ENERGY TRANSITION:
ENABLING TECHNOLOGIES FOR
DEMAND FLEXIBILITY, REGULATION &
BUSINESS MODELS

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“It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change.”

Charles Darwin
Acknowledgments

This Project is dedicated to:

My Everis workmates, due to their help.

My Project tutors, at Everis and at the University.

My family and friends, due to their support during this year.
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1. RESUMEN EN ESPAÑOL

Este resumen en español del TFG “Energy Transition: Enabling Technologies for Demand Flexibility, Regulation & Business Models” trata de explicar las nociones y temáticas básicas que se presentan en el proyecto. Se comienza con un resumen ejecutivo para después exponer la motivación y objetivos y posteriormente analizar los tres puntos principales de manera más detallada.

En el presente resumen no se incluyen referencias ni datos bibliográficos, de la misma manera que tampoco se añaden gráficos, tablas ni figuras al estar todo ello en el proyecto como tal. Solo se incluyen reseñas dirigidas al trabajo principal en inglés cuando los conceptos explicados necesiten de mayor profundización para ser entendidos.

1.1. RESUMEN EJECUTIVO

Hoy en día, la energía eléctrica se considera esencial, ya que es un producto consumible básico. La forma en que evoluciona la sociedad la hace cada vez más dependiente de la tecnología, lo que implica una dependencia también de la energía eléctrica. La eficiencia del sistema eléctrico no solo tiene repercusiones económicas, sino que también influye en el entorno social y ambiental.

De esta manera, en los últimos años, las compañías más grandes y los países más avanzados han estado pensando en un nuevo modelo y mercado de energía eléctrica, en el que se prioricen la eficiencia, la seguridad, el autoconsumo y la flexibilidad de la demanda (Demand Flexibility). Esto se conoce como la transición energética que consiste básicamente en un nuevo mercado de energía que evita el mercado tradicional y vertical donde la electricidad va de los generadores a los consumidores a través de los Transmission System Operators (TSO) y de los Distributed System Operators (DSO). En este nuevo mercado, los clientes se convierten en jugadores activos en la generación e intercambio de energía y se benefician de ello.

Este cambio se convierte en una posibilidad real a través de las tecnologías habilitadoras que se analizan en este informe. Estas tecnologías principalmente son la energía solar fotovoltaica, energía eólica, cargas inteligentes, vehículos eléctricos y baterías de almacenamiento de energía; y deben examinarse para determinar cuáles son las mejores opciones para integrarse en el sistema y qué tipo de ventajas ofrecen. Además, todas las investigaciones de estas innovaciones tienen un impacto directo en otras condiciones sociales y ambientales debido a que estas tecnologías que pueden aplicarse en otros campos.

En este sentido, en este informe, se estudia el State-of-the-art de cada activo y se determina la mejor opción de cada tecnología; la importancia del activo se evalúa para analizar si su impacto es realmente perjudicial para la flexibilidad de la demanda; los tipos de servicios que el activo puede ofrecer; y finalmente, cuál es la manera de integrar la tecnología para lograr el mayor beneficio. Hasta ahora, estas tecnologías se están volviendo económicamente atractivas y actualmente se están integrando, pero, en un futuro próximo, llegarán a ser más baratas y mucho más rentables.
Esa es la razón por la que muchos países diferentes, principalmente los Estados Unidos de América (EEUU) y la Unión Europea (UE), están adaptando sus regulaciones para adaptarse a la transición energética. De hecho, están imponiendo leyes obligatorias a sus estados miembros para abrir el mercado eléctrico a los clientes a través de compañías y “agregadores” (se explica en “Introducción y motivación).

En el informe “Energy Transition: Enabling Technologies for Demand Flexibility, Regulation & Business Models”, la regulación de los EEUU y la UE es uno de los principales temas tratados. Aquí, las legislaciones anteriores y más recientes se exponen y analizan en detalle, y se presentan conclusiones y recomendaciones para aprovechar la transición energética. Además, se muestra un estudio profundo de los diferentes mercados de EEUU (NYISO y CAISO) y de la UE (Alemania, Reino Unido y Francia) y sus programas principales, teniendo en cuenta las características principales de cada uno y su grado de eficacia.

Sin embargo, estas conclusiones y recomendaciones sobre mercados y regulaciones deben probarse con datos reales que demuestren la rentabilidad de esas medidas, por lo que en el informe se exponen cuatro casos de negocio. En ellos se estudian diferentes estados de EEUU tomando datos reales de población y de programas particulares que se han establecido en la zona; luego se muestran los resultados y las comparaciones para demostrar la rentabilidad o no de estas inversiones. Y, por supuesto, este informe proporciona algunas recomendaciones de modificación al reglamento que se estableció en esos casos, a veces positivos y otras no tanto.

Resumiendo:

- Esta investigación se enfoca en comprender cómo la mayor penetración del autoconsumo afectará a la regulación y los modelos de negocio actuales en el sector eléctrico.
- Hoy en día se están produciendo cambios importantes en la forma de generación y consumo de electricidad, fundamentalmente debido a la confluencia de diversos factores que afectan a los sistemas de distribución eléctrica. Las nuevas tecnologías o servicios, como la flexibilidad de la demanda, el autoconsumo, el almacenamiento de energía y los avances en dispositivos electrónicos de control, están generando nuevas oportunidades en el suministro y consumo de electricidad. Al mismo tiempo, el rápido abaratamiento de las tecnologías de la información y la comunicación (TIC) permite un consumo más eficiente, una mejor visión del uso de la red y un mejor control de los sistemas eléctricos.
- Este informe presenta un marco para la proactividad reguladora y la reforma del mercado, a fin de lograr una evolución eficiente del sistema eléctrico en las próximas décadas. El objetivo es facilitar y lograr la integración de todos los recursos, independientemente de si están centralizados o distribuidos, todo lo cual puede contribuir a un suministro eléctrico eficiente para los consumidores.
1.2. INTRODUCCIÓN Y MOTIVACIÓN

Este proyecto está pensado para dar una visión sobre la transición energética y sobre cómo esta es impulsada por la tecnología. Hoy en día, con innovaciones como las cargas inteligentes (Smart loads), la energía solar fotovoltaica (Solar PV), la energía eólica (Wind power), el almacenamiento de energía (Energy Storage) y los vehículos eléctricos y su integración en la red (Vehicle-to-grid), cada vez más desarrolladas y menos costosas, se puede llegar a conseguir un mercado energético más eficiente y seguro.

Este proyecto analizará el mercado de la energía a través de tres bloques principales: desarrollo de tecnologías habilitadoras de la transición energética, cómo está cambiando la regulación y cómo debe cambiar para aprovechar estas innovaciones y, finalmente, los modelos de negocios que se pueden lograr a través de la combinación de tecnologías y regulación.

La transición energética está cambiando el mercado de energía tradicional y está generando muchas oportunidades de negocio en el presente y generará aún más en el futuro cercano. Es un tema de tremenda relevancia en el panorama tecnológico, eléctrico y económico actual. Además, tendrá un impacto en la vida de toda la población debido a que cada consumidor individual podrá convertirse en proveedor de energía para el sistema por medio de agregadores.

Los agregadores representan un papel clave en esta transición energética. Permitirán que los consumidores (con baterías, cargas inteligentes o energía solar fotovoltaica en los hogares) se involucren en el mercado logrando una gestión eficiente de sus tecnologías y obtengan un valor económico.

Hoy en día, existen problemas regulatorios en algunos países que deben modificarse para garantizar un mercado de energía de libre comercio y la integración de las nuevas tecnologías. Las primeras soluciones ya se han implementado en los EE.UU. y el Reino Unido con el desarrollo de la respuesta a la demanda teniendo en cuenta el papel de los agregadores y los consumidores.

Además, la UE ha implementado el Winter Package, regulación por la cual los estados miembros de la UE regularán el mercado de la energía y alentarán a los consumidores finales a participar junto con los generadores de manera no discriminatoria. Este es el comienzo de la transición en Europa, pero este informe no solo evaluará los beneficios de estas medidas, sino que dará recomendaciones para lograr una transición energética con suministro seguro, eficiente y de libre mercado.

La transición energética también es la manera de detener la emisión de gases de efecto invernadero y el cambio climático, priorizando las fuentes renovables e integrando nuevas tecnologías no contaminantes. Este objetivo está declarado en el European commitment 20/20/20 y en el Winter Package.

Con respecto a la motivación para realizar este proyecto, de Febrero a Julio de 2018, el autor de este TFG ha estado trabajando en i-deals (Everis) y la transición energética ha sido uno de los temas principales tratados durante este periodo. El autor ha comprendido la relevancia de la misma y cómo cambiará la facturación eléctrica y forma de consumir de cada consumidor. Cada persona podrá participar en un mercado
que tradicionalmente ha sido administrado por muy pocas empresas y, en muchos casos, que ha funcionado como un monopolio.

1.3. OBJETIVOS

El primer objetivo de este proyecto es analizar los principales componentes de la transición energética, comprender por qué todos los integrantes del mercado deben sumarse a esta oportunidad, dar recomendaciones sobre las tecnologías presentes y futuras que deberían integrarse y cómo debería cambiar la regulación para permitir un mercado energético más eficiente y seguro.

Este proyecto es una gran fuente de conocimiento y está destinado a abordarse como una profunda investigación, análisis y guía del mercado energético actual y futuro.

A continuación, se enumeran los pasos para lograr el objetivo final:

- Se debe realizar una investigación de las **principales tecnologías** para comprender por qué esta transición es posible y la forma en la que está impulsada por la tecnología. El almacenamiento de energía, las cargas inteligentes, la generación descentralizada (Distributed generation) con energía solar fotovoltaica, la generación a escala (Grid scale generation) con energía eólica y las tecnologías de Vehicle-to-grid deben investigarse y analizarse, concluir la mejor opción de cada una de ellas y obtener recomendaciones para los reguladores del sistema.

- La **regulación** tradicional y actual debe ser modificada, por lo que se analizarán sus ventajas y desventajas. Se evaluarán los cambios en la legislación que ya se han hecho y se expondrán las recomendaciones pertinentes. Este proyecto podrá dar conclusiones a los reguladores debido al análisis tecnológico previo.

- Finalmente, con todos los conocimientos anteriores, se podrá realizar el **estudio de modelos de negocio** reales y actuales. Estos casos de negocio brindarán una visión práctica de cómo esta transición es posible y mucho más rentable para todos los participantes del sistema (TSO, DSO, agregadores y consumidores). Aún más, estos modelos demostrarán que la tecnología estudiada anteriormente encaja con los casos reales y justificará toda la inversión necesaria para su desarrollo.

Para concluir, se mostrarán las conclusiones finales sobre el futuro mercado energético: Recomendaciones de las tecnologías que deben utilizarse para obtener el mayor rendimiento al mejor coste; análisis de las mejores regulaciones y legislación para asegurar un mercado de competencia justa, seguro y la eficiente; y finalmente, sugerencias de negocios para obtener las inversiones más valiosas.
1.4. **CONTEXTO**

En esta sección se introducen las nociones del mercado eléctrico poniendo el ejemplo de su funcionamiento en España y las funciones de Red Eléctrica de España (REE). Los **principales componentes del sistema** son:

- Los centros y plantas de generación.
- Las líneas de transporte de alta tensión.
- Las estaciones de trasformación.
- Las líneas de transporte de media y baja tensión.
- Los centros de control.
- El centro de control eléctrico nacional.

A su vez, se describen también los actores principales del mercado:

- Generadores.
- Transportistas.
- Operadores del sistema.
- Distribuidores.
- Comercializadores.
- Consumidores.

Por otra parte se presentan también los principales tipos de generación de energía eléctrica:

- Centrales térmicas.
- Centrales nucleares o atómicas.
- Centrales “atmosféricas” (utilizan recursos como el agua embalsamada o el viento)
- Centrales fotovoltaicas.

A raíz de este análisis surge un tema central como es la generación por medio de energías renovables no contaminantes.

La **prioridad de las energías renovables** se debe al calentamiento global. Europa ha propuesto el compromiso europeo 20/20/20, lo que significa la necesidad de reducir los gases de efecto invernadero en un 20%, mejorar la eficiencia energética en un 20% y lograr el 20% de la generación de energía con recursos renovables; y esos tres objetivos deben alcanzarse para 2020. Más aún, recientemente se ha lanzado otra norma, el Winter Package, que determina que un 27% de la generación de energía debe ser producida con recursos renovables para 2030.

Otro tema importante que debe tenerse en cuenta es la **interconexión** entre diferentes sistemas, la razón principal es que si un sistema está aislado y sufre la parada inesperada de un generador, la consecuencia lógica e inmediata es que el equilibrio que debe existir entre producción y demanda de energía eléctrica puede descompensarse. De este modo la interconexión entre sistemas ofrece la posibilidad de compensar estas diferencias entre producción y demanda recogiendo energía de sistemas conectados.
Pero esta no es la única ventaja de la interconexión internacional. Otra no menos interesante es que permite evacuar la electricidad generada a partir de fuentes renovables (la energía de las renovables suele ser intermitente y difícilmente controlada debido a que dependen del viento, el sol, etc., es decir, las fuentes naturales) en un momento en que esta generación no puede ser absorbida por el sistema eléctrico de la zona y, en consecuencia, no se aprovecha, lo que obliga, por ejemplo, a desconectar parques eólicos.

En este sentido, la interconexión cobra gran importancia no solo entre sistemas eléctricos entre países sino dentro de los sistemas entre todos los elementos de la red. Esta es la manera de conseguir la transición energética y el nuevo modelo de mercado energético en el que las nuevas tecnologías habilitadoras de la demanda exigen una conexión total y continua entre distintos sistemas y con los operadores de la red.

Profundizando en el mercado eléctrico y centrándose en la economía se puede analizar la siguiente situación:

En un entorno liberalizado, en el que la actividad de generación tiene lugar en un marco de mercado libre, los diferentes diseños posibles se pueden resumir básicamente en dos: un modelo de "solo energía", en el que el precio de mercado es el único ingreso de los generadores y un modelo de "precio de mercado + pago por capacidad", en el que los generadores reciben el precio de mercado y un pago adicional como incentivo a la inversión y la disponibilidad. Abajo se explica cada modelo:

**Modelo de "Energy only"**: para que el modelo de "solo energía" funcione correctamente, el precio de mercado debe ser lo suficientemente alto en momentos de máxima demanda para que una planta de energía de vanguardia (que solo se genera en esos momentos) recupere sus costes fijos.

**Modelo de "Market price + payment for capacity"**: el modelo de "solo energía" es actualmente inviable en muchos países, principalmente porque los precios particularmente altos, incluso solo unas pocas horas al año, resultan muy controvertidos desde el punto de vista político. De hecho, las regulaciones españolas no permiten ofertas en el mercado diario por encima de € 180 / MWh. Dada esta restricción, para que las plantas tengan la oportunidad de recuperar sus costes fijos, debe diseñarse un sistema de pagos regulados, adicional al precio de mercado, que tiene que ver con el valor de la ENS (Energía no suministrada) y con el límite que se impondrá al precio (cuento mayor sea la diferencia entre el valor de la ENS y este límite, mayor será el pago de capacidad para un nivel de calidad de suministro determinado). Con este esquema se busca que haya suficiente inversión para satisfacer los puntos de demanda, incentivar la inversión y que las plantas estén disponibles en momentos de alta demanda.

Otro sistema de pagos de capacidad, desarrollado principalmente en algunos estados de la costa este de los EE.UU., es el derivado de imponer a los proveedores la obligación de cubrir su demanda anual máxima con "tickets de capacidad". Estos boletos deben comprarse a los generadores, que reciben un ingreso complementario a cambio de estar disponibles. A diferencia del sistema de pagos regulados, en el que es la Administración la que establece el precio de los pagos por capacidad, y es la
interacción de la oferta y la demanda lo que determina la cantidad de capacidad demandada; con los "tickets de capacidad" es la Administración la que define la cantidad de capacidad demandada, y es la interacción entre la oferta y la demanda de los "tickets de capacidad" la que establece su precio.

En conclusión, el diseño actual del mercado ofrece, en teoría, a los generadores una garantía de recuperación de los costos de inversión y los costes vinculados a la disponibilidad a través de pagos regulados que complementan los ingresos en el mercado. Sin embargo, las recientes decisiones regulatorias, motivadas por la presión del regulador para reducir la tarifa, introducen incertidumbres que pueden afectar las decisiones de operación y mantenimiento de activos existentes con altos costes fijos, por un lado, y decisiones de inversión en nueva capacidad. Estos tipos de decisiones regulatorias son un ejemplo de un "círculo vicioso regulatorio".

Por lo tanto, para crear las condiciones adecuadas para que los inversionistas respondan a las necesidades de inversión en el sistema y para que las compañías mantengan sus activos operativos, para que los consumidores se beneficien de una mayor seguridad de suministro, la Administración debe ofrecer una garantía de estabilidad en la regulación de las compañías generadoras.

Este es uno de los problemas que se resolverán con la flexibilidad en la demanda eléctrica, ahora se expondrán algunos otros problemas del sistema y se presentarán algunas soluciones posibles, todas ellas dentro del modelo de transición energética que se discute en esta investigación.

Después de haber analizado los temas económicos del mercado eléctrico, otras dificultades principales del modelo actual se exponen:

En general, un modelo energético sostenible se caracterizaría por patrones de producción y consumo que concilian el desarrollo económico, social y ambiental, satisfaciendo las necesidades energéticas de las generaciones actuales sin comprometer las posibilidades de las generaciones futuras. Para que esto sea posible, el modelo energético debe tener en cuenta tres elementos básicos:

- **Seguridad energética**: debe garantizar la continuidad del suministro a precios razonables para los consumidores.
- **Competitividad**: no debe representar un peligro para la competitividad de la economía y su crecimiento.
- **Sostenibilidad ambiental**: la producción y el consumo de energía no deben tener un impacto inasible en el medio ambiente. Dentro de esta área, el sector energético, como responsable del 80% de las emisiones de gases de efecto invernadero, debe desempeñar un papel muy importante en la lucha contra el cambio climático.

El modelo energético actual se caracteriza por un crecimiento constante del consumo de energía, basado en recursos finitos, principalmente combustibles fósiles.

Según las previsiones de la Agencia Internacional de Energía (AIE), la demanda mundial de energía primaria crecerá en el escenario de referencia a una tasa anual del 1,5% hasta 2030, con un peso predominante de combustibles fósiles que permanecerá.
por encima del consumo total, por lo que el carbón, el gas natural y el petróleo representarán el 80% de la energía consumida en 2030 como se puede ver en la Figure 3 (Ver en el Documento).

La insostenibilidad económica, ambiental y social del modelo energético global se revela por sus propios elementos característicos.

En términos de insostenibilidad económica, cabe destacar que una economía basada en el consumo de recursos energéticos fósiles finitos (gas, carbón y petróleo) se verá comprometida en su competitividad frente al crecimiento previsible de la tendencia experimentado por los precios de las materias primas energéticas. Por otro lado, como se muestra en la Figure 4 (Ver en el Documento), el crecimiento de los precios del petróleo puede ser mitigado por la aplicación de políticas ambientales dirigidas a alcanzar el escenario de 450 ppm (que incluye importantes medidas adicionales para limitar el aumento de temperatura a 2 grados Celsius).

Por otro lado, en el caso de las economías que dependen en gran medida de las fuentes extranjeras para cubrir sus necesidades energéticas, existe el riesgo de altos precios derivados de la evolución de los mismos en el extranjero por las interrupciones del suministro. Un ejemplo de esto fue la interrupción del suministro de gas ruso en enero de 2008, que afectó a varios países de la Unión Europea, causada por un conflicto entre Rusia y Ucrania.

En términos de sostenibilidad ambiental, como se ha mencionado anteriormente, la evolución del consumo de energía en el escenario de referencia implica un aumento en las emisiones de gases de efecto invernadero (GHG: Greenhouse Gas) que es mucho mayor que el requerido para limitar el aumento de la temperatura global a 2 grados centígrados. En este sentido, existe un consenso generalizado a nivel internacional, basado en el análisis del IPCC (Intergovernmental Panel on Climate Change) sobre la necesidad de reducir las emisiones globales en al menos un 50% en 2050 en comparación con los niveles de 1990 para evitar un aumento de temperatura superior al mencionado.

Desde el punto de vista social, el modelo energético actual no permite el acceso a formas avanzadas de energía (principalmente electricidad) a 2 mil millones de personas, con las implicaciones negativas que esto tiene en términos de desarrollo humano y potencial de crecimiento económico futuro.

En general, estas dificultades existen debido al modelo eléctrico actual; sin embargo, en esta revisión, se expone un nuevo modelo de sector eléctrico que corrige los problemas de dicho modelo. Se basa principalmente en el estado de la técnica de las diferentes tecnologías y el desarrollo en el futuro de las mismas, por lo que la innovación debe ir de la mano con esta transición.

De este modo, en la actualidad, los sistemas de energía eléctrica en Europa, los Estados Unidos y otras partes del mundo están experimentando varios cambios guiados por las tendencias:

- Incremento de la descentralización de los sistemas de energía debido a la penetración de los DER (Distributed Energy Resources): Solar PV, Wind power,

- Proliferación de las TIC (Tecnologías de la Información y las Comunicaciones).
- Consumidores de energía activos y responsables con el precio.
- Aumento de la interconexión de la electricidad con otras infraestructuras críticas.
- Crecimiento de recursos energéticos renovables variables.
- Esfuerzos de mitigación del cambio climático global.

A continuación, se van a analizar de manera breve lo expuesto en las tres secciones más importantes de este proyecto (Enabling Technologies for Demand Flexibility, Regulatory Framework y Business Cases and Case Studies).

1.5. Tecnologías habilitadoras de la flexibilidad de la demanda

Como se ha visto en el "Contexto", existen nuevas tecnologías que han llegado al sector energético y que pueden transformar los activos y la infraestructura de operación y comercio del mercado. Estas tecnologías van desde la digitalización, las TIC, Big Data, IoT y las Smart loads, que pueden configurar una administración de sistemas más autónoma y precisa, hasta tecnologías más específicas, que desafían al sector energético, como los DER que permiten la flexibilidad de la demanda.

En esta sección el objetivo es mostrar cómo se integran los DER y las nuevas tecnologías en el nuevo modelo energético y analizar las bondades y defectos de cada una de ellas y sacar conclusiones a raíz del análisis.

De este modo, se presentan los apartados principales en los que se explican dichas tecnologías y las conclusiones a las que se ha llegado, dejando los datos específicos fuera de este resumen. (Para mayor análisis acudir al Documento).

1.5.1. Energy Storage

El Energy Storage permite al cliente final mejorar sus necesidades de energía al mover el consumo de las horas pico a las más baratas o combinando este almacenamiento con tecnologías de energía solar fotovoltaica principalmente. Además, es un componente importante para dar adaptabilidad al sistema en general y permite la administración dinámica de los irregulares RES (Renewable Energy Resources).

En los últimos años ha habido muchas innovaciones en el almacenamiento de energía, por lo que, hasta ahora, existen cuatro tecnologías principales de almacenamiento que pueden aplicarse al sistema de energía.

- Lead acid batteries: aunque representan las soluciones con el coste más bajo, su eficiencia, rendimiento y vida útil más corta representan problemas muy importantes para incorporar estas baterías al sistema de energía en comparación con las siguientes tecnologías que se muestran a continuación.
High temperature batteries: no pueden operar para aplicaciones residenciales o comerciales debido a sus altas temperaturas durante el funcionamiento y sus altos costos cuando se producen en pequeñas escalas. Por lo tanto, están situados para operaciones de mayor escala, como las industriales, las micro redes y combinadas con RES.

Flow batteries: tienen aplicaciones similares a las baterías de altas temperaturas, son especialmente adecuadas para operaciones a gran escala en industrias y micro redes grandes con tiempos de descarga de hasta unas pocas horas. Sin embargo, las diferentes características necesarias en estas baterías, como los espacios grandes, los ruidos fuertes y los altos costes, hacen que no sean realmente adecuadas para sistemas pequeños como los comerciales y residenciales.

Lithium ion batteries: estas baterías hasta ahora, y en el futuro cercano, representan la mejor tecnología de almacenamiento de energía para sistemas comerciales y residenciales, principalmente debido a su alta densidad de energía y su bajo coste en pequeñas instalaciones. Con respecto a las redes industriales y de gran escala, se debe realizar un estudio específico en cada caso para determinar la mejor tecnología habilitadora teniendo en cuenta los requisitos de energía, vida útil del sistema y costes máximos de instalación.

A continuación se detallan las conclusiones a las que se ha llegado tras analizar cada tipo de batería (Para mayores detalles acudir al Documento):

- El Energy storage ofrece un equilibrio razonable de energía, potencia, ciclo de vida, seguridad y coste, así como de restricciones de espacio, lo que las hace adecuadas para la mayoría de las aplicaciones de almacenamiento distribuido previstas para la transición energética. De esta manera, estas tecnologías de almacenamiento deben garantizar tres aspectos clave: coste, confiabilidad y seguridad, y facilidad de implementación y estandarización. Otros indicadores de desempeño pueden analizarse como características adicionales, pero no deben comprometer ninguno de los tres aspectos anteriores.

- La batería de iones de litio es la innovación elegida para uso residencial y comercial y puede satisfacer la mayoría de los requisitos en aplicaciones de microcréditos y clientes industriales. Estas aplicaciones pueden servirse utilizando células EV más baratas producidas en masa en lugar de células personalizadas de bajo volumen. Además, en la actualidad, los sistemas de módulos de iones de litio ya están en el mercado de múltiples proveedores y ya se pueden utilizar para lanzar y ampliar una oferta comercial para la transición energética.

- La lithium-ion batterie puede considerarse una tecnología madura que seguirá un camino de desarrollo evolutivo con avances principales en cátedros de alta capacidad y voltaje y ánodos de mayor capacidad. Además, se espera que los costos proyectados de la batería de ion de litio disminuyan debido a las economías de escala y los avances en la curva de aprendizaje.
1.5.2. Electric Vehicle (EV)

En primera instancia, la generalización de los vehículos eléctricos en la sociedad infiere un enorme incremento en la demanda de energía en las zonas urbanas. Sin embargo, los EV pueden convertirse en un operador que utiliza instalaciones de carga bidireccionales para habilitar el vehículo a las necesidades de la red. Se podría utilizar como un elemento importante del sistema público o como una característica para las redes de casas inteligentes que se basan en el uso de la estación de carga.

Estas estrategias de carga se conocen como Grid relief strategies y pueden ser beneficiosas no solo para los administradores de la red al poder distribuir temporalmente la carga a un momento de menor demanda sino también para los usuarios de los vehículos eléctricos al reducir los costes de carga por el uso de energía más barata.

Las principales estrategias de carga de vehículos se enuncian a continuación (Para mayores detalles acudir al Documento):

- **Opportunity charging**: es el uso común, la carga del vehículo eléctrico comienza cuando se enchufa. Los costos de electricidad son generalmente un 11% más altos que el precio promedio anual de la electricidad debido a los picos de demanda que se producen.
- **Delayed charging**: el tiempo de carga se retrasa a propósito según el uso de la demanda evaluado por el operador de la red (tasas de tiempo de uso) y el horario del conductor o propietario. Con este método, los costos de energía bajan al 85%-93% del precio promedio de la electricidad.
- **Smart charging (V1G)**: al utilizar tecnología e innovaciones habilitadas, este método obtiene una administración del estado de carga similar al Delayed Charging excepto que la carga de energía se ajusta según los presuntos requisitos de energía de futuros. Con este método, los costos de energía se reducen al 75% del precio promedio de la electricidad.
- **Vehicle to Grid (V2G)**: Smart charging (V1G) administrada por un Energy management system (EMS), basada en señales de precios, puede reducir los costos de energía para el usuario final al tiempo que facilita la generación, transmisión, distribución y restricciones al eliminar la demanda máxima inducida por el uso simultáneo de carga del EV no gestionada. Esta integración del cambio inteligente con un sistema de gestión de energía forma el método de Vehicle to Grid (V2G).

A continuación se detallan las conclusiones a las que se ha llegado tras analizar los EV (Para mayores detalles acudir al Documento):

- La carga de EV no ha tenido un impacto significativo en la red debido a la baja penetración en el mercado automotriz. Sin embargo, varios estudios destacan el potencial de perturbar la red debido al aumento de la carga máxima si la carga no se gestiona adecuadamente.
- Smart charging, que modula la velocidad de carga en función de las restricciones de la red (impulsada por los precios) ofrece la posibilidad de aplanar la curva de demanda.
• Estándares (OCPP, IEC 62196, ISO 15118 y OpenADR) que permiten la buena incorporación de EV, funciones modernas como V1G y V2G con la red y sus utilidades están en desarrollo y deben definirse para desarrollar más los modelos de negocios. Además, las investigaciones sobre el impacto del V2G en la degradación de la batería deben completarse para poder negociar buenas garantías entre los proveedores de EV y los usuarios finales.
• Se debe desarrollar una estrategia de monetización de cobro de EV final, que debe basarse primero en considerar los EV como una carga controlable y predecible para la optimización de los costes de energía para el usuario final (precios en tiempo real y cargas máximos) así como un activo de generación de ingresos para ser incorporado en los mercados de flexibilidad.
• Finalmente, aunque el potencial de V1G y V2G es enorme, no deben considerarse fuentes de generación de ingresos relevantes en el corto plazo debido a la complejidad de su aplicación final.

1.5.3. Smart Loads

Las Smart Loads están relacionadas con la administración, el control y la conectividad de la energía, lo que permite a los clientes ofrecer la energía del sistema desde el lado de la demanda a cambio de tarifas económicas. Es decir, la informatización de estos procedimientos se considera un factor de gran relevancia para dar adaptabilidad a la red.

Más aún, permite una de las funciones principales del EMS (Energy Management System) y la función del "agregador". Sin embargo, el potencial de ahorro y la complejidad de su implementación en algunos casos limitan su integración en la vida real.

Así, se analizan los 3 segmentos diferentes donde se pueden integrar cargas inteligentes:

• Segmento industrial: la mayoría de las cargas industriales se administran mediante sistemas legales o de control de Supervisory Control and Data Acquisition (SCADA) a los que no se puede acceder fácilmente. Sin embargo, en un futuro próximo, los SCADA abiertos y los Sistemas de gestión de edificios y la implementación de IoT permitirán una conexión directa de carga. Además, el acceso de terceros a los SCADA a través de las interfaces de programación de aplicaciones (API) permitirá a los expertos de la industria desarrollar algoritmos de soluciones de software para definir la mejor manera de ofertar cargas manejables en los diferentes mercados y optimizar el despacho de energía.
• Segmento comercial: calefacción, ventilación y aire acondicionado (HVAC), el calentamiento de agua y la iluminación son las cargas más grandes en los edificios comerciales y residenciales grandes y normalmente están controlados por humanos sin tener en cuenta la eficiencia energética y la comodidad del usuario. En promedio, en la UE-27, el calentamiento de agua y espacio representa el 19% de la demanda eléctrica total en el sector terciario: la iluminación representa el 20%, la ventilación 12.4% y el aire acondicionado casi
el 3%. En España, el aire acondicionado y las bombas de calor en el sector terciario representan 25,6 GW de potencia instalada. Por lo tanto, las unidades más grandes y el control centralizado de las HVAC brindan oportunidades significativas para cargas controlables en el sector terciario.

- Segmento residencial: en la actualidad, el HVAC y el calentamiento de agua son las cargas manejables más importantes (en el futuro se espera que los EV también lo sean), pero ambos normalmente requieren acceso a un panel de control fijo y operación remota. Sin embargo, el desarrollo de sistemas de hogares inteligentes (Figure 17) ofrece una amplia gama de soluciones para la gestión de cargas conectadas. Los centros de información permiten centralizar varias unidades conectadas y su administración a través de una única interfaz. De esta manera, los termostatos conectados están desempeñando un papel principal como dispositivos conectados, ya que administran la carga conectada más importante en términos de potencia, capacidad de regulación y tiempos de operación, como el aire acondicionado, pero también pueden administrar otras cargas importantes que estarán presentes en todo momento.

A continuación se detallan las conclusiones a las que se ha llegado tras analizar las Smart Loads (Para mayores detalles acudir al Documento):

- Las Smart Loads permiten administrar las cargas conectadas con el fin de reducir los costos de la energía adquirida de acuerdo con los precios de la energía por hora, reducir el consumo de energía al hacer un uso más eficiente de la energía y evitar los aumentos de precio por energía pico. Sin embargo, la mayor parte de la administración de carga no se realiza automáticamente y requiere la intervención de un EMS, lo que aumenta la complejidad de su implementación y limita su implementación en tiempo real.

- A nivel industrial, los sistemas SCADA gestionan los sistemas más intensivos en energía en grandes empresas industriales y comerciales. Ya hay miles de edificios comerciales con sistemas SCADA en España y la mayoría de ellos nunca han cambiado sus puntos de ajuste predeterminados. El acceso a los SCADA ya desplegados desbloquea la posibilidad de administrar de manera eficiente cada una de las cargas conectadas, lo que proporciona un ahorro de energía al cliente.

- A nivel residencial, los sistemas HVAC son clave en la demanda de potencia máxima. Por lo tanto, el mayor impacto puede obtenerse sustituyendo los termostatos existentes por los conectados inteligentes que pueden no solo optimizar el ahorro de energía al mismo tiempo que mantienen la comodidad utilizando múltiples fuentes de datos (detección de presencia, proximidad, histéresis, pronóstico del tiempo, etc.) y algoritmos con autoaprendizaje.

- La relación entre el almacenamiento de energía y las cargas inteligentes debe analizarse en cada caso, tanto a nivel industrial como a nivel comercial y residencial, para no obtener una solución en la que una tecnología tenga un impacto negativo en la otra.
1.5.4. Distributed Generation

Esta sección básicamente trata del nuevo papel de los consumidores tradicionales, que ahora se convierten en generadores a pequeña escala.

Los precios más bajos que están alcanzando las nuevas tecnologías, principalmente en relación con el almacenamiento de energía y la energía solar fotovoltaica, están permitiendo nuevas oportunidades comerciales, como la gestión y la generación de energía de los propios clientes.

Por lo tanto, se analizarán tres grupos de tecnologías en la generación distribuida:

- **Energía solar fotovoltaica (Solar PV)**: representa la opción más asequible de las tres. Al aprovechar las economías de escala generadas en la fotovoltaica a gran escala, obtiene el menor costo de energía (costo / kW), con valores desde 1400 hasta 2900 $ / kW. Además, esta tecnología tiene un mantenimiento bajo o nulo, no produce ruido y puede dimensionarse adecuadamente para todos los segmentos de clientes.

- **Energía eólica (Wind power)**: con respecto al costo de la energía, el viento a pequeña escala es mucho más costoso que el viento a gran escala con costos de 5000 a 10000 $ / kW para sistemas con una capacidad de potencia inferior a 10 kW y costos de 4000 a 8000 $ / kW para sistemas entre 10 y 100 kW. Además, el ruido y el impacto visual hacen que los lugares donde se pueda instalar esta tecnología tengan que ser muy específicos. En consecuencia, las micro redes son la aplicación más adecuada donde las escalas más grandes permiten precios de energía más competitivos.

- **Combined Heat and Power (CHP)**: se ha utilizado ampliamente en el sector industrial, pero reducirlo a los sectores comercial y residencial es difícil para las tecnologías disponibles.

A continuación se detallan las conclusiones a las que se ha llegado tras analizar la Distributed Generation (Para mayores detalles acudir al Documento):

- Aunque se considera que tres tecnologías principales se ajustan a la generación distribuida, la generación de energía solar fotovoltaica es, con diferencia, la tecnología más rentable. La energía eólica no es asequible debido a sus mayores costos por kW en pequeña escala, ruido e impactos visuales. CHP no es asequible debido a que es difícil de escalar a los sectores comercial y residencial.

- Dentro de la energía solar (Para comprender las tecnologías de paneles solares que se van a comentar acudir al Documento): Actualmente los módulos de c-Si son la solución viable más eficiente y económica. Han experimentado reducciones de costes rápidas debido a la mejora de la tecnología y la incertidumbre del mercado debido a la capacidad de sobreproducción y las distintas proyecciones de demanda que han reducido los márgenes de los módulos. Se espera que el desarrollo evolutivo de la tecnología debido a la producción en masa y los avances en la curva de aprendizaje se proyecen para reducir aún más los costos.

- Perovskites es el único competidor potencial que, en caso de tener éxito, significaría que se eliminaría toda la cadena de valor de c-Si, lo que refuerza la
última afirmación (c-Si parece ser la mejor opción en el presente y en el futuro cercano).

1.5.5. Grid Scale Generation

El establecimiento de plantas de recursos de energía renovable cerca de lugares donde se consume electricidad, como ciudades y comunidades, elimina aspectos del desperdicio del sistema y permite una mejor administración de la red, especialmente cuando se combinan con innovaciones de almacenamiento de energía.

De este modo, dos soluciones RES parecen ser las más asequibles, son la energía eólica y la energía solar fotovoltaica. (En este apartado se muestra más importancia en la energía eólica en el Documento, para mayor información acudir a él).

A continuación se detallan las conclusiones a las que se ha llegado tras analizar las tecnologías habilitadoras de la Grid scale generation:

- Grid Scale Generation participa en el Nuevo Mercado de Energía que implica Recursos de Energía Renovable, por lo tanto, todas las tecnologías analizadas en esta sección no son contaminantes. Las RES son la manera de lograr una administración superior de la red, flexibilidad y minimizar pérdidas y accidentes.
- La generación de energía eólica es actualmente la mejor tecnología para Grid Scale Generation y se espera que reduzca sus costos de LCOE, CAPEX y OPEX debido a investigaciones recientes para mejorar la eficiencia y las economías de escala de las instalaciones, logística y materiales.

1.5.6. Energy Management System (EMS)

Este futuro sistema de gestión se relaciona con la mezcla de Energy storage, sistemas de generación y Smart loads para trabajar sincronizados y contenidos, en unidades individuales por medio de un EMS, y en un grupo de estas unidades por medio de agregadores, y en asociación con el sistema principal.

En resumen, un EMS es un sistema de software que monitoriza, controla o analiza la energía en un edificio. Incluye servicios de automatización de viviendas y edificios, gestión personal de energía, análisis y visualización de datos, auditoría y servicios de seguridad relacionados.

Para comprender mejor las implicaciones del EMS en diferentes situaciones, se explican dos casos, cuando se usa en una vivienda común y en edificios más grandes. Para detalles de la diferencia entre el Home Energy Management System (HEMS) y el Building Energy Management System (BEMS) acudir al documento.

A continuación se detallan las conclusiones a las que se ha llegado tras analizar los EMS:

- La mayoría de los EMS en el mercado se limitan a la visualización de información y algoritmos básicos. La maximización del uso de datos para optimizar la utilización de activos y permitir fuentes alternativas de generación
de ingresos para el usuario final brinda la oportunidad de crear casos de negocios más atractivos.

- La generalización de los diferentes DER, como las cargas inteligentes, está aumentando la implementación de EMS en casas y edificios.
- El desarrollo de los medidores inteligentes está permitiendo la recopilación de información que permite continuar desarrollando análisis y nuevos algoritmos.
- El crecimiento del EMS se basa en la posibilidad de demostrar ahorros potenciales de energía con los activos implementados, la optimización operativa de esos activos y el sistema en su conjunto es clave para maximizar el retorno de la inversión realizada por el cliente.
- El EMS es un factor clave para obtener el Nuevo Mercado de Energía, ya que representa una de las herramientas más importantes para Respuesta a la Demanda (Demand Response).
- Los grupos de BEMS y HEMS serán gestionados por un agregador que intercambiará información con el VPP y con el operador del sistema. Aunque esto se explica en la sección: “Virtual Power Plant”.

1.5.7. Virtual Power Plant (VPP)

Las VPP son controladas por agregadores y juntas conforman el New Management System, que significa un centro de control central e interconectado que analiza y utiliza los avances de Big Data, TIC, los dispositivos de IoT (Internet de las Cosas) y los DER, con el objetivo final del comercio de energía en los mercados mayoristas, la prestación de servicios auxiliares a los operadores de red y controlar el libre mercado energético entre los usuarios y los distribuidores.

En resumen, una VPP es un sistema que combina información de los EMS y de los agregadores con la información del operador del sistema. Se basa en un software que obtiene un uso óptimo de la red que controla la demanda y el suministro de energía y la interacción entre ambos. La figura 31 del Documento representa muy bien el concepto de VPP.

En conclusión, las VPP representan el último paso para conseguir el New Energy System, que es más eficiente, económico y que permite un libre mercado de energía. (Para datos concretos sobre funcionamiento y desarrollo acudir al Documento).

1.6. MARCO REGULATORIO

1.6.1. Estados Unidos

Este este resumen en español se van a mostrar únicamente las conclusiones a las que se han llegado tras analizar la legislación eléctrica y energética en distintos mercados en Estados Unidos.

El sistema de energía en los EEUU es un sistema complicado en el que colaboran innovaciones, autoridades y marcos regulatorios distintivos. En la actualidad, dos
modelos notables para la comercialización de energía funcionan en los Estados Unidos:

- **Modelo de monopolio regulado**: en este modelo, las comisiones estatales controlan los proveedores de energía coordinados verticalmente.
- **Modelo competitivo**: en este modelo, los generadores de electricidad pueden acceder directamente al marco de transmisión y participar en los mercados de energía con descuento. Los reguladores del sistema presentaron rivalidad en los mercados de energía con el objetivo de mejorar la efectividad, reducir el coste para el cliente y disminuir las obstrucciones para participar como proveedor.

Los **mercados competitivos** sirven al 66% de los clientes en los Estados Unidos. El objetivo de los dos modelos es proporcionar energía de manera segura y fiable a los clientes finales.

Las “utilities” sin participación económica en el resultado de los intercambios de energía operan en los mercados mayoristas. Para participar en el mercado, los generadores de electricidad presentan sus ofertas para cada período de programación, que generalmente se utiliza en los Estados Unidos. La programación de cinco minutos se usa en la mayor parte del mercado energético. Las ofertas incorporan el costo de solicitud, que se calcula según el OPEX de la planta y la capacidad ofrecida. En general, como se explica en el bloque “Context”, los operadores del sistema envían las ofertas de costo mínimo primero hasta que se responda completamente a la demanda; entonces, la última oferta con el precio más caro establece el precio del mercado. Los LMP (Locational Marginal Pricing) incorporan tres partes diferentes: valor energético del mercado, gastos de bloqueo y pérdidas de transmisión.

Los mercados competitivos no se limitan al intercambio de energía, por ejemplo, las plantas de generación pueden proporcionar diferentes servicios para ayudar al sistema de transmisión. Estos son conocidos como servicios auxiliares y son: “black start”, soporte de voltaje y reservas de operación. Los operadores de la red también organizan el intercambio de derechos de transmisión presupuestarios, lo que permite al propietario pagar por adelantado los costos de obstrucción de la transmisión y puede utilizarse como un tipo de apoyo contra la imprevisibilidad de los costos. Además, se han insertado cuotas de capacidad para aumentar la confiabilidad de la red al proporcionar un ingreso adicional para los generadores en relación con su factor de capacidad.

El desarrollo continuo de Demand Response y REG (Renewable Energy generation) ha planteado nuevos desafíos para los operadores de marcos competitivos. Los dispositivos DR instan a los compradores a cambiar su utilización en el futuro cercano, principalmente a través de programas de obligaciones e incentivos porque el DR puede desarraigar los activos más costosos, expandir la productividad financiera del marco y puede brindar servicios complementarios y de fiabilidad de manera adecuada. Finalmente, con respecto a DR, la Orden 745 de FERC pedía a los administradores de la red que pagaran a los activos de DR el coste total de mercado de la energía, además, como se explica en el Documento, recientemente el Tribunal Supremo ha mantenido esta orden.
La energía solar fotovoltaica y la eólica incrementan la imprevisibilidad y la volatilidad de la red, lo que puede aumentar el costo y la sofisticación de ajustar la carga de energía de la red. Las medidas que pueden aliviar con éxito los costos de la integración de REG son, entre otras: demanda y flexibilidad de la oferta, estructura de transmisión más descentralizada, variedad geográfica, mejor programación y previsión.

Además, la energía solar fotovoltaica y la energía eólica, y REG en general, tienen un costo variable cercano a cero, lo que disminuye el valor de compensación del mercado en relación con la medida de los activos de REG disponibles en un momento dado. Esto puede crear la vulnerabilidad de ingresos y la insuficiencia de otros generadores presentes y futuros. A largo plazo, la vulnerabilidad de los ingresos puede disminuir la calidad del sistema debido a que los miembros actuales pueden renunciar y los miembros inminentes pueden elegir no participar. El objetivo de los mercados de capacidad es aumentar la confiabilidad de los ingresos para los generadores y, por lo tanto, incrementar la confiabilidad del sistema.

La participación en mercados competitivos en los EEUU podría ofrecer experiencia a otros sistemas eléctricos en el mundo, como Europa y Asia. La estructura de los mercados de los EEUU y sus partes son las consecuencias de un largo desarrollo y la consolidación de las experiencias obtenidas de los aspectos de desperdicio y errores del mercado.

1.6.2. Europa

Como en el apartado anterior, en este resumen se muestran únicamente las conclusiones a las que se han llegado tras analizar el mercado eléctrico y energético en Europa y más concretamente en Alemania, Reino Unido y Francia.

- El Winter Package determina el camino para alcanzar el nuevo mercado de energía que implica la flexibilidad de la demanda del sistema. El Winter Package es un camino al cambio de regulación que se necesita realizar (se explica con detalle en el Documento) para lograr un mercado de energía basado en fuentes de energía renovables, eficiencia energética y centrado en el cliente que se convertiría en parte activa del sistema.

- La European Commission con directivas anteriores y con el nuevo Winter Package exige que los estados de la UE garanticen que los reguladores nacionales habiliten los activos del lado de la demanda, como DR y REG, para participar en el suministro en los mercados minoristas y de gran escala. Cuanto más notable es la coordinación entre los países europeos, más notables son las economías de escala y los servicios de DR. Con esta coordinación y economías de escala, se reducirá el costo de la generación distribuida, se mejorará la efectividad de la red, se reducirá el costo de otras tecnologías, como el almacenamiento, lo que permitirá reducir el costo de las reservas de energía. Además, el desarrollo de los servicios de DR supondrá una nueva fuente vital de ingresos para las organizaciones locales y los hogares.

- Con respecto a las ventajas potenciales de la DR y las obstrucciones administrativas, se requiere un desglose del plan estratégico de la DR en cada estado miembro para garantizar un avance real y práctico. Estos planes deben
incorporar objetivos reales para el desarrollo de la actividad del cliente y deben incorporar indicadores clave de rendimiento (Key Performance Indicator: KPI) que verifiquen el correcto cumplimiento de los objetivos establecidos. Solo un esfuerzo organizado y compuesto puede romper las barreras existentes debidas al sistema de red tradicional y verticalmente integrado.

- Ha llegado el momento de alinear los mercados energéticos con los objetivos energéticos de Europa. La Market Design Initiative (MDI) abre las puertas a la unificación y estandarización de la flexibilidad en el lado de la demanda, incluidos los roles, programas y obligaciones explicados en los países de la UE. Actualmente, es cierto que el potencial máximo del mercado de vitalidad interior europeo solo se aprovechará si los clientes, como industrias, empresas y hogares, pueden participar en la transición energética de la UE. Este debe ser uno de los objetivos del esquema del mercado y requerirá un cambio clave en la demanda.

1.7. CASOS DE NEGOCIO

En este bloque se exponen algunos casos que integran Demand Response y las tecnologías habilitadoras, el objetivo es analizar situaciones prácticas y realizar y medir el impacto tecnológico y económico de la transición energética. De este modo, en este resumen se van a exponer los dos principales casos teóricos a los que se debe dar más importancia en el mercado, y en el Documento se presentan los casos prácticos, con datos concretos, que reflejan la bondad o no de su implementación real.

1.7.1. Optimización de contratos

Una opción para generar ahorros es reducir los costos de utilización de la red. Los grandes clientes eléctricos tienen que pagar impuestos por usar la red en función de la carga y el consumo máximos; por lo tanto, si se reducen los picos de carga, los costos de utilización disminuirán. Además, algunos países compensan a los clientes que demandan energía de manera atípica, lo que significa que su mayor consumo coincide con los períodos de menor actividad.

En segundo lugar, otra opción es obtener tarifas flexibles para obtener ganancias de ella. Como se ha visto anteriormente, los precios del mercado de la energía varían durante el día, por lo que los períodos pico son más caros que los de poca actividad, por lo que si un cliente puede transferir sus cargas de energía a los períodos más económicos a través de las tecnologías de DF (Demand Flexibility), este cliente reducirá sus costos. Además, en algunos países hay tarifas que compensan la producción de energía producida en la red en horas pico, por lo que aquí hay otra opción para obtener ganancias. Sin embargo, los diferentes contratos y tarifas deben ser monitorizados profundamente para asegurar ganancias tanto para la red y las TSO, como para el cliente en cuestión.
1.7.2. Comercio en el mercado mayorista

Los mercados de energía abiertos y competitivos son uno de los temas más importantes de todo este proyecto. Los mercados tradicionales tal como están implementados no permiten que la demanda participe en el mercado, sin embargo, todo ello está cambiando a medida que la regulación cambia a su vez.

En general, los participantes en los mercados tienen que pagar una tarifa por la energía comercial, por lo que el rol del agregador es realmente importante: este reúne a algunos clientes para lograr suficiente energía como para comerciar con ellos y con los operadores y obtener ganancias para ambos.

1.8. CONCLUSIONES

Se muestran 6 recomendaciones principales derivadas de los análisis realizados mediante el reconocimiento de un papel más activo del distribuidor y el consumidor, la integración de las nuevas tecnologías en la red y la correcta asignación de incentivos para garantizar el funcionamiento eficiente de la misma.

1. Mejorar precios y tarifas reguladas por servicios de electricidad.

La única forma de poner en juego todos los recursos, tanto distribuidos como centralizados, para lograr una operación y planificación eficientes del sistema eléctrico, consiste en mejorar tanto los precios asociados con los servicios de electricidad ofrecidos como los cargos regulados asociados con ellos.

Las medidas que permitirían cubrir estos objetivos serían las siguientes:

- Minimizar las distorsiones debidas a los cargos diseñados para la recaudación de impuestos y la recuperación de los costos de las políticas energéticas. Estos costos deben salir de la tarifa y ser recuperados por otros mecanismos.
- Las tarifas y los cargos no pueden ser variables, ni se deben aplicar soluciones de balance de red.
- No distorsionar la señal de precio de la electricidad. Las ayudas para ciertos tipos de clientes, tales como clientes vulnerables o industriales, deben realizarse sin alterar los precios o cargos que sean aplicables. Los subsidios fuera de la tarifa deben realizarse a través de los mecanismos apropiados.
- Implementar de forma masiva medidores inteligentes, con el objetivo de que las inyecciones y extracciones de electricidad reales de la red determinen el pago que deben realizar los usuarios, es decir, el uso real de la red.

2. Mejorar la regulación de la actividad de distribución.

El marco regulatorio en el que las empresas distribuidoras realizan su actividad debe mejorarse, permitiendo la implementación de nuevos modelos de negocio más eficientes e innovadores.
Las medidas que se pretenden llevar a cabo serían las siguientes:

- Asignación de incentivos que dependen de los servicios prestados por los servicios públicos, destinados a recompensar las mejoras en la calidad, la reducción de las pérdidas en la red, la mejora de los tiempos de interconexión y el ahorro de costos en las operaciones de inversión.
- Implementación de incentivos para la innovación a largo plazo para acelerar las inversiones en I + D, así como para fomentar el aprendizaje sobre las nuevas tecnologías que pueden conllevar, a priori, mayores riesgos para la red.

3. **Minimizar la aparición de conflictos de intereses.**

Se debe realizar una reevaluación exhaustiva de la estructura de la industria eléctrica para minimizar la aparición de posibles conflictos de intereses.

Para ello, se necesita:

- Realizar una asignación correcta de las funciones principales que se encuentran en el centro de los mercados energéticos: proveedores de servicios de red, operadores de sistemas y plataformas de mercado, asegurando así el correcto funcionamiento del sector eléctrico.
- Independencia financiera entre actividades abiertas a la competencia y reguladas. Se acepta una supervisión reguladora suficiente para situaciones en las que la separación total de actividades no es posible o ineficiente.

4. **Mejora del diseño del mercado eléctrico mayorista.**

Para integrar mejor el autoconsumo y compensar la flexibilidad creando un campo de juego equilibrado para todas las tecnologías es necesario proponer una mejora en el diseño del mercado mayorista.

Para alcanzar estos objetivos, es necesario:

- Que los mercados permitan la realización de transacciones lo más cerca posible al tiempo real, para recompensar, entre otras cosas, la flexibilidad de los recursos.
- Actualizar el formato de las ofertas en el mercado, con el objetivo de reflejar las necesidades de los nuevos agentes.

5. **Incrementar la importancia de la ciberseguridad.**

La conexión de los sistemas de autoconsumo, las nuevas aplicaciones inteligentes y la mayor complejidad en los mercados eléctricos refuerzan la importancia de contar con sistemas adecuados de ciberseguridad.

Para esto:

- Se necesitarán estándares sólidos en términos de ciberseguridad para todos los dispositivos interconectados a la red eléctrica.
- Además, la rápida evolución de posibles amenazas subraya la importancia de que las soluciones se desarrollen e implementen de manera rápida y eficiente.

6. **Ahorro de costes a través de un mejor uso del autoconsumo.**

El valor del autoconsumo como generación de origen fotovoltaico y baterías, depende enormemente de la ubicación geográfica de las instalaciones.

Es por eso que:

- No se puede establecer un valor estándar para todos los recursos distribuidos.
- Cada ubicación donde alguien quiera implementar los recursos distribuidos debe analizarse individualmente.
- Las instalaciones fotovoltaicas y de baterías son más eficientes si se desarrollan a gran escala. La pequeña escala no siempre es la mejor opción.
2. EXECUTIVE SUMMARY

Nowadays, electric power is considered essential, since it is a staple expendable commodity. The way in which society evolves makes it increasingly dependent on technology, thus implying a dependence also on electrical energy. The efficiency of the electrical system not only has economic repercussions, but also influences the social and environmental environment.

In this way, in the last years, biggest companies and most advanced countries have been thinking about a new electric energy model and market, in which efficiency, security, self-consumption and Demand Flexibility (DF) are prioritised. This is called the energy transition that basically consist in a new energy market that eschews the traditional and vertical market were the electricity goes from generators to consumers through transmission system operators (TSOs) and distribution system operators (DSOs). In this new market customers become active players in generation and energy exchange and get profit of it.

This change becomes a real possibility through enabling technologies that are analysed in this report. These main technologies are Solar PV, Wind Power, Smart Loads, Electric Vehicles and Energy Storage Batteries; and they need to be examined in order to determine which ones are the best options to be integrated in the system and what kinds of advantages do they offer. Furthermore, all the investigations of this innovations directly impact in other social and environmental conditions due to these technologies can be applied in other fields.

In this sense, in this report, the state-of-the-art of each asset is studied, and the best option of each technology determined; the importance of the asset is evaluated to analyse if its impact is really disruptive for Demand Flexibility; the kinds of services the asset can offer; and finally, which is the way to integrate the technology in order to achieve the best benefit. Up until now, these technologies are becoming economically attractive and they are currently being integrated, but, in the near future, they will come to be cheaper and much more profitable.

That is the reason why many different countries, mainly the United States of America (USA) and the European Union (EU) are adapting their regulations to adjust to the energy transition. In fact, they are imposing mandatory laws to their member states to open the electric market to customers through companies and aggetators (it is explained in the “Introduction”).

In “Energy Transition: Enabling Technologies for Demand Flexibility, Regulation & Business Models” report, regulation of USA and EU is one of the main topics covered. Here, previous and latest legislations are exposed and analysed in detail, and conclusions and recommendations to them are presented in order to take advantage of the energy transition. Furthermore, a deep study of the different markets of USA (NYISO and CAISO) and EU (Germany, United Kingdom and France) and its principal programs is shown taking into account the main characteristics of each one and how good they are.

However, these conclusions and recommendations about markets and regulations must be proven with real data that test the profitability of those measures, thus in the
report four **business case drivers** are exposed. They study different states of USA taking real data of population and of particular programs that have been settled there; then results and comparisons are shown to prove the profitability or not of these investments. And, of course, this report gives some amendments to the regulation that was set in those cases, sometimes positive and other not that much.

**Summarizing:**

- This research focuses on understanding how the greater penetration of self-consumption will affect regulation and current business models in the electricity sector.
- Nowadays important changes are taking place in the form of generation and consumption of electricity, fundamentally due to a confluence of factors that affect the electrical distribution systems. New technologies or services, such as demand flexibility, self-consumption, energy storage, and advances in power and control electronics devices, are generating new opportunities in the supply and consumption of electricity. At the same time, the rapid cheapening of information and communication technologies (ICTs) are allowing a more efficient consumption of electricity, a better vision of the use of the network as well as better control of electrical systems.
- This report presents a framework for regulatory proactivity and market reform, in order to achieve an efficient evolution of the electricity system over the coming decades. The objective is to facilitate and achieve the integration of all resources, regardless of whether they are centralized or distributed, all of which can contribute to an efficient electricity supply for consumers.
3. INTRODUCTION, OBJECTIVES AND STRUCTURE

3.1. INTRODUCTION

This project is thought to give a vision on the energy transition, and how it is driven by technology. Nowadays technologies such as Smart loads, Solar PV, Wind Power, Energy storage and Vehicle to grid that are raising through maturity and lower costs, could make a more efficient and secure energy market.

This project is going to analyse the energy market through three main blocks: Technologies that enable the energy transition, how the regulation is changing and must change in order to take advantage of these innovations, and finally, the business models that can be achieved through the mix of technologies and regulation.

The energy transition is changing the traditional energy market and is generating many business opportunities even more in the near future. It is a topic of tremendous relevance in the present technological, electric and economic outlook. Furthermore, it will impact in the life of all the population due to every single consumer will be able to become provider of energy to the system by means of aggregators.

Aggregators represents a key role in this energy transition, they will enable the consumers (with batteries, smart loads or solar PV in households) to engage the market by achieving an efficient management of their technologies and getting economic value of it.

Nowadays there are some regulatory issues in some countries that need to be amended in order to ensure a free trade energy market and integrate novel technologies. The main solutions have already been mainly implemented in USA and UK with the development of the demand response taking into account the role of aggregators and consumers.

In addition, EU have deployed the Winter Package due to which member states of the EU are going to regulate the energy market and encourage final consumers to participate alongside generators in a non-discriminatory manner. This is the beginning to the transition in Europe but this report will not just assess the bounties of these measures, but it will give recommendations to achieve an energy transition with security supply, efficiency and free trade.

Energy transition is also the way to stop the emission of Green House Gases (GHG) and the climate change by prioritising renewable sources and by integrating non-polluting novel technologies. This objective is yet declared in the European commitment 20/20/20 and the Winter Package.

Regarding the motivation for making this project, last four months (in the time when this report is written) the author of this TFG has been working in i-deals (Everis) and the energy transition has been one of the main topics addressed during this period. The author has understood the relevance of it and how it is going to change every electric billing of each consumer. Every single person will be able to participate in a
market that traditionally has been managed by very few enterprises and in some cases that has operated like a monopoly.

### 3.2. OBJECTIVES

The very first objective of this project is to analyse the main facts of the energy transition, understand with everyone must join this opportunity, give recommendations of the present and future technologies that should be integrated and how regulation should change to enable a more efficient and secure energy market.

This project is a huge source of knowledge and it is intended to be addressed as a deep research, analysis and guide of the actual and future energy market.

The following graph represents how the steps to achieve the final objective:

![Figure 1: Objectives. [Source: Own.]](image)

- A research of the main technologies must be done in order to understand why this transition is possible because it is driven by technology. Energy storage, smart loads, decentralised generation with solar PV, grid scale generation with wind power and vehicle to grid technologies must be researched and analysed and, then concluding the best option of each technology in order to obtain good recommendations for the regulators of the system.
- Traditional and present regulation needs to be amended that is why it will be analysed with its advantages and disadvantages. The changes in the legislation that have already been done will be assessed and recommendations will be exposed. This project will be able to give conclusions to the regulators due to the previous technological analysis.
- Finally, with all earlier knowledge the study of real and present business models will be able to be made. Furthermore, these business cases will provide a practical vision of how this transition is possible and much more profitable for all players (TSOs, DSOs, aggregators and consumers). Even more, these models will prove that the technology previously studied fit with real cases and will justify all the investment in its development.
To conclude the project final conclusions of the future energy market will be indicated: recommendations of the technologies that should be used to tap into the best potential ones; analysis of the best regulations and legislation to ensure a fair competition market, the security and the efficiency; and finally, business suggestions to get the most worthwhile investments.

### 3.3. STRUCTURE

In the report there are four main chapters: Context, Enabling technologies, Regulation and Business models.

First of all, the first block introduces the reader in the energy market, how does it work and who are the main players. It will try to make readers aware of the importance of the energy transition and how the flexibility of electric demand impact on it. This chapter especially focus on Red Eléctrica de España (REE) the transmission system operator (TSO) in Spain, it is explained its role in the energy market and how it has to control the security in the supply and the efficiency in the system.

Secondly, it is analysed the state-of-the-art of the enabling technologies of the energy transition in order to conclude the benefits that each asset could provide to the flexibility of the demand. This chapter focus mainly on the maturity of each technology and how their production costs and selling prices are going down as market begin integrating them. The technologies assessed are mainly energy storage (Batteries), distributed generation (Solar PV), grid scale generation (Wind power), controllable loads, V2G (Vehicle-to-grid), energy management system (EMS) and the role of the aggregator.

Thirdly, the regulatory framework will be assessed, focusing on different markets in United States (CAISO, NYISO), the future and present framework in Europe (UK, Germany, Spain), and on few markets in Asia. But the most important block here is the recommendations and amendments that will be exposed to obtain the new energy market ensuring security supply, efficiency and free trade.

Fourthly, all previous information will let to test some business models and determine how profitable and legal they are and how will they develop in the future. This real business cases will be able to conclude which are the best profitable inversions in the electric sector and which are the technologies that should be used.

Finally, last conclusions of the TFG are shown, after having discussed all the energy situation, the author will be able to give recommendation to get the best energy transition to the new electric market.
4. CONTEXT

In order to introduce you in the electric sector and how is the Operation of the Electrical System, Spain is going to be taken as an example.

4.1. FUNDAMENTAL KNOWLEDGE

In Spain, REE (Red Eléctrica de España) is a titular company and manages the transmission system and is the responsible of the operation of the electrical system in Spain, in other words, REE is a TSO (Transmission System Operator) and the System Operator in Spain. This will be explained more deeply hereafter.

An electrical system is the set of elements that operate in a coordinated manner in a given territory to meet the demand for energy electric, in Spain there are seven basic components:

- **The centres or generation plants**, where electricity is produced, and tension rises to transport it.
- **Electricity transport lines high voltage**, which manages, develops and maintains REE.
- **Transformer stations** (substations of transport or distribution) that reduce the voltage of the line.
- **The medium and low voltage distribution lines** that carry electricity to the consumers.
- **The facilities of customers or consumers** of electric power.
- **The control centres** of the generating companies, distributors and marketers.
- **A national electric control centre** from which is managed, coordinated and operated electrical system, and that is also managed by REE.

However, there are still some principal actors that need to be presented in order to better understand the system:

- **Generators**: They are the agents that produce electric power, regardless of type of technology they use for it. The Generation is a liberalized activity.
- **Carrier**: It is the company that transports electricity from the power stations where produces up to the consumption centres where it is delivered to the distributors. In Spain, by law, there is a single transporter, as it has been explained, who is REE (Red Eléctrica de España).
- **System operator**: It is the company, in this case also REE, which is responsible that the whole process of the operation of the electrical system works smoothly. The key is to achieve the balance between generation and energy consumption. It is done through the Electric Control Centre (Cecoel) and its activity is really important due to electricity cannot be stored on a large scale, so it mostly must be produced in the same moment that it is been consumed.
• **Distributors:** These are the companies that carry electricity to final customers: the streets, homes, businesses, etc., when they receive it from the carrier in the substations annexed to the major centres of consumption. Although there are numerous companies who exercise this activity, in each area of Spain can only be one distributor. Or, what is the same, until our house only the cables of one single company can arrive.

• **Marketers:** As its own name indicates, they are the agents that trade with the energy. They buy it in the electric market and sell it to consumers. They are those who pass us the receipt of light. It is also a liberalized activity.

• **Consumers:** That is, you and any other person or company that in a moment given consumes electricity.

After examining the principal actors and components of the system, an overall look of the **energy generation** will be exposed. Basically, there are 4 ways of generation, the first two of them are pollutant and the last two of them use renewable energies:

• **Thermal power plants:** There are different types, depending on the material they are fed: fossil fuels (coal, fuel and natural gas), urban waste or biomass, without forgetting those of combined cycle. Its burning produces also a pressure steam that moves a turbine connected to a generator.

• **Nuclear or atomic power plants:** Operate through the fission of a nuclear fuel (uranium or plutonium, for example) that, when generated pressure steam, starts a turbine connected to a generator that is the one that produces the electricity that then passes to the network.

• "**Atmospheric**" **Centrals:** They are those that use resources like dammed water or the wind. In this case, the pallets of the Hydraulic turbine or wind turbine propellers move the turbine directly which feeds the generator. Electricity thus produced then passes to the network.

• **Photovoltaic power stations:** The contained energy in photons the sunlight becomes directly in electricity and passes well to the network.

The priority of renewable energies is due to the global warming. Europe have proposed the **European commitment 20/20/20**, what means the need to reduce greenhouse gases by 20%, to improve energy efficiency by 20% and to achieve 20% of energy generation with renewable resources; and those three objectives have to be achieved by 2020. Even more, recently another standard has been released, the **Winter Package**, which determines a 27% of energy generation with renewable resources by 2030.

For that matter, REE is highly concerned with sustainable development and the fight against climate change. So, it has developed different actions:

• **The integration of renewable energies:** The European and national commitment to these energies (hydro, wind, solar and biomass), that generate electricity without emission greenhouse gases and use resources indigenous peoples, will reduce our external energy dependence.
• **Energy efficiency**: The impulse of demand management initiatives pursue achieve greater efficiency, both in the operation of the electrical system as in the own energy consumption.

• **Reducing emissions**: In 2012, the rate of emissions associated with equipment of substations, mainly of SF6, it was reduced to 0.99%, which it practically means reaching the goal of 1% marked for 2015.

• **Tree protection**: Compensation of emissions is carried out through of the REE Forest, a project of reforestation with which they have compensated more than 60,000 tons of CO2 in its five years of operation.

• **Adaptation to climate change**: REE constantly assesses the risks potential that climate change could have about your activity as a carrier and operator of the electrical system, while prepares performances to do against the risks already identified.

• **The extension of the company's commitment to the stakeholders**: Or what is it same, a communication policy of the carbon footprint of REE, collaboration in initiatives to fight against climate change, action development of awareness.

Other important subject that needs to be considered is the **interconnection between different systems**, the main reason is that if a system is isolated and suffers the unexpected stop of a generator, the logical and immediate consequence is that the balance that must exist between the production and demand of electric power can be decompensated.

However, in a system interconnected with many other systems, the unexpected stop of a generator also causes an alteration of the electric parameters. But this time, as all the systems are united in the same network, everyone will contribute their bit to replace the lost production of the damaged generator. That is, there will be so many generators that will bring the shoulder that the parameters of the system will hardly be affected. There lies the need for interconnection. Therefore, the Spanish peninsular system is connected with our European neighbours, Portugal and France, through it, to the European network; and with Morocco and, through it, to the North African network.

But this is not the only advantage of international interconnection. Another no less interesting is that allows to **evacuate electricity generated from renewable sources** (energy from renewable is usually intermittent and difficultly controlled due to they depend on the wind, the sun, etc., that is to say, natural sources) at a time when this generation does not can be absorbed by the Spanish electrical system and, consequently, it does not take advantage, what it forces, for example, to disconnect wind farms.

### 4.2. SYSTEM CONTROL

**REE objective as system operator** is to cover all the energy demand that the customers do. And to achieve it, it puts into play a tactic that pursues above all the coordination among the group of participants. Because only of the correct and balanced strategy among the energy producing centres, the network of transport in high voltage,
the substations that they reduce that tension and the distribution network to each home, business and street, electricity will get there where it is necessary at the precise moment.

To achieve this objectives, different three parts are going to be explain: the preparation of the system, the operation and the analysis.

Electric system needs a preparation that consists of three indispensable stages:

- **The forecast of future electricity consumption**: It is an essential aspect to calculate the generation and network needs to long term. Then, in the day to day and hour to hour readjustments will be made depending on the capricious reality.
- **The determination of the generation power what to install**: That is, what will be the production needs required by a society that every day presents itself more dependent on electricity.
- **Transportation network planning**: Related to the previous point, here what is involved is to keep in mind how will carry that energy that will be needed in the future from the centres where it is generated even the consumers.

The secret of success is to foresee the evolution of energy demand (Figure 2), because foreseeing it allows the operator of system identify generation needs of energy and plan accordingly the network of transport, so that there is no lack of power to cover consumption, or build generators moreover, neither the lines collapse and provoke a lack of supply coverage.

But how does the system operator know the electric power consumption throughout the system electric in real time? Well, thanks to a very advanced technology and to the collaboration of agents of the electrical system, the operator of the system is able to capture the precise data to know in real time the instant consumption of electric power. And it represents it in some special graphics, **the demand curve**.
As seen, the prevision plays a very important role, but in real time there is a new player: **The electric market.** In the Península Ibérica it is called MIBEL (Mercado Ibérico de la Electricidad) and their **main players** are:

- **The generators**, which present offers of sale of all the energy they have available at the price they consider convenient.
- **Marketer companies** (those that pass the receipt for the electricity that it is consumed), which present their offers of purchase of the energy that, according to their forecasts, they will need, also at the price that they estimate convenient.
- **The users of the international interconnections**, who come to buy or sell energy, with authorization to establish international exchanges.
- **Direct consumers**, large customers who come to buy energy directly to the market.

Conversely, this market requires to be managed by an institution, in this case is the **OMIE** (Operador del Mercado Ibérico de Energia) that establishes production programs and consumption for each hour of the next day. Those groups that have offered the best price will start, and those with more elevated offers will kept stopped. The daily market price is established having in consideration the last offer married in each hour. All programmed generators are remunerated at the marginal price of each hour, independently of the offers submitted, and with him also the settlements are calculated. The established programs are added to the delivery and energy intake programs established in the daily electricity market through bilateral contracting with physical delivery between sellers and buyers of energy, giving rise to the so-called daily base program of operation for the next day⁷.

After the daily market, the operator of the system carries out an analysis to determine if the electrical system is safe or if, on the contrary, there is a risk situation in which they
could occur blackouts. If the program is not technically feasible, the operator of the system will modify it.

Deepening the electric market, and focusing on the economy: In a liberalized environment, in which the generation activity takes place in a free market framework, the different possible designs can be summarized basically in two: a "energy only" model, in which the market price is the only income of the generators, and a "market price + payment for capacity" model, in which the generators receive the market price and an additional payment as an incentive to investment and availability. Down below each model is explained:

"Energy only" model: In order for the "energy only" model to work properly, the market price must be high enough at times of maximum demand so that a state-of-the-art power plant (which only generates at those times) recovers its fixed costs.

"Market price + payment for capacity" model: The "energy only" model is currently unviable in many countries, mainly because particularly high prices, even only a few hours a year, result very controversial from the political point of view. In fact, Spanish regulations do not allow offers in the daily market above € 180 / MWh. Given this restriction, in order to give the plants an opportunity to recover their fixed costs, a system of regulated payments, additional to the market price, must be designed and that has to do with the value of the ENS (Energy not supplied) and with the limit to be imposed on the price (the greater the difference between the value of the ENS and this limit, the higher the capacity payments must be for a given quality level of supply). With this scheme it is pursued that there is sufficient investment to meet the demand points, incentivize investment, and that the plants are available at times of high demand.

Another system of capacity payments, developed mainly in some states of the east coast of the USA, is the derivative of imposing on suppliers the obligation to cover their maximum annual demand with "capacity tickets". These tickets must be purchased from the generators, who receive a complementary income in exchange for being available. Unlike the system of regulated payments, in which it is the Administration that establishes the price of capacity payments, and it is the interaction of supply and demand that determines the quantity of capacity demanded; with the "capacity tickets" it is the Administration that defines the quantity of capacity demanded, and it is the interaction between offer and demand of "capacity tickets" that establishes its price.

In conclusion, the current design of the market offers, in theory, to generators a guarantee of recovery of investment costs and costs linked to availability through regulated payments that complement the revenues in the market. However, recent regulatory decisions, motivated by the pressure of the regulator to reduce the tariff, introduce uncertainty that may affect the decisions of operation and maintenance of existing assets with high fixed costs, on the one hand, and investment decisions in new capacity. These types of regulatory decisions are an example of a "regulatory vicious circle".

Therefore, to create the right conditions for investors to respond to the investment needs in the system and for companies to maintain their operating assets, so that consumers benefit from greater security of supply, the Administration should offer a guarantee of stability in the regulation of generation companies.
This is one of the problems that will be resolved with the flexibility in the electric demand, now some other problems of the system will be exposed, and some possible solution will be introduced, all of them are inside the future electricity model that is discussed in this report.

After having analysed, economic topics of the electric market, other main difficulties of the actual model are going to be exposed:

In general, a sustainable energy model would be one characterized by production and consumption patterns that reconcile economic, social and environmental development, meeting the energy needs of present generations without compromising the possibilities of future generations to meet their own needs. For this to be possible, the energy model must take into account three basic elements:

- **Energy security**: must guarantee the continuity of supply at reasonable prices for consumers.
- **Competitiveness**: should not pose a danger to the competitiveness of the economy, and its growth.
- **Environmental sustainability**: the production and consumption of energy must not have an unaffordable impact on the environment. Within this area, the energy sector, as responsible for 80% of greenhouse gas emissions, must play a very important role in the fight against climate change.

The current energy model is characterized by a constant growth of energy consumption, based on finite resources, mainly fossil fuels.

According to the forecasts of the International Energy Agency (AIE), the global primary energy demand will grow in the reference scenario at an annual rate of 1.5% until 2030, with a predominant weight of fossil fuels remaining above the total consumption, so that coal, natural gas and oil will represent 80% of the energy consumed in 2030 as can be seen in Figure 3.

![Figure 3: Evolution of global primary energy consumption. [Source: World Energy Outlook 2012.]]
The economic, environmental and social unsustainability of the global energy model is revealed by its own characteristic elements.

In terms of economic unsustainability, it is noteworthy that an economy based on the consumption of finite fossil energy resources (gas, coal and oil) will be compromised its competitiveness against the foreseeable trend growth experienced by the prices of energy raw materials. In addition, as shown in Figure 4, the growth of oil prices may be mitigated by the application of environmental policies aimed at reaching the 450 ppm scenario (which includes important additional measures to limit the increase in temperature to 2 Celsius degrees).

![Figure 4: Projected evolution of oil demand in thousands of barrels per day and oil prices in dollars per barrel. [Source: World Energy Outlook 2012.]](image)

On the other hand, in the case of economies that are heavily dependent on foreign sources to cover their energy needs, the price risk derived from the evolution of energy prices is compounded by the interruption of supply in the face of possible situations of various kinds. An example of this was the interruption of Russian gas supply in January 2008, which affected several countries of the European Union, caused by a conflict between Russia and Ukraine.

In terms of environmental sustainability, the evolution of energy consumption in the reference scenario implies an increase in Greenhouse Gas (GHG) emissions that is much higher than that required to limit the increase in global temperature to 2 Celsius degrees. In this sense, there is a generalized consensus at the international level - based on the IPCC analysis on the need to reduce global emissions by at least 50% in 2050 compared to 1990 levels to avoid an increase in temperature above that mentioned.

From the social point of view, the current energy model does not allow access to advanced forms of energy (mainly electricity) to 2 billion people, with the negative implications that this has in terms of human development and future economic growth potential.

All in all, these difficulties exist due to the actual electric model and market, however in this review, a new power sector model is exposed which amends the problems of the
actual one. It is mainly based on the state-of-the-art of the different technologies and the future development of them, so innovation must go together with this transition.

4.3. POWER SECTOR TRANSITION

Already today electric power systems in Europe, the United States and other parts of the world are experiencing several changes guided by the trends:

- Increasing decentralization of power systems due to the penetration of DERs (Distributed Energy Resources).
- Proliferation of ICTs (Information and Communications Technologies).
- Active and price-responsible energy consumers.
- Increased interconnectedness of electricity with other critical infrastructure.
- Growth of variable renewable energy resources.
- Global climate change mitigation efforts.

4.3.1. DERs

In the new power model DERs are going to be treated as main players, more specifically they are defined as any resource capable of providing services that is located in the distribution system. In most power systems they remain minor players, however their deployment and smart energy consumption are generally on the rise. Some DERs examples that are running in several markets at present are listed below:

**Solar PV**: Nearly one in five customers in Hawaii and one in 10 single-family homes in California has already a rooftop solar PV system\(^{10}\); and in Germany 98% of all solar PV is connected to low and medium voltage distribution grids\(^{11}\).

**Energy storage**: Energy storage resources such as thermal energy storage and lithium-ion batteries are becoming more competitive. Furthermore, battery energy storage projects are currently located in the United States within distribution systems\(^{12}\).

**CHP (Combined Heat and Power)**: Already in 2015, these units and fuel cells accounted for 8% of all generation capacity in the United States\(^{13}\); besides, 75 percent of reinforcement age capacity in the United States is filled by diesel or natural gas\(^{14}\).

**Wind farms**: Onshore wind farms connected at distribution voltage are becoming increasingly widespread and they currently have reached significant capacity in many power systems\(^{15}\).

**HVAC (Heating, Ventilation and Air-Conditioning) systems, water heaters**: They collectively represent over 80% of the demand resources for PJM\(^{16}\) (TSO in the United States).
4.3.2. ICTs / price-responsible demand

The digitization makes it less demanding to ascertain and convey the estimation of power services with better transient and spatial granularity. Digitization in blend with the new energy assets displayed above is enabling systems to be overseen all the more effectively, possibly finishing the worldview of inactive system administration, in which the systems are measured to take care of the total peak demand of detached purchasers. Indeed, this digitization is empowering energy demand to take an interest effectively in their arrangement.

In the PJM market in the eastern United States, almost 11 GW of demand side assets cleared in the limit advertise for conveyance in 2019 and 2020. Furthermore, request side assets offer a normal of about 1.5 GW of limit day by day in the synchronized hold advertise17. Altogether, adaptable demand side assets in PJM earned generally $825 million in incomes from taking an interest in PJM's different markets in 201518. While PJM has turned out to be a pioneer in actuating request in vitality and limit markets, it isn't the only one. Request assets give in excess of 1 GW of limit in the NYISO advertise.

The expanding digitalization of the power division through the organization of ICTs is additionally encapsulated in the rollout of cutting edge metering foundation and other network sensing foundation in the United States and Europe. In the United States, around 59 million shrewd meters have been conveyed, covering more than 40% of metered locales19. In the European Union, progressed meter organizations are relied upon to reach 72% of consumers by 202020.

As ICTs multiply all through power systems, administrative organizations, utilities, and aggregators are progressively using new duty structures — undoubtedly, in the second quarter of 2016, 42 of 50 US states made a move to change levies or on the other hand address DERs in some way21.

. These new tax structures run from innovation particular request accuses connected to those of dispersed assets to time-of-utilization rates and three-section levies with continuous energy costs, request charges, and settled charges.

In any case, the expanded digitalization of the power framework has made new vulnerabilities. Ensuring a country's power framework from digital assaults is a basic national security issue and an imperative need for electric utilities. As the digital assault on the Ukrainian power grid illustrated on December 201522, electric utilities are defenceless against assault and will turn out to be all the more so in the one decade from now as utility frameworks utilize more advanced controls and as activities and metering and resource management frameworks turn out to be more interconnected.

4.3.3. Interconnectedness

Natural gas: It is picking up conspicuousness in the energy mix of numerous nations. Some view gaseous petrol as a change fuel to decrease CO2 emanations and help incorporate discontinuous renewables. The introduced limit of flammable gas joined cycle control plants has developed drastically in late decades in both the United States and Europe, furthermore, the power segment has turned into a more considerable
shopper of petroleum gas. Gas utilization for power generation in the United States has developed from 4% to 33% of aggregate power utilization amid the most recent 25 years\(^2\). To be sure, without precedent for US history, natural gas created more power than coal in 2016. In addition, gas-based DERs, including fuel cells, have turned out to be promising innovations to give both power and warmth toward the end-customer level. As indicated by the US Department of Energy, nearly 25 percent of Fortune 100 organizations presently utilize fuel cells to produce spotless, proficient, and dependable power to control server farms, phone towers, corporate structures, retail offices, or forklifts\(^2\).

The electricity and natural gas divisions of numerous nations are in this way interdependent, furthermore, they will turn out to be considerably more so after some time.

**EVs (Electric Vehicles):** Electric vehicles speak to an essential new class of power clients, a developing section of power request that is portable on timescales not already observed in the electric power sector. This fragment can go about as both a critical, adaptable, or schedulable request and conceivably even an adaptable and appropriated supply asset. EV entrance is low today yet ascending in the lion's share of markets. Internationally, 2015 EV request expanded by additional than 80% more than 2014. EVs could achieve 20% of new vehicle deals worldwide by 2030 and 35% by 2040\(^2\). Extrapolating that normal selection rate to the US market, about 16 million EVs could be voyaging US streets by 2030, with on the request of 1,000 GWh of battery stockpiling limit. While gauges fluctuate generally, about all point toward an expanding infiltration of electric vehicles.

### 4.3.4. Renewable energy resources

The development of dispersed assets is occurring against the setting of a progress to a more renewable and intermittent energy mix. Around the world, the power asset blend is being changed by the development of sustainable power source assets, for example, inland and seaward breeze, sunlight based PV and concentrated sun based power, biomass, little and expansive hydro, geothermal, and marine vitality\(^2\).

All around, sustainable power source assets included 213 TWh in 2015, a sum generally equivalent to add up to 2015 power request development. Additionally, 2015 was a record year for interest in sustainable vitality: In absolute, almost $286 billion was contributed internationally to send around 134 GW of sustainable power source assets, barring extensive hydro, speaking to almost 54 % of all new power limit\(^2\). Looking forward, the world's biggest power markets, including the US, EU, China, India, Brazil, and Mexico are for the most part intending to grow sustainable power source age fundamentally in the coming decade.
This worldwide move to inexhaustible assets isn’t without unintended outcomes and developing agonies. Altogether, Western European utilities have lost many billions of dollars of market value in the previous decade. For example, three of the largest utilities in Germany (EnBW, RWE and E.ON) collapsed by 45% to 66% over the previous 6 years. Difficulties stay in incorporating more prominent offers of sustainable power source, yet the incline is clear: Renewable vitality assets are not any more a specialty asset in numerous worldwide power frameworks, yet rather one of the biggest wellsprings of new producing limit.
4.3.5. Global climate change mitigation efforts

It is fundamentally based on The Paris Agreement (12 December 2015) which is an understanding inside the United Nations Framework Convention on Climate Change (UNFCCC) managing greenhouse gas (GHG) emissions relief, adjustment, and fund beginning in the year 2020. The Agreement points long haul objective of keeping the expansion in worldwide average temperature to well beneath 2°C above pre-industrial levels; and to intend to constrain the expansion to 1.5°C, since this would essentially decrease dangers and the effects of environmental change.

Moreover, on 30 November 2016 the European Commission published the Winter Package that was mentioned above. Among different other objectives that will be explain below, one of them is the target of cutting greenhouse emissions 20% below 1990 levels by 2020 (Europe 2020 Strategy) and 27% by 2030. Indeed, even quickly developing medium salary nations like Mexico and China have sworn to top and afterward lessen their aggregate emissions in the coming decade. The multifaceted progress under path on the planet's electricity sections in this way incorporates the drive toward a lower-carbon energy supply.29
5. ENABLING TECHNOLOGIES FOR DEMAND FLEXIBILITY

5.1. INTRODUCTION

As it has been seen in the “Context”, there are some new technologies that have arrived to the energy sector that are able to transform it from the assets and infrastructure to the market operation and trading. These technologies goes from digitalization, ICTs, Big Data, IoT and smart loads that are able to set a more autonomous and precise system administration to specific technologies that are challenging the energy sector like DERs (Solar PV, wind farms, CHP, Energy Storage and HVAC) which enable the flexibility in the demand side.

But before deepening in the analysis of each technology it is crucial to understand a little bit more about DERs and the new ways of providing electricity services. DERs are any resources capable of providing electricity services and located in the distribution system. They can be partitioned into two unmistakable classes: DERs introduced particularly to give electricity services, for example: energy storage devices, solar PV frameworks with keen inverters, control hardware, or disseminated fossil generation; and assets that exist essentially for reasons other than to give power benefits however that can be tackled for this reason, for example: flexible demand and electric vehicles.

Cost-reflective prices and charges for electricity services can make the conditions to boost DERs of the top notch to be introduced just when DERs will include esteem. Besides, these cost-reflective prices and charges empower existing demand and DERs to make esteem by presenting the proprietor to the potential advantage of locks in in the market.

It is vital to note of that demand is both a consumer of electricity services and a potential provider of services, so demand have to be considered as a potential resource. Notwithstanding, it is essential here to recognize demand providing a service and the more productive utilization of electricity services. Here is going to be explain this difference:

The demonstration of choosing to devour or on the other hand not devour electrical power service in view of the cost of such services does not itself give a power benefit. Reacting to high power costs by abridging consumption is just a statement of the degree to which a given operator esteems the utilization of electrical energy. This adaptable demand can be an imperative wellspring of enhanced proficiency in control frameworks however constitutes the monetarily productive utilization of a service, not the arrangement of a service. In this report the more efficient consumption of electricity services is called as price-responsive demand.

Then again, an operator with flexible demand might have the capacity to make a forward responsibility to provide a future response, where the responsibility itself has a value past the last energy consumption. A flexible demand specialist may confer in progress to remain by and be prepared to modify utilization with a specific end goal to convey an extra administration, for example, working saves, firm limit, or system limit.
edge. This dedication itself conveys esteem unmistakable from the final consumption of energy, and may bring about extra backup or duty costs, and may require instalment of extra pay past abstaining from paying for energy that was not expended. In this report the demand providing a service is called as demand response.

It is critical likewise to take note of that the specialized and financial qualities of DERs are as changed as the DERs themselves, and there is noteworthy variety in cost what's more, execution among even really similar DERs. This is basic, as it features the uselessness of endeavouring to characterize a solitary value for all DERs.

To start with, there are cost and execution contrasts between advancements inside a given class of DERs. For instance, in the electrochemical battery class, lithium-ion batteries furthermore, lead acid batteries have altogether different execution qualities. Thus, inside the class of solar PV, thin film and c-Si (crystalline silicon) frameworks have diverse characteristics. All in all, these will be shown in the next section when energy storage and decentralized generation is concerned.

Secondly, there are cost and execution contrasts between innovations of a given kind. For instance a c-Si PV module with 15 percent effectiveness may in like manner cost altogether not as much as a c-Si module with 20 percent module effectiveness. The figure below additionally shows the execution variety inside the c-Si PV innovation type. Two identically sized 10 KW PV c-Si PV systems and identically found in Arizona can create drastically different energy results relying upon orientation and regardless of whether they utilize tracking systems. PV systems conveying double hub tracking systems delivered up to 33 percent more energy in a given month than PV systems without tracking.

![Figure 7: c-Si PV systems in Phoenix, Arizona. [Source: NREL.]](image-url)
At long last, there are cost and execution contrasts inside identical advances at a given scale. For illustration, the levelized cost of a c-Si PV system with 5 KW scale will be altogether higher than the levelized cost of one with 100 MW. In the figure below it is demonstrates the variety in 2015 LCOEs (levelized costs of energy) for solar PV at distinctive scales in New York State\textsuperscript{32, 33}.

![Figure 8: LCOEs of NY solar PV installations of various scales. [Source: SIEMENS]](image)

Nevertheless, another key recognizing highlight of DERs is that their little scale makes new open doors for aggregators in power systems. Historically an aggregator is an organization that goes about as a middle person between power end-clients and DER proprietors and the power system members who wish to serve these end-clients or exploit the services gave by these DERs\textsuperscript{34}.

Yet, today, aggregators are performing numerous new capacities for example, offering the supply of amassed DERs into wholesale markets, utilizing burdens to give auxiliary services, and then some. Much of the time, these aggregators are rising close by customary retail aggregators, contracting with organize clients officially under contract with retailers, and making coordination challenges. Aggregators are empowering more value signs to be sent to agents, enabling new agents to end up dynamic in the task and arranging of the power system, and drawing in agents in novel ways.

Now, in this section of the report, the focus is to show how DERs and new technologies are integrated in the power sector of the future and then an analysis of each technology will be made.

In such a way in this section some of this technologies are going to be addressed, so in order to clarify and focus the attention of the reader on these, a scheme has been done, it is right down (It has to be read bottom-up). Besides a first interaction with the new techs it also provides an introduction to the Energy Management System and to the Virtual Power Plant.
Virtual Power Plant

Virtual power plants are controlled by aggregators and together they conform the New Management System which means a central and interconnected control center that exploits data and correspondence advancements, IoT (Internet of Things) gadgets and DERs (Distributed Energy Resources) including all the new systems that have been shown below, such as Distributed Generation, Grid Scale Generation, Energy Storage, Smart Loads and Electric Vehicles, with the end goal of trading energy in wholesale markets and giving ancillary services to grid operators as well as controlling the free energy market between users and distributors.

Energy Management System

This future management system is related to mix the storage systems, generation frameworks and smart loads to work synchronized and self-contained, in individual units by means of an EMS, and in a group of these units by means of an aggregators, and in association with the main system.

Distributed Generation

This section basically means that Consumers are becoming small-scale generators.

The lower prices that new technologies are reaching mainly regarding energy storage and Solar PV are enabling new business opportunities such as management and generation of own customers energy.

Grid Scale Generation

The establishment of renewable energy resources plants close to places where electricity is consumed, such as, cities and communities, disposes of framework wasteful aspects, such as misfortunes, and empowers a superior administration of the framework, particularly when they are combined with energy storage innovations.

Electric Vehicle

In the first instance the generalization of electric vehicles in the society infers a huge increment in power demand in urban zones.

However, EVs may turn into an applicable operator utilizing bidirectional charging facilities to empower vehicle to grid administrations. It could be utilized as a major aspect of the public system or as a feature for smart house frameworks relying upon the charging station usage.

Energy Storage

Stationary storage empowers the final client to improve their vitality needs by moving consumption from peak hours to cheaper ones or joining this storage with Solar PV technologies.

Furthermore it is a major component in giving adaptability to the system in general and permits dynamic administration of irregular RES.

Smart Loads

Smart loads are related to administration, control and connectivity of the energy which allow customers to offer the system energy from the demand side in return for economic tariffs.

That is to say, the computerization of these procedures empowers a noteworthy open door in giving adaptability to the grid.

Table 1: Enabling Technologies for Flexibility of Electricity Demand. [Source: Own.]
At this point the different technologies are going to be analysed, the state-of-the-art of each one and how suitable they are. To begin, they are segmented in five sections: Stationary storage, Distributed generation, Grid scale generation, Smart Loads and Vehicle to grid; finally the Energy management system and the Virtual management system will be examined.

5.2. ENERGY STORAGE

In the last years there have been a lot of innovations in energy storage, thus, up until now, there are four main storage technologies that can be applied to energy system. Here below it is analysed each innovation indifferent situations.

- **Lead acid batteries**: Although they mean solution with the lowest cost their efficiency, performance and shorter lifespan represent very important issues in order to incorporate this batteries to the energy system in comparison with the following technologies that are shown below.

- **High temperature batteries**: They are not able to operate for residential or commercial applications due to their high temperatures when operating and their high costs when produced in small scales. Thus, they are situated for larger scale operations such as industrial ones, micro grids and combined with RES.

- **Flow batteries**: They have similar applications to high temperatures batteries, they are especially suited for large scale operations in industries and large micro grids with discharge times of up to quite a few hours. However, different characteristics needed in these batteries such as big spaces, loud noises and high costs make them not really proper for small systems like commercial and residential ones.

- **Lithium ion**: These batteries up until now, and in the expected future, represent the best energy storage technology for commercial and residential systems, mainly because of their high energy density and their cost in small installations. Regarding industrial and larger scale grids, a specific study in each case must be done in order to determine the best enabling technology taking into account energy requirements, lifespan of the system and maximum installation costs.

As it will be analysed in the next paragraphs, lithium-ion and flow batteries seem to be the most fitting technologies for residential and commercial systems and industrial and large scale grids respectively. In this way, in order to better analyse these technologies a technology overview have been done from the least suitable to the most:

5.2.1. Lead acid batteries

These batteries are the most developed electrochemical distributed storage innovation with many set up providers in the market. The utilization of cheap materials because of
reusing chains and bottomless crude materials defeat the vast majority of the worries related with the utilization of lead as the fundamental dynamic component. Be that as it may, their execution is poor contrasted with different advances regarding energy and cycle life (IRENA, 2015b). Here there are shown the two main types of these batteries:

**Flooded** lead acid batteries: Their main advantage is their cost, there are no other electrochemical storage technology as cheap as them. However, they have a lot of disadvantages such as poor energy and cyclability, in addition, they need well-ventilated spaces and permanent maintenance to replace water. All these weak points mean that they cannot be used in residential zones. Their main characteristics are summarized in the following chart.

![Table 2: Advantages and disadvantages of flooded batteries. [Source: International Energy Agency.]](image)

**Valve Regulated** Lead Acid batteries (VRLA): Valve regulated batteries improve the ventilation in comparison with flooded ones, they have an inner valve framework that avoids gas venting consequently making them maintenance free and sensibly useful for indoor use without particular ventilation. In any case, they keep up the poor cycling, short lifespan and low energy efficiency and they have higher expenses that flooded ones. Their main characteristics are summarized in the following chart.
Table 3: Advantages and disadvantages of valve regulated batteries. [Source: International Renewable Energy Agency.]

In order to embody this characteristics in a numerical way it is presented a table with the main properties of both types:

<table>
<thead>
<tr>
<th></th>
<th>Flooded LA 2016</th>
<th>VRLA 2016</th>
<th>Flooded LA 2030</th>
<th>VRLA 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density (Wh/L)</td>
<td>400</td>
<td>300</td>
<td>500</td>
<td>450</td>
</tr>
<tr>
<td>Energy installation cost (USD/kWh)</td>
<td>650</td>
<td>600</td>
<td>700</td>
<td>650</td>
</tr>
<tr>
<td>Cycle life (equivalent full-cycles)</td>
<td>10</td>
<td>12</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Calendar life (years)</td>
<td>10</td>
<td>12</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Depth of discharge (%)</td>
<td>50</td>
<td>60</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Round-trip efficiency (%)</td>
<td>70</td>
<td>80</td>
<td>60</td>
<td>70</td>
</tr>
</tbody>
</table>

Figure 9: Lead acid batteries. Cost and markets to 2030. [Source: IRENA.]

In conclusion, as it has been outlined Lead acid batteries are the cheapest option for electrochemical energy storage. While flooded batteries can be used for mass storage with RES, valve regulated batteries may be utilized in many other distributed storage systems although they imply higher costs.

5.2.2. High temperature batteries

These batteries use both ceramic electrolytes and liquid active materials (the types of the liquid materials determine the kind of battery. They need high temperatures in order to operate, between 250°C and 350°C. There are two main types of these batteries:

NaS batteries: Sodium-Sulphur (NaS) batteries have really good energy density that why they have been generally utilized for large scale storage, mainly in Japan. They basically operate as it is shown in the figure below, active materials needs to be kept in liquid state, which is the reason why they require an external heating unit to keep the system in the correct temperature window when idle (300-350°C). High temperature reactive elements pose corrosion and fire risks.
**NaNiCl (ZEBRA):** These batteries operate similarly to NaS ones, however Na and Ni electrodes are used and NaAlCl and NaNiCl$_2$ as electrolytes, which permits and operation with lower temperatures (250ºC-300ºC) and lower maintenance and they use less corrosive substances which provide a safer alternative.$^{40}$

The table below shows the main properties of both batteries:

![Figure 10: NaS battery. [Source: ISEA.]](image)

In conclusion, high temperature batteries are a good solution to supply large scale electricity storage at a reasonable price, particularly, the NaS batteries has been more popular because of their cheaper active materials. As it will be shown in the next paragraph, they can compete with the flow batteries in large scale micro grids for mass storage. However, at present, their feasibility is in doubt due to their cost, performance and safety all in all.

### 5.2.3. Flow batteries

Flow batteries have more or less the same applications that high temperature batteries, the main difference with other batteries is that the electro active materials are stored in tanks separated from the electrodes, which implies certain advantages such as huge storage capacity (several hours, even days) because electrolyte volume can be

![Figure 11: High temperature batteries. [Source: IRENA.]](image)
increased. Furthermore, this batteries can operate at ambient temperatures. Nevertheless, the electrolytes have to be pumped into the cells which implies disadvantages such as the complex equipment and the decrease in efficiency due to the pumping loses. There are two main types of these batteries that are exposed below:

**Vanadium Redox** Flow Batteries (VRFB): Vanadium Redox batteries as its name indicates use redox reactions in the cell with vanadium in different oxidation states (which eliminates contamination risks in the electrolyte\(^{41}\)). The redox reaction is:

- \( \text{V}^{4+} \rightleftharpoons \text{V}^{5+} + e^- (+) \)
- \( \text{V}^{3+} + e^- \rightleftharpoons \text{V}^{2+} (-) \)

This flow battery category is determine as “pure flow” which means that all active material are out of the cell. Their operation and main characteristics are exposed in the figure and the table below:

![Figure 12: VRFB operation mechanism. [Source: Research Gate.]](image-url)
### Table 4: VRFB advantages and disadvantages. [Source: National Science Review.]

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long cycle life (10 000+ full cycles, with 10 to 20 times this possible)</td>
<td>Low electrolyte stability and solubility limit energy density, and low specific energy limits use in non-stationary applications</td>
</tr>
<tr>
<td>Relative high energy efficiency (up to 85%), but lower than Li-ion</td>
<td>Precipitation of V₂O₅ at electrolyte temperatures above 40°C can reduce battery life and reliability, although this can be managed</td>
</tr>
<tr>
<td>One of the most mature flow batteries with multiple demonstration and deployed at MW scale</td>
<td>High cost of vanadium and current membrane designs</td>
</tr>
<tr>
<td>Design E/P ratio can be optimised to suit specific application</td>
<td>Unoptimised electrolyte flow rates can increase pumping energy requirements and reduce energy efficiency</td>
</tr>
<tr>
<td>Long-duration (1-20 hours) continuous discharge and high discharge rate possible</td>
<td></td>
</tr>
<tr>
<td>Quick response times</td>
<td></td>
</tr>
<tr>
<td>Same element in active materials on electrolyte tanks limits ion cross-contamination</td>
<td></td>
</tr>
<tr>
<td>Electrolyte can be recovered at end of project life</td>
<td></td>
</tr>
<tr>
<td>Heat extraction due to electrolyte prevents thermal runaway</td>
<td></td>
</tr>
</tbody>
</table>

**Zinc Bromine Flow Battery (ZBFB):** Unlike VRFB, ZRFB are included in hybrid flow batteries which means that one of the active materials is inside the power conversion unit. The main difference between these two batteries, despite the pure and hybrid flow, is that ZBFB use cheap electrolytes, such as Bromine and Zinc, in contrast, they have lower efficiency and higher corrosion risk. They have a complex operation mechanism divided in charging and discharging, and their lifespan is lower. Here a table with the main characteristics is exposed:

Table 5: ZRFB advantages and disadvantages. [Source: National Science Review.]

In order to embody this characteristics in a numerical way it is presented a table with the main properties of both types:

![Table showing the advantages and disadvantages of ZRFB.](source)

Figure 13: Flow batteries. [Source: IRENA.]

In conclusion, flow batteries are not suitable for small systems like commercial and residential places due to their low energy density. As it has been seen, they potential markets are the large grids, due to their power storage capacity, and integrated with renewable power resources in grid scale generation and in industrial systems. Different studies ensure the potential of these batteries of reduce their costs due to the increasing enabling electro active materials, such as organic molecules as a more inexpensive and safer alternative.\(^{43}\)
5.2.4. Lithium ion

Regarding the operation mechanism of the Lithium ion batteries, they exchange Li+ between anode and cathode with an electrolyte which is usually a liquid organic solvent; the cathode is generally made from lithium intercalation compounds as it will be shown. The figure below represents the operating principle.

[Figure 14: Operating principle of a lithium ion battery. [Source: ISEA.]]

There is a huge kind of lithium-based battery systems but here just 4 lithium-ion batteries are going to be analysed due to they have the best and most suitable properties. They have balanced and high energy and power density, even high cycle life and safety. Although, as it was said, there are many type of combinations with these batteries just the main four types are exposed in this research:

Lithium Nickel Cobalt Aluminium (NCA): They have has good energy and power capabilities but concerns about its safety at moderate temperatures reduces its applicability in stationary applications. Nevertheless, they have good cycle life and long storage calendar.

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good energy and good power capability</td>
<td>Moderate charged state thermal stability which can reduce safety</td>
</tr>
<tr>
<td>Good cycle life newer systems</td>
<td>Capacity can fade between 40°C and 70°C</td>
</tr>
<tr>
<td>Long storage calendar life</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: NCA advantages and disadvantages. [Source: Navigant Research.]
**Lithium Nickel Manganese Cobalt (NMC):** There have been many researches about these combinations in order to reduce costs. All in all, this type of batteries get a good balance between energy, power and safety and achieve the highest energy density of all lithium ion batteries. Thus, they have been usually implemented in electric vehicles and small systems\(^{46}\).

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good combination of properties</td>
<td>Problems with patents in some countries</td>
</tr>
<tr>
<td>They can be adapted for power or high energy</td>
<td></td>
</tr>
<tr>
<td>They can operate at high voltages</td>
<td></td>
</tr>
</tbody>
</table>

*Table 7: NMC advantages and disadvantages. [Source: Navigant Research.]*

**Lithium Iron Phosphate (LFP):** With these materials there is an improvement of many properties including safety and with low costs. However, due to the lower-rated cell voltage they only get a discrete energy density\(^{47}\).

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good thermal stability</td>
<td>Lower energy density</td>
</tr>
<tr>
<td>Very good cyclability</td>
<td></td>
</tr>
<tr>
<td>Very good power capability</td>
<td></td>
</tr>
<tr>
<td>Low costs</td>
<td></td>
</tr>
</tbody>
</table>

*Table 8: LFP advantages and disadvantages. [Source: Navigant Research.]*

**Lithium Titanate (LTO):** LTO cells have some advantages for stationary applications that require good cyclability due to their power and chemical stability, thus, they are normally used in microgrids, RES and ancillary services. Furthermore, their low energy density and high costs make them suitable for these power intensive applications\(^{48}\).
**ADVANTAGES** | **DISADVANTAGES**
---|---
Very good thermal stability | Titanium high costs
Good cyclability | Reduced cell voltage
High discharge capability | Low energy density
There are not solid electrolyte interphase problems

Table 9: LTO advantages and disadvantages. [Source: Navigant Research.]

In order to embody this characteristics in a numerical way it is presented a table with the main properties of the four main types:

![Figure 15: Lithium ion batteries. [Source: IRENA.]](image)

In addition, the expected costs of Lithium ion batteries have been analysed; they are expected to drop rapidly due to cell cost reductions. Economies of scale thanks to EV battery manufacturing growth and advancements in the learning curve are expected to reduce costs up to 74 $/kWh\(^49\).
In conclusion, Lithium ion batteries are the most balanced innovation between technology and cost for residential and commercial operation, mainly due to their high energy density, cyclability, safety. Regarding industrial and bigger grids their performance is correct enough although other possibilities can be studied in each case.

### 5.2.5. Conclusion

After analysing energy storage technologies three main statements are exposed:

- **Electrochemical storage** offers a reasonable balance of energy, power, cycle life, safety and cost as well as no site restrictions which makes them adequate for most distributed storage applications envisaged for the New Downstream. In this way this storage technologies must ensure three key aspects: Cost, Reliability and Safety and Ease of deployment and standardization. Other performance indicators can be analysed as extra characteristics but must not compromise any of the three aspects above.

- **Lithium ion battery** is the innovation of choice for residential and commercial and may well serve most requirements in industrial customers and microgrids applications. These applications can be served using cheaper mass produced EV cells rather than custom low volume cells. Furthermore, at present modular li-ion systems are already in the market from multiple vendors and can be already used to launch and scale-up a commercial New Downstream offering.

- Li-ion can be considered a maturing technology that will follow an evolutionary development path with main advancements in high capacity and voltage cathodes and higher capacity anodes. In addition, projected Li-ion battery costs are expected to drop due to economies of scale and advancements in the learning curve.
5.3. ELECTRIC VEHICLE (EV)

Electric Vehicle global penetration is still modest, although there are many hybrid models, and lately two-place cars have been developed, the global percent of electric vehicles just goes up to 1%. However, it is estimated that EVs will reach 54% of new car sales and 33% of the global car fleet by 2040.

Here it is a BNEF research that has been studied in order to determine different patterns to verify the viability of Vehicle-to-grid. Thus, BNEF estimates that EVs electricity consumption will reach 1800 TWh in 2040 from 6 TWh in 2016 but it will just represent 5% of global consumption. However, EV charging patterns could concentrate power demand in short periods which could negatively affect the grid, as an example, just imagine that all the electric vehicles from certain places are connected to the net charging their batteries, this will impinge on the net as a demand peak.

Nevertheless, the objective of vehicle-to-grid is to implement the smart charging and other methods (Grid relief strategies) that will turn this negative impact in a positive one, because this required energy will be delivered as appropriate. In order to clarify this issue an EIA research has been studied. EIA estimated smart-charging of 150 million EVs would reduce capacity requirements by 65 GW while in the case of 500 million EVs would reduce capacity 110 GW. Smart charging flexibility could avoid respectively, USD 100 billion and USD 280 billion of investment in electricity infrastructure.

Grid relief strategies can also be beneficial, not only for utilities but for EV users, that want to reduce the costs of charging their vehicles. The different charging strategies are analysed and the cost for the end user in the following paragraphs:

- **Opportunity charging**: It is the common usage, the electric vehicle charging begins when it is plugged. Electricity costs are usually 11% higher than the annual average electricity price due to the demand peaks that are made.

- **Delayed charging**: the timing of charging is delayed on purpose according to demand usage assessed by the grid operator (Time of Use rates) and driver’s schedule. With this method energy costs fall to 85%–93% of the average electricity price.

- **Smart charging (V1G)**: Using enabling technology and innovations this method gets a state-of-charge management similar to delayed charging, except that the charge of energy is adjusted based on the presumed energy requirements of future trips. With this method energy costs fall to 75% of the average electricity price.

<table>
<thead>
<tr>
<th>Method</th>
<th>Energy</th>
<th>Degradation</th>
<th>Range Anxiety</th>
<th>Schedule</th>
<th>Future Trip</th>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opportunity</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Delayed</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Smart charging</td>
<td>Adjusted</td>
<td>Increased</td>
<td>Increased</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Table 10: Impacts of three charging methods (per charge event). [Source: NREL, WEVA]*
Smart-charging (V1G) enabled by connected charger or governed by an Energy management system (EMS), based on pricing signals, can reduce energy costs for the end user while easing generation, transmission, distribution and constraints by eliminating peak demand induced by simultaneous non-managed EV charging. This integration of Smart-changing with an Energy Management System forms the **Vehicle to Grid (V2G)** method.

Thus, as it was exposed, EVs have the potential of serving the electric grid as independent distributed energy source. Most vehicles are parked almost 95% of their time and, if they remain connected to grid, they can be used to support the grid. There are two options, Smart charging (V1G) in which EV adjust their charging speed to the grid requirements and minimizes energy costs or Vehicle to Grid (V2G) in which the EV is also able to backfeed power to the grid. Both alternatives can accomplish benefits in order to provide flexibility to the grid:

- **Peak shaving**: As it was indicated above, smart charging may flatten power demand while V2G can supplement the available generation.
- **Reserves**: load shedding and energy injection available in case of failure of a generation unit.
- **Voltage regulation**: reactive power management can compensate local voltage variations.
- **Frequency regulation**: Electric vehicles may adjust their charging speed or inject energy back into the grid to keep frequency between the limits set by the grid operator.
- **Renewable energy integration**: EVs may charge in periods of abundant cheap renewable generation in order to prevent renewable curtailment.
- **Transmission and Distribution (T&D) deferral**: scheduling EV charging or discharging of stored energy into valley hours can prevent transmission and distribution infrastructure upgrades.

However, there are some main differences between these two methods that are shown in the following table:
### Smart Charging (V1G)

Charging power reduction is equivalent to injecting energy to the grid and vice versa: Frequency regulation up and down and Load shedding for reserves or peak management.

These aids to the net are only available during charging periods.

Smart charging method has no impact on battery degradation.

The technology for V1G is already available, charging units can be controlled by EMS responding to price signals or directly controlled by the utilities and operators.

### Vehicle-to-Grid (V2G)

Energy can be backfeed to the grid providing multiple ancillary services.

Manageable power doubles compared with the case of using EV as a controllable load.

Max power output, load shedding and discharge, is available only during charging. However power from discharge, half of the maximum power, is available if the EV is connected with a power station.

Battery discharging may impact battery degradation. The EV degradation will be dependent on the number of events in which the EV participates.

The technologies needed for V2G (communication or metering) are already available but limited deployment makes them still expensive.

<table>
<thead>
<tr>
<th>Table 11: V1G &amp; V2G. [Source: University of Warwick.]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Smart Charging (V1G)</strong></td>
</tr>
<tr>
<td>Charging power reduction is equivalent to injecting energy to the grid and vice versa: Frequency regulation up and down and Load shedding for reserves or peak management.</td>
</tr>
<tr>
<td>These aids to the net are only available during charging periods.</td>
</tr>
<tr>
<td>Smart charging method has no impact on battery degradation.</td>
</tr>
<tr>
<td>The technology for V1G is already available, charging units can be controlled by EMS responding to price signals or directly controlled by the utilities and operators.</td>
</tr>
</tbody>
</table>

Key to the development of either V1G or V2G is the standardization of communication between utilities and EV industry. Standards such as OpenADR or OCPP will allow utilities to create a smart charging ecosystem that can improve grid management, enhance energy efficiency and lower the costs of deployment.

At present, there are several pilot projects of V2G and also Vehicle to home (V2H) although no relevant real-life deployment has occurred yet. There are several challenges that need to be solved before any meaningful deployment of V2G takes place:

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Vehicle charger restrictions: Currently most of the EVs in the market are built with unidirectional power electronics that prevents any energy flow from the battery to the grid.

Charging station restrictions: Although new charging stations are capable of handling bidirectional energy flows, there are still unidirectional units which are not suitable for V2G usage.

EV manufacturer restrictions: In addition to unidirectional chargers, EV manufacturers can restrict V2G in the battery’s guaranty terms due to the failures that V2G can cause on it. Battery is the most expensive part of the EV and has a long warranty period.

User’s concerns: Furthermore, last point may influence owners too, they may be reluctant to engage in V2G programs due to battery degradation concerns and their potential impact on battery’s warranty.

Lack of defined business models: Battery degradation in V2G use depends on multiple parameters which makes difficult to create revenue sharing models for the EV owner.

Thus, main barriers came from the lack of generalization of the modern technology in EVs, the lack of knowledge about the implications and consequences of this innovation and the lack of business models in order to compensate the EV owner for participating in any flexibility program. A potential way to solve these issues is the involvement of the utilities and the operators of the system in the production and generalization of this technology between the electric vehicles suppliers and the final users.

5.3.1. Conclusion

In conclusion, after analysing V1G and V2G technologies five main statements are exposed:

• EV charging has not make a significant impact on the grid due to the still low penetration in the car market. However, several studies highlight the potential to disturb the grid due to the increase of peak load if charging is not adequately managed.

• Smart charging, which modulates charging speed based on grid constraints (driven by prices) provide the possibility to flatten the demand curve.

• Standards (OCPP, IEC 62196, ISO 15118 and OpenADR) that enable the good incorporation of EV and the modern functions like V1G and V2G with the grid and the utilities are under development and need to be defined to further develop business models. Furthermore, researches about the impact of the V2G on the battery degradation must be completed in order to negotiate good guaranties between EV suppliers and final users.

• A final EV charging monetization strategy must be developed, which should be based first on considering EVs as a predictable controllable load for the optimization of energy costs for the end user (real time prices and peak charges) as well as a revenue generation asset to be bid on flexibility markets.
Finally, although the potential of V1G and V2G is huge, they must not be considered as relevant revenue generation sources in the short term due to the complexity of their final application.

5.4. SMART LOADS

Smart and controlling loads are enabling load management, which is an important economic issue for final client and to provide efficiency to the grid. Load management has the potential to reduce the costs of the energy procured from the grid according to hourly energy prices and avoid any peak power penalties. Even more, it enables one of the main functions of the EMS and the role of the “aggregator” providing extra capacity to grid from the demand side. However, savings potential and the complexity of its implementation in some cases limits its real-life deployment.

Thus, the 3 different segments where smart loads can be integrated are analysed:

- **Industrial segment:** Most industrial loads are managed by legacy or proprietary Supervisory Control and Data Acquisition (SCADA) systems which cannot be easily accessed. Nevertheless, in the near future open SCADAs and Building Management Systems and the deployment of IoT will enable straightforward direct load connection. Furthermore, third party access to SCADAs via Application Programming Interfaces (APIs) will enable industry experts to develop software solutions algorithms to define the best way to bid manageable loads in the different markets and optimize energy dispatching.

- **Commercial segment:** Heating, Ventilation and Air-Conditioning (HVAC), water heating and lighting are the biggest loads in commercial and large residential buildings and are normally human controlled without considering energy efficiency and user’s comfort. On average in the EU-27 space and water heating represented 19% of the total electricity demand in the tertiary sector: lighting accounted for 20%, ventilation 12.4% and air conditioning nearly 3%. In Spain air conditioning and heat pumps in the tertiary sector account for 25.6 GW of installed power. Thus, larger units and centralized control HVAC provide significant opportunities for controllable loads in the tertiary sector.

- **Residential segment:** Nowadays, HVAC and water heating are the most important manageable loads (in the future it is expected that EVs will be as well) but both normally require accessing a fixed control panel and remote operation. However, the development of smart-home (Figure 17) systems offer a wide range of solutions for the management of connected loads. Information hubs allow to centralize multiple connected units and their management though a single interface. In this way, connected thermostats are taking a preeminent role as connected devices as they manage the most important connected load in terms of power, regulation capabilities and operation times such as air conditioning but can also manage other major loads that will be present in an ever electrified home such as water heating and heat pump heating. HVAC and water heaters represented 17.2% of electricity consumption in Spain in 2015. However, their predictable use patterns, relevance in peak use periods
GW of installed power), fine adjustment and potential long responses make them the most suitable controllable loads. Increased electrification will enlarge the air conditioning and heat pumps installed base and new units will already provide built in connected capabilities.\textsuperscript{57}

Buildings account for nearly one-third of global final energy consumption and 55\% of the global electricity demand. Specifically, building energy consumption was 11 PWh in 2014 and is expected to reach 20 PWh in 2040. Thus, load management is an enabler for creating Demand Side Management programs such as Energy Efficiency or Demand Response. It is estimated 10\% cumulative energy efficiency savings (65 PWh) in buildings from their central scenario between 2017 and 2040 by using real-time data.\textsuperscript{58} (Figure 18)
Regarding the relation between **Energy Storage and Flexible Demand**, it is important to stress that sometimes they clash, that is to say, energy storage and demand flexibility (supported by smart loads) are approximately inversely proportional. This can sound a little strange but below it is shown a case study that explain it.

In this **Case Study** there is a stimulation of the adoption of DERs in reaction to power taxes, atmosphere conditions, innovation cost, and execution parameters, in the instance of a family household both in New York and in Texas. The key contributions for this re-enactment are the forthright cost of batteries and the degree of demand response.

Flexibility in the demand is expanded at the point when the temperature setting of cooling and warming loads is figured out how to tweak energy utilization specifically periods by extending the temperature of comfort dead-band. What's more, flexibility in the demand is amplified by connecting more energy end-utilizes, such as water heaters and air conditioners. In this way, in the Figure 21 and Figure 22 there are 5 states regarding to adaptability: no flexibility demand (No Flex), dead-band temperatures of 1°C in air conditioning (AC 1°C), dead-band temperatures of 2°C in air conditioning (AC 2°C), dead-band temperatures of 1°C and 2°C in water heating and air conditioning (AC & WH) and dead-band temperatures of 2°C or more in water heating and air conditioning (AC & WH 2°C).

In both cases, demand flexibility has a noteworthy negative effect on the benefit of batteries. As the measure of adaptability expands, the cost of batteries should essentially decay for batteries to be gainful. These re-enactments demonstrate that flexibility in the demand has the potential to decrease battery income streams.
Figure 19: The Impact of Flexible Demand and Battery Cost on Battery Profitability in NY. [Source: MIT.]

Figure 20: The Impact of Flexible Demand and Battery Cost on Battery Profitability in Texas. [Source: MIT.]

As annotation it is remarkable to say that a critical contrast between the cases is the accessibility of the warm asset. The warmer atmosphere in Texas prompts more prominent utilization of air conditioning, which thus implies more prominent potential for smart loads to decrease client bills. Without flexibility, batteries are productive at a higher initial cost in Texas be that as it may, as in New York, any measure of adaptability
rapidly lessens the income opportunities. In this way, the measure of the thermal resource can essentially influence the result.

5.4.1. Conclusion

In conclusion, after analysing smart loads technologies four main statements are exposed:

- **Smart loads** allows to manage connected loads in order to reduce the costs of energy procured according to hourly energy prices, reduce energy consumption by making a more efficient use of energy and prevent peak power penalties. However, most of the load management is not done automatically and requires the intervention of EMS thus increasing the complexity of its implementation and limiting its real time life deployment.

- **At industrial level**, SCADA systems manage the most energy intensive systems in industrial and large commercial. There are already thousands of commercial buildings with SCADA systems in Spain and the majority of them have never changed their default set points. Accessing already deployed SCADAs unlocks the possibility of efficiently managing each of the connected loads providing energy savings to the customer.

- **At residential level**, HVAC systems are key in peak power demand. Therefore, the biggest impact can be obtained by substituting existing thermostats by smart connected ones able to not only to optimize energy savings while maintaining comfort by using multiple data sources (presence detection, proximity, hysteresis, weather forecast, etc.) and self-learning algorithms.

- **Relation between energy storage and smart loads** must be analysed in each case, at industrial level as well as at commercial and residential level, in order not to get a solution in which one technology impacts negatively the other one.

5.5. Distributed Generation

This section tries to explain the importance of power generation in the Demand Side of the system, and not just savings and auxiliary capacity as it has mainly shown in the last 3 sections. Therefore, three groups of technologies considered to fit within distributed generation are going to be analysed:

- **Solar PV**: It represents the most affordable option of the three of them. As it takes advantage of the economies of scale generated in large scale PV, it gets the least cost of power (cost/kW), with values from 1400 to 2900 $/kW. Furthermore, this technology has low or null maintenance, no noise and can be adequately dimensioned to all customer segments.

- **Wind power**: Regarding the cost of power, small scale wind is much more expensive than large scale wind with costs from 5000 to 10000 $/kW for systems with a power capacity lower than 10 kW and costs from 4000 to 8000 $/kW for systems between 10 to 100 kW. Moreover, noise and visual impact make that the places where this technology could be installed have to be very

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specific. Consequently, microgrids are the most suitable application where larger scales allow for more competitive energy prices.\textsuperscript{61}

- **Combined Heat and Power (CHP):** It has been widely used in the industrial sector but scaling it down to the commercial and residential sectors is difficult for the available technologies. Main four CHP technologies are analysed:\textsuperscript{62}
  
  o **Stirling engines:** They are waste heat recovery units attached to conventional boilers with limited electrical output and operating only when the boiler is on which means extra costs from 3000 to 5000 $/kW. Therefore, payback times of 10-20 years, even with subsidies, what make them not feasible.
  
  o **Combustion engines:** They are only viable in large residential or commercial segments due to their huge power output. Furthermore, high noise, low thermal and electric efficiency, fuel and maintenance costs and not being suited for continuous operation limit their applicability.
  
  o **Microturbines-CHP:** This technology has some issues, such as CHP turbine sizing (25-1000 kW), high costs, and electricity and heat ratio that reduce the adaptability of CHP to large residential, commercial, industrial and certain microgrid applications. They could be a good technology match for a combined electricity and gas offering.
  
  o **Fuel Cells-CHP:** Fuel cells are the most efficient option with the highest electric output of all the alternatives. However, they are designed for constant operation which limits their applicability to certain residential and commercial energy with non-stable consumption profiles. Moreover, their upfront costs (4000-10000 $/kW), fuel costs and maintenance do not allow to build a sustainable business case at the moment.\textsuperscript{63}

In such a way the best option by far for distributed generation is Solar PV, this technology is deepened below.

### 5.5.1. Solar PV

Solar PV added 71 GW of capacity in 2016 worldwide versus 51 GW of Wind Power due to the ongoing decarbonisation of the energy sector and the growing competitiveness of solar PV in all markets. Solar module costs with the current technologies are projected to further drop due to incremental advances in the technology, moreover, new technologies under development could accelerate this process due to they will intensify the competition for the best innovation.\textsuperscript{64}

Nowadays, Solar PV market share is split between two types of technology:

- **Crystalline silicon c-Si:** Crystalline silicon can be classified into poly-crystalline (poly-Si or multi-Si) and mono-crystalline (mono-Si). Poly-Si is less efficient that mono-Si but cheaper. Crystalline silicon rapid production growth and the development of a competitive supply chain has allowed c-PV technology to have a 94% market share (70% p-Si and 30% mono-Si).\textsuperscript{65} (Figure 13)

- **Thin-film PV:** Thin-film technologies accounted approximately for 6% of the PV market in 2016. The three main thin-film technologies are CdTe (3.7% share),
CIGS (1.6%) and a-Si (0.6%). Thin-film traditionally had an advantage over c-Si in terms of lower module costs but lower efficiency which came at the expense of higher balance of system. Today c-Si cost per Wp\(^1\) is more advantageous so the least efficient thin-film technologies (a-Si) may soon disappear\(^6^6\).

![Figure 21: Solar PV percentage of global annual production. [Source: Fraunhofer ISE.]](image)

As it is said before novel technologies under development may compete with c-Si Solar PV, they are exposed below\(^6^7\):

- **Perovskites** (Technology Readiness Level\(^2\) (TRL) 4): This innovation is still in laboratories but have already achieved cell efficiencies comparable to those of best thin-film technologies. Moreover, further efficiency gains reaching those of c-Si are expected, because of this and low cost materials and manufacturing process could make this technology disrupt the PV market in the near future.

Other alternatives not as affordable as perovskites are also exposed:

- **Organic cells** (TRL 9): Organic cells are expected to have low cost materials with tunable band gaps and flexible substrate deployment and lightweight cells.
- **Quantum-dot photovoltaics** (TRL 3-4): Quantum dots cells use nanocrystals made of semiconductor materials that exhibit quantum mechanical properties as the absorbing PV materials in which band gaps can be tuned by modifying particle size.
- **Multi-junction (MJ) solar cells** (TRL 9 standard semiconductors, TRL 4 new semiconductors): MJ cells stack several semiconductors with different band gaps able to absorb a bigger share of the solar spectrum and achieve higher efficiencies. New lower cost semiconducting materials could reduce the technology cost over standard semiconductors.

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\(^1\) Watt-peak: In a Solar PV installation one Wp means one W of peak power, that is to say, the measure of a solar PV power is in terms of the maximum power it can obtain.

\(^2\) TRL is a method adopted by the NASA of estimating technology maturity that examines program concepts, technology requirements, and demonstrated technology capabilities.
Given the cost rapid cost reduction experienced by current commercial technologies, especially c-Si, any new technology shall demonstrate relevant cost and performance advantages over established technologies to gain market share. So far only Perovskites seem to have potential to compete but by the time their stability is addressed their potential cost advantage may be eroded by c-Si. Current efficiencies are shown in the following picture.

![Efficiency comparison of solar PV technologies 2018](Source: Fraunhofer ISE)

In order to contrast different technologies and how they may be assembled in the Power system a Case Study has been made: The advantages of Energy Storage and the influence of Solar PV on the network costs.

This case study delineates how high entrances of housetop Solar PV increment distribution network extension expenses and how energy storage may offer answers for relieve these incremental expenses in the future. This case considers a network in which the introduced limit of rooftop PV is required to increment over a specific period. For setting, it is supposed that this development is driven by endowments, for example, a feed-in tariff or net metering.

A DSO could react to expanding PV entrance by expanding the limit of the wires, introducing extra voltage controllers, and putting resources into other system hardware, with ensuing increments in complete system cost.

As it show bellow in Figure 23, now and again the financial effect of meeting a huge (more noteworthy than 20 percent) part of load with solar PV generation can be vast, in fact, in the most outrageous case, doubling the cost of the system. This brings up essential issues: How should these expenses be allotted? Are there "non-wires" arrangements that can bring down network costs? On the off chance that the system clients that produce the expenses are required to pay for them, would they despite everything choose to put resources into PV generators?
In Figure 23 it is also shown that the establishment of BTH\(^3\) energy storage mitigates the effect of Solar PV and empowers vast amounts of PV ability to be associated with the network without altogether expanding arrange costs. In Figure 23, the level of entrance of energy storage is demonstrated utilizing SF (Storage factor) as a parameter, which is relative to the diminishment in maximum net PV infusion to the network acquired by including energy storage.

In spite of this cost-relieving impact, getting storage is not really the most cost-effective way to deal with the system effects of distributed generation, for two reasons:

- In the first place, it isn’t clear whether storage is less expensive than traditional system arrangements. At current battery prices, storage is in all likelihood not less expensive than ordinary system arrangements in the greater part of cases.
- Second, there could be other, more financially savvy arrangements, for example, PV reduction or smart loads and demand response. In this case study it is proposed: a cost-reflective arrangement of prices and charges would uncover the minimum cost solutions for addressing grid difficulties.

### 5.5.2. Conclusion

In conclusion, after analysing distributed generation technologies two main statements are exposed:

- Although there are three main technologies considered to fit within distributed generation Solar PV generation is the most cost efficient technology by far in

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\(^3\) Behind-the-meter: It is a sustainable power source creating facility, for this situation, a Solar PV system, that produces power proposed for on location use in a home, business offices or commercial buildings.\(^{52}\)
the three segments regarded. **Wind power** is not affordable due to its higher costs per kW in small scale, noise and visual impacts. **CHP** is not affordable due to being difficult to scale down to the commercial and residential sectors.

- Currently **c-Si** modules are the most efficient and economic viable solution. They have experienced fast cost reductions due to technology improvement and market uncertainty due to overproduction capacity and varying demand projections that has reduced module margins. Evolutionary development of the technology due to mass production and advancements in the learning curve are expected projected to further reduce costs.
- **Perovskites** are the only potential challenger, that, in case of succeeding, would mean that the whole c-Si value chain would be scrapped which reinforces the last statement (c-Si seems to be the best option at present and in the near future).

## 5.6. GRID SCALE GENERATION

Grid Scale Generation includes mainly RES near to consumption sites such as cities and towns, the principal objective is to obtain a superior administration of the network, flexibility, and minimize loses and misfortunes.

Therefore, two RES solutions seems to be the most affordable, they are wind power, and solar PV, which are analysed in the following paragraphs:

### 5.6.1. Wind Power

Wind Power is a huge resource nowadays, global wind resources are estimated to be 487GW in 2016 (Figure 24). The main inconvenient with this technology is disability of producing electricity when it is needed, it is produced when wind blows, that is the reason why the wind energy market in 2016 was 54.6 GW while the installed capacity is near to 487 GW as it was said before. Almost all installed wind power capacity used Horizontal Axis Wind Turbines (HAWT), they are installed either onshore or offshore, the second ones take advantage of stronger winds but require a higher initial investment and also have higher operation and maintenance costs.
Although most HAWT is the most common turbine due to its greater efficiency and power output, two turbine types (HAWT & VAWT) are investigated in this research, taking into account their main advantages and disadvantages.

Generally the main parts of a large scale wind turbine are the followings although depending on the turbine type some parts will not be included:

- **Rotor:** It includes blades, hub and pitch system.
- **Nacelle:** It includes rotor shaft, bearings, gearbox and generator, mechanical brake and yaw system.
- **Tower and foundation.**
- **Electrical system:** It includes power feed cables, lightning protection, power converter and transformer.
- **Control system:** It includes sensors, and actuators.

Figure 16 shows a scheme of the main components of both configurations:
**Horizontal Axis Wind Turbines (HAWT)**

These turbines have the principle rotor shaft and electrical generator at the highest point of the tower, and it must be pointed into the breeze. Regarding the size of the turbine: little turbines are pointed by a straightforward breeze vane set square with the rotor, while large turbines by and large utilize a breeze sensor combined with a servo engine to transform the turbine into the breeze. Most large breeze turbines have a gearbox, which transforms the moderate turn of the rotor into a quicker revolution that is more appropriate to drive an electrical generator.

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<tr>
<th>Main Advantages</th>
<th>Main Disadvantages</th>
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<tr>
<td>HAWT turbines have high effectiveness due to the perpendicular move to the breeze of the blades, thus, they get energy through the entire turning region. On the other hand, all vertical axis wind turbines, include different kinds of responding activities, requiring air thwart surfaces to backtrack against the breeze, which brings down efficiency.</td>
<td>Huge infrastructure must be done to help the overwhelming generator, blades and gearbox. This implies an enormous construction project where the different components must be lifted into position. This means important investment costs.</td>
</tr>
<tr>
<td>The tall tower base enables access to more grounded breeze in places with wind shear. As an example, in some wind shear locations, each ten meters up wind speed is incremented by 20% so the power output by 34%.</td>
<td>Their stature makes them prominently visible crosswise over huge territories, upsetting the landscape, causing big visual impact and creating local opposition. This can be a problem for selecting the installation places.</td>
</tr>
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</table>

Mechanisms to face the wind must be used which drive up the installation. This is needed due to the failures that are caused by turbulence and wind variations. Therefore, due to high winds mechanisms to stop the blades’ turn are required in order to prevent the structure to crumble away.

*Table 12: Horizontal Axis Wind Turbines Advantages and Disadvantages. [Source: GWEC.]*

**Vertical axis wind turbines (VAWT)**

The most characteristic feature is the vertical orientation of the rotor shaft which enables that the turbine does not need to be facing the wind. That is the reason why this configuration is preferential on locations where the breeze heading is exceedingly...
variable or where there are violent breezes. Furthermore, this configuration permits many components, such as the gearbox and the generator, to be placed on the ground, which facilitate the installation and the maintenance. However, the principle disadvantage of a VAWT is that it makes drag while pivoting into the breeze. As an annotation, there are two primary VAWT subtypes: Darrieus and Savonius\textsuperscript{73}.

<table>
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<tr>
<th>Main Advantages</th>
<th>Main Disadvantages</th>
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<tr>
<td>VAWT system can be placed closer the ground, Which requires less and easier maintenance.</td>
<td>These turbines generally have lower efficiencies than HAWTs due to the extra drag that they have as their blades pivot into the breeze. However, modern turbines that decrease drag are under development.</td>
</tr>
<tr>
<td>They are submitted to lower and more regular wind speeds which implies that no yaw systems is required.</td>
<td>Rotors are placed near the ground where wind speeds are lower and do not exploit higher breeze speeds above.</td>
</tr>
<tr>
<td>They can work at areas where taller structures are disallowed so they can exploit areas where housetops, peaks, ridgelines, and passes funnel the breeze and increment wind speed.</td>
<td>They seem as a novel technology to those not familiar with the wind business due to VAWTs are not ordinarily developed. This has regularly made them the subject of wild cases and speculation tricks in the course of the most recent 50 years.</td>
</tr>
</tbody>
</table>

\textit{Table 13: Vertical Axis Wind Turbines Advantages and Disadvantages. [Source: GWEC.]} 

After having analyzed the two main types of turbine configurations, the main ways to draw on this technologies are shown. Two main option are currently developed, Wind turbines located onshore and offshore.

**On-Shore Wind Power**

As it is shown the development of wind power technologies has been significant during the last year, and different turbines have been researched although only two of them are enough efficient and affordable. Even more, most of On-shore wind power plants use HAWTs which can be considered the standard ones due to their better efficiency and power output.
Therefore HAWT investigations are focused on optimizing and reducing the costs of each component in order to reduce the Levelized Cost of Energy\(^4\) (LCOE). Thus, the Capital Expenditure\(^5\) (CAPEX) is a crucial issue, mainly because it is LCOE’s main component for on-shore wind power. As annotation, NREL calculations show CAPEX weight in LCOE is 76% of the weight while the Operation and Maintenance Expenditure\(^6\) (OPEX) accounts for the remaining 24%. In order to better analyze the costs of the initial investment, the CAPEX breakdown is shown in the figure below\(^5\). The weight of each segment is an indicator of which are the areas that attract most part of the innovations and R&D efforts from the industry.

\[\text{Figure 26: On-shore wind Power CAPEX breakdown. [Source: NREL.]}\]

Reducing both CAPEX and OPEX costs while augmenting the produced energy (capacity factor) are the key levers to improve cost competitiveness of wind power. Thus the main innovations related to on-shore wind power have been oriented to\(^7\):

- Innovations carried out in the turbine itself (design, size, materials, manufacturing process, etc.).
- The optimization of the operation and the reduction of the necessary maintenance to ensure the reliability of the system.

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\(^4\) LCOE: It calculates the lifetime costs of building and operating a power plant divided by energy production.

\(^5\) CAPEX: In this context, it refers to the investment that is needed to build a power plant, from the initial design to the beginning of the normal operation of the plant.

\(^6\) OPEX: In this context, it refers to the ongoing costs for running a power plant during its lifetime.
• Improving the system balance and the way the turbines interact with their environment (i.e. grid) and installation costs (e.g. civil works).
• Increasing the Annual Energy Production (AEP).

In conclusion, after analysing on-shore wind power technologies three main statements are exposed:

• With the current technology, onshore wind has almost reached grid parity in several markets in sites with good wind resources. LCOE is projected to further reduce up to 18% in 2025.
• Onshore wind power is a mature technology in which LCOE reductions have been obtained by increases in the capacity factor. Projected LCOE reductions attributable to technology development in 2025 range between 4.5 and 7%. Main innovations are aimed at maximizing energy capture wind by optimizing rotor sizing and increasing hub heights.
• Repowering of old sites with higher average wind speeds is one of the best alternatives to develop cost competitive installations as part of the development and construction costs are already incurred.

Off-Shore Wind Power:
This kind of Wind Power plants are situated in the oceans and seas where wind speed reaches higher values. This industry is moving fast from a niche technology to a mainstream supplier of low-carbon electricity. In fact, recent government auction results show that the industry has achieved unprecedented levels of competitiveness through rapid progress in technology, industrial growth and a reduction in the cost of capital. 

Nowadays there are 12.6 GW of offshore wind operating in Europe and it is expected to produce 7% to 11% of the EU’s electricity demand by 2030, although this is only a fraction of the resource potential available in the European sea basins. Some forecasts shows that offshore wind could in theory generate between 2,600 TWh and 6,000 TWh per year at a competitive cost.

Additionally, off-shore wind power can be divided in two section, plants near the shore (fixed-bottom offshore) and plants far away the shore (floating offshore). In this analysis just main characteristics and LCOE differences are going to be considered.

Differences between Off-Shore wind technology and On-Shore wind technology

• The environmental and operational conditions determine factors such as hub height or rotor diameter. Similarly, the situation of the plant make that offshore has much higher complexity because of heavier equipment and more difficult installation.
• On the other hand, vessel transport reduces some of the restrictions associated with the logistics of large nacelles and blades compared with road
transport of onshore components. This allows to use higher nameplate turbines which further simplifies installation and maintenance as a lower number of turbines need to be installed. Nevertheless, the lower number of vessels hinders the transport of the materials compared to the number of trucks available to onshore generation.

These differences are reflected in the CAPEX of both kinds of power generation.

![Pie Chart: On-Shore vs Off-Shore CAPEX](Source: ETSII UPM.)

**Wind power technologies LCOE**

LCOE is a main factor in order to determinate the value of a technology, therefore an analysis of the main types of wind power generation is shown. As annotation, these LCOEs have been calculated differentiating technology impacts from impacts factoring not only technology but scale effects and efficiencies across the value chain.
Figure 28: Wind Power LCOE’s prediction. [Source: Berkeley Lab.]
Taking into account On-shore wind power, it can be considered a mature technology in which no technology breakthroughs are expected but an evolutionary approach. LCOE reductions range are expected to be between 10-12% to 2020 and mainly come from optimized rotor dimensions and rotor materials followed by drive train enhancements are more sizable for low speed turbines. On the other hand, offshore wind power is nowadays a technology under development, which confers it a greater room for improvement (30% for fixed-bottom and 25% of floating are expected to 2030).

Regarding other way of grid scale generation non-conventional wind power and solar PV are superficially studied:

### 5.6.2. Non-conventional wind power

There are three main other options for wind power, here they are just going to be superficially described:

- **Airbone Wind Energy (AWE):** At present, conventional onshore wind turbines cannot access wind resources available at 200 meters high, where the wind blows constantly at a higher speeds. Alternative technologies such as AWE can capture part of these high altitude wind resource by suspending at high altitude an energy capturing system such as tethered kites or airfoils. These allows increasing the capacity factor from 30-35% to 60%. However, the short lifespan of the suspended element due to the crash risk and the barriers to operate at certain altitudes due to the coincidence with commercial aviation routes.

- **Piezoelectric Wind Turbines (PWC):** These turbines use magnetic attractive and repulsive force to create mechanical oscillation in piezoelectric bimorphs which is then converted into electric charge through direct piezoelectric effect. This technology have not generally used due to its little development.

### 5.6.3. Solar PV

- Solar PV technology is projected to reduce its LCOE at a faster pace than offshore wind. However, there is not a winning technology as high quality wind sites with the adequate turbines will provide LCOEs below the ones of most solar PV sites.

- In general terms, solar PV and wind on-shore have complementary generation profiles which minimizes pool price volatility risks induced by variable penetration rates of non-manageable renewable resources.
5.6.4. Conclusion

In conclusion, some notes about grid scale generation are exposed:

- Grid Scale Generation takes part in the New Energy Market which implies Renewable Energy Resources, thus every technology analysed in this section is non-polluting. RES are the way to achieve a superior administration of the network, flexibility, and minimize loses and misfortunes.

- Wind Power generation is currently the best technology for grid scale generation and is expected to reduce its LCOE, CAPEX and OPEX costs due to recent investigations to improve efficiencies and economies of scale of installations, logistics and materials that are required.

5.7. ENERGY MANAGEMENT SYSTEM (EMS)

An EMS is a software system that monitors, controls, or analyses energy in a building. It includes home and building automation services, personal energy management, data analysis and visualization, auditing, and related security services.

In order to better understand the implications of the EMS in different situations two cases are explained, when it is used in a common house and in bigger buildings. Thus, Home Energy Management System (HEMS) and Building Energy Management System (BEMS) are differentiated:

5.7.1. Home Energy Management System (HEMS)

The concept of HEMS has changed in the last few years. In the recent past the House energy system was considered as a system deployed by utilities of the energy system while, at present, the HEMS is considered as the thinking and controller gadget of the smart home. This shift has been necessary due to the technology development of smart loads and DERs in general, the control of the different devices of a house in order to get a more efficient and economic administration of the energy is currently a key issue.
Therefore this market has been incremented their benefits and it will continue doing this in the near future. According to Navigant Research: “Global revenue attributed to HEM devices is expected to grow from almost $2.3 billion in 2016 to $7.8 billion in 2025”\(^\text{80}\) (many devices such as smart thermostats and smart lighting devices are here included). Furthermore, it has been observed that vendors are increasingly offering a wide range of compatible devices since Apple has announced their smart home platform, which, in turn, will drive the adoption of HEMS in the coming years.

As it is obvious, the energy savings and demand response have been incremented as HEMS have been developing. Regarding specific dates: “Continuous energy monitoring down to appliance level with online feedback will provide on average 12% energy saving, can be as high as 30% and is the baseline for any other energy saving projects”\(^\text{81}\). In addition, by adding remote control and automation to the main loads (thermostat, lighting, EV, HVAC…) and taking decisions on how to run the loads based on external data like weather forecasting, market price signals or habits, the potential savings are higher. Furthermore, smart thermostats will provide potential energy savings of 10-12% for heating and 15% for cooling\(^\text{82}\).

### 5.7.2. Building Energy Management System (BEMS)

BEMS is basically like a HEMS but bigger and with more complex connections and software due to the more devices that it has to control. As it is happening with the HEMS the market of the BEMS continues to evolve, in this case with an increasing focus on the value of data in commercial buildings. This evolution is fueled by two technology trends: the Internet of Things (IoT) and cloud and edge computing. In addition to technology developments, customer education has steadily improved\(^\text{83}\).
These trends are expediting BEMS investments that address pain points for commercial customers.

BEMS solutions vary in levels of integration and functional complexity; each offering is progressively more integrated and connected than its predecessor. Data collected and analyzed from building systems can be integrated into a larger enterprise system. Such a system, in turn, contributes to IoT use cases such as occupancy data for space utilization, location data for behavior analytics in the retail sector, security and access control via smartphone applications, and more.

In terms of solution architecture, BEMS offerings can include software, services, and hardware in an array of combinations designed to address the customer’s specific needs. Factors affecting the likelihood of BEMS adoption include concerns over security, competition between automation and human input, and central management practices.

Regarding specific data Navigant Research affirms: “Global BEMS market revenue is expected to grow from $4.0 billion in 2017 to $13.1 billion by 2026”\(^8\). However, the difficulty for vendors and end users in this market is the uniqueness of each building and the wide variety of individual needs, resources, and owner and operator experience levels.
Beyond the Energy Management System there are three main blocks that enable the well operation of the system:

- **Data Analytics**: As all modern technologies, big data analysis in order to get different parameters, anticipate to the normal behaviour and operate according to the electrical market is absolutely necessary in the EMS. Thus, as algorithms are based in the understanding of the technology and the markets it is mandatory a deep knowledge of a specific area to develop the outstanding ones. Furthermore, datasets are required to apply artificial intelligence or machine learning.

- **Connectivity**: The main part of the EMS is a controller and an artificial intelligent gadget that need to be connect with all different devices that are included in a modern building or house. The principal problem is that these devices are usually from diverse brands and vendors so a HUB is needed to
centralize the access to every asset. The big challenge is to integrate open
standards so communications won’t be an issue with the different devices.

- **Customer interaction:** The usability of the different applications has a
  starring role in the EMS. Selecting the proper channels and the best moment
to address the customer with the optimal message involves more of a
sociologic approach than a technical one. Although in order to get the
optimum solution human interaction has to be reduced to the minimum, so in
many cases it is better not to interact and control everything remotely.

5.7.3. Conclusion

In conclusion, after analysing the EMS six main statements are exposed:

- Most EMS in the market are limited to the display of information and basic
  dispatching algorithms. **Maximization on data use** to optimize asset
  utilization and enable alternative revenue generation sources for the end user
  provides an opportunity to build more attractive business cases.

- The generalization of the different **DERs** such as smart loads is increasing the
  implementation of EMS in house and buildings.

- The development of the **Smart meters** is letting the collection of many
  information which enables to continue developing analysis and new
  algorithms.

- The EMS growth will be based on being able to demonstrate potential energy
  savings with the deployed assets, the operational optimization of those assets
  and the system as a whole is key to maximize return on investment made by
  the client.

- The EMS is a key factor to get the New Energy Market, because they
  represent one of the most important tools for **Demand Response**.

- Groups of BEMSs and HEMSs will be managed by an **aggregator** that will
  exchange information with the VPP and with the system operator. Although
  this will be explained in the following section: “Virtual Power Plant”.

5.8. **VIRTUAL POWER PLANT (VPP)**

A VPP is a system that combines information from the energy management systems
and aggregators with the information from the system operator. It is based on a
software that obtain optimum usage of the network controlling the energy demand
and supply and the interaction between both of them. Figure 31 represents really well
the VPP concept.
VPP systems can help transform classic passive consumers into active “prosumers” (producers and consumers). This can be achieved through the integration and remote control of a fleet of EMS in charge of the aggregators that have to monitor, optimize and control DER technologies such as distributed generation with wind power and solar PV, energy storage, EVs, and smart loads. Prosumers will be active participants in delivering services tailored to their own needs and preferences but that also serve the larger grid.

VPP devices amplify the esteem for end clients, DSOs and TSOs. The system provides value for the final user in terms of lower energy costs by obtaining the electricity in cheaper periods and revenue streams (those obtained when energy is transferred from the final user to the grid). In addition, the system provides value to the distribution utility in terms of lower capital investments in grid infrastructure or peaking power plants. Even more, VPP offers value to Transmission grid operators in terms of regulation of ancillary services such as spinning reserves.

Basically, the operation mechanism of a Virtual Power Plant is the following:

- The VPP receives the system energy needs from the operator and transmit this information to the aggregators though specific participation requests. They check their numerous EMSs in order to correspond the anticipated system needs. The VPP determines which are the best positioned EMSs to respond to the necessities of the system and communicates it the involved aggregator.
- On the other side, EMSs connected to the same VPP are always collecting information from their DERs with smart meters and optimizing their usage with the information received from the VPP in order to reach the best comfort and economic benefit for their owner. Furthermore, EMSs respond to the participation requests from the VPP in the way they are able to in that moment, for example: Feeding energy to the grid, providing voltage regulation or reducing the power consumption of the air conditioning system.

Regarding capital needs to assemble VPP instruments, the capital costs appended to the development of new power plants is noteworthy ($900/MW for Gas plant in the USA). In examination, the expense per megawatt for a VPP that exploits the assorted arrangement of existing resources is more or less $80/MW. Moreover, the investment in the software that makes the VPP does not convey either ecological
obligation or the danger of stranded investment. The VPP worth can only be incremented as time passes as new markets rise for network services. On the other hand, an interest in traditional resources conveys the danger of long haul degrading.

As indicated by Navigant Research: "Global VAM implementation spending is expected to reach $2.1 billion annually by 2025". By then, programming spending will represent 90% of aggregate VAM implementation spending.

**In conclusion**, Virtual Power Plants represent the last step to afford the New Energy System which is more efficient, economic, and that enables an open energy market.
6. REGULATORY FRAMEWORK

6.1. UNITED STATES

6.1.1. Introduction

The electric framework that serves the United States is partitioned into three interconnections, which likewise cover parts of Canada and Mexico. The interconnections overhauling the adjacent United States are the Electric Reliability Council of Texas (ERCOT) Interconnection, the Eastern Interconnection and the Western Interconnection as it is shown in Figure 32.

While all the power generation plants inside every interconnection are synchronized and electrically interconnected, the three interconnections are not synchronized, and direct current control must be changed over to direct current capacity to be exchanged between interconnections. In this manner, there is little power stream or framework coordination between the interconnections, and power markets don't cross the limits. The working frequency for all interconnections in North America is 60 Hertz (Hz).

**Figure 32: North American power grid’s interconnections. [Source: NERC.]**

There are two main institutions that govern this electric system: the North American Electric Reliability Corporation (NERC) whose fundamental objective is to guarantee the reliability of the system; and the Federal Energy Regulatory Commission (FERC)
that regulates the power transmission between states and the large-scale commerce of electricity. They play really important roles in this system and as the explanation of the United States power system continues they are go into be appearing.

NERC coordinates eight regional entities that are in charge of maintaining the reliability standard in their territories. In addition, inside these territories the electricity supply and demand is controlled by balancing authorities (BAs).

6.1.2. Natural monopolies and competition

Rivalry in certain economic exercises, for example, supply of electricity or water, may convert into higher expenses because of the duplication of foundation. In these situations, a monopoly may benefit the market all the more effectively. Power generation, transmission, and distribution have extensive capital expenditure (CAPEX) and low operational expenditure (OPEX); having two power suppliers in a single administration region could increase the cost. In this way, electric utilities were worked and directed at the state level as monopolies all through the United States during the twentieth century87.

In these traditionally controlled markets, vertically integrated utilities deal with the majority of the fragments of the power esteem chain inside their administration domain, including generation, transmission, and distribution.

However, in 1978, Congress ordered the Public Utilities Regulatory Policies Act (PURPA), expecting utilities to buy electricity from little power plants. Thus, PURPA opened the monopolistic power market to independent power producers (IPPs)88. Furthermore, in 1996, FERC issued Orders 888 and 889, which expected utilities to distribute distinct rates for electrical administrations and ordered proprietors of transmission frameworks to offer power generators access to their system89. Accordingly, Order 888 recommended the development of ISOs which are free associations that have operational control and offer open transmission connection.

In 1999, FERC found that there were as yet noteworthy obstructions to guaranteeing that the United States had a plentiful supply of power at best price. This provoked FERC to start a procedure taking into account the following topics:

- The apparent absence of even-handed access to transmission framework.
- The economic building wasteful aspects in the activity of the system90.

The procedure finished in the issuance of Order 2000, which built up the idea of the regional transmission organization (RTO) and sketched out its capacities and qualities which are fundamentally the same as the ones for ISOs. Nowadays ISOs and RTOs serve around 66% of power buyers in the United States, with customary BAs serving the rest91.

Finally, FERC Order 890 was issued in 2007 to require receptiveness, straightforwardness, coordination, and fairness in transmission arranging forms, and FERC Order 1000, issued in 2011 with the objective of expanding coordinated effort in the arranging and development of territorial and between provincial transmissions, empowers impartial and prudent cost allotments for new transmission lines92.
6.1.3. Wholesale Markets in the U.S.

United States power markets have both large-scale and retail parts. Large-scale markets include the offers of power among electric utilities and distributed system operators (DSOs) before it is sold to customers. Retail advertisements include the offers of power to customers. Both large-scale and retail markets can be traditionally controlled or free trade markets.

As the Figure 33 shows a few sections (grey) of the United States wholesale power market are traditionally managed, implying that vertically-incorporated utilities are in charge of the whole stream of power to buyers. That is to say, they possess the generation, transmission and distribution frameworks used to serve power consumers.

However, different parts of the large-scale market such as Northeast, Midwest, Texas, and California are rebuilt fair competition markets (CAISO, NYISO and PJM are the most relevant). These business sectors are controlled by independent system operators (ISOs) or regional transmission operators (RTOs). ISOs and RTOs utilize free trade market instruments that permit autonomous power generators and non-utility generators to exchange control. In rebuilt fair competition markets, TSOs and utilities are regularly in charge of retail power administration to clients and are less inclined to possess generation and transmission assets.
6.1.4. Retail Electricity Markets in the US

Retail markets are define at the state-level and can be traditionally managed or fair competitive. As it can be seen in the Figure 34 in grey, consumers cannot pick who produces their energy and are required to buy from the utility around their zone in a traditional retail power market such as Northwest, Southeast and nearly all the west except California. In these states, most renewable power source activities are owned by utilities. Subsequently, growing substantial green power projects in a traditionally managed state and asserting renewable power source utilize can frequently be difficult.

Free trade retail power markets (blue) enable power customers to pick between different retail providers. These power markets have opened generation for rivalry from autonomous power generators in 24 states, in the Figure 34 they appear in blue, some of them are California, Texas and most of the Northeast. Washington D.C. and 18 of these states have likewise presented retail decision, which permits private and additionally industrial purchasers to pick their own particular power supplier and generation choices, including sustainable power source.

In these fair competition markets, municipally-owned utilities may not offer their clients retail decision. Note that the market isn't generally isolated plainly between traditionally managed markets and competitive markets. A few states, similar to California, are halfway rebuilt markets and just allow certain purchasers to take part in retail decision.

Figure 34: Retail Electric Power Markets. [Source: Federal Energy Regulatory Commission.]
6.1.5. Flexibility in the U.S. market

As it is explained, the objective of the section: “Regulatory Framework”, it is to analyse the progress of the different markets (mainly U.S. and Europe) in order to value if they are going in the best way to the development of the energy transition. That is why, in this section demand response (DR) and renewable energy generation (REG) in the United States must be examined.

**Demand Response** utilizes tariffs or projects to empower here and now changes in energy use by final customers. Economic programs to encourage demand response pay taking part clients to diminish their consumption amid lack occasions or when the cost of producing power is higher\(^94\). DR can give financial advantages by dislodging the most costly assets in a market with competition; in other words, assets in the far-right half of the generation load as it is shown in Figure 35. In 2013, the potential pinnacle decrease in ISOs/RTO zones from interest reaction program was 29 GW\(^95\).

![Image](image.png)

**Figure 35: Hypothetical Generation Load. [Source: NREL.]**

In **energy markets**, diminishing stack, amid times in which the demand is high, can keep away from the requirement for the most costly generation assets. Normally, DR suppliers submit offers to shorten stack in day-ahead and intraday markets\(^96\). The economic return that suppliers get can be the market clearing price or a small amount of it. However in 2011, FERC promulgated Order 745, setting up rules for the investment of DR in power markets and called for ISOs/RTOs to pay DR assets the full market price of energy\(^97\). Order 745 was tested in court under the contention that DR is a retail exchange and consequently outside the purview of FERC. Be that as it may, the Supreme Court as of late maintained Order 745, reaffirming FERC's ward to control the demand side of large-scale markets\(^98\).

DR is utilized to guarantee asset sufficiency in **capacity markets**. At present, in some markets demand response means a big percentage of the capacity that is available, for instance, in PJM, DR represents just about 10% of accessible framework capacity\(^99\). Experience demonstrates that DR can provide resource sufficiency cost-viably. Furthermore, instalments to PJM capacity market members were $11.8 billion lower than what they would have been if no DR assets had been offered into the bartering\(^100\).

Regarding **Renewable Energy Generation** remarkable characteristics that differentiate from other energy sources are indicate below:
• REG has very little OPEX.
• REG increase grid stack variability.
• REG has limited capacity value.

These characteristics challenge the traditional operation of the electric market:

The variability of wind power and solar PV generation requires a higher measure of adaptability to keep up safe levels of here and now framework unwavering quality. Moreover, working traditional assets on a more flexible way could spread their OPEX, and if there are large amounts of operating REG, capacity resources may likewise be much more required, which could bring about higher clearing prices in capacity markets.

Low OPEX empower REG to offer at zero or negative prices (due to the near-zero OPEX together with federal incentives), and this way, lessening the clearing value paid to all energy markets members. In addition, REG inconstancy can rise the Locational Marginal Pricing (LMP) unpredictability. On balance, REG integration could negatively influence the future reliability of the energy system101.

However, the recent changes that has been made in the U.S. electric sector can help the integration of REG, nevertheless, the recommendations that this report is giving are going to increase moreover the cost-effectively integration of all these new technologies and ways of energy generation. In this report seven manners to enable the integration of REG are exposed:

• **System flexibility**: This is a very general topic that is explained above, it allows the integration of REG due to the net load variability that renewable sources imply, system flexibility is needed to reduce the this variability and get a continuous electric stack.

• **Cycling conventional resources**: This topic is related the previous one, it rises the flexibility in the system. However cycling fossil-fuel plants could increase wear and tear and thus rise their OPEX, it is demonstrated that this rise is not really significant (2% of the savings in fuel costs)102.

• **Demand Response**: The aggregators and the technologies explained in the previous block that enables the demand response play a very important role for the integration of REG. Fast and automated response is needed to get a secure energy system.

• **Storage systems**: Batteries greatly increase the energy supplies that are required when there is a decompensation between generation and demand.

• **Scheduling**: If the market is managed with an hourly dispatch it will be really difficult to deal with variability, thus in the United States five-minute scheduling is used in most of the energy market103.

• **Transmission**: Extra transmission foundation can empower REG integration from different places in the U.S. because interconnecting REG in remote areas enables to match supply and demand. Geographic decent variety in the area of renewable sources helps the changeability of wind and solar PV assets. Figure 36 demonstrates the impact of aggregating numerous plants in Southern California.
- **Forecasting**: Wind and solar forecasting is a really interesting option to facilitate REG integration. Shorter forecasts and faster scheduling frequency enable system operators to lessen the measure of energy reserves at a given time (Figure 37). In fact, in a 2014 in the Western Interconnection, almost all grid administrators revealed utilizing wind forecasts for day-ahead schedule\textsuperscript{104}. There are three main activities to get a forecast: wind and solar energy prediction based on weather forecasts, re-enactment of generation and local power forecast\textsuperscript{105}.

At this point a review of two of the main markets in the U.S. is presented. Are they integrating REG in an appropriate way? Are they using the proper technologies? Are they taking action to get the energy transition?
6.1.6. NYISO

NYISO manages the transmission network of the state of New York, which in 2013 had a maximum generation capacity of 39,704 MW. The historical maximum of consumption occurred in the summer of 2006 with 33,035 MW, resulting in a capacity margin of 17%. The NYISO manages two types of Demand Response programs: Reliability and economic programs\textsuperscript{106}.

**Reliability programs:** Its mission is to provide load reductions in the system when the operator considers that operational reserves will be insufficient. The programs managed by the NYISO are the following:

**Emergency Demand Response Program (EDRP):** It is a program for LSE (Load Serving Entities), final clients and aggregators that wish to offer their demand reductions in the market. The conditions to participate in this market are:

- Need for installation of measuring equipment by intervals and its corresponding verification by the NYISO of its correct operation.
- Minimum contribution capacity to the program is 100 kW per zone and with a response capacity of no more than 2 hours for participants of the program without intermediaries such as aggregators or LSE.
- Generation systems located behind the meter can participate in the program.
- Minimum capacity of 0.5 MW for aggregators of distributed load groups.
- It is a voluntary program in which there is no penalty for not delivering the agreed load.
- Payments are made for reduced energy with respect to the consumption baseline.
- It is a program compatible with the DADRP (It is later explained). If bids have been submitted in both, the DADRP offer will be first marketed and, if the reduction is greater than that offered in the DADRP, it will be paid according to the price of the EDRP program.

**ICAP-Special Case Resources (ICAP SCR):** Mandatory program in which LSEs, aggregators and end customers that, through a Responsible Interface Party (RIP), can offer power reductions in case of shortage of operational reserves.

- The communication of an event is made at least two hours in advance.
- The minimum demand reduction capacity is 100 kW.
- Aggregators with a maximum limit of 100 MW are allowed.
- Participants will receive payments for capacity and, in case of being dispatched, payments for energy cut off on their consumption baseline.
- Non-compliance with the contracted power reductions implies incurring penalties.
- Participants in the ICAP-SCR program cannot participate simultaneously in the EDRP program.

**Economic programs:** DR programs based on economic incentives are characterized by the fact that suppliers participate in the markets as a conventional generation unit. The two programs are the Day-Ahead Demand Response Program (DADRP) in which
they participate in the energy market and the Demand-Side Ancillary Service Program (DSASP) for the auxiliary services market.

**Day Ahead Demand Response Program** (DADRP): It is a program in which LSEs, aggregators and end users offer demand reductions in the daily energy market as an asset equivalent to a generation unit receiving in exchange the Locational Market Price (LMP). The requirements to participate are the following:

- Demand response providers must have devices for measuring consumption by intervals, users will be responsible for the cost of installing the hardware and administrative costs.
- NYISO does not allow the participation of distributed generation systems behind the meter. However, it has been ordered by the FERC to eliminate this restriction.
- The offered capacity must be at least 2.0 MW.
- The formation of the price of the offers has two components: a payment for the energy in ($ / kWh) not less than $75 / kWh; and a payment for start of operation ($) which is finally combined in a single price ($ / kWh) that is introduced in the system.

**Day Ahead Ancillary Service Program** (DSASP): It is a program in which LSEs, aggregators and end users offer demand reductions in the daily market and in real-time auxiliary services. The services available for DR are frequency regulation and operational reserves. Operational reserves are categorized according to whether they are synchronized with the network (spinning and non-spinning reserves) and their response time (10 minutes and 30 minutes). The requirements to participate are the following:

- The minimum capacity to participate is 1 MW.
- Participating charges can simultaneously make offers for frequency regulation services and spinning reserves together with one of the two reliability programs (ICAP SCR or EDRP) but not both.
- For the frequency regulation service, the supplier will be able to participate in the daily and real-time market as long as it can respond to the orders given through the Automated Generation Control (AGC) system in less than 6 seconds. In the case of operational reserve providers, the response time to the network operator's orders must be less than 5 minutes.
- Offers for the frequency regulation service are divided into a price per capacity ($ / kW) and a price per kW of variation ($ / kW). Likewise, the response rates in (kW / min) and (kW / sec) must be indicated to establish the order of dispatch.

### 6.1.7. CAISO

The electricity market in California has certain peculiarities since, although it faced market deregulation and has a network operator (CAISO) that manages the transmission network and the electricity markets, its large utilities are vertically integrated because they still conserve a part of its generation infrastructure after deregulation.
The installed capacity in California in 2013 was 78,133 MW, and its maximum historic consumption is 61,162 MW\(^\text{107}\). However, the withdrawal of the San Onofre nuclear power plant or the increase in distributed generation due to the boom in residential and commercial solar PV installations are creating management problems for distribution networks to utilities and the network operator.

California has defined three demand response programs in which it is able to participate in both the energy and reserve markets:

**Participating Loads**: This is a program reserved for LSEs that offer to cut the consumption of individual loads (including pumping units) or aggregate loads in the market in real time or in the market of auxiliary services such as non-spinning reserves.

**Proxy Demand Response** (PDR): It is a program in which consumers have the possibility to participate through LSEs and aggregators. The markets in which it is possible to participate are the daily energy market, the Residual Unit Commitment (RUC), the real-time energy market and the auxiliary services market such as Non-Spinning Reserve. Participation in the markets is carried out through a Scheduling Coordinator who will send the economic offers and will also be responsible for communicating the instructions of the network operator to the participants.

**Reliability Demand Response Product** (RDRP): This is a new product in force since the spring of 2014 created to maintain the reliability of the system. The RDRP is compatible with emergency programs managed by utilities and their aggregators and allows them to be integrated into the wholesale market managed by CAISO. This product can be introduced in the daily market of energy and in the market in real time but only in emergency situations of the network.

The conditions of participation in these programs are the following:

- The minimum load to participate in the PDR program is 100 kW.
- In the RDRP program, the minimum load to participate as Reliability Demand Response Resource (RDRR) will be 0.5 MW and charges may be added up to reach the set limit. The participating loads must reach the committed reduction level in 40 minutes and keep it for 4 hours.
- The time margins of the notices before the effective reduction of the load depends on the market in which it participates. In the day-ahead market it will be 24 hours in advance while in the real-time market it will be 5 minutes and 15 minutes in the auxiliary services market.
- The charges that provide auxiliary services of non-spinning reserves should receive notifications in a maximum of 1 minute, reach the capacity dispatched by the operator in 10 minutes and maintain it for at least 30 minutes.

### 6.1.8. Summary and Conclusions

The energy system in the U.S. is a complicated device where distinctive advances, authorities, and regulatory frameworks collaborate. At present, two noteworthy models for power commercialization work in the United States:
- **Regulated monopoly model**: In this model state commissions control vertically coordinated energy suppliers.
- **Competitive model**: In this model electricity generators can straightforwardly get to transmission framework and take part in discount power markets. Regulators of the system presented rivalry in power markets with the objective of enhancing effectiveness, bringing down customer cost, and diminishing the obstructions to partake as a supplier.

As it is said before, competitive markets serve 66% of the clients in the United States. The objective of the two models is to furnish energy securely and dependably to end customers.

Autonomous institutions with no economic stake on the result of energy exchanges work wholesale markets. In order to take part in the market, electricity generators present their offers for each scheduling period, which is regularly in the U.S. five-minute scheduling is used in most of the energy market. Offers incorporate asking cost, which it is calculated depending on the plant’s OPEX, and capacity offered. All in all, as it was explained in the Context block, system operators dispatch the minimum cost offers first until the demand is completely responded; then the last offer with the most expensive price sets the price of the market. LMPs incorporate three different parts: Market’s energy value, blockage expenses, and transmission losses.

Competitive markets are not restricted to power exchanging, for example, generation plants can furnish different services to help the transmission system. These are known as auxiliary or ancillary services and they are black start, voltage support and operating reserves. Grid operators additionally arrange the exchanging of budgetary transmission rights, which enable the owner to pay ahead for transmission clog costs and can be utilized as a type of supporting against cost unpredictability. Furthermore, capacity instalments have been inserted to increment grid reliability by giving an extra income for generators relatively to their capacity factor.

The ongoing development of Demand Response and REG has postured new challenges to competitive framework operators. DR devices urge buyers to change their utilization in the near future, mostly through duties and incentive programs because DR can uproot the most costly assets, expanding the financial productivity of the framework, and can give dependability and ancillary services cost-adequately. Finally, regarding DR, FERC’s Order 745 called for network managers to pay DR assets the full market cost of energy, what is more, as it has been explained, recently the Supreme Court has maintained this order.

Solar PV and wind power increment grid stack unpredictability and volatility which can raise the cost and sophistication of adjusting the network energy load. Measures that can cost-successfully alleviate the expenses of integrating REG are mainly among others: demand and offer flexibility, more decentralized transmission structure, geographic variety, better scheduling and forecasting.

In addition, Solar PV and wind power, and REG in general, have close to zero variable cost, which lessens the market clearing value relatively to the measure of REG assets available at a given time. This can make income vulnerability and inadequacy for other present and planned generators. In the long haul, income vulnerability can diminish the
unwavering quality of the power framework on the grounds that current members may resign and imminent members may pick not to participate. The objective of capacity markets is to raise income reliability for generators and, thus, increment framework dependability.

The involvement with competitive markets in the U.S. could offer experience to other electric systems in the world such as Europe and Asia. The structure of the U.S. markets and their parts are the consequences of a long development and the consolidation of experiences gained from market wasteful aspects and mistakes.

6.2. EUROPE

6.2.1. Introduction

The European electricity market is hierarchically constituted (Figure 38 represents this organization). The most minimal level of the system includes private consumers, industrial customers, energy providers and those entities that both consume and provide energy, the “prosumers”. They all are organized in Balance Responsible Parties (BRP), this expression refers to entities such as DSOs and utilities. They are accountable for adjusting the electric demand and supply of their consumers and suppliers. Furthermore, BRPs purchase needed energy or offer it, if it is exceeded, from outside their group in case they are not able to balance the supply and the demand inside the group. Ultimately, BRPs stand for the second level of the market structure.

Different BRPs are gathered into Market Balance Areas (MBA), they are managed by market operators such as TSOs that have to control the security in the network and the correct transmission of the electricity and they, as it is explained in the Context, are able to take active measures to ensure the stability in the area where they have jurisdiction.

Finally, last level of this organization is the Integrated European Market that organize the different TSOs of the European countries. Nowadays, the European Network of Transmission System Operators for Electricity (ENTSO-E) manages 43 TSOs from 36 different European countries

However, this hierarchical structure corresponds to the traditional energy market that is lately changing with the incorporation of flexibility in the electric demand, and the renewable energy sources. The power transition in the European electricity market is deeply explained in the Winter Package.
6.2.2. Winter Package

The Winter Package determinates many characteristics of the future power sector transition in Europe, all in all, it determinates the regulatory measures that every member of the power system is going to compulsorily fulfill. There are three main categories in this package:

- **Proposals amending existing energy market legislation**: This category of measures is intended to achieving another market plan, the market design initiative (MDI) and incorporates a mandate altering and cancelling Directive 2009/72 (E-Directive), another control on the inside power market, changing and revoking Regulation 714/2009 (E-Regulation), and in addition another control cancelling Regulation 713/2009 on the ACER Regulation (third package of electricity market liberalisation measures)\(^{109}\).

- **Proposals amending existing climate change**: This classification of measures means to better adjust and incorporate environmental change objectives into this new market plan. This class incorporates a completely changed Renewables Directive 2009/28 (RED) and a completely amended Energy Efficiency Directive 2012/27 (EED), both to go into constrain on 1 January 2021\(^{110}\).

- **Proposals for new measures**: Ultimately, a proposed direction on Governance of the Energy Union, the Governance Regulation, and the proposition for another control on chance readiness in the power sector, the Risk Regulation, are altogether new measures\(^{111}\).
These three categories are going to be explained in five different sections, but they are going to be mixed in order to better understand what the objective of this really important package is and why it is the key to the power sector transition in Europe but also in the rest of the world. The figure below shows the different sections that are going to be explained.

![Figure 39: Winter Package. Energy value chain. [Source: Allen & Overy LLC.]](image)

**New market design**

The Commission, upheld by the Council, has grasped a goal-oriented arrangement for the European Union's power market, it will be a noteworthy instrument in understanding the progress to a low carbon economy by 2050. This implies EU residents and also industrial clients ought to continuously change to power not just as a wellspring of light, warming and cooling yet in addition transportation.

The quickly expanding offer of RES (Renewable Energy Resources) in electricity generation, together with more decentralized generation and self-consumption, has additionally raised doubt about traditional electricity market models. A decentralized market has more players and makes new parts, for example, aggregators and 'prosumers' (entities that consume and produce energy at the same time). In the meantime Europe's electricity market is presently better interlinked through interconnecting systems. This has the both advantages and disadvantages.

More prominent irregularity in provisions has made a requirement for greater adaptability and responsiveness both on the supply and the request side, as an example if the sun does not shine or the wind does not blow. The market needs to value the costs associated with giving that adaptability and reflect them in the general cost of electricity and its services.

These purported capacity remuneration mechanisms, if not legitimately outlined, can have major unfriendly outcomes on the working of the inward power market. Indeed,
even where markets and frameworks work well, be that as it may, the danger of a power crisis can't be avoided and the outcomes of such crises are probably going to be felt past national fringes, particularly in interlinked markets. That is why emergency counteractive action and administration can't be viewed as a purely national duty.

**Generation**

As it has been shown above Member States are required by the present RED to help the offer of RES by 2020 to 20% of definite energy utilization due to the Europe 2020 strategy, and the Winter Package adds another broad focus of 27% has been set for 2030. Albeit frequently scrutinized for its absence of aspiration, it is for the most part perceived that proceeding with state money related help will in any case be required to meet this objective.

One of the main objectives of the European Union, taking into account electricity generation, is to ensure stability for investors because of obvious reasons. That is the reason why the draft RED supplements the MDI by presenting diverse measures went for pulling in investments in the medium and long haul and by decreasing regulatory barriers on RES producers. As it has been said, this is a crucial objective of this package, nevertheless, investment levels in RES have dropped a 60% from 2011 to the present. In order to fulfil that objective two main articles were published:

- **Article 15**: “Member States shall ensure that investors have sufficient predictability of the planned support for energy from renewable sources. To this aim, Member States shall define and publish a long-term schedule in relation to expected allocation for support, covering at least the following 3 years and including for each scheme the indicative timing, the capacity, the budget expected to be allocated, as well as a consultation of stakeholders on the design of the support.”

- **Article 6**: “Without prejudice to adaptations necessary to comply with State aid rules, Member States shall ensure that the level of, and conditions attached to, the support granted to renewable energy projects are not revised in a way that negatively impacts the rights conferred thereunder and the economics of supported projects.”

Winter package does not just assumed that all this targets are going to be fulfil, nevertheless it integrates a regulation that determines what to do if all these targets are missed. Concretely, on the off chance that, having evaluated these mind boggling plans, the Commission builds up that the Union direction isn't met all things considered or that national baselines are not regarded, at that point Article 27 might apply. This arrangement sets out a few alternatives for Member States to expand their commitments to the RES target. One such choice, which is probably going to demonstrate dubious, is a prerequisite to make a budgetary commitment to a financing stage to be set up at Union level to add to sustainable power source ventures, oversaw specifically or in a roundabout way by the Commission.
Furthermore, Article 5 presents the obligatory opening of national help plans to RES establishments situated in other Member States regardless of whether this is just on a progressive premise. No less than 10% of recently upheld capacity must be opened up every year in the vicinity of 2021 and 2025, and no less than 15% between 2026 and 2030.117

On the other hand, the legislation bears in mind capacity market mechanisms in order to remunerate electricity generators and demand providers in response to threatened shortages of electricity that some Member States have. In spite of the fact that the EU all in all is at present in a circumstance of overcapacity, a several nations may well face certifiable security of supply challenges, thus, substantial quantities of existing power plants will be eliminated soon, as they can't meet EU emanation and natural gauges.

The Sector Inquiry intended to check whether well working markets can trigger adequate interest in ability to take care of future demand and to distinguish the market and administrative disappointments that block speculation. The Sector Inquiry for sure distinguished various market disappointments some of which are relied upon to be managed by the MDI. Meanwhile if markets do not provide the correct flags and don’t convey high costs now and again of shortage, venture won’t happen. Without satisfactory apparatuses to animate cost responsive request by conclusive purchasers, national experts regularly top retail costs. National guidelines for overseeing adjusting markets may by and by top the cost in forward business sectors. Different types of value bending caused from an inability to portray offering zones in a proper way undermine cross-outskirt exchange and lessen motivations to put resources into new interconnector limit.

Finally, the Final Report concludes: “capacity mechanisms must be open to explicit cross-border participation in order to minimise distortions to cross-border competition and trade, ensure incentives for continued investment in interconnection and reduce the long-term costs of European security of supply.”118

Wholesale markets

The Commission keeps up that a goal-oriented new energy market design is required not exclusively to mirror the changing specialized highlights of power generation and frameworks yet additionally to live up to purchasers’ desires, convey genuine advantages from new innovation, encourage speculations, strikingly in renewables and low carbon generation, and perceive the relationship of European Member States with regards to energy security.

Here a really important role is played by the ROCs (Regional Operational Centres), they are created due to the Commission that aims to ensure a more coordinated regional approach to TSOs (Transmission System Operators). According to the E-Regulation: “all transmission system operators shall establish regional operational centres […]. Regional operational centres shall be established in the territory of one of the Member States of the region where it will operate. […]Regional operational centres shall complement the role of transmission system operators by performing functions of regional relevance. They shall establish operational arrangements in order to ensure the efficient, secure and reliable operation of the interconnected transmission
system.\textsuperscript{119} ROCs, thus, get empowered to adopt decisions above TSO: “Transmission system operators shall implement the binding decisions issued by the regional operational centres except in cases when the safety of the system will be negatively affected.”\textsuperscript{120}

At this point, an important question should be answer: Who is the institution that coordinates regulatory decisions? Well, ROCs report to ACER as well as to NRAs (National Regulatory Authorities). However, The Winter Package shies away from unifying administrative powers in the hands of ACER, it foresees ACER as a coordinator. Thus, the chief role of ACER as an organizer of the activities of national regulatory authorities is protected yet constrained new skills are to be allocated to ACER when divided national basic leadership on issues of cross-outskirt pertinence could prompt issues or irregularities for the inner market.

Finally, The Commission asserts that there is a great deal to be done on the demand side of power markets to guarantee that they work for the full advantage of business and family buyers, and additionally for “prosumers” and aggregators who deliver energy through self-generation or offer surplus power back to the grid. Demand response grasps something other than effective utilization of electricity, it is an imperative wellspring of adaptability in the power framework. Dynamic consumers ought to have the capacity to move their demand progressively, decreasing peak load\textsuperscript{121}.

\textbf{Distribution}

The European Commission proposes to fortify the legislative structure for collaboration between DSOs (Distribution System Operators) and TSOs to guarantee that all data and information is shared and that the utilization of conveyed assets is facilitated. The point is to guarantee cost-productivity and secure and solid operation of the systems regarding the daily operation and long-term planning.

Regulators need to ensure that the DSOs have sufficient financial incentives to enhance and update their systems, to secure and associate distributed generation and to contract with other specialist co-ops, and in addition to manage nearby clog administration. On the other hand, the Commission clarifies different networks services of DSOs: data management, storage, integration of electrical vehicles recharging points and to ensure demand flexibility\textsuperscript{122}.

Another important issue to be addressed is the LECs (Local Energy Communities), which are associations that are value rather than profit driven. The Commission requires that Member States receive a lawful system that guarantees the LECs to claim, set up or rent network arranges and to self-ruling oversee them, and that these networks can get to every single sorted out market either specifically or through aggregators or providers\textsuperscript{123}. This way, the distribution system is going to be the key to flexibility with the new role of the DSOs and the new LECs.
Retail markets

The Commission considers that retail power markets have not had a competition that would enable customers to partake in the advantages from rivalry upstream. In this way, dynamic customers, known as “prosumers”, are to be urged to produce, store, devour and offer self-generated power on every single sorted out market, separately or through aggregators.

However, here appear two main issues: Price and data management. To what involves price, the Commission determines that power providers might be allowed to decide the cost at which they supply to clients; Member States may, be that as it may, guarantee the assurance of the energy poor or helpless clients124.

Regarding data management, the Commission proposes to build up regular guidelines. Member States are obliged to indicate who may approach the information of the last client with the client's unequivocal assent. Information in this setting incorporates metering, consumption information and data required for exchanging. The qualified gatherings conceivably accessing these information are clients, providers, TSOs, DSOs, aggregators and different gatherings providing electricity or different services to clients. Finally, the Article 24 makes clear that “regulated entities which give information services should not benefit from that activity”125.

Last but not least, two really important articles need to be mentioned regarding “prosumers” and aggregators, both major elements in this report, because there are the key to get flexibility in the demand side. Article 17 of the E-Regulation expects NRAs to support last purchasers, including those offering demand response through aggregators and dynamic customers to take part close by generators in a non-biased way in all organised markets126. And Article 13 of the E-Regulation gives final clients the privilege to contract with an aggregator straightforwardly, and without the earlier assent of the energy provider127.

Conclusion

In conclusion, the Winter Package determines the path to reach the new energy market that involves the flexibility of the demand side of the system. The Winter Package is a begging to the regulation change that is needed to be done and that will be explain in this report in order to achieve an energy market based on renewables power sources, energy efficiency and focused on the customer that would become active part of the system.

At this point a review of two of the main markets in Europe is presented. Are they integrating REG in an appropriate way? Are they using the proper technologies? Are they taking action to get the energy transition?

The general situation of many European countries have been analysed but in this report just the three main markets are exposed:
6.2.3. Germany

The Germany electricity system is the largest in the European Union with an installed capacity of 171,566 GW and according to the Boston Consulting Group estimates, Germany's installed capacity can exceed 250 GW in 2030, driven mainly by an increase in electricity generation investments in Solar PV and wind power.

The Federal Network Agency (FNA) and the four TSOs (TransnetBW, TenneT DE, Amprion, 50Hertz) operating in Germany have created the GCC initiative (Grid Control Cooperation) where they publish the needs of the system to participate in the capacity reserve market. Participants in the market offer through the platform “regelleistung” and the GCC resolves the process later.

The loads contributed within the DR programs by the users must be verified by the TSO to ensure that the minimum technical requirements regarding the level of reliability and automation capacity of the installation for the control of electrical consumption are met.

The programs open to the DR are primary, secondary and tertiary reserves and they were established and regulated by the FNA in June 2010. With the same purpose of maintaining generation reserve capacity in the system, but with contribution of greater capacities, is created by the Energy Industry Act (EnWG) in December 2012 the “Verordnung über Vereinbarungen zu abschaltbaren Lasten” (AbLaV) (Ordinance on the agreements for interruption of charges) and the program "Interruptible Loads" to which the large industries connected to medium and high voltage networks can participate.

The requirements to participate in these programs are:

**Primary Control Reserve (PCR):**
- Minimum capacity of 1 MW.
- Response time less than 30 seconds to reach the capacity offered.
- Automatic notification and activation.
- Availability up to 15 minutes and to participate several times per day.

**Secondary Control Reserve (SCR):**
- Minimum capacity of 5 MW with increments of 1 MW.
- Response time less than 5 minutes to reach the capacity offered.
- Automatic notification of the TSO.
- Availability: from 15 minutes to 12 hours and several times a day.
- Activation Remote-controlled.

**Minute reserve (MR) or Tertiary control reserve (TCR):**
- Minimum capacity of 5 MW.
- Response time less than 15 minutes to reach the capacity offered.
- Telephone notification of the TSO.
- Availability from 15 minutes to 4 hours and several times per day.
- Activation: Automatic activation by Merit Order List Server.
Interruptible Loads, AbLaV: There are currently 1,136 MW under management in these programs, with 3,000 MW being the total offered by the TSO’s. There are two types of programs that differ by the form of activation: **Immediately Interruptible Loads** (SOL), Controlled by frequency variations; and **Quickly Interruptible Loads** (SNL), direct Control by the TSO.

The requirements of the programs are the following:

- 1,500 MW offered in each modality every month.
- Minimum capacity of 50 MW and maximum of 200 MW.
- Minimum availability of between 15 min and 1 h at any time, several times a day a minimum of 4 times per week.
- Availability of demand reduction continuously in time intervals of a minimum of 4h every 7 days, and 8h every 14 days.
- Response time of less than 1 second in SOL, and of less than 15 minutes in SNL.
- Payments for availability are 2,500 €/MW per month.
- Payments for activations are 100-400 €/MWh.

<table>
<thead>
<tr>
<th>ENTSO-E's terminology</th>
<th>German TSOs’ terminology</th>
<th>ToL Capacity Contracted</th>
<th>Load Access &amp; Participation</th>
<th>Aggregated Load Accepted</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCR</td>
<td>Primary control reserve (PCR)</td>
<td>+ / –</td>
<td>≤ 670 MW</td>
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<tr>
<td>FRR</td>
<td>Secondary control reserve (SCR)</td>
<td>SCR +</td>
<td>≤ 2500 MW</td>
<td>(n/a)</td>
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<td></td>
<td></td>
<td>SCR –</td>
<td>≤ 2500 MW</td>
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<tr>
<td>mFRR</td>
<td>Minute reserve (MR)</td>
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<td>1513 MW</td>
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<td></td>
<td></td>
<td>MR –</td>
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<td>Interruptible loads</td>
<td>Immediately Interruptible loads (SOL) – AbLaV</td>
<td>485 MW</td>
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<tr>
<td></td>
<td>Quickly Interruptible loads (SNL) – AbLaV</td>
<td>929 MW</td>
<td>(648 MW)</td>
<td>✓</td>
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</tbody>
</table>

*Table 14: Electricity balancing market products in Germany. [Source: SEDC.]*

### 6.2.4. United Kingdom

The United Kingdom has been the first market to open DR programs in Europe. The regulatory entity in the country, National Grid, allows the participation of the DR in all balancing markets in the UK. However, in the last years there have been some problems between stakeholders and providers and, as a result, many operational requirements have not been appropriate for DR. If these problems are not amended in the near future UK will not be anymore an appropriate country to enable DR.

National Grid has the Frequency Control by Demand Management (FCDM) and the Firm Frequency Response (FFR) programs for frequency regulation and for the operational reserve the program of Fast Reserve Firm Service (FRFS) and Short Term Operating Reserve (STOR) which covers the majority of the shares in terms of DR in
the British market. Nevertheless, UK just has one dedicated programme for Demand Response: Demand-Side Balancing Reserve (DSBR).

The characteristics to participate in each program are:

**Short Term Operating Reserve** (STOR): Operational reserve program open to offers by suppliers 3 times a year. The characteristics that must meet to participate in the market are:

- Minimum capacity of 3 MW.
- Maximum response time after operator instructions of 240 minutes although response times of 20 minutes are normally required.
- Ability to maintain daily weekday participation with a window of 11-13 hours a day.
- The time of return to the conditions prior to the event should not exceed 1,200 minutes.

**Firm Frequency Response** (FFR): It is programme for frequency regulation that is open to DR providers in both profiles: dynamic and non-dynamic. The requirements to participate are as follows:

- Minimum capacity of 10 MW.
- There is not a maximum response time specified.
- Ability to maintain participation several times per day.
- Activation: Automatic.

**Fast Reserve Firm Service** (FRFS): It is an operational reservation service similar to the STOR but with more demanding requirements in terms of response time and capacities, what isn’t attractive for DR services.

- Minimum capacity of 50 MW offered.
- The response time must be less than 2 minutes and the capacity reduction must be maintained at least 15 minutes.
- The response speed must be at least 25 MW / min.
- Ability to maintain response between 10 and 15 times a day.
- Activation: Automatic.

**Demand Side Balancing Reserve** (DSBR): It is the only programme that is fully dedicated to DR and was introduced in 2015. It facilitate companies to reduce their energy consumption in period of high demand. The characteristics are as follows:

- Minimum power of 0.1 MW.
- The response time must be less than 2 hours.

**Frequency Control by Demand Management** (FCDM): It is a program of frequency regulation in which the participating loads must meet the following requirements:

- Minimum capacity of 3 MW.
- It is triggered at a 49.7 HZ static set point.
- Constant availability except for the periods indicated by the supplier of the load.
- The reduction in demand must be made within a maximum period of 2 minutes and must be maintained for 30 minutes.
- Activation: Automatic.

<table>
<thead>
<tr>
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<tr>
<td>FCR</td>
<td>Firm Frequency Response (FFR)[h]</td>
<td>Dynamic 180 MW</td>
<td>✓ (n/a)</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Non-Dynamic 0 MW</td>
<td>✓ (n/a)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>FRR</td>
<td>Fast Reserve Firm Service (FRFS)[h]</td>
<td>Dynamic 2313 MW</td>
<td>✓ (n/a)</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Non-Dynamic 54 MW</td>
<td>✓ (n/a)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>RR</td>
<td>Short-Term Operating Reserve (STOR)[h]</td>
<td>Committed 2420.6 MW</td>
<td>✓ (n/a)</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Flexible 757.7 MW</td>
<td>✓ (n/a)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>RR</td>
<td>Demand-Side Balancing Reserve (DSER)</td>
<td>318.7 MW</td>
<td>✓ (n/a)</td>
<td>✓</td>
</tr>
<tr>
<td>FCR</td>
<td>Frequency Control by Demand Management (FCDM)</td>
<td>Not public</td>
<td>✓ (n/a)</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 15: Electricity balancing market products in United Kingdom. [Source: SEDC.]

6.2.5. France

In 2003, industrial customers began taking part of the DR mechanism, later, in 2007, residential loads began to enter the system through aggregators. Finally in 2014, the first programme that allow DR participation was constituted: the FCR, and in the same year, the FRRa.

Nowadays France is becoming one of the best countries in Europe in relation with DR integration, getting a very active electricity market due to new legislations that enables the energy transition. In fact, last years, Réseau de Transport d’Electricité (RTE), the French regulator and TSO, has tried to open ancillary service markets to DR.

This are the programmes created in France in order to enable the participation of DR in electricity markets:

**Réglage Primaire de Fréquence** (Primary Control, FCR): Both FCR and FRRa were issued same year, they enables DR participation to the transmission grid and both are based on bilateral contracts. French TSO is analysing the possibility of spread these programmes to distribution and aggregators. The requirements to participate in FCR are:

- Minimum power of 1 MW.
- The response time must be less than 30 seconds.
- Ability to maintain triggered continuously.
- Activation: Automatic.

**Réglage Secondaire de Fréquence** (Secondary Control, FRRa): The requirements to participate in FRRa are:
- Minimum power of 1 MW.
- The response time must be less than 15 minutes.
- Ability to maintain triggered continuously.
- Activation: Automatic.

**Réserves rapides** (Fast Reserve, FRRm): The requirements to participate in FRRm are:

- Minimum power of 10 MW. Although it is planned to be reduce to 1-5 MW.
- Response times of 13 minutes are normally required.
- Ability to maintain triggered continuously. Although it is planned to participate only during certain days instead of 24/7.

**Réserves complémentaires** (Complementary Reserve, RR): The requirements to participate in RR are:

- Minimum power 10MW. Although it is planned to be reduce to 1-5 MW.
- Response times of 30 minutes are normally required.
- Ability to maintain triggered continuously. Although it is planned to participate only during certain days instead of 24/7.

**Appel d’Offres d’Effacement** (Demand Response Call for Tender, DSR-RR): The requirements to participate in DSR-RR are:

- Minimum power 10MW.
- Response times of 2 hours are normally required.
- Ability to maintain triggered up to 60 days/year.
- Activation: Manual. Although it is planned to be automatic in the near future.

<table>
<thead>
<tr>
<th>ENTSO-E’s terminology</th>
<th>TSO’s terminology</th>
<th>Total Capacity Contracted</th>
<th>Load Access &amp; Participation</th>
<th>Aggregated Load Accepted</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCR</td>
<td>Primary Control (Réglage Primaire de Fréquence)</td>
<td>600 - 700 MW</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>FRRa</td>
<td>Secondary Control (Réglage Secondaire de Fréquence)</td>
<td>600 - 1000 MW</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>FRRm</td>
<td>Fast Reserve (Réserves rapides)</td>
<td>Max. 1000 MW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR</td>
<td>Complementary Reserve (Réserves complémentaires)</td>
<td>Max. 500 MW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 16: Electricity balancing market products in France. [Source: SEDC]*
6.2.6. Summary and conclusions

In this regulatory study of European electricity market three main trends have been detected:

The regulatory structure in the EU for DR is profoundly divided:

- The integration of DR in Europe is currently fractured due to it is still in initial advancement stages. Another important reason to understand this fragmentation is the different regulatory frameworks that have the European countries, that is to say, every member state has a distinct administrative structure and that is why the level of development to opening up electricity markets to customer cooperation. This is a tricky advancement with regards to the objective of getting an Integrated Energy Market.

European balancing markets are enabling demand side assets:

- As it has been analysed, in France UK and Germany and many other member states, controllers and TSOs have been enhancing the program prerequisites of their distinctive balancing items to empower demand side assets integration. Furthermore, TSOs and service suppliers have been together amending the referral methodologies of implementing the different assets in order to better complement both sides and achieve a more efficient advancement.

In the larger part of nations customer access to DR providers or aggregators is hazardous:

- Purchasers have the decision to choose any outsider supplier of, for instance, energy management services they like. Be that as it may, in most European markets, customers cannot pick a different services supplier for giving Demand Response. They are limited to their provider, or possibly require their provider’s consent before working with an outsider aggregator. Frequently the provider is in competition with the aggregator, or may have different motivations to hamper the take-up of DR, and in this way has a motivator to obstruct the aggregator from working with the purchaser.

- In most of the European countries, the roles and duties are hazy, and do not take into account guide access of consumers to services suppliers and aggregators, in this way, they do not offer them an easy way to market. The more inside and out the investigation, the more this issue is comprehended as a basic hindrance all through Europe to the advancement of demand response. There is consequently a critical need to elucidate the part of the new market members, for example, third party aggregators, and their connection with the rest of market members, like DSOs and utilities, when helping customers offer their flexibility into the market.

- However there are a few nations, such as France, that have set up institutionalized arrangements between the two market performers (DSOs and aggregators). Regardless of the qualities and shortcomings that one can discover in the systems of these few member states, they have reduced dangers for all market member and have empowered customer access to the market through aggregators.
• The power markets were deregulated particularly to enhance customer benefits through market rivalry. However today, member state control keeps on obstructing these customer benefits, breaking the guarantee made to European residents when deregulation occurred.

6.3. CONCLUSION

In conclusion, after having analysed the European electricity market, the Winter Package, and the current situation of the countries in general and Germany, UK and France particularly, some recommendations are exposed:

• As it has been exposed, Commission with previous directives and with the Winter Package mandates that EU states must guarantee that national regulators empower demand side assets, such as DR and REG, to partake supply in large-scale and retail markets. The more noteworthy the coordination between European countries, the more noteworthy the economies of scale and the heartier DR services become. With this coordination and economies of scale the cost of distributed generation will be lowered, the effectiveness of the network will be improved, the cost of other technologies such as storage will also be lowered enabling lower the cost of energy reserves. Moreover the development of DR services will involve a vital new source of income for local organizations and households.

• Regarding the potential advantages of DR and the administrative obstructions, DR strategic plan disaggregated is required in each member state to guarantee real and practical advancement. These plans ought to incorporate real objectives for customer demand side development, and should incorporate Key Performance Indicators (KPIs) that verified the correct compliance of the targets set. Just an arranged and composed exertion can break the existing barriers due to the traditional and vertically-integrated grid system.

• The time has come to carry our energy markets into line with Europe’s energy targets. The market design initiative (MDI) make an open door for unification and standardisation of the flexibility in the demand side, including elucidated roles, programmes and obligations over EU countries. It is presently certain that the maximum potential of the European inside vitality market will only exploit if the customers, such as industries, companies and households, are enabled to engage the energy transition of the EU. This must be one of the objectives of the market outline and will require a key change in the demand side of the power market.
7. BUSINESS CASES AND CASE STUDIES

In this block some cases that integrates Demand Response and the enable technologies are exposed. They are both, real cases that have been already developed and hypothetical cases that are thought to be profitable or not. The objective is to analyse practical situations and to realise and measure the technological and economic impact of the energy transition.

7.1. THEORETICAL CASES

First of all, theoretical cases are exposed. They will show if everything in this report have a meaning, a present and future application and where are the main opportunities to invest profitably. Here six universal business cases are suggested:

7.1.1. Contract optimization

One option to generate savings is reducing grid utilization costs. As it is known, big clients have to pay taxes for using the net based on maximum load and consumption; thus, if load peaks are reduced the utilization costs will decrease. Moreover some countries compensate customers that demand energy in an atypical way, this means that their highest consumption matches with off-peak periods.

Secondly, another option is to get flexible tariffs in order to get profit from it. As it is known, energy market prices vary during the day so peak periods are more expensive that off-peak ones, so if one customer is able to shift their energy loads to the cheapest periods through DF technologies this client will reduce its costs. Furthermore, in some countries there are tariffs that compensate the own produced energy delivering to the grid at peak hours so here there is another option to get profit. Nevertheless, different contracts and tariffs needs to be deeply monitored in order to ensure gain for both, the grid and TSO, and the customer at issue.

7.1.2. Trade on the wholesale market

Open and competitive energy markets are one of the most important subjects of this whole project. Traditional markets as it was exposed did not let demand size to participate in the market, nevertheless it is changing as regulation does the same.

Generally, participants in the markets have to pay a fee for trading energy that is why the role of the aggregator is really important, it brings together some customers in order to achieve enough energy to trade with it and get profit.

7.1.3. Balancing group settlement

As it was presented in “Regulatory Framework”, the BRPs help system operators to balance the energy between both sides of the market, the producers and the
consumers. They have to keep their region stable so there are not decompensations that may involve additional costs.

7.1.4. Offer reserve capacity
In order to keep the energy flowing and the frequency in the same value (depending on the country: Europe 50 HZ, USA 60 Hz) there must some producers and consumers that have to offer reserve capacity when consumption exceed production. In this way, TSOs compensate providers and customers that offer this capacity, for example, an oil plant that is able to quickly start its production when energy is needed is going to be compensated by doing so.

7.1.5. Local system management
Another way of helping the system to be always balanced is that the aggregator or a group of customers not also trade with the rest of the grid but stabilize their loads. This more or less the same work of the BRP but in a more locational environment. This helps to reduce costs so reserve capacity is not so needed, and plants that are not working do not need to be connected.

7.1.6. Large scale grid stabilization services
Finally, stabilization of the system have to be monitor in a greater level too, different countries grids should cooperate to exchange loads between them. The more connection the more stable the net will be, this will drive to a reduction of grid costs that impact in energy rates.

7.2. REAL CASES
Secondly, real cases are analysed to see in practise if the theoretical cases have a real application and if they are profitable or not. In “Real Cases” the focus is put in the first two theoretical business cases (Contract optimization and Trade on the wholesale market). Four main real cases are exposed in this report, the data is taken from a tough study done by Rocky Mountain¹²⁹ regarding the USA market; here main results and conclusions are shown so it is clarified the economic impact of Demand Flexibility.

7.2.1. Case 1: Real-Time Pricing
This case talks about the program called Real-Time Pricing (RTP) presented by Commonwealth Edison (ComEd) in 2007. Taking part clients in the program are given day-ahead evaluations of hourly vitality costs, and can adjust the timing of their utilization in like manner. The vitality price really paid by clients changes each hour to mirror the market-clearing price in the large-scale market. In this case it is investigated
the cost savings that flexibility in the demand side gives for both a client participant of the real-time pricing rate and a common client who could select to enter the program.

There are some initial facts that have been taken into account in order to calculate the final results, these facts are presented in the following table.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Case Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>Commonwealth Edison (ComEd)</td>
</tr>
<tr>
<td>Program Name/Rate Design</td>
<td>Residential Real-Time Pricing (RTP)</td>
</tr>
<tr>
<td>Geography/Location</td>
<td>Chicago, USA</td>
</tr>
<tr>
<td>Customers Participating</td>
<td>Approximately 10,000</td>
</tr>
<tr>
<td>Fixed Charges</td>
<td>$11.35 / month</td>
</tr>
<tr>
<td>Demand Charges</td>
<td>$4.05 / kW-month (Previous year’s peak)</td>
</tr>
<tr>
<td>Energy Charges</td>
<td>Varies hourly; 2014 average</td>
</tr>
<tr>
<td></td>
<td>$0.042/kWh</td>
</tr>
<tr>
<td>Customer PV Array Size Analysed</td>
<td>None, no impact on results</td>
</tr>
</tbody>
</table>

*Table 17: Case 1 facts. [Source: Rocky Mountain.]*

Main results:

<table>
<thead>
<tr>
<th></th>
<th>Default Rate</th>
<th>RTP</th>
<th>+AC</th>
<th>+EV</th>
<th>+DHW</th>
<th>+Dryer</th>
<th>+Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Charge</td>
<td>$1,840</td>
<td>$1,588</td>
<td>$1,568</td>
<td>$1,493</td>
<td>$1,441</td>
<td>$1,427</td>
<td>$1,332</td>
</tr>
<tr>
<td>Customer Charge</td>
<td>$183</td>
<td>$189</td>
<td>$189</td>
<td>$189</td>
<td>$189</td>
<td>$189</td>
<td>$189</td>
</tr>
<tr>
<td>Demand Charge*</td>
<td>$358</td>
<td>$313</td>
<td>$241</td>
<td>$233</td>
<td>$233</td>
<td>$233</td>
<td>$233</td>
</tr>
<tr>
<td>Total DF Costs</td>
<td>-$21</td>
<td>-$8</td>
<td>$18</td>
<td>$83</td>
<td>$601</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Costs</td>
<td>$2,024</td>
<td>$2,135</td>
<td>$2,049</td>
<td>$1,915</td>
<td>$1,881</td>
<td>$1,931</td>
<td>$2,354</td>
</tr>
</tbody>
</table>

*Table 18: Case 1 results. [Source: Rocky Mountain.]*

* Demand Charges are other type of charges paid by clients, they are based on the peak electricity usage of a customer during a billing period, and these peaks are generally sized on 15-minute intervals. Utilities will observe the maximum demand of a customer during different time intervals in a day, and will charge a different $/kW rate for the different intervals.
Main conclusions:

- **Load shifting potential:** Demand Flexibility (DF) can transfer **20% of annual kWh** from peak hours with high prices to hours with lower costs. Specifically, a client participant of the RTP with DF buy energy at an average price of $0.036 / kWh, on the other side, a standard customer buy at an average of $0.044 / kWh.

- **Cost-effective DF strategies:** In this situation, three of the five innovations broke down make up the most financial item package for clients. Smart loads to control air conditioning (AC) are the slightest cost DF alternative because of their negative cost of shifted energy due to the considerably lower warming expense. EV charging is the following most cost-effective choice at $0.01 per kWh, and in addition the biggest move opportunity, because of the minimal effort of empowering controls in EV charging gear and the huge adaptability of vehicle battery capacity. Domestic hot water (DHW) is the other alternative, moving the greater part its vitality request into bring down cost hours. DF dryers (smart cycle delay switch) and energy storage, at current costs, do not show up practical for continuous cost arbitrage under this particular rate.
Customer bill savings: For a common client of Commonwealth, changing to the RTP rate would expand bills by 5%, however utilizing flexiwidths under the RTP rate can lead rather to a 7% net savings. The blend of DF strategies such as smart loads, electric vehicle and domestic hot water could offer savings of $250/year, or 12% of the yearly customer bill, for a RTP program client. A significant part of the reserve funds potential is driven by utilizing vitality in bring down cost hours but also a 35% of the savings are related to moving vitality to lower cost hours.

Market sizing: Roughly 10,000 clients as of now are on the RTP rate and they represent the actual savings. Accepting similar potential over all enlisted clients, the reserve funds from as of now RTP clients go up to $1.3 million every year. Nonetheless, the reserve funds potential offered by DF could be utilized to enlist a greater amount of ComEd’s 1.2 million packaged clients to the pick RTP program, or then again draw in a portion of the 2.3 million clients served by competitor in Commonwealth Edison’s region to agree to accept the ComEd program. These clients speak to a $250 million for every year bill savings. And, finally, the investment needed for enabling these technologies means an opportunity for vendors of $910 million (approx. $260/home).

7.2.2. Case 2: Residential Demand Charges

This case talks about a residential design program introduced in Arizona by Salt River Project (SRP) that is intended to reduce monthly client peak demand. This rate structure, as of now being contested, is required for clients introducing new distributed generation such as solar PV. The financial aspects of joining solar PV with DF innovations are broke down in this study, they are combined, as it was said before, in order to limit peak periods and hence lessen client bills already in this program, and additionally for a client out of this rate who may introduce solar PV and switch to this program.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Case Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utility</strong></td>
<td>Salt River Project (SRP)</td>
</tr>
<tr>
<td><strong>Program Name/Rate Design</strong></td>
<td>E-27 Customer Generation Price Plan</td>
</tr>
<tr>
<td><strong>Geography/Location</strong></td>
<td>Phoenix, USA</td>
</tr>
<tr>
<td><strong>Customers Participating</strong></td>
<td>Fewer than 100 in 2015</td>
</tr>
<tr>
<td><strong>Fixed Charges</strong></td>
<td>$20/customers &amp; $32.44/new customers</td>
</tr>
<tr>
<td><strong>Demand Charges</strong></td>
<td>From $3.55/kW to $34.19/kW-month</td>
</tr>
<tr>
<td><strong>Energy Charges</strong></td>
<td>From $0.039/kWh to $0.063/kWh</td>
</tr>
<tr>
<td><strong>Customer PV Array Size Analysed</strong></td>
<td>6 kW (50% of annual customer demand)</td>
</tr>
</tbody>
</table>

**Table 19: Case 2 Facts. [Source: Rocky Mountain.]**

Main results:

<table>
<thead>
<tr>
<th></th>
<th>Default Rate</th>
<th>E-27</th>
<th>+AC</th>
<th>+EV</th>
<th>+DHW</th>
<th>+Dryer</th>
<th>+Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Charge</strong></td>
<td>$2,640</td>
<td>$528</td>
<td>$511</td>
<td>$541</td>
<td>$537</td>
<td>$538</td>
<td>$537</td>
</tr>
<tr>
<td><strong>Customer Charge</strong></td>
<td>$240</td>
<td>$389</td>
<td>$389</td>
<td>$389</td>
<td>$389</td>
<td>$389</td>
<td>$389</td>
</tr>
<tr>
<td><strong>Demand Charge</strong></td>
<td>$1,917</td>
<td>$1,232</td>
<td>$746</td>
<td>$705</td>
<td>$594</td>
<td>$433</td>
<td></td>
</tr>
<tr>
<td><strong>Total DF Costs</strong></td>
<td></td>
<td>$13</td>
<td>$26</td>
<td>$52</td>
<td>$332</td>
<td>$397</td>
<td></td>
</tr>
<tr>
<td><strong>Total PV Costs</strong></td>
<td></td>
<td>$1,255</td>
<td>$1,255</td>
<td>$1,255</td>
<td>$1,255</td>
<td>$1,255</td>
<td></td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td>$2,880</td>
<td>$4,089</td>
<td>$3,399</td>
<td>$2,956</td>
<td>$2,938</td>
<td>$3,109</td>
<td>$3,011</td>
</tr>
</tbody>
</table>

**Table 20: Case 2 Results. [Source: Rocky Mountain.]**
Main conclusions:

- **Peak demand reduction**: By planning the task of significant burdens to keep away from high pinnacle amid the 1–8 pm, the DF strategies and the solar PV combined are capable to cost-successfully decrease peak demand by **48% every month**.

- **Cost-effective DF strategies**: As in the previous case, EV charging and AC smart thermostats are the least expensive DF choices. In third place, DHW is additionally a very cheap option, however the aggregate decrease accomplished is bring down in light of the fact that DHW demand isn’t very crest incidental in SRP’s domain. Dryers and batteries, at up-to-date costs for DF advances, don’t seem cost-effective for this particular rate, to some degree in light of the fact that the lower-cost adaptability from AC, EV charging, and DHW can relieve the most elevated level demand charges.
- **Customer bill savings:** If clients without solar PV that are on the default rate want to introduce solar PV they are going to be included on the E-27 rate. This installation would mean an increment add up to costs by over 40% due to PV financing costs. Be that as it may, our examination finds that DF can decrease net bills under the E-27 rate by up to $1,100/year which means a reduction of an average of 41%. This means that the investment done by the customer would be recovered in more or less a year.

- **Market sizing:** When E-27 Customer Generation Price Plan was introduced fewer than 100 clients joined in, nevertheless the potential of this program is so huge that it clients are incorporating this rate continuously. As DF technologies are becoming cheaper more customers are joining the program due to the investment is recovered in less than a year so there is no cost penalty. If all SRP common customers pursued DF and join in the program there is a bill saving chance of $240 million every year and a peak reduction of 673MW. Furthermore, the investment needed for enabling these technologies means an opportunity for vendors of $110 million (approx. $300/home) taking into account DF technologies, and regarding solar PV, this investment means a new energy market of 1.8 GW, that is to say, a $6.3 billion of investment.

### 7.2.3. Case 3: Non-Exporting Rooftop Solar PV Rate

This case studies the economic repercussions of offering a non-export scenario to solar PV customers. This program was made by the Hawaiian Electric Company (HECO) due to the suggestion of the Hawaii Public Service Commission.

In the situation described in this case, solar PV proprietors get no remuneration or bill credit for PV energy they fare to the network, as to say, household generation has esteem to the proprietor just if utilized by itself. In this study, an analysis of the financial matters of DF advances for a full-service client considering including a solar PV framework under the non-send out rate. It is shown a big 10 kW PV framework since for this situation, the financial matters bolster huge cluster sizes. This size is likewise appropriate for the generally high-use client incorporated into this investigation.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Case Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>Hawaiian Electric Company (HECO)</td>
</tr>
<tr>
<td>Program Name/Rate Design</td>
<td>DG 2.0 Non-Export Proposal</td>
</tr>
<tr>
<td>Geography/Location</td>
<td>Honolulu, USA</td>
</tr>
<tr>
<td>Customers Participating</td>
<td>270,000 utility &amp; 51,000 NEM clients</td>
</tr>
<tr>
<td>Fixed Charges</td>
<td>$9.00/month</td>
</tr>
<tr>
<td>Demand Charges</td>
<td>None, no impact on results</td>
</tr>
<tr>
<td>Energy Charges</td>
<td>From $0.34/kW to $0.37/kWh</td>
</tr>
<tr>
<td>Customer PV Array Size Analysed</td>
<td>10 kW (80% of household demand)</td>
</tr>
</tbody>
</table>

Table 21: Case 3 Facts. [Source: Rocky Mountain.]

Main results:

<table>
<thead>
<tr>
<th></th>
<th>Default Rate</th>
<th>PV Non-Export</th>
<th>+AC</th>
<th>+EV</th>
<th>+DHW</th>
<th>+Dryer</th>
<th>+Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Charge</td>
<td>$8,572</td>
<td>$4,882</td>
<td>$4,550</td>
<td>$4,224</td>
<td>$3,667</td>
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</tr>
<tr>
<td>Demand Charge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total DF Costs</td>
<td></td>
<td></td>
<td>$29</td>
<td>$42</td>
<td>$68</td>
<td>$133</td>
<td>$373</td>
</tr>
<tr>
<td>Total PV Costs</td>
<td></td>
<td></td>
<td>$1,291</td>
<td>$1,291</td>
<td>$1,291</td>
<td>$1,291</td>
<td>$1,291</td>
</tr>
<tr>
<td>Total Costs</td>
<td>$8,680</td>
<td>$6,281</td>
<td>$5,978</td>
<td>$5,665</td>
<td>$5,134</td>
<td>$5,070</td>
<td>$4,655</td>
</tr>
</tbody>
</table>

Table 22: Case 3 Results. [Source: Rocky Mountain.]

Figure 46: Case 3 Results: Annual Supply Costs. [Source: Rocky Mountain.]
Main conclusions:

- **On-site consumption impacts**: The joined control procedures can about twofold on location consumption of housetop PV contrasted with the uncontrolled case. In the initial case, just 53% of generation is spent on-site; however with all savvy DF levers among those contemplated, about 90% of PV generation is spent on-site.

![Figure 47: Case 3 Results: On-Site Consumption of Solar PV. [Source: Rocky Mountain.]](image)

- **Cost-effective DF strategies**: Air conditioning set-point changes and ideal EV charging, taking into account that an EV is just thought to be connected to at home and equipped for daytime charging weekends, are the minimum costly strategies to increment on location utilization, trailed by warm capacity in DHW. Electric dryers and energy storage (batteries) are both altogether more costly adaptability strategies than the other three ones, however are still financially savvy in this situation given HECO's high power rates. Extra battery limit could probably empower close to 100% practical on location utilization.

![Figure 48: Case 3 Results: Demand Flexibility Strategies. [Source: Rocky Mountain.]](image)

- **Customer bill saving**: For client that do not have solar PV but is considering to get it in HECO region, expecting the present rate structures even with no export remuneration, could achieve financial benefit, because of the high volumetric rates that HECO has. The mix of PV with DF strategies minimize this customer bill over **$4,000 every year** including PV and DF costs. Furthermore, for a client that already has a solar PV the integration of DF technologies can save an additional **$1,600 per year**. Another important reason why large PV
system (10 kW) should be used in HECO’s region is that they return many more savings. Last issue to be explained is the fact that DF strategies must be utilized, for example, if a PV system is integrated without DF strategies it will reduce the customer bill in $1,400 per year, while if DF technologies are integrated the saving will be $4,000, as it was said before.

- **Market sizing:** In spite of the fact that HECO as of now serves about 50,000 net energy metering (NEM) clients and will keep on offering a rate choice that remunerates clients for exporting energy beside its non-send out alternative, Demand Flexibility may keep on expanding the market for new clients, contingent upon definite changes to Net Energy Metering (NEM) terms. Furthermore, HECO takes note of that non-send out frameworks won't be liable to an interconnection survey study, generously decreasing the time from a marked client contract to a working solar PV system. In this study, it is shown that yearly client bill savings from DF go up to **$110 million every year** if all clients in HECO region introduce solar PV under the mentioned non-export program. Moreover, there is business opportunity of up to **$81 million** for vendors to provide customers with the enabling technology. Finally, the potential rooftop PV market goes up to **380 MW**, or **$1.3 billion** of investment at the present costs.

### 7.2.4. Case 4: Avoided Cost Compensation for Exported PV

This case examines how good are the measures taken by Alabama Power. This utility has initiated a program that includes avoided cost * compensation for the energy exported by rooftop PV and limited capacity charges to $5/kW-month. The financial matters are here examined for both kind of clients, those with common rate that are thinking about getting a solar PV and moving to PAE rate, and for those that already have a PV system. Due to these measures it will be shown that results are not as profit as the previous case.

---

*A Avoided cost is the marginal cost for a similar measure of vitality gained through another methods, for example, development of another facility or buy from a substitute provider. It is regularly used to calculate a reasonable cost for energy originated by cogenerators or other energy makers that meet with the public regulation. The utilization of avoided cost rates is expected to counteract wastage and enhance proficiency by protecting fair prices from RES and small cogenerators*.132.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Case Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>Alabama Power</td>
</tr>
<tr>
<td>Program Name/Rate Design</td>
<td>Alabama Power Family Dwelling Residential Service &amp; and Purchase of Alternative Energy (PAE)</td>
</tr>
<tr>
<td>Geography/Location</td>
<td>Birmingham, USA</td>
</tr>
<tr>
<td>Customers Participating</td>
<td>Less than 100 at the present, 1.2 million utility residential customers</td>
</tr>
<tr>
<td>Fixed Charges</td>
<td>$14.50/month, additional $5/kW-month of PV capacity for customers on rate PAE</td>
</tr>
<tr>
<td>Demand Charges</td>
<td>None, no impact on results</td>
</tr>
<tr>
<td>Energy Charges</td>
<td>$0.111/kWh &amp; exports earn $0.0316/kWh (June–Sept), $0.0288/kWh (October–May)</td>
</tr>
<tr>
<td>Customer PV Array Size Analysed</td>
<td>4 kW (35% of household demand)</td>
</tr>
</tbody>
</table>

Table 23: Case 4 Facts. [Source: Rocky Mountain.]

Main results:

<table>
<thead>
<tr>
<th></th>
<th>Default Rate</th>
<th>PV Rate</th>
<th>+AC</th>
<th>+EV</th>
<th>+DHW</th>
<th>+Dryer</th>
<th>+Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Charge</td>
<td>$2,087</td>
<td>$1,559</td>
<td>$1,555</td>
<td>$1,413</td>
<td>$1,395</td>
<td>$1,395</td>
<td>$1,366</td>
</tr>
<tr>
<td>Customer Charge</td>
<td>$174</td>
<td>$424</td>
<td>$424</td>
<td>$424</td>
<td>$424</td>
<td>$424</td>
<td>$424</td>
</tr>
<tr>
<td>Demand Charge</td>
<td></td>
<td></td>
<td>-$58</td>
<td>-$58</td>
<td>-$45</td>
<td>$20</td>
<td>$408</td>
</tr>
<tr>
<td>Total DF Costs</td>
<td></td>
<td></td>
<td>-$58</td>
<td>-$58</td>
<td>-$45</td>
<td>$20</td>
<td>$408</td>
</tr>
<tr>
<td>Total PV Costs</td>
<td></td>
<td></td>
<td>$914</td>
<td>$914</td>
<td>$914</td>
<td>$914</td>
<td>$914</td>
</tr>
<tr>
<td>Total Costs</td>
<td>$2,261</td>
<td>$2,897</td>
<td>$2,834</td>
<td>$2,693</td>
<td>$2,688</td>
<td>$2,753</td>
<td>$3,112</td>
</tr>
</tbody>
</table>

Table 24: Case 4 Results. [Source: Rocky Mountain.]
Main conclusions:

- **On-site consumption impacts:** Just little PV frameworks approach cost-adequacy under the Alabama Power's PV rate structure on account of the solar PV particular limit charge. DF can increment on location utilization from little frameworks from 64% without smart loads to more than 93%. That is to say, it practically does not export any energy.

- **Cost-effective DF strategies:** DF from AC and DHW controllers are most cost-effective. EV charging is likewise financially savvy yet speaks to a littler load-shifting potential given the little PV volume. Dryers and energy storage batteries are not profitable, mainly because of the little PV system and the subsequent constrained potential for load-shifting in the wake of applying other adaptability levers.
Figure 51: Case 4 Results: Demand Flexibility Strategies. [Source: Rocky Mountain.]

- **Customer bill saving**: Because of low retail rates, small array size (4 kW) and a moderate capacity factor (18.4%) for solar PV in Alabama, housetop photovoltaic system is scarcely profitable at present installation costs, indeed, even under rate structures that would be beneficial for PV, for example, no fixed charges for solar PV or net energy metering (NEM). Thus, regarding PAE program of Alabama Power with its avoided costs compensations and the generally high solar PV quotas, a customer without photovoltaic system and in the default rate will not get profitability of this investment nowadays. For example, the cost penalty of integrating a solar PV system is $636/year in the customer bill, however if DF strategies are implemented this penalty diminishes to $427/year, this bad results are also because of the non-bypassable capacity charge. Be that as it may, for a client with a current PV framework, DF innovations can decrease net service charges by $209/year which means an 11% of total bill.

- **Market sizing**: As it is exposed in the analysis this new rate with solar PV is not profitable nevertheless both photovoltaic systems and the rest of demand flexibility technologies continue going cheaper, that is why supposing that PV systems costs are diminishing a 10% each year and the service rates are increasing annually a 3% it is possible to estimate that household PV will achieve the parity in 2023, and solar PV plus DF technologies will get it in 2020. Furthermore, if the system becomes self-consuming so the PV charge eluded the parity will be achieve in 2018. Thus if in 2020 all Alabama Power customers integrate solar PV the net bill savings can be $210 million per year, which implies an investment for vendors of $230 million ($400/home), and a rooftop PV market of up to 2.9 GW, which means $10 billion of investment.
8. CONCLUSIONS

8.1. CONCLUSIONS

6 main recommendations are raised derived from the analyzes carried out by the recognition of a more active role of the distributor and consumer, the integration of new technologies in the distribution network or the correct allocation of incentives in order to ensure efficient operation of the net.

1. **Improve prices and regulated charges for electricity services.**

   The only way to bring into play all resources, both distributed and centralized, achieving an efficient operation and planning of the electricity system, involves improving both the prices associated with the electricity services offered and the regulated charges associated with them.

   The measures that would allow to cover these objectives would be the following:

   - Minimize the distortions due to those charges designed for the collection of taxes and the recovery of the costs of energy policies. These costs must come out of the tariff and be recovered by other mechanisms.
   - Rates and charges cannot be variable, nor should solutions of “net balance” type be applied.
   - Do not distort the price signal of electricity. The aids for certain types of clients, such as vulnerable or industrial clients, must be made without altering the prices or charges that are applicable. Subsidies outside the tariff would be the appropriate mechanisms.
   - Massively deploy smart meters, with the aim of real electricity injections and extractions from the network determine the payment to be made by users, that is to say, the real use of the grid.

2. **Improve the regulation of distribution activity.**

   The regulatory framework in which the distributing companies carry out their activity must be improved, allowing the implementation of new, more efficient and innovative business models.

   The measures that are intended to be carried out would be the following:

   - Allocation of incentives that depend on the services provided by the utilities, aimed at rewarding improvements in quality, reduction of losses in the network, improvement of interconnection times as well as cost savings in investment operations.
   - Implementation of incentives for long-term innovation to accelerate investments in R&D, as well as to encourage learning about new technologies that may entail, a priori, greater risks for the network.
3. **Minimize the appearance of conflicts of interests.**

A thorough re-evaluation of the structure of the electricity industry must be carried out in order to minimize the appearance of potential conflicts of interests.

To do this, it is needed:

- To make a correct assignment of the main functions that are at the center of the energy markets: network service providers, system operators and market platforms, thus ensuring the correct functioning of the electricity sector.
- Financial independence between activities open to competition and those that are regulated. Sufficient regulatory oversight is acceptable for situations in which the total separation of activities is not possible or inefficient.

4. **Improvement of wholesale electricity market design.**

In order to better integrate self-consumption and to compensate for flexibility by creating a balanced playing field for all technologies, it is necessary to propose an improvement in wholesale market design.

In order to achieve these objectives, it is necessary:

- That the markets allow the realization of transactions as close as possible to real time, in order to reward, among other things, the flexibility of resources.
- To update the format of the offers in the market, with the aim of reflecting the needs of new agents.

5. **Increase the importance of cybersecurity.**

The connection of self-consumption systems, the new intelligent applications and the greater complexity in the electricity markets reinforce the importance of having adequate cybersecurity systems.

For this:

- Solid standards in terms of cybersecurity will be needed for all the devices interconnected to the electricity network.
- In addition, the rapid evolution of possible threats underscores the importance of solutions being developed and implemented quickly and efficiently.

6. **Cost savings through better use of self-consumption.**

The value of self-consumption as a generation of photovoltaic origin and batteries, enormously depends on the geographical location of the facilities.

That is why:

- A standard value cannot be established for all distributed resources. Regulatory initiatives of the "Value of solar" style are erroneous.
- Each location where someone wants to deploy the distributed resources must be analyzed individually.
Photovoltaic and battery installations are more efficient if they are developed on large scale. The small scale is not always the best option.

8.2. FUTURE INVESTIGATION LINES

“Energy Transition: Enabling Technologies for Demand Flexibility, Regulation & Business Models” is a research that can be amplified in different terms:

- The study of the enabling technologies for demand flexibility must be updated as time goes by, regarding current prices, how do they fit into the electricity market, and their impact on the market.
- It would be needed to supervise the current regulation of different countries, such as Asia (China and Japan mainly, and their impact on the market and give recommendations to these measures. In addition, other future investigations lines would be updating EU and USA’s regulation and verifying if they are doing well in order to get maximum benefit of energy transition.
- Finally, it would be a good option to complete the report with more business cases that prove the cost saving that can be obtain with this market model. In addition, up-to-date business cases would be analyzed to test the current profitability of the investments in the market.
9. IMPACT VALUATION. SOCIAL AND PROFESSIONAL RESPONSIBILITY

9.1. SOCIO-ECONOMIC IMPACT

The energy transition that is analysed in this report directly impact in social and economic issues because it covers the assembling of a new energy market through the development of novel technologies with the objective of reaching a more stable, secure and interconnected energy system.

The social and economic impacts can be segmented in four different issues:

- First of all, the new market design will finish with the traditional vision of a vertical system where suppliers generate the energy and the customers consume it. With this new design demand size, it is every person that needs energy, becomes active participant in the market. Now clients can generate energy for self-consumption with rooftop PV, and can export energy to the market when it is required.

- Secondly, the technology innovations needed to develop the energy transition are leading to a huge technologic growth that not just enables the new energy market but enables many other areas of the society. Furthermore, as it was exposed in the business cases, the vendors of these technologies can take advantage of this situation which means a very profitable investment for them.

- Thirdly, as it has been seen in the business cases savings to the grid are ensured, this new model greatly reduce the costs of transmission due to the decreasing in peak loads.

- Finally, blackouts in the grid are greatly reduced due to the interconnection of the network, the importance of demand flexibility that improves the parity between generation and consumption. This follows to a more secure and reliable electric grid.

9.2. ENVIRONMENTAL IMPACT

The generation of electrical energy involves the emission of different pollutants depending on the type of power plant used, with the highest levels of pollutants being the coal and combined cycle power plants.

In this type of power plants the generation of pollutants is mainly due to two causes:

- On the one hand, the burning of fossil fuels causes gases such as: \( \text{SO}_x \), \( \text{NO}_x \), \( \text{CO}_2 \) and ashes. \( \text{SO}_x \) and \( \text{NO}_x \) that combined with water and oxygen give rise to \( \text{HNO}_3 \) and \( \text{H}_2\text{SO}_4 \), which are responsible for the nutrient impoverishment of the soil and the change of the pH of the water due to its deposition of ions. This effect has the name of acid rain. \( \text{CO}_2 \) that cause the elevation of the average temperature of the planet, the effect called greenhouse effect.
They also raise the temperature of the seas or reservoirs where they empty and produce thermal changes in the liquids used in cooling systems.

Nevertheless, the new energy market is looking for a more eco-friendly generation betting hard on renewable energy sources, even more, regulation, both in USA and EU, is promoting this these generation with public subsidies and imposing taxes to certain levels of pollution.

Currently electricity generation sources are distributed like it is shown in the following graphs:

*Figure 52: Electricity Generation Sources in USA 2017. [Source: U.S. Department of Energy.]*
9.3. SOCIAL AND PROFESSIONAL RESPONSIBILITY

Taking as reference the Deontological Code of Industrial Engineers collected on its official website, this work seeks to meet each of the ethical standards described in the Code:

- Independence: Manifesting objectivity and security in decision making.
- Integrity and honesty: Behaving with honesty and diligence during the performance of services.
- Protection of society and the environment: Giving absolute priority to the safety, health and well-being of society and customers, while seeking to achieve good results while respecting sustainable development.
- Responsibility: Showing a commitment to the actions and opinions given.
- Truthfulness: Contrasting ideas and opinions.
- Advertising: Showing a reliable image of the capabilities.
- Knowledge dissemination: Providing new knowledge for the benefit of society.
- Remuneration and fees: Being fair in terms of hours, work and quality.
10. PLANNING AND BUDGET

10.1. PLANNING

In a very first interaction with the tutor of this final grade project, Isabel Ortiz, the topic was going to be an oil station construction project. The time schedule and first information research was done, nevertheless, the author of this TFG began working in Everis as a fellow focusing on different kinds of project with a common topic: Energy business. That is the reason why this became a really interesting subject and with a lot of potential in the near future, so the topic of the final grade project changed to “Energy transition: Enabling Technologies for Demand Flexibility, Regulation & Business Models”.

After that change, the author and the tutor got the ball rolling and the time schedule was assembled in different stages:

1. Familiarization:

This stage can be considered as the one with the greatest time dedicated, since the topic to be developed in this work requires a deep knowledge of it. This stage represents the very first interaction with the topic, the main concepts of the energy system were studied and understood.

This level is structured in the following way:

- A general information research about the energy business and the energy transition.
- Selection of the most important information.
- Reading and comprehension of the articles selected.
- Structuration of the final degree project after having more knowledge about the energy business and the energy transition.
- Redaction of “Context”.
- After that, a deeper research was done, to get general information about enabling technologies and regulation.

2. Deeper research:

This stage continues the work done in the previous one but adds deepening to the research, analysis of the actual energy system and first recommendation approach to achieve the energy transition.

This stage is structured as follows:

- Getting really interesting and important files from substantiated sources that enable to achieve conclusions about the best technological options of each case.
- Analysing the official articles from USA and EU to understand the actual regulation and offer recommendations that would allow the market to be more secure, efficient and competitive.
- Redaction of “Enabling technologies of Demand Flexibility” and “Regulatory Framework”.
- Finally, raising some interesting business cases that would prove the economic profit of the energy transition.

3. Results and conclusions.

After having studied the previous stages, there is the enough preparation to provide proper results, recommendations and conclusions.

Thus, this level is organized as follows:

- Providing results to the raised business cases and giving recommendations and conclusions about which is the best investment and why.
- Redaction of “Business Cases”,
- Analysing the whole project on balance and offering conclusions on this investigation work.


After having developed the previous steps the different sections of the present report are carried out. These chapters are those corresponding to the planning and budget, evaluation of the social and environmental impact, etc.

Prior to the delivery of the report, a complete review of this work is made.

5. Trabajo Fin de Grado defence.

Prior to the TFG's own defence, a preparation of the same is required.

In the following table activities that have been done are shown:
<table>
<thead>
<tr>
<th>Activities</th>
<th>Start date</th>
<th>End date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiarisation</td>
<td>25/01/2018</td>
<td>31/03/2018</td>
</tr>
<tr>
<td>Everis proposal</td>
<td>25/01/2018</td>
<td>25/01/2018</td>
</tr>
<tr>
<td>Reunion with the tutor</td>
<td>27/01/2018</td>
<td>27/01/2018</td>
</tr>
<tr>
<td>Studying general knowledge about the energy market</td>
<td>27/01/2018</td>
<td>15/02/2018</td>
</tr>
<tr>
<td>Structuring the project</td>
<td>10/02/2018</td>
<td>15/02/2018</td>
</tr>
<tr>
<td>Researching information</td>
<td>8/02/2018</td>
<td>20/03/2018</td>
</tr>
<tr>
<td>Selecting information</td>
<td>20/03/2018</td>
<td>25/03/2018</td>
</tr>
<tr>
<td>Redaction of “Context”</td>
<td>25/03/2018</td>
<td>31/03/2018</td>
</tr>
<tr>
<td>Deeper research</td>
<td>01/04/2018</td>
<td>19/06/2018</td>
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<tr>
<td>Analysing enabling technologies</td>
<td>01/04/2018</td>
<td>01/05/2018</td>
</tr>
<tr>
<td>Results and conclusions of enabling technologies</td>
<td>01/05/2018</td>
<td>07/05/2018</td>
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<tr>
<td>Redaction of “Enabling technologies of Demand Flexibility”</td>
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<td>Analysing regulations</td>
<td>05/05/2018</td>
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</tr>
<tr>
<td>Results and conclusions of regulations</td>
<td>05/06/2018</td>
<td>12/06/2018</td>
</tr>
<tr>
<td>Redaction of “Regulatory Framework”</td>
<td>12/06/2018</td>
<td>19/06/2018</td>
</tr>
<tr>
<td>Results and Conclusions</td>
<td>01/07/2018</td>
<td>15/09/2018</td>
</tr>
<tr>
<td>Studying and reflecting on the researches</td>
<td>01/07/2018</td>
<td>25/07/2018</td>
</tr>
<tr>
<td>Researching and calculating business cases</td>
<td>15/07/2018</td>
<td>31/07/2018</td>
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<td>Redaction of “Business cases”</td>
<td>31/07/2018</td>
<td>07/08/2018</td>
</tr>
<tr>
<td>Results and conclusions of the whole project</td>
<td>01/09/2018</td>
<td>15/09/2018</td>
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<tr>
<td>Final report redaction</td>
<td>15/09/2018</td>
<td>28/10/2018</td>
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<tr>
<td>Redaction of the rest of the sections</td>
<td>15/09/2018</td>
<td>25/09/2018</td>
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<tr>
<td>Revision</td>
<td>25/09/2018</td>
<td>31/10/2018</td>
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<td>Summary in Spanish</td>
<td>20/09/2018</td>
<td>28/10/2018</td>
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<td>TFG defence</td>
<td>15/11/2018</td>
<td>05/12/2018</td>
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<td>TFG defence preparation</td>
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<td>TFG defence</td>
<td>05/12/2018</td>
<td>05/12/2018</td>
</tr>
</tbody>
</table>

*Table 25: TFG planning. [Source: Own.]*
Figure 54: Gantt diagram. [Source: Own.]
10.2. BUDGET

In order to estimate the costs incurred in carrying out the TFG, only the resources used for their own development will be considered. The economic analysis will be divided into two parts: costs of human resources and costs of material resources.

10.2.1. Costs of human resources

The cost estimate associated with the project's human resources is based on the tasks specified and their duration in the temporal planning of the activities. An average salary of 12€/h has been set for the student equivalent to the remuneration of a fellow at Everis, 35€/h to the university tutor as a teacher and 35€/h to the Everis tutor as a consultant.

<table>
<thead>
<tr>
<th>Human Resources</th>
<th>Hours</th>
<th>Price(€)/Hour</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information research</td>
<td>136</td>
<td>12</td>
<td>1.632 €</td>
</tr>
<tr>
<td>Information analysis</td>
<td>176</td>
<td>12</td>
<td>2.112 €</td>
</tr>
<tr>
<td>Study, Results and Conclusions</td>
<td>176</td>
<td>12</td>
<td>2.112 €</td>
</tr>
<tr>
<td>Report redaction</td>
<td>216</td>
<td>12</td>
<td>2.592 €</td>
</tr>
<tr>
<td>Student costs</td>
<td>704</td>
<td>12</td>
<td>8.448 €</td>
</tr>
<tr>
<td>Research help</td>
<td>50</td>
<td>35</td>
<td>1.750 €</td>
</tr>
<tr>
<td>Guide in analysis</td>
<td>30</td>
<td>35</td>
<td>1.050 €</td>
</tr>
<tr>
<td>Revision</td>
<td>30</td>
<td>35</td>
<td>1.050 €</td>
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<tr>
<td>Everis tutor costs</td>
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<td>Project help</td>
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<td>University tutor costs</td>
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<tr>
<td><strong>Human Resources Total Costs</strong></td>
<td></td>
<td></td>
<td><strong>13.698 €</strong></td>
</tr>
</tbody>
</table>

Table 26: Human resources costs. [Source: Own.]

10.2.2. Costs of material resources

This section includes the price of research file licenses, the price of registration for 12 ECTS and the costs associated with printing and binding. It has been ruled out to include costs that are difficult to quantify, such as electricity consumption, transport costs or air conditioning in the workplace.
### Table 27: Material resources costs. [Source: Own.]

<table>
<thead>
<tr>
<th>Material Resources</th>
<th>Price(€)</th>
<th>Amortization(€)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software license (Office 2016)</td>
<td>149</td>
<td>50</td>
<td>50 €</td>
</tr>
<tr>
<td>Researches licenses</td>
<td>2000</td>
<td>500</td>
<td>500 €</td>
</tr>
<tr>
<td>Personal computer</td>
<td>1150</td>
<td>230</td>
<td>230 €</td>
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<tr>
<td>TFG registration</td>
<td>156</td>
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<td>156 €</td>
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<tr>
<td>Printing and binding</td>
<td>70</td>
<td></td>
<td>70 €</td>
</tr>
<tr>
<td>Human Resources Total Costs</td>
<td></td>
<td></td>
<td>1.006 €</td>
</tr>
</tbody>
</table>

**10.2.3. Project final cost**

Final cost of the TFG is calculated as the addition of the human resources and material resources costs and the addition of a 21% of the IVA.

### Table 28: Project final costs. [Source: Own.]

<table>
<thead>
<tr>
<th>Budget</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Resources</td>
<td>13.698 €</td>
</tr>
<tr>
<td>Material Resources</td>
<td>1.006 €</td>
</tr>
<tr>
<td>Cost without IVA</td>
<td>14.704 €</td>
</tr>
<tr>
<td>IVA (21%)</td>
<td>3.087,84 €</td>
</tr>
<tr>
<td>Total budget</td>
<td>17.791,84 €</td>
</tr>
</tbody>
</table>

Therefore, Final budget for the development of this Trabajo Fin de Grado is: **17.791,84 €**.
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