulfill that goal.

On the other hand, current Spanish projects are based on the improvement of the bio-ecosystems which are affected by the power plants in order to achieve adequate water sustainability. The awareness about the prospective future water situation was the reason whereby several projects nowadays are mainly focused on the recovery of old reservoirs, river flows, etc.

Wind energy has suffered the largest and most efficient development in the last couple of decades. This was promoted by continuous technological improvements on the wind turbines which made possible an easier integration of this technology on the Spanish electricity grid. As it was previously mentioned in the report, the aim of the country is to achieve in between **21 to 25%** of electricity production thanks to wind energy by 2020.

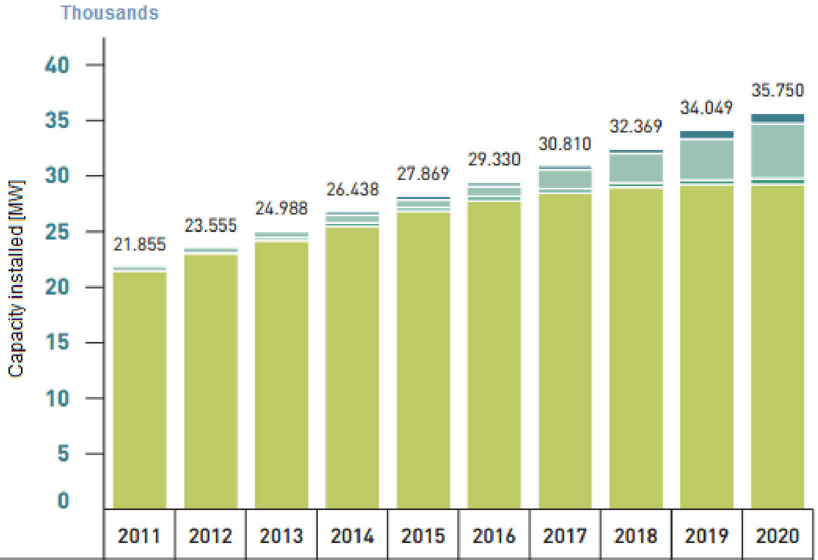
However, several impediments are still found in the projection of new wind parks. First of all, the management mechanisms must be able to performance efficiently because they must be able to keep some non-related-with-wind aspects completely under control in order to achieve a real good performance of wind energy within the grid.

It means, the growth of the wind capacity could be limited by the ability of the grid to provide a fast-enough answer to the new capacity's request to be fully integrated and connected to the grid. In this sense, it is prior to improve the grid quality and the cross border capacity with Center Europe.

In relation to that, if a non-adequate management of wind energy generation appears these other challenges can arise:

- In off-peak hours with lower electricity demand, the generation from the wind parks could not be properly injected in the grid which means a partial disconnection of wind parks.
- It is mandatory the installation of other manageable sources to improve the balance in moments with less wind source available.
- Prospected creation of storage systems for the energy generated, in order to improve its performance.

According to the 2011-2020 planning for Spanish renewable sources, the initial goal was to achieve **35.750 MW** of capacity installed, from which **750 MW** would be installed off-shore. It can be seen on the following figure 15.1. However, and facing the current conditionings, only close to **30.000 MW** are expected to be achieved.



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total wind Energy	21.855	23.555	24.988	26.438	27.869	29.330	30.810	32.369	34.049	35.750
■ Off-shore capacity	0	0	2	22	22	52	102	230	480	750
■ "Repowering" On-shore	189	228	314	477	738	1.163	1.835	2,719	3,925	5,328
■ Low power wind energy	0	5	15	35	60	100	150	200	250	300
■ On-shore capacity - "dismantled"	21.666	23.322	24.657	25.904	27.049	28.014	28.723	29.220	29.395	29.372

Figure 15.1. Expected increment of wind energy installed capacity 2011-2020, *PER 2011-2020*.

Spain depends primarily on wind energy's development in order to achieve their established "green goals". As mentioned above, even though it has been growing dynamically, it still needs to be boosted in order to become fully competitive.

The on-shore installed capacity calls for a repowering to improve old wind turbines and their connection to the grid. The wind parks which were installed prior to 1998 are closely to reach the technologic obsolescence and the end of their useful life and also the majority of them have unitary power lower than **500 kW**.

On the other side, off-shore installation is a major issue in the Spanish renewable development. The current experimental projects, such as Ainaga Off-shore in the Canary Islands or Bimep in the Basque Country, are essential and need to be fully supported and boosted if Spain wants to reach an adequate international competitiveness in a short period of time. Fundamentally, the huge amount of money which is required to be invested in order to promote them is the major inconvenience at the moment. Nevertheless, Spain starts to take advantage of its littoral potential and foresees the installation of in between three and five off-shore commercial wind parks by 2020.

With regard to the solar energy situation, the promoters have been largely complaining and trying to finally make a turn of the screw. While in 2007 Spain installed close to **40%** of total world’s solar capacity, it barely installed 49 MW in 2015, only a **0,09%** of which was installed worldwide. Currently, they assure that an approaching solar energy expansion is unavoidable and ascertain that solar energy will be finally exploited as it deserves. The potential is calculated as an average annual irradiation of **1.600 kWh/m^2** and places Spain in a leading position.

One step in order to reach this improvement in solar techs is to avoid the so-called “Solar tax”, which was installed in 2013 for installations larger than **10 kW**. This would mean a great step for auto consumption development, which promoters and organizations affirm to be the best option for making people aware and for promoting solar generation in any company, farm, etc. The Spanisch actual electricity oligopoly impeded a proper development for this technology and it was the main cause for this “tax” implementation. This is another situation that must be reversed in order to follow the current European green transition. [105]

Photovoltaic energy suffered the largest damage after the solar “boom”. But luckily this energy has become a reality worldwide, not only at European level, fact that brings brighter expectations in order to recover its “lost” status in Spain. Photovoltaic energy presents a fully competitive price in comparison with non-renewable sources and it will become even more competitive if this “green” trend keeps going on. If the existing Spanish government will fix the photovoltaic recovery as prior goal, it could be translated into new **2.100 MW** of capacity installed and more than 5.500 new jobs. [106]

The thermal solar energy can be divided into two different usages and in both it appears to start to gain more weight as the times goes by. Fortunately, the efficiency of this technology has been research enough in order to make it sufficiently important within the energetic mix.

In one hand, thermal solar energy could become fully competitive within the heating sector. In this context, thermal solar energy has become fully joined with the current building normative and it is planned to be installed in order to provide hot water for sanitary use and other issues from district heating networks. Not only that, there are also various projects which involved thermal solar energy in the installation of desalination plants.

On the other hand, it comes electricity generation with thermal solar energy. During the last years it efficiency has largely improved (it is shown in figure 10.4) but, even though the optimum efficiency can be found in between **100-200 MW** of installed capacity, every facility reaches only up to **50 MW** due to the restrictive policies of the former special regime. On this basis, Spain directs its activities mainly in two fields: the efficiency of this technology must keep evolving while larger and more competitive power plants are projected to be installed in a close future - while trusting in a parallel progress within the energetic policies for renewable sources.

Moreover, currently every new thermal solar power plant is projected to be installed with thermal storage facilities, which will greatly contribute for better management of this technology. If it continues this development it will reach a fully competitive and mature status shortly that would transform it into a really good asset for the energy generation in Spain.

Spain has also been pioneer with the installation of the first commercial wave energy power plant in 2011. The country truly believes that Spanish nearby seas offer unlimited opportunities and it is starting deeper researches on it. While the main objective focuses in supporting Mutriku’s power plant and fulfill an appropriate performance, other maritime possibilities are currently being under study. The major initiative from the Spanish government with junction with EVE and IDAE, is the so-called facility Bimep (Biscay Marine Energy Platform).

Bimep is a maritime facility located on the North of the country which involves a surface of 5,3 km^2 and it is located at 1.700 meters to the closest point of coast. The aim of it is to test energy-collecting devices for maritime energy in order to demonstrate their technical and economic viability. Through this, they aim to guarantee a certain security and assurance prior to move into a big scale commercialization process. The facility counts with modern underwater grid connections and communication system in order to fulfill its task. They provide the option to different generation companies to install their renewable devices there, for both electricity generation or just for testing. [107]

Biomass is one the larger wager that Spain has currently, due to the substantial expansion of its agricultural, forestry and forest masses.

Biomass is broadly extended within the thermal sector and produces heat and hot water for sanitary use, in both large and little scales. Large scale normally refers to industry uses, in which the produced heat is obtained by agro forestry industrial waste.

Its competitiveness with respect to traditional fuels is the major challenge for biomass nowadays. Since ordinarily developed and socially-accepted technologies are used, it produces serious difficulties for a regular customer to choose a biomass stove instead of a traditional one – as example considering a small scale biomass for thermal uses. In case of larger power plants, due to the initial investment and lower trust in the technologies, producers still believe that conventional technologies perform better and hesitate when taking the risk of installing a biomass power plant for thermal usage, with or without cogeneration. In addition to that, the technologies have not been yet fully developed since the Spanish biomass trend began not long ago.

Promoting support schemes would be also really useful for the sector. Even though the potential is recognized as huge, the current Spanish normative does not show a positive support on electricity generation in Spain through this kind of fuel.

An appropriate development for the biomass sector requires an efficiency boost but overall, it claims for social awareness, even more than in other technologies. That is because biomass electricity generation or thermal heating could be easily installed in particular consumer's facilities. Together with current researches on efficiency improvement in energy crops which take place in Spanish research facilities, public organizations such as Avebiom, APPA or ADHAC continuously promote the biomass transition.

In regard to that, pellet manufacturing appears as a great opportunity in order to increase efficiency and to create new jobs in the sector at the same time. In parallel, the other field in which biomass it is considered to be a key point is District heating – as explained previously in chapter 14.

Finally, biogas and solid urban waste participates in minor shares on the Spanish energetic mix. However, biogas is considered as a great opportunity in order to manage some agricultural and forestry waste along the Spanish rural zones while solid urban waste can be reused for thermal and electric purposes while at the same time promotes a better and more sustainable management of residuals. [11]

16. Conclusion

Spain is involved in a renewable transition following the relevant developed countries' trend that arose as international agreement since the Kyoto Protocol took place. According to that, Spain started the installation and promotion of diverse renewable technologies and currently counts with a significant amount of them distributed across the country. From them, hydroelectric and wind energy store the major shares in generation up while "younger" technologies such as biomass and wave energy start to appear in the Spanish panorama.

The renewable tendency is flowing and a wide amount of "green" promoters and organizations truly believe in and continuously support the Spanish renewable electricity park's growth. This aims to improving both the renewable generation and the own dependability of the country, provided by a smaller need of foreign imports. A smooth but reliable transition to the sustainable world will not only help the country with its economic situation but also will provide it with a better appearance at European and worldwide level.

Following the trend during the last years, several energetic cooperatives have been created in order to generate and sell "green" electricity. However, they are still not common in Spain, in where its five huge electric companies practically dominate the whole electricity market. To get an idea, while more than 500 different cooperatives are found only in Germany, Spain counts with scarcely ten. Among which Som Energia, GoiEner, Zencer or Nosa Enerxía must be highlighted.

In addition, even if the installed capacity keeps growing, it will never be able to achieve an effective integration if the electricity grid does not develop accordingly. It is therefore imperative to improve the grid's quality, through continuous enlargements and performance checks. Likewise a significant addition to the cross border exchange capacity is required above all. The grid must be able to provide quick responses to the fluctuating energy technologies and Spain needs here international back up in order to achieve its goal.

Accordingly, the present day support schemes cannot be any prolonged. The so-called "reasonable profitability" worked appropriately in order to reduce the tariff deficit but it becomes completely useless when talking about renewable energy promotion. A new normative is utterly required for the promoters to take the chance and increase the "green" electricity generation and hence bring the Spanish conventional fuel's dependence to an end.

Last but not least, awareness programs will be really useful in order to reach the Spanish population. A renewable transition does not only mean to have several renewable-based power plants distributed across the country but also the renewable implementation within a daily basis. The renewable sources must be adequately promoted in order to be able to change the customers' minds about their comfort zone – based still in conventional fuels. Biomass household-stoves or auto-consumption solar panels are the best examples within this field.

To sum up, a “green generation” is possible, but it is not only a matter of installing a huge amount of renewable capacity. It involves a simultaneous synchronization of economic, technical and social aspects in both national and international levels. Even though we are not going through the most adequate limitations-related moment and more technological development is still required for the electricity transmission. However, every explained aspect must be taken into account and keep pushing this renewable transition. A correct renewable integration depends completely on the ability of coordinate every participant of the electricity sector, in both national and international level, and combined it with an active social awareness which promotes the renewable sources against the conventional fuel’s ease and habit to which everyone is used to.

The 2020 renewable goals established by the European Union are not unreachable for Spain, but still more effort is required. It is now the moment, once that the country has finally stepped over the financial recession and parallel to the arisen sustainable worldwide awareness when the country, promoters, government and population must join forces and bet for a fully renewable transition in a close future.

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TRABAJOS DE FIN DE GRADO / FIN DE MÁSTER

Escuela de
Ingeniería y Arquitectura
Universidad Zaragoza

INFORME DEL DIRECTOR/PONENTE DEL TRABAJO FIN DE GRADO/MÁSTER

Datos del estudiante y del trabajo: (1)

Apellidos: Adiego Calvo

Nombre: Blanca

Título: Estudio detallado del potencial e integración efectiva de las energías renovables en España

Grado/Máster: Máster en Ingeniería Industrial

Especialidad: Energía y tecnología de calor y fluidos

Evaluación y comentarios sobre el trabajo realizado por el estudiante:

Aspectos a evaluar:	Muy alta	Alta	Normal	Baja	Muy baja
Amplitud y alcance de la labor realizada		✓			
Complejidad del trabajo	✓				
Creatividad	✓				
Dedicación, eficacia	✓				
Meticulosidad y rigor		✓			
Metodología	✓				

Comentarios adicionales: (2)

A large amount of data was analysed with real dedication and motivation from the student.

Autorizo la presentación: **SI** ☑ **NO** ☐

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Fdo.:

Graz, 19.4.2017

Ponente del TFG/TFM,

DEPARTAMENTO DE DIRECCIÓN Y ORGANIZACIÓN DE EMPRESAS
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Fdo.: LUIS NAVARRO ELOLA

Zaragoza, a día 19 de Abril de 2017

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