Estudio de la producción y consumo responsable en el marco del desarrollo sostenible

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DECLARA

Que la presente tesis doctoral titulada “Estudio de la producción y consumo responsable en el marco del desarrollo sostenible”, llevada a cabo por Gustavo Piñeiro Villaverde, y realizada bajo mi supervisión dentro del Programa Oficial de Doctorado de Análisis Económico y Estrategia Empresarial, reúne los requisitos para su depósito y optar al grado de doctor.

A Coruña, 23 de Mayo de 2022

Fdo. María Teresa García Álvarez

La presente tesis doctoral se ha realizado por Gustavo Piñeiro Villaverde en la Universidade de A Coruña y bajo la dirección de la Dra. María Teresa García Álvarez.

Y para que así conste, firman el presente documento.

A Coruña, 23 de Mayo de 2022

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RESUMEN

El objetivo de la presente tesis doctoral es obtener una mejor comprensión de los factores que determinan el desarrollo de patrones de producción y consumo sostenibles (PCS) en la Unión Europea (UE). Debido a que el sector energético es el mayor productor de emisiones de dióxido de carbono (CO_2), un especial énfasis se realizará en su estudio en diversos aspectos de la investigación.

La revisión de la literatura pone de manifiesto una serie de necesidades y carencias que permiten definir los objetivos específicos de la investigación. En este contexto, se analiza si la orientación a la sostenibilidad es un factor impulsor de la innovación en las empresas de servicios públicos. Asimismo, se identifican los principales factores que definen la PCS en la UE-28 y sus vínculos con la productividad de los recursos. Finalmente, se analizan los efectos de políticas climáticas, tanto de oferta como de demanda, en las emisiones de CO_2 en el sector eléctrico.

Los resultados muestran cómo la orientación a la sostenibilidad conlleva mayores innovaciones, se identifican los principales factores que definen la PCS (economía circular- de reciclaje, consumo de recursos y uso sostenible de recursos) y se muestra qué políticas específicas de cambio climático reducen las emisiones de CO_2. A partir de tales resultados, se proponen políticas específicas a los *policy-makers*.

RESUMO

O obxectivo da presente tese doutoral é obter unha mellor comprensión dos factores que determinan o desenvolvemento de patróns de produción e consumo sostibles (PCS) na Unión Europea (UE). Debido a que o sector enerxético é o maior produtor de emisións de dióxido de carbono (CO_2), unha especial énfase realizarase no seu estudo en diversos aspectos da investigación.

A revisión da literatura pon de manifesto unha serie de necesidades e carencias que permiten definir os obxectivos específicos da investigación. Neste contexto, analízase se a orientación á sustentabilidade é un factor impulsor da innovación nas empresas de servizos públicos. Así mesmo, identifícanse os principais factores que definen a PCS na UE-28 e os seus vínculos coa produtividade dos recursos. Finalmente, analízanse os efectos de políticas climáticas, tanto de oferta como de demanda, nas emisións de CO_2 no sector eléctrico.

Os resultados mostran como a orientación á sustentabilidade conleva maiores innovacións, identifícanse os principais factores que definen a PCS (economía circular-de reciclaxe, consumo de recursos e uso sostible de recursos) e móstrase que políticas específicas de cambio climático reducen as emisións de CO_2. A partir de tales resultados, propóñense políticas específicas aos *policy- makers*.

ABSTRACT

The objective of this doctoral thesis is to obtain a better comprehension of the factors that determine the development of both sustainable consumption and production (SCP) in the European Union (EU). As the energy sector has been the main producer of carbon dioxide emissions (CO_2), a special emphasis in its study is made in different issues of the present research.

The literature review shows various needs and shortcomings that allow to define the specific objectives of the research. In this context, it is analysed if sustainability-orientation is a driver of innovation in utilities. Likewise, the main factors that define SCP in the EU-28 are identified, as well as their links with resource productivity. Finally, the effects of both offer and demand climate policies on CO_2 emissions in the electricity sector are analysed.

The results suggest that sustainability orientation result in greater innovations. Likewise, the main factors that define SCP are identified (recycling-circular economy, resources consumption and sustainable use of resources). Finally, it is shown what specific climate policies reduce CO_2 emissions. From these results, specific policies are proposed for policy-makers.

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1 Introducción

1.1 Motivación

La importancia de desarrollar patrones de producción y consumo sostenible (PCS) ha sido ya mostrada en el marco de las Mesas Redondas Europeas para la Producción Limpia, en el Simposio de Oslo, en el año 1994. En este contexto, se define PCS como "el uso de servicios y productos relacionados, los cuales responden a necesidades básicas y traen una mejor calidad de vida mientras minimizan el uso de recursos naturales y materiales tóxicos, así como, las emisiones de residuos y contaminantes sobre el ciclo de vida del servicio o del producto; por lo que no pone en peligro las necesidades de generaciones futuras" (Ministerio de Medio Ambiente de Noruega, 1994, p. 5).

El concepto de PCS fue posteriormente reconocido en el Plan de Aplicación de Johannesburg, en el año 2002, en la Cumbre Mundial sobre el Desarrollo Sostenible. En este caso, se enfatiza la necesidad de implementar importantes cambios en la forma en que las sociedades consumen y producen para poder lograr un desarrollo sostenible. Más específicamente, se establece "el apoyo y promoción de programas marco de 10 años (10YFP) para el desarrollo de iniciativas regionales y nacionales que permitan acelerar el cambio hacia la producción y el consumo sostenible para promover el desarrollo económico y social dentro de la capacidad de carga de los ecosistemas" (Naciones Unidas, 2002, p. 7). Tales programas marco de 10 años sobre patrones de producción y consumo sostenible fue adoptado en la Conferencia Rio+20 (Naciones Unidas, 2012, párrafo 226).

Más recientemente, la Agenda 2030 para el Desarrollo Sostenible, adoptada en el año 2015, establece 17 objetivos y 169 medidas. El Objetivo número 12 busca asegurar patrones de PCS. Para ello, se establece que "Nosotros (los países) nos comprometemos a hacer cambios fundamentales en la forma en que nuestras sociedades producen y consumen bienes y servicios" (Naciones Unidas, 2015, p. 24). La finalidad es conseguir, entre otros, los siguientes objetivos prioritarios en el año 2030: gestión sostenible y uso eficiente de recursos naturales, reducción de la generación de residuos mediante la prevención, reducción, reciclaje y reutilización, así como, la provisión de información relevante para el desarrollo sostenible y la adopción de estilos de vida harmoniosos con la naturaleza.

En este contexto, la política de desarrollo sostenible se ha implantado como una política clave en la Unión Europea (UE), que considera los factores sociales, económicos y medioambientales como inseparables e interdependientes. La finalidad de este nuevo marco regulatorio es satisfacer las necesidades de las generaciones actuales sin poner en peligro la capacidad de las generaciones futuras de satisfacer las suyas propias.

Para ello, la UE ha integrado diversas acciones de desarrollo sostenible en la Estrategia de Desarrollo Sostenible de la Unión Europea y el Plan de Acción de Tecnologías Medioambientales; para las cuales la producción y el consumo sostenible son cuestiones prioritarias. Estos factores son también destacados en la Estrategia Europa 2020 (Consejo de la Unión Europea, 2010a), en la Agenda 2030para el Desarrollo Sostenible (Consejo de la Unión Europea, 2014) y en la Visión Estratégica de la UE 2050 (Consejo de la Unión Europea 2019, 2011a, 2011b) para conseguir los objetivos de sostenibilidad.

PCS tiene como finalidad integrar la sostenibilidad medioambiental con el crecimiento económico, de tal forma que se desvincule la degradación medioambiental del crecimiento económico y se aplique la filosofía de “hacer más con menos”. Esto implica la necesidad de potenciar una economía eficiente en recursos y energía.

Así, PCS maximiza el potencial de las empresas para transformar los desafíos ambientales en oportunidades económicas y proporcionar una mejor oferta de productos/servicios para los consumidores. El objetivo que se persigue es mejorar el comportamiento medioambiental general de los productos a lo largo de su ciclo de vida, aumentar la demanda productos y tecnologías de producción que hayan incorporado mejoras medioambientales y ayudar a los consumidores a tomar sus decisiones de compra proporcionando información medioambiental de los productos.

En este marco, la UE aprueba su Plan de Acción de Consumo y Producción Sostenible y Política Industrial Sostenible (SCP/SIP) en el año 2008 (Comunicación de la Comisión Europea, 2008). Este Plan de Acción incluye una serie de propuestas de PCS, basadas en promover productos eficientes en recursos y respetuosos con el medioambiente, así como concienciar a los consumidores con la finalidad de contribuir a la mejora medioambiental de los productos e incrementar la demanda de productos más sostenibles. Además, tal Plan de Acción tiene como finalidad incentivar a la industria de la UE a obtener ventajas de las oportunidades para innovar.

En este contexto, la innovación se sitúa como un elemento clave en el contexto de la sostenibilidad. La Agenda 2030 para el Desarrollo Sostenible identifica la innovación, entendida como nuevas formas de práctica y organización sociales, así como productos y procesos tecnológicos nuevos o mejores; como un elemento clave no sólo para conseguir el Objetivo 9 (construir infraestructuras resilientes, promover la industrialización inclusiva y sostenible y fomentar la innovación), sino también para la consecución del resto de objetivos marcados en la Agenda 2030 (Consejo de la Unión Europea, 2014).

El estudio de las cuestiones planteadas podría ser especialmente relevante en el caso de sectores con una mayor incidencia en las emisiones de dióxido de carbono (CO_2). En este contexto, destaca el sector energético puesto que es el principal productor de este tipo de emisiones en la UE (más del 80%) (Eurostat, 2021).

En el ámbito de la innovación, uno de los pilares fundamentales para la producción sostenible, es necesario considerar que en el sector energético han acaecido importantes cambios en los últimos años, relacionados primeramente con el proceso de liberalización y, posteriormente, con la sostenibilidad. Ambos factores pueden incidir de forma relevante en el proceso de innovación de las empresas ubicadas en dicho sector. Así, la liberalización conlleva una reorientación de la innovación, desde el ámbito de la cooperación industrial al ámbito individual empresarial, donde las cuestiones económicas adquieren un elemento primordial, así como la selección de proyectos con periodos de amortización más cortos y el desarrollo de innovaciones de productos orientados al cliente (Jamasb y Pollit, 2011). Más aún, la sostenibilidad pasa a situarse como un elemento clave en este sector, tal y como se muestra en los objetivos de política energética de la Unión Europea. Tales objetivos no incluyen únicamente la seguridad de suministro y la competitividad, sino también la protección medioambiental (Consejo de la Unión Europea, 2006). Esto ha conllevado el inicio de prácticas de eco-innovación en el sector, que supone el desarrollo de un enfoque global bajo la etiqueta de innovación orientada a la sostenibilidad (Klewitz y Hansen, 2014).

En este contexto, la presente tesis doctoral aborda el estudio de cómo las empresas energéticas llevan a cabo sus estrategias de innovación en el marco de la liberalización y estudia si la orientación a la sostenibilidad promueve la capacidad de innovación en tales empresas. La existencia de evidencia en este contexto es limitada en el sector energético, utilizando mayoritariamente la metodología del caso, no siendoademás concluyentes sus resultados (Erzurumlu y Yu, 2018; Sagar y Holdren, 2002).

Otro de los retos que debe abordarse es profundizar en la investigación de PCS desde un punto de vista global. A pesar de que existe una amplia investigación relacionada con PCS a nivel sectorial, como en los sectores energético, textil, alimentación, construcción, etc., apenas existe evidencia empírica que permita identificar, desde un punto de vista global, los principales factores impulsores de la sostenibilidad y de la productividad de recursos.

La presente tesis doctoral contribuye en este ámbito mediante la identificación de los principales constructos que definen PCS en la UE-28, así como analizando sus vínculos con la productividad de los recursos, variable considerada como uno de los principales indicadores tradicionales para conseguir el Objetivo de Desarrollo Sostenible 12: Consumo y Producción Sostenible en la Unión Europea.

Finalmente, y tal como se argumentó al inicio de la introducción, el sector energético es considerado como clave en el ámbito de la PCS. En el año 2007, la UE enfatiza en la importancia de garantizar que el aumento de la temperatura media global no supere los niveles pre-industriales en más de 2ºC (Comisión de la Unión Europea, 2007). En este contexto, posteriormente, la UE aprueba el Paquete de Energía y Cambio Climático para 2020, el cual establece las políticas energéticas y climáticas que seguirá la UE hasta dicho año. Tales políticas se basan principalmente en el desarrollo de energía renovables (E-FER), complementado por acciones de eficiencia energética. De forma más concreta, el Paquete de Energía y Cambio Climático para 2020 (Consejo de la Unión Europea, 2010b) establece los siguientes objetivos: (i) reducir en un 20% las emisiones de gases de efecto invernadero (desde los niveles de 1990), (ii) conseguir que el 20% de la energía proceda de fuentes renovables y (iii) mejorar en un 20% la eficiencia energética.

A pesar de que el cambio climático ha sido el principal conductor del Paquete de Energía y Cambio Climático para 2020, los desafíos de la política energética fueron también ampliamente tratados en la UE en dicho ámbito. Así, se establecen los siguientes tres principales objetivos: seguridad de suministro, sostenibilidad y competitividad. Esto lleva a la puesta en marcha de diferentes acciones, desde el punto de vista de la oferta, tales como la promoción de E-FER para conseguir su despliegue a gran escala o el fomento de tecnologías de captura de carbono. Desde el punto de vista de la demanda, la eficiencia energética ha sido el elemento esencial para alcanzar los objetivos establecidos para el año 2020.

Posteriormente, la UE aprueba el Marco sobre Clima y Energía para 2030 (Consejo de la Unión Europea, 2014) con la finalidad de desarrollar un sistema energético más seguro, sostenible y competitivo, que permita a la UE obtener el objetivo de reducción de emisiones de CO_2 en el año 2050. En este contexto, se establecen los siguientes objetivos: (i) reducir en un 40% las emisiones de gases de efecto invernadero (desde los niveles de 1990), (ii) conseguir que el 27% de la energía proceda de fuentes renovables y (iii) mejorar en un 27% la eficiencia energética.

Se insiste, de nuevo, en políticas relacionadas con el desarrollo de E-FER, eficiencia energética y sostenibilidad. Así, este nuevo marco es desarrollado sobre la base del Paquete de Energía y Cambio Climático para 2020 y está en consonancia con la perspectiva a largo plazo establecida en la Hoja de Ruta hacia una economía competitiva con reducidas emisiones de carbono para 2050 (Consejo de la Unión Europea, 2011a) y la Hoja de Ruta de Energía para 2050 (Consejo de la Unión Europea, 2011b).

Más recientemente, en diciembre de 2019, la UE presenta el Pacto Ecológico Verde (Consejo de la Unión Europea, 2019) con la finalidad de conseguir la neutralidad climática para el 2050. Para ello, la UE aprueba un conjunto de propuestas que permitan que las políticas climática, energética, de transporte e impuestos reduzcan las emisiones netas de CO_2 en, al menos, un 55% para el año 2030, con respecto a los niveles de 1990. Adicionalmente, la UE propone incrementar el objetivo vinculante de E-FER en el mix de energía al 40% e incrementa los objetivos de eficiencia energética y los hace vinculantes para conseguir una reducción conjunta del 36%-39% en el consumo de energía primaria y final.

Debido a la importancia que ha dado la UE al sector energético para reducir las emisiones de CO_2, otro de los retos que debe abordarse es profundizar en el efecto que tienen las distintas acciones aprobadas por la UE, tanto desde el punto de la vista de la demanda como de la oferta, en reducir las emisiones de CO_2. La literatura previa, tal y como se comentará en el capítulo 2, se ha centrado principalmente en el análisis único de las políticas de oferta, dejando fuera del estudio la perspectiva de la demanda, no obteniéndose además resultados concluyentes.

1.2 Objetivos

El principal objetivo de la presente tesis doctoral es contribuir a la investigación, en el ámbito de PCS, con la finalidad de obtener una mejor comprensión de los factores que determinan el desarrollo de patrones de producción y consumo sostenibles. Debido a que el sector energético es el mayor emisor de emisiones de CO_2, un especial énfasis se realizará en su estudio en diversos aspectos de la tesis doctoral.

En este contexto, los objetivos específicos que se plantean son los siguientes:

- Analizar si la orientación a la sostenibilidad, en el actual contexto de liberalización, es un factor impulsor de la innovación en las empresas de servicios públicos (donde se incluye el sector energético).
- Analizar si la orientación a la sostenibilidad es un factor impulsor de la innovación en las empresas de servicios públicos (donde se incluye el sector energético).
- Identificar los principales factores que definen PCS en la UE-28, así como sus vínculos con la productividad de los recursos.
- Analizar los efectos de las políticas climáticas, tanto de oferta como de demanda, en la reducción de emisiones de CO_2 en el sector eléctrico.
- Proponer diversas recomendaciones a los *policy-makers*, en el ámbito de la PCS, basadas en los resultados obtenidos en la investigación empírica.

1.3 Metodología

En la presente investigación se han desarrollado tres estudios cuantitativos, utilizándose las metodología de Datos Panel y el Análisis Factorial y Regresiones.

Los datos del primer trabajo de investigación de la presente tesis doctoral, que analiza los efectos de la orientación a la sostenibilidad en los resultados de innovación de las empresas de servicios públicos en España, son extraídos del Panel de Innovación Tecnológica, publicado por el Instituto Nacional de Estadística (INE). Esto ha permitido crear un panel de 82 empresas españolas de electricidad, agua y gas para el periodo 2005-2012.

Por otra parte, en el segundo trabajo de investigación, que identifica los factores que contribuyen a PCS y sus vínculos con la productividad de los recursos, los datos para el análisis de los 28 estados miembros en el periodo 2000-2019 son extraídos a partir de la Oficina Estadística de la Unión Europea (Eurostat),

Finalmente, en el tercer trabajo de investigación, que analiza los efectos de políticas climáticas tanto desde el punto de vista de la demanda como de la oferta sobre las emisiones de CO_2 en el sector eléctrico, los datos son extraídos a partir de la Oficina Estadística de la Unión Europea (Eurostat), lo que permite crear un panel de 28 estados miembros para el periodo 2000-2019.

En el primer y el tercer trabajo de investigación se aplica la metodología de Datos Panel, utilizando el paquete de *software* STATA (v. 12 y 13), y en el segundo trabajo de investigación se utiliza el Análisis Factorial y Regresiones, utilizando el paquete de *software* SPSS (v. 25).

La metodología de Datos Panel incluye una muestra de agentes para un periodo determinado de tiempo. Por tanto, esta técnica combina ambos tipos de datos: dimensión temporal y dimensión estructural. El principal objetivo de esta metodología es capturar la heterogeneidad no observable, ya sea entre los agentes (individuos, empresas, países), así como también en el tiempo; puesto que dicha heterogeneidad no se puede detectar con estudios de series temporales ni con estudios de corte transversal (Baronio y Bianco, 2014). Por tanto, esta técnica permite realizar un análisis más dinámico al incorporar la dimensión temporal de los datos.

Asimismo, la metodología de Datos Panel permite analizar dos cuestiones especialmente relevantes cuando se opera con este tipo de información y que forman parte de la heterogeneidad no observable: (i) los efectos individuales específicos y (ii) los efectos temporales (Baronio and Bianco, 2014; Arellano, 1992). Los primeros hacen referencia a aquellos efectos que afectan de forma desigual a cada uno de los agentes que conforman la muestra, los cuales son invariables en el tiempo y afectan de manera directa a las decisiones que tomen dichas unidades. Por otra parte, los efectos temporales son aquellos que afectan por igual a todas las unidades individuales del estudio.

Por otra parte, el Análisis Factorial es una técnica de reducción de la dimensionalidad de los datos. Su objetivo es buscar el número mínimo de dimensiones capaces de explicar el máximo de información contenida en los datos.Mediante el Análisis Factorial, frente a otros métodos (como el análisis de varianza o el de regresión), todas las variables del análisis son independientes -en el sentido de que no existe a priori una dependencia conceptual de unas variables sobre otras-. Más específicamente, el objetivo del Análisis de Componentes Principales es simplificar la información que da una matriz de correlaciones para hacerla más fácilmente interpretable.

Con respecto al análisis de regresión, se ha aplicado el Método de Regresión Paso a Paso, como complemento del Análisis Factorial, cuyo objetivo es encontrar, entre todas posibles variables explicativas, aquéllas que expliquen mejor la variable dependiente sin ser una combinación lineal de las demás. En cada paso es introducida solo la variable que cumple los criterios de entrada, analizado el valor p asociado con el estadístico t (si $p<0,05$, la variable es introducida) (Rodríguez-Jaume y Mora-Catalá, 2001).

1.4 Estructura de la tesis

La estructura de la presente tesis doctoral está formada por 4 capítulos, junto con el resumen de la investigación y las referencias bibliográficas.

Este Capítulo 1 incluye una explicación de la investigación, contextualizando la importancia de la misma en la actualidad, así como la motivación y objetivos de la presente tesis doctoral. A continuación, se muestra la sección de metodología, que contiene una explicación de las métodos utilizados en la investigación, así como una sección adicional que recoge la estructura de la tesis.

En el Capítulo 2 se presenta una revisión de la literatura en cuanto a los ámbitos analizados en la presente tesis doctoral. Así, se presenta el estado del arte en cuanto al estudio de los efectos de la liberalización y la orientación a la sostenibilidad en el proceso de innovación. Esta cuestión es especialmente relevante para obtener una mejor comprensión de la innovación, factor primordial para conseguir los objetivos de la Agenda 2030 para el Desarrollo Sostenible. Asimismo, se identificarán, mediante la revisión de la literatura, los factores que determinan patrones de PCS, así como los efectos específicos de políticas climáticas concretas encaminadas a reducir las emisiones de CO_2. Finalmente, se extraen las principales conclusiones obtenidas a partir de la revisión de la literatura, que permitirá justificar la investigación realizada en la presentes tesis doctoral

El Capítulo 3 muestra una sección de discusión y conclusión general de los resultados obtenidos en la tesis doctoral, así como el desarrollo de una serie de propuestas de recomendación específicas realizadas a los *policy-makers,* con la finalidad de mejorar la situación en PCS en la UE. Asimismo, se hace referencia a las limitaciones de la investigación, así como a las líneas futuras que se abordarán en la investigación.

Finalmente, el Capítulo 4 recoge las tres publicaciones originales de la presente tesis doctoral, donde se presentan los resultados obtenidos en el marco de este trabajo de investigación. Tales resultados se describen a través del compendio de tres trabajos de investigación publicados en revistas internacionales indexadas en el *Journal of CitationReport.*

2 Estado del arte

En este capítulo se presenta una revisión del estado del arte relacionado con el trabajo de la tesis doctoral, prestando especial atención a los factores que influyen en PCS, con la finalidad de realizar posteriormente diversos análisis empíricos que permitan evaluar la situación de la UE en este ámbito, así como proponer políticas de recomendación, si es necesario, para cumplir con los objetivos de sostenibilidad.

Debido a la importancia que tiene el sector energético en este contexto, puesto que es el principal productor de emisiones de CO_2 en la UE, la revisión de la literatura se centrará en el análisis de diversos aspectos de PCS aplicados a este sector.

2.1 Innovación y sostenibilidad

La innovación ha sido considerada como un elemento clave en el campo de investigación de PCS. Para analizar los efectos del actual marco de sostenibilidad sobre la innovación en las empresas energéticas, es necesario partir de los cambios esenciales que han conllevado los procesos de liberalización acaecidos en este sector sobre dicha decisión.

Así, el sector energético, en particular, y el sector de las *utilities* (empresas de servicios públicos), en general, han estado sujetos tradicionalmente por una elevada regulación, intervención pública directa e incluso titularidad pública, que ha conllevado que el riesgo de las decisiones de innovación se situara en el cliente (Munari, Roberts y Sobrero, 2002; International Energy Agency, 1994). Estos sectores se han caracterizado por una escasa innovación de productos, en comparación con las empresas que operan en entornos no regulados. Sin embargo, las innovaciones de proceso fueron mucho más comunes y fueron consideradas una cuestión técnica. Markard, Truffer e Imboden (2004) describen dicho régimen tecnológico para el caso de la industria de suministro de electricidad, indicando: “En tiempos de monopolio, la toma de decisiones se orientaba principalmente a la calidad técnica y la seguridad desuministro. Las inversiones en la red, por ejemplo, se llevaron a cabo de acuerdo con un cronograma fijo y regular, y las empresas trataron de lograr el mejor estándar técnico disponible. Los costes o retornos financieros jugaron un papel más bien menor. Los consumidores de electricidad se consideraban principalmente desde un punto de vista técnico” (Markard, Truffer e Imboden, 2004, pp. 204-205). Asimismo, los gobiernos lideraron programas de investigación y desarrollo (I&D) a largo plazo, mientras que las empresas de servicios públicos cooperaron en el desarrollo de nuevos conocimientos a través de centros tecnológicos conjuntos, proyectos de demostración y diferentes acuerdos de colaboración (Bell y Schneider, 1999; Thomas, 1996; McGowan, 1993).

Sin embargo, la liberalización en estos sectores (electricidad, gas, agua) cambia las reglas de juego del entorno competitivo tradicional. De esta forma, la reestructuración sectorial, la privatización, el establecimiento de nuevos regímenes regulatorios y/o la introducción de la competencia han transferido la mayor parte del riesgo de los clientes a los propietarios. Por tanto, es de esperar que todas estas reformas favorables al mercado tengan un importante efecto en el comportamiento innovador de las empresas de servicios públicos, fomentando la innovación empresarial (Markard y Truffer, 2006). Sin embargo, esto conlleva la eliminación de la cooperación en toda la industria, una mayor preferencia por los proyectos con períodos de recuperación más cortos y un producto orientado al cliente (Jamasb y Pollit, 2008). En este contexto, la investigación se centra básicamente en analizar los cambios en el volumen sectorial de recursos de I&D, obteniéndose una importante unanimidad en cuanto a la reducción de las inversiones sectoriales en I&D en diferentes jurisdicciones después de las experiencias de liberalización (Jamasb y Pollit, 2015; Schmitt y Kucsera, 2014; Erdogdu, 2013; Kim, Kim y Flacher, 2012; Sterlacchini, 2012; Sanyal y Cohen, 2009; Nemt y Kmmen, 2007; Dooley, 1998). Sin embargo, se sabe muy poco sobre cómo las empresas de servicios públicos logran sus estrategias de innovación a nivel de empresa en un entorno liberalizado; es decir, qué actividades (inputs) se necesitan para generar innovaciones (outputs).

Una vez contextualizados los cambios descritos previamente en la innovación, como consecuencia de la liberalización, es necesario considerar los efectos del actual contexto de sostenibilidad sobre las innovaciones en las empresas de servicios públicos.Las presiones para adaptarse a la nueva situación, donde se busca PCS, provienen de casi todas las partes interesadas relevantes: gobiernos y reguladores, organizaciones no gubernamentales, comunidades locales, inversores, empleados, proveedores o clientes. Harvey y Schaefer (2001) identificaron los *stakeholders* con una base de poder institucional (legislación gubernamental y autoridades reguladoras en materia medioambiental) como los más influyentes en la decisión de innovar. Es necesario también considerar la influencia de las organizaciones no gubernamentales sobre los gobiernos y las empresas (Boström y Hallström, 2010), así como, los informes de sostenibilidad que se están convirtiendo en mecanismos de comunicación con los inversores y el público en general (Stjepcevic y Siksnelyte, 2017).

Las innovaciones de producto y proceso son herramientas disponibles para adaptarse a este nuevo contexto. Así, el diseño de productos verdes puede conllevar el desarrollo de ventajas competitivas en las organizaciones (Kaenzig, Heinzle y Wüstenhagen, 2013). A nivel operativo, los objetivos económicos y medioambientales tienden a converger puesto que la innovación de proceso tiende a estar centrada en la eficiencia técnica (Wehn y Montalvo, 2018).

Las limitadas prácticas iniciales de ecoinnovación han evolucionado lentamente hacia un enfoque más integral, bajo la etiqueta de innovación orientada a la sostenibilidad (Klewitz y Hansen, 2014), que ha conllevado la realización de cambios intencionales en los productos o procesos de las empresas para crear valor social y ambiental, además de retornos económicos (Adams *et al.,* 2016). Este tipo de innovación tiene como objetivo aliviar las tensiones entre los aspectos ambientales, sociales y objetivos financieros de la empresa (Organización para la Cooperación y el Desarrollo Económicos, 2012; Carrillo-Hermosilla *et al*., 2010).

Suárez-Perales *et al.* (2017) establecen que la orientación a la sostenibilidad está asociada con una mayor innovación. Las empresas de servicios públicos integran cada vez más los objetivos de sostenibilidad en sus procesos de innovación. Sin embargo, sigue siendo una pregunta abierta si, en el caso específico de tales empresas, la orientación a la sostenibilidad está impulsando el resultado de la innovación. La evidencia existente de los servicios públicos es limitada, basada en estudios de casos y con resultados no concluyentes (Erzurumlu y Yu, 2010; Sagar y Holdren, 2002). Nash (2009) establece que el Plan de Acción de Consumo y Producción Sostenible y Política Industrial Sostenible (Comunicación de la Comisión Europea, 2008) no establece objetivos obligatorios cuantificables ni fechas para su cumplimiento, lo que puede conllevar que el efecto sobre las innovaciones no sea necesariamente el esperado.

2.2 Producción sostenible y consumo sostenible

Desde un punto de vista global, con la finalidad de llevar a cabo acciones específicas que promuevan el desarrollo de patrones de PCS, una detallada comprensión de los factores que contribuyen a la producción y consumo sostenibles se convierte en un elemento esencial.

En este contexto, Bengtsson *et al.* (2018) identificaron dos enfoques para el estudio de SCP: el enfoque de eficiencia y el enfoque sistémico. El primero se centra en la mejora tecnológica y en la elección informada del consumidor, en el que la promoción de métodos de producción más eficientes es la base. Por otro lado, el enfoque sistémico enfatiza más en cuestiones relacionadas con volúmenes globales de compra, características distributivas, así como cambios institucionales y sociales relacionados.

Haas *et al.* (2015) resaltaron la importancia de incrementar la circularidad de la economía, con el objetivo de conseguir patrones de PCS, utilizando las siguientes estrategias: reciclaje y reutilización de recursos, el cambio de combustibles fósiles a energías renovables, y la reducción del nivel global de consumo de recursos. El reciclaje contribuye a la reducción del consumo de recursos en la economía, cuestión prioritaria en el actual entorno de recursos limitados, puesto que implica el reprocesamiento de residuos al final de su vida útil en productos, materiales o sustancias que pueden reutilizarse en la cadena de producción y consumo. Por otro lado, los combustibles fósiles se convierten, en los procesos productivos, en emisiones de gases de efecto invernadero y otros residuos que no se pueden reciclar en la economía, con los consiguientes problemas ambientales relacionados con el calentamiento global y el cambio climático. De ahí, la importancia de apostar por las fuentes renovables, caracterizadas por estar ampliamente disponibles e implicar un menor impacto ambiental. Finalmente, la reducción del consumo de recursos se convierte también en una acción prioritaria en el actual contexto de recursos limitados.

De manera similar, Nash (2009) realizó un análisis crítico de patrones de PCS en la UE e identificó el uso de recursos, las tecnologías disponibles, el diseño de productos, y la demanda de los consumidores como los principales desafíos a considerar por la Comisión Europea. En este contexto, el consumo inteligente, la producción orientada al ciclo de vida del producto y los programas de acción global fueron las principales acciones desarrolladas por la UE. Así, el consumo inteligente se relaciona con la promoción de la concienciación medioambiental, tanto a productores como a los consumidores, en sus elecciones de producción y consumo respectivamente (ecodiseño y etiquetado). Por otra parte, la producción orientada al ciclo de vida del producto requiere del desarrollo de herramientas para promover la eficiencia de los recursos (sistemas de gestión y auditoría medioambiental). También es necesario considerar que, en la UE, se ha invertido también en el desarrollo de programas de inversión que apoyan el mercado global de outputs medioambientales, tales como la Asociación Internacional para la Cooperación en Eficiencia Energética.

En este contexto, se han producido importantes avances en la producción sostenible, ya que varios productos se han vuelto más eficientes en cuanto a recursos y energía, mientras que el consumo de recursos ha ido aumentado, considerándose éste como uno de los principales retos en la política medioambiental de la UE (Kalmykova, Rosado y Patrício, 2016).

Scholl *et al.* (2010) y Mont y Dalhammar (2005) mostraron la importancia de las etiquetas ecológicas nacionales con el fin de desarrollar un enfoque más integral que integre la sostenibilidad social en instrumentos de consumo sostenible, así como el desarrollo de una base de datos que proporcione información sobre el ciclo de vida relacionado con el impacto económico, social y medioambiental de los productos. Mont y Plepys (2008) resaltan la importancia de la intervención del gobierno para promover que los productores busquen oportunidades comerciales que requieran un menor consumo de recursos en la producción de outputs. Hale (2018) identifica la conciencia ambiental de los consumidores como el principal elemento para crear un consumo sostenible, destacando la necesidad de reforzar el desarrollo de políticas relacionadas con este ámbito.

Además de los aspectos mencionados, múltiples estudios han señalado la importancia y necesidad de inversión en investigación, desarrollo e innovación (I&D&i) tanto desde el punto de vista gubernamental como desde el punto de vista empresarial, para el desarrollo efectivo de medidas encaminadas al logro de PCS. Así, Adedoyin, Alola y Bekun (2020) mostraron que los gastos en I&D, especialmente los destinados a la promoción de energías renovables, mejoran la sostenibilidad medioambiental, mientras que Stevens (2010) denotaba la relevancia del rol del gobierno en el desarrollo de patrones de PCS a través de inversiones e incentivos para I&D. Del mismo modo, la inversión privada en I&D puede hacer una contribución significativa al crecimiento económico sostenible (Zafar *et al.,* 2019; Ravšelj y Aristovnik, 2018).

En este contexto, se puede concluir que no existe unanimidad sobre los principales factores que determinan la sostenibilidad en la UE-28, no existiendo un marco global en este ámbito. Los factores relacionados con acciones específicas fueron identificados en la literatura previa (por ejemplo, economía circular en Figge *et al.*, 2018; Di Maio *et al.*, 2017; Haas *et al.*, 2015; consumo inteligente y producción orientada al ciclo de vida del producto en Nash, 2009; y la intervención gubernamental en Hale, 2018; Mont y Plepys, 2008). Más aún, los trabajos en este ámbito se han centrado principalmente en el análisis de sectores específicos. Así, podemos encontrar varios estudios relacionados con PCS en sectores como la energía (Sáez-Martínez *et al.*, 2016; Herring y Sorrell, 2009), el textil (Gardetti y Torres, 2017; Niinimäki y Hassi, 2011), alimentación (García-Herrero *et al.,* 2018; D´Silva y Webster, 2017), urbanismo (Vergragt y Dendler, 2016), construcción (Luo *et al.*, 2017) o sector servicios (Welford, Young y Ytterhus, 1998), así como análisis centrados únicamente sobre el comportamiento del consumidor y la actitud hacia la sostenibilidad (Lakatos *et al.*, 2008; Young *et al.,* 2009; Tanner y Kast, 2003). De ahí, la necesidad de continuar con la investigación en este ámbito con la finalidad de proporcionar un marco global que permita analizar, de forma conjunta, los factores de PCS.

2.3 Políticas de cambio climático y emisiones de dióxido de carbono

Debido a la importancia que otorga la UE al cambio climático en el ámbito de la PCS, un análisis de los efectos que conllevan las políticas, tanto de oferta como de demanda, sobre las emisiones de CO_2 podrían ser un elemento clave para conocer las fortalezas y debilidades de este tipo de acciones en la sostenibilidad. En este contexto, el sector de la energía muestra una especial relevancia, tal y como se comentó previamente, puesto que es el principal productor de emisiones de CO_2 (más del 80%).

En este campo de investigación, gran parte de la literatura previa, con el fin de evaluar la efectividad del cambio climático y políticas energéticas, ha presentado los efectos de diferentes políticas sobre las inversiones en E-FER o sobre la capacidad de E-FER en la UE. Marques y Fuinhas (2012) analizaron los efectos de las políticas de promoción de E-FER en el desarrollo de tales tecnologías de producción limpia en 23 estados miembros, durante el período 1990-2007, mediante la metodología de datos panel. Sus resultados ponen de manifiesto que algunas políticas de apoyo a las E-FER (obligaciones de cuotas, etiquetado de productos, investigación y programas de desarrollo) no fueron impulsores de tales tecnologías de producción limpias. No obstante, las políticas de incentivos/subsidios (incluidos los sistemas de primas) fueron eficaces en la promoción de E-FER. Por otro lado, Jenner, Groba e Indvik (2013) analizaron los efectos de los sistemas de primas, en 26 estados miembros, en el período comprendido entre 1992 y 2008. Mediante el método de datos de panel, no encontraron evidencia sólida de que la mera existencia de esta política hubiera impulsado el desarrollo de la energía eólica. García-Álvarez, Cabeza-García y Soares (2008) estudiaron los efectos de los sistemas de primas y las políticas de obligación de cuotas en la capacidad instalada de energía solar fotovoltaica en la UE-28 para el período comprendido entre 2000 y 2014. El método fue una regresión de mínimos cuadrados ordinarios combinados agrupados a nivel de país. Sus resultados indicaron que solo los sistemas de primas tuvieron impactos significativos en la capacidad instalada de la energía solar fotovoltaica. No obstante, las principales características de diseño de esta política (tamaño de la tarifa y duración del contrato) no tuvieron un efecto significativo en el desarrollo de dicha tecnología de producción. Sin embargo, Alolo, Azevedo y El Kalak (2020), analizaron el efecto de los sistemas de primas en la inversión en energía eólica y solar fotovoltaica, mediante el método de Datos de Panel, en la UE-27 durante el período 1992-2015. Sus resultados indicaron que la mera existencia de un sistema de primas no conllevaba necesariamente un aumento en la inversión en energía eólica y solar fotovoltaica, pero las características de diseño de tales políticas se situaron como los elementos más importantes para aumentar la inversión en E-FER.

Por tanto, no existe unanimidad acerca de los efectos de las políticas de promoción de E-FER en el desarrollo de tales tecnologías de producción limpias en la UE. Además, una variable *proxy* de la descarbonización en el sector de la energía basada en un incremento de la capacidad de E-FER, en mayor generación de E-FER o en mayor inversión en E-FER puede no ser lo más adecuado. Esto se debe a que un incremento en la capacidad de E-FER sin reducir la generación de electricidad basada en combustibles fósiles no puede ser una solución al cambio climático (Martin y Saikawa, 2017).

En última instancia, desde la perspectiva del cambio climático, la cuestión más relevante es si las políticas desarrolladas son eficaces en la reducción de las emisiones de CO_2, más que en el incremento de E-FER. En este contexto, como muchas variables interdependientes afectan al comportamiento del mercado de electricidad y, por lo tanto, a la evolución de las emisiones de CO_2, varios enfoques han sido utilizados con el objetivo de analizar la contribución de diferentes factores técnicos y socioeconómicos.

Karmellos *et al.* (2016) estudiaron, mediante un modelo de análisis de descomposición, los factores impulsores de emisiones de CO_2 del sector eléctrico en la UE-28 en el período 2000-2012. Para ello, consideraron cinco factores: nivel de actividad, intensidad de electricidad, generación de electricidad, eficiencia energética, combinación de combustibles y comercio de electricidad. Sus resultados mostraron que la reducción de la intensidad de electricidad fue el principal factor en periodos de crecimiento económico, mientras que la contribución del resto de factores se produjo con posterioridad. Del mismo modo, Dogan y Seker (2016) analizaron los efectos de las E-FER y energías que no utilizan fuentes renovables, los ingresos reales y la apertura comercial de las emisiones de CO_2 sobre modelos de curva ambiental de Kutnets, entre 1980 y 2012, utilizando técnicas de estimación de panel. Sus resultados muestran que las E-FER y el comercio redujeron las emisiones de CO_2, mientras que las energías no renovables contribuyeron a la degradación medioambiental.

Por otra parte, Almeida, Nevas, Marques y Patrício (2020) analizaron, mediante el método de datos de panel, los efectos de la regulación medioambiental y la concienciación medioambiental sobre las emisiones de CO_2 en 17 países de la UE (Austria, República Checa, Dinamarca, Finlandia, Francia, Alemania, Grecia, Hungría, Irlanda, Italia, Lituania, Polonia, Portugal, Eslovaquia, España, Suecia y Reino Unido) durante el período de tiempo comprendido entre 1995 y 2017. Los ingresos por impuestos ambientales se utilizaron como proxy de la regulación medioambiental, y el número acumulado de políticas de promoción de E-FER como proxy de la concienciación medioambiental. Los resultados mostraron que ambas variables (regulación y concienciación medioambientales) fueron efectivas para reducir las emisiones de CO_2. Mediante el análisis de descomposición de índices, Rodrigues *et al.* (2020) estudiaron los factores que impulsan las emisiones de CO_2 para la generación de electricidad en la UE durante dos subperiodos: 2000-2007 y 2007-2015.Sus resultados mostraron que cambios en el *mix* de combustibles fósiles, mediante la sustitución de carbón por gas, y mejoras de eficiencia en el uso de la electricidad fueron los principales impulsores de reducciones de emisiones de CO_2 en el período 2000-2007. En el período 2007-2015, el desarrollo de E-FER, así como las mejoras en eficiencia en la producción y uso de electricidad fósil fueron los principales factores que conllevaron reducciones de emisiones de CO_2.

De forma más general, Busu y Nedelcu (2021) estimaron en la UE, durante el periodo 2000-2019, el impacto de las E-FER, la eficiencia bioenergética, los biocombustibles, la urbanización, la población y el producto interior bruto (PIB) per cápita sobre las emisiones de CO_2, utilizando el método de datos de panel. Los resultados mostraron que las tecnologías de producción limpia, así como los factores bioenergéticos estuvieron correlacionados negativamente con las emisiones de CO_2. Sin embargo, la urbanización, la población y el PIB per cápita se correlacionaron positivamente con dichas emisiones.

Además, también se desarrollaron enfoques dinámicos con la finalidad de estudiar cambios dinámicos. En este contexto, Kounetas (2018) analizó, en 23 estados miembros, la dinámica de distribución del consumo de energía y emisiones de CO_2, sus intensidades, así como el índice de carbonización, durante el período comprendido entre 1970 y 2010. El método se basó en la dinámica de distribuciones de sección transversal. Los resultados mostraron que la hipótesis de los patrones de convergencia no era válida. Así, se observaron grandes diferencias en los estados miembros según el tipo de clima con respecto a las variables analizadas. De ahí, la importancia de que las políticas energéticas y climáticas europeas puedan implementarse en términos del paradigma de no convergencia. Del mismo modo, Bąk *et al.* (2021) estudiaron, por medio de métodos jerárquicos, la tendencia de cambios relacionados con la descarbonización energética, así como grupos tipológicos diferenciados de estados miembros con dinámicas similares en este campo de investigación. Se aplicó el análisis a 26 estados miembros (excepto Malta y Reino Unido) entre 2000 y 2018. Sus resultados mostraron que la implementación de la política climática, por parte de los propios países, fue el principal factor en reducir las emisiones de CO_2. Sin embargo, el estudio encuentra dos grupos de estados miembros - aquéllos que eran reacios a reducir dinámicamente las emisiones de CO_2 (países europeos centrales y orientales) y aquellos estados miembros que apoyaron una política climática fuerte (resto de países de la UE)-.

La revisión de la literatura en este ámbito pone de manifiesto que la mayor parte de los estudios se han basado principalmente en políticas climáticas relacionadas con la oferta, no obteniéndose resultados concluyentes, y enfoques que no proporcionan, con precisión, los efectos de cada política específica. Por lo tanto, la necesidad de continuar con la investigación en este ámbito queda justificada por la necesidad de considerar los efectos de políticas, tanto desde el punto de vista de la demanda como de la oferta, analizando su impacto en la reducción de emisiones de CO_2. Este tipo de análisis podría permitir a los *policy-makers* obtener una mejor comprensión de la eficacia de acciones específicas, tanto desde el punto de vista de los productores como de los consumidores.

2.4 Conclusiones del estado del arte: justificación de la investigación

Las conclusiones obtenidas tras revisar el estado del arte en el ámbito de la PCS pone de manifiesto las siguientes cuestiones:

- Necesidad de profundizar acerca de cómo las empresas de servicios públicos (donde se incluyen las empresas energéticas) realizan sus estrategias de innovación a nivel de empresa en un entorno liberalizado.
- Falta de resultados concluyentes acerca de cómo las empresas de servicios públicos orientadas a la sostenibilidad influyen en sus resultados de innovación.
- Ausencia de un marco global en el ámbito de la PCS que permita identificar y analizar las relaciones, de forma conjunta, de los factores que influyen en PCS.
- Necesidad de considerar de forma conjunta, tanto políticas climáticas de oferta como de demanda, para obtener una mejor comprensión de los efectos específicos de acciones de distinto tipo en la reducción de emisiones de CO_2.

La presente tesis doctoral aborda tales necesidades y carencias detectadas con la finalidad de obtener una mejor comprensión de PCS en la UE, que permita proponer, si es necesario, políticas de recomendación a los *policy-makers* en ámbitos concretos y específicos de sostenibilidad.

3 Discusión y conclusiones

3.1 Discusión

El objetivo de la presente tesis doctoral es contribuir a la investigación, en el ámbito de PCS, con la finalidad de obtener una mejor comprensión de los factores que determinan el desarrollo de patrones de producción y consumo sostenibles. Para ello, se han desarrollado tres estudios con análisis empírico, donde se presta una especial atención al sector energético, debido a que se caracteriza por ser el mayor productor de emisiones de CO_2.

En el primer trabajo, se identifican los factores que determinan las innovaciones de producto y proceso de las empresas de servicios públicos en un entorno liberalizado, y se analiza si la orientación a la sostenibilidad, en el actual contexto, es un factor impulsor de la innovación en tales empresas. Los resultados ponen de manifiesto que: (i) la adquisición de conocimiento externo intangible —licencias, patentes y otros inventos— no supone un papel relevante para innovación en empresas de servicios públicos. Esto puede deberse a que el proceso de desregulación en el sector haya sido relativamente débil, tal y como muestran Marino, Parrotta y Valletta (2019), (ii) el resto de las actividades de innovación—I&D, adquisición de maquinaria y otras métodos de búsqueda de conocimiento no formal— son importantes inputs para el éxito del proceso de innovación (tanto de productos como de procesos), (iii) las empresas de servicios públicos utilizan diferentes combinaciones de actividades en ambos tipos de innovaciones (la innovación de productos requiere de capacidades internas de I&D y procesos de búsqueda no formales descendentes y la innovación de procesos necesita de mercados de tecnología —I&D externo y tecnología incorporada en el equipamiento—). Resultados similares son obtenidos en la industria manufacturera por Vega-Jurado, Gutiérrez-Gracia y Fernández-de-Lucio (2009), (iv) no hay evidencia clara que muestre la complementariedad entre I&D interno y la adquisición de conocimiento externo.

Asimismo, en este trabajo de investigación se obtiene que la orientación a la sostenibilidad aumenta la probabilidad de generar innovaciones. De esta forma, las empresas de servicios públicos que declaran que los objetivos de sostenibilidad son relevantes tienden a ser más innovadoras. Estos resultados son similares a aquéllos obtenidos en otras investigaciones (Varadarajan, 2017; Seebode, Jeanrenaud y Bessant, 2012; Nidumolu y Prahalad, 2009), que muestran que la orientación a la sostenibilidad es un impulsor clave de la innovación empresarial, debido a las presiones externas de los diferentes *stakeholders*. Así, los resultados muestran que las empresas de servicios públicos activan la innovación en la búsqueda de soluciones que mitiguen el impacto ambiental o que cumplan con las normas ambientales y de salud y las regulaciones de seguridad. Sin embargo, la orientación a la sostenibilidad no es obtenido como el factor más relevante en la innovación.

En el segundo trabajo se identifican los principales factores que definen PCS en la UE-28, así como sus vínculos con la productividad de los recursos. Los resultados obtenidos permiten identificar tres factores determinantes: economía circular - de reciclaje, consumo de recursos y uso sostenible de recursos. Asimismo, se obtiene que el factor economía circular - de reciclaje tiene un impacto positivo y significativo en la productividad de los recursos. La reutilización y el reciclaje convierten los residuos en productos y materiales utilizables en la cadena productiva o en el ámbito doméstico, lo que contribuye a reducir el consumo de recursos en la economía y esto, a su vez, permite aumentar la productividad de los recursos. Este resultado concuerda con lo señalado por Schroeder, Anggraeni y Weber (2019) y Hass *et al.* (2015). Por tanto, es posible avanzar hacia formas de PCS y aumentar la productividad de los recursos mediante la promoción de prácticas relacionadas con la economía circular y el reciclaje. Estas prácticas, tal como las define la Agencia Europea de Medio Ambiente (2016), pueden estar basadas en: diseño ecológico, reparación, reutilización, renovación, refabricación, uso compartido de productos, prevención de residuos y reciclaje de residuos.

Por otra parte, el análisis realizado sugiere que el factor consumo de recursos tiene un efecto positivo y significativo, aunque en menor medida, sobre la productividad de los recursos. Resultados similares son obtenidos por Hale (2018) y Mont y Plepys (2008), en el sentido de que un uso eficiente de los recursos tenderá a aumentar la productividad de los mismos, lo que permitirá reducir el riesgo de escasez de recursos, con el consiguiente menor impacto medioambiental. Del mismo modo, se obtiene que la inversión pública y privada en I&D permite afrontar la incertidumbre asociada al cambio climático de una manera consistente con el crecimiento económico sostenible, apoyando el cambio tecnológico necesario para tal fin, tal y como indican Baker y Solak (2014).

Finalmente, el factor uso sostenible de los recursos engloba la variables relacionadas con la producción sostenible, especialmente las relacionadas con la energía. Según Zafar *et al.* (2019), es de esperar un efecto positivo de la producción sostenible sobre el crecimiento económico y, por tanto, sobre la variable de productividad de los recursos. Sin embargo, a partir del análisis realizado, no surge una relación significativa, ya que no existe correlación entre este factor y la productividad de los recursos. No obstante, las cargas factoriales indican claramente el efecto positivo del aumento de la cuota de E-FER en la disminución de emisiones CO_2 y de la inversión del ámbito privado en I&D para promover tales tecnologías de producción limpias.

En el tercer trabajo, se analizan los efectos de políticas climáticas de la UE, tanto de oferta como de demanda, en la reducción de emisiones de CO_2 en el sector eléctrico. Los resultados obtenidos muestran que, desde el punto de vista de la oferta, el desarrollo de políticas de promoción de E-FER (sistema de primas y obligación de cuotas), especialmente en el caso de la energía eólica, conlleva una reducción de emisiones de CO_2. Estos resultados son similares a los obtenidos por Yi (2015).

Desde el punto de vista de la demanda, los resultados muestran que la implementación de políticas de impuestos de energía no conllevan un impacto significativo sobre la reducción de emisiones de CO_2. Así, parece que esta política por sí sola no puede promover patrones de consumo de energía más sostenibles o modificar sustancialmente el comportamiento de los hogares de tal forma que conlleve una reducción significativa en el consumo de energía o en las emisiones de CO_2. Resultados similares son obtenidos en estudios previos en los casos de la UE (Sorrell, 2015; De Almeida *et al.*, 2011), así como América Latina (Bersalli, Menanteau y El-Methni, 2020) y EEUU (Yi, 2015).

De forma adicional, los resultados sugieren que la tasa de desempleo y la demanda energética para calefacción influyen en las emisiones de CO_2. En este sentido, un aumento en la tasa de desempleo está asociado con una menor actividad económica y, además, con una reducción de la demanda eléctrica y, por tanto, de las emisiones de CO_2 (Busu y Nedelcu, 2021; Yi, 2015). En el caso del aumento de la demanda de energía para calefacción, se observa en ligero incremento de las emisiones de CO_2, en línea con los resultados obtenidos por Drummond (2010) y Metcalf (2008).

3.2 Implicaciones para la práctica

Los resultados obtenidos en la investigación empírica de los tres trabajos publicados, que conforman la presente tesis doctoral, permiten proponer las siguientes recomendaciones a los *policy-makers*, en el ámbito de PCS:

- Promover el desarrollo de prácticas de economía circular, reciclaje y reutilización, tanto en la propia administración pública (por ejemplo, priorizando el uso de materias primas recicladas en obras públicas), como en la industria (por ejemplo, fomentando la visibilidad y el reconocimiento, por parte de los consumidores, de certificaciones de etiquetas ecológicas, para fomentar que las empresas obtengan las mismas, o exigiéndolas paracontrataciones con la administración), como en los hogares (por ejemplo, impulsando campañas escolares enconsumo responsable, reutilización y reciclaje).
- Mantener y fortalecer el compromiso con las políticas de promoción de E-FER, lo que permitiría reducir la dependencia de las importaciones de combustibles fósiles y, al mismo tiempo, reducir las emisiones de CO_2. Asimismo, tales tecnologías de producción limpias permiten estimular el desarrollo económico verde y asegurar un suministro energético diversificado.
- Incrementar la inversión de I&D&i, puesto que podría contribuir a prácticas relacionadas con la economía circular, mediante la mejora tecnológica continua de los procesos, desde el diseño hasta la fabricación y la recuperación final de los materiales. Además, esta medida podría resultar también en mejoras en eficiencia energética de las instalaciones de generación de electricidad, así como en la reducción de su impacto ambiental.
- Profundizar en el ámbito de la sostenibilidad en los sectores de servicios públicos (electricidad, gas y agua), con la finalidad de promover una mayor innovación (tanto de productos como de procesos) en las empresas ubicadas en tales sectores.
- Profundizar en acciones, desde el punto de vista de la demanda, relacionadas con el consumo sostenible, puesto que la política de impuestos a la energía parece no ser demasiado efectiva en la reducción de la demanda (como se ha demostrado en Bersalli, Menanteau y El-Methni, 2020; Sun *et al.*, 2020; De Almeida *et al.*, 2011; así como en los resultados de la presente tesis doctoral). El refuerzo de acciones en este ámbito podría ser esencial para mitigar las emisiones de CO_2 en

la UE. En este contexto, la adopción de políticas públicas para promover la concienciación medioambiental (por ejemplo, mediante la promoción de campañas escolares sobre el consumo responsable de energía) podría ser una medida complementaria de los impuestos sobre el consumo de energía.

- Fortalecer acciones que permitan incrementar la eficiencia energética, tales como el mantenimiento y mejora de las subvenciones a la eficiencia energética de los edificios existentes, la promoción de edificios de consumo energético muy bajo (viviendas pasivas) o aumentar la inversión para la sustitución de electrodomésticos ineficientes.

Estas recomendaciones están en consonancia con en el enfoque de la Comisión Europea en su Pacto Ecológico Verde (Consejo de la Unión Europea, 2019). Así, las acciones planteadas se ajustan a lo que la Comisión propone en su Comunicación *Un nuevo Plan de Acción de Economía Circular para una Economía Europea más Limpia y Competitiva* (Comisión Europea, 2020), en términos de empoderamiento de los consumidores y compradores públicos, circularidad en los procesos de producción, el establecimiento de requisitos para el uso de materiales reciclados en la construcción o la coordinación de iniciativas en el ámbito de la economía circular a través del Instituto Europeo de Innovación y Tecnología.

3.3 Conclusiones

La prevención y reducción de la contaminación medioambiental, así como la promoción de PCS, han sido cuestiones primordiales en el marco de la Estrategia de Desarrollo Sostenible de la Unión Europea.Estas acciones son especialmente relevantes para asegurar, a largo plazo, la base física de la sociedady de la economía, de tal forma que se respeten los límites tolerables de los recursos del planeta y mejore la protección medioambiental.

La presente tesis doctoral profundiza la investigación en este ámbitode la siguiente forma: (i) análisis de cómo las empresas de servicios públicos (donde se incluyen las empresas energéticas) orientadas a la sostenibilidad influyen en sus resultados de innovación, debido a la falta de resultados concluyentes por la literatura previa, (ii) propuesta de un marco global que permita identificar y analizar las relaciones, de forma conjunta, de los factores que influyen en PCS, debido a que el análisis previo en este ámbito se ha centrado a nivel sectorial, (iii) análisis, de forma conjunta, de políticas climáticas tanto de oferta como de demanda, para obtener una mejor comprensión de los efectos específicos de acciones de distinto tipo en la reducción de emisiones de CO_2, puesto que la literatura previa se ha centrado en el análisis de un único tipo de políticas.

Los resultados de la investigación ponen de manifiesto que la orientación a la sostenibilidad en las empresas de servicios públicos conlleva mayores innovaciones (tanto de producto como de procesos), aunque dicho factor no es el principal impulsor de la innovación. Asimismo, se identifican los principales factores que definen PCS en la UE-28: economía circular-de reciclaje, consumo de recursos y uso sostenible de recursos, así como sus vínculos con la productividad de los recursos. En este contexto, se obtienen que los factores economía circular-de reciclaje y consumo de recursos conllevan un impacto positivo y significativo sobre la productividad de los recursos. Sin embargo, el factor uso sostenible de recursos no conlleva un efecto significativo sobre la productividad de los mismos, siendo necesario reforzar acciones en este ámbito. Finalmente, los resultados muestran que las principales políticas de promoción de E-FER en la UE-28 (sistema de primas y obligación de cuotas) conllevan una reducción de emisiones CO_2, mientras que la política de impuestos a la energía no ha supuesto un impacto significativo sobre la reducción de tales tipos de emisiones.

A partir de los resultados obtenidos, se proponen acciones en ámbitos concretos y específicos de la sostenibilidad a los *policy-makers* con la finalidad de conseguir mayores patrones de PCS en la UE-28.

3.4 Limitaciones y futuras líneas de investigación

La presente tesis doctoral presenta una serie de limitaciones, que es necesario considerar, las cuales son, a su vez, la base para presentar algunas de las futuras líneas de investigación.

En primer lugar, no es posible desagregar el sector de servicios públicos en tres industrias diferentes: electricidad, gas y agua. Aunque las mismas presentan rasgos comunes de las industrias de red, se caracterizan también por tener diferentes características tecnológicas y regulatorias. Por tanto, sería valioso un estudio separado para cada industria, el cual tendrá que basarse en otras fuentes de información.

Asimismo, la base de datos PITEC no permite a los investigadores identificar las empresas. Por tanto, no es posible complementar la información de la empresa con otras fuentes para realizar un análisis más completo.

Por otra parte, es necesario considerar que el primer trabajo de la presente tesis doctoral se ha centrado en la innovación de productos y procesos. Sin embargo, las innovaciones en marketing, organizacionales e incluso de modelo de negocio son otras áreas que podrían ser interesantes de estudiar. En dicho trabajo, tampoco se han considerado factores externos determinantes de la innovación. Por ejemplo, los subsidios y otros mecanismos de apoyo afectan, de forma relevante, a la decisión de innovar. Así, la inclusión de factores externos podría enriquecer el análisis. Otra cuestión relevante en este análisis es que, debido a la cultura organizacional monopolística tradicional, las *utilities* son relativamente nuevas en el paradigma de innovación abierta (Chesbrough, 2003). Sin embargo, muchas grandes *utilities* son ahora participantes comunes en el mercado de empresas de riesgo (*corporate venturing*) externo. Así, las mismas buscan activamente ideas y *startups* que puedan complementar sus portfolio de conocimiento. Esta nueva realidad podría ser considerada para futuras investigaciones.

Con respecto al análisis factorial, el área de investigación de PCS es complejo, con múltiples factores interrelacionados. Con la finalidad de obtener medidas homogéneas de los datos iniciales, se decidió tener en cuenta los valores per cápita de las variables y no los valores absolutos de cada uno de los estados miembros, el estudio no incluye posibles diferencias institucionales, estructurales o de política entre países, lo que puede tener una influencia en los resultados. Por otro lado, dado que la disponibilidad de datos es limitada, en la investigación realizada se decidió considerar la relación entre las variables sin tener en cuenta su evolución a lo largo del tiempo. Una posible línea para futuras investigaciones, dependiendo de la disponibilidad de datos, sería realizar el análisis, aunque sea cualitativo, de la influencia de la variable país, por una parte, y de la variable tiempo, por otra parte, sobre los resultados para determinar si la relación obtenida es consistente.

En cuanto a la metodología de datos panel, es necesario considerar que la muestra no incluye muchos países, lo que puede haber afectado a los resultados. Asimismo, el análisis de los efectos de las políticas de cambio climático, desde el punto de vista de la oferta, relacionadas con los mecanismos de promoción de E-FER podría ser más exhaustiva, ya que el estudio de sus elementos de diseño podrían ser tan importantes para promover las E-FER como la elección de la propia política específica. La investigación futura debería considerar estos temas ampliando el análisis a una muestra más grande, como es el caso de la Organización para la Cooperación y el Desarrollo Económicos (OCDE), con la finalidad de aumentar el número de observaciones. Además, en lo que respecta a la política de oferta de cambio climático analizada, el estudio podría incorporar, en la investigación futura, dos elementos de diseño adicionales (importe y duración del contrato) con el fin de obtener una mejor comprensión de las principales fortalezas y/o debilidades de cada política en la reducción de emisiones de CO_2.

4 Bibliografía común

Bibliografía

Abuín, J.R. (2007). *Regresión Lineal Múltiple*. Madrid, Spain: IdEyGdM-Ld. Obtenido de https://bit.ly/3lgpFVa

Adams, R., Jeanrenaud, S., Bessant, J., Denyer, D. &Overy, P. (2016). Sustainability-oriented innovation: A systematic review. *International Journal of Management Reviews*, 18(2), 180–205. https://doi.org/10.1111/ijmr.12068

Adedoyin, F.F., Alola, A.A. & Bekun, F.V. (2020). An assessment of environmental sustainability corridor: the role of economic expansion and research and development in EU countries. *Science of the Total Environment*, 713, 136726. https://doi.org/10.1016/j.scitotenv.2020.136726

Agencia Europea de Medio Ambiente (2020). *Trends and Projections in Europe 2020. Tracking Progress towards Europe's Climate and Energy Targets*. Luxembourg: Publications Office of the European Union. Obtenido de https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2020

Agencia Europea de Medio Ambiente (EEA) (2016). Circular Economy in Europe—Developing the Knowledge Base. *EEA Report*, 2/2016, European Environment Agency, Copenhagen, Denmark. Obtenido de https://www.eea.europa.eu/publications/circular-economy-in-europe

Agencia Internacional de Energía (IEA) (1994). *Electricity Supply Industry. Structure, Ownership and Regulation in OECD Countries*. Paris, France: OECD.

Almeida Neves, S.A., Marques, A.C. & Patrício, M. (2020). Determinants of CO_2 emissions in European Union countries: does environmental regulation reduce environmental pollution? *Economic Analysis and Policy*, 68, 114–125. 10.1016/j.eap.2020.09.005

Alolo, M., Azevedo, A. & El Kalak, I. (2020). The effect of the feed-in-system policy on renewable energy investments: Evidence from the EU countries. *Energy Economics*, 92, 104998. 10.1016/j.eneco.2020.104998

Alonso, H.C. (2021). Impact of renewable energies on greenhouse gas emissions in Mexico. *Problemas del Desarrollo*, 52, 59–83. https://doi.org/10.22201/iiec.20078951e.2021.204.69611

Arellano, M. (1992). *Introducción al análisis econométrico con datos de panel*. Madrid: Banco de España, Servicio de Estudios. Obtenido de https://repositorio.bde.es/bitstream/123456789/6480/1/dt_9222.pdf

Azapagic, A. & Perdan, S. (2000). Indicators of Sustainable Development for Industry: a general framework. *Process Safety and Environmental Protection*, 78, 243–261. https://doi.org/10.1205/095758200530763

Bąk, I., Barwińska-Małajowicz, A., Wolska, G., Walawender, P. &Hydzik, P. (2021). Is the European Union making progress on energy decarbonisation while moving towards sustainable development? *Energies*, 14(13), 3792. https://doi.org/10.3390/en14133792

Baker, E. & Solak, S. (2014). Management of energy technology for sustainability: how to fund energy technology research and development. *Productions and Operation Management*, 23, 348–365. https://doi.org/10.1111/poms.12068

Baltagi, B. (2008). *Econometric Analysis of Panel Data*. Chichister, UK: John Wiley & Sons.

Baronio, A. & Vianco, A. (2014). *Datos de panel. Guía para el uso de Eviews*. Departamento de Matemática y Estadística de la Facultad de Ciencias Económicas, Universidad de Río Cuarto. Obtenido de https://www.researchgate.net/publication/328812382_Datos_de_Panel_Guia_para_el_uso_de_Eviews

Bell, R.A. & Schneider, T.R. (1999). Balkanization and the future of electricity R&D. *The Electricity Journal*, 12(6), 87–98. https://doi.org/10.1016/S1040-6190(99)00043-3

Bengtsson, M., Alfredsson, E., Cohen, M., Lorek, S. & Schroeder, P. (2018). Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. *Sustainability Science*, 13(6), 1533–1547. DOI: 10.1007/s11625-018-0582-1

Berkhout, P.H.G., Ferrer-i-Carbonell, A. & Muskens, J.C. (2004). The ex post impact of an energy tax on household energy demand. *Energy Economics*, 26, 297–317. https://doi.org/10.1016/j.eneco.2004.04.002

Bersalli, G., Menanteau, P. & El-Methni, J. (2020). Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America. *Renewable and Sustainable Energy Reviews*, 133, 110351. https://doi.org/10.1016/j.rser.2020.110351

Blanchard, P., Huiban, J.P., Musolesi, A. & Sevestre, P. (2013). Where there is a will, there is a way? Assessing the impact of obstacles to innovation. *Industrial and Corporate Chang*e, 22, 679–710. 10.1093/icc/dts027

Boström, M. & Hallström, K.T. (2010). NGO power in global social and environmental standard-setting. *Global Environmental Politics*, 10, 36–59. 10.1162/GLEP_a_00030

Broin, E.Ó., Nässén, J. & Johnsson, F. (2015). Energy efficiency policies for space heating in EU countries: A panel data analysis for the period 1990–2010. *Applied Energy*, 150, 211–223. 10.1016/j.apenergy.2015.03.063f

Busu, M. & Nedelcu, A.C. (2021). Analyzing the renewable energy and CO_2 emission levels nexus at an EU level: A panel data regression approach. *Processes*, 9, 130. https://doi.org/10.3390/pr9010130

Caeiro, S., Ramos, T.B. & Huisingh, D. (2012). Procedures and criteria to develop and evaluate household sustainable consumption indicators. *Journal of Cleaner Production*, 27, 72–91. https://doi.org/10.1016/j.jclepro.2011.12.026

Capros, P., Kannavou, M., Evangelopoulou, S., Petropoulos, A., Siskos, P., Tasios, N., Zazias, G. & DeVita, A. (2018). Outlook of the EU energy system up to 2050: The case of scenarios prepared for European Commission's "clean energy for all Europeans" package using the PRIMES model. *Energy Strategy Reviews*, 22, 255–263. https://doi.org/10.1016/j.esr.2018.06.009

Carrillo-Hermosilla, J., Del Río, P. & Könnölä, T. (2010). Diversity of eco-innovations: Reflections from selected case studies. *Journal of Cleaner Production*, 18(10-11), 1073-1083. https://doi.org/10.1016/j.jclepro.2010.02.014

Cassiman, B. & Veugelers, R. (2006). In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition. *Management Science*, 52, 68–82. 10.1287/mnsc.1050.0470

Chesbrough, H.W. (2003). *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA, USA: Harvard Business Press.

Cohen, W.M. & Levinthal, D.A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35, 128–152. http://dx.doi.org/10.2307/2393553

Comisión Europea (2020). *A New Circular Economy Action Plan for A Cleaner and More Competitive Europe*. Brussels, Belgium: European Commission. Obtenido de https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

Comisión Europea (2007). *Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: Limiting Global Climate Change to 2 Degrees Celsius, the Way Ahead for 2020 and Beyond*. Brussels, Belgium: Commission of the European Communities. Obtenido de https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52007DC0002

Comisión Europea (2000). *Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for the Community Action in the Field of Water Policy*. Brussels, Belgium: European Commission. Obtenidode https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32000L0060

Comisión Europea (2008). Consumption and Production and Sustainable Industrial Policy Action Plan. SEC(2008)2110, SEC(2008) 2111, COM/2008/0397 final. Brussels, Belgium: European Commission. Obtenido de https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52008DC0397

Consejo de la Unión Europea (2019). *The European Green Deal*. COM(2019) 640 Final. Brussels, Belgium: European Commission. Obtenido de https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0004.02/DOC_1&format=PDF

Consejo de la Unión Europea (2011a). *A Roadmap for Moving to a Competitive Low Carbon Economy in 2050*. COM(2011)112. Brussels, Belgium: European Commission. Obtenido de https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:EN:PDF

Consejo de la Unión Europea (2011b). *Energy Roadmap 2050*. COM(2011)885 Final. Brussels, Belgium: European Commission. Obtenido de https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0885:FIN:EN:PDF

Consejo de la Unión Europea (2014). *Energy 2020: A Policy Framework for Climate and Energy in the Period from 2020 to 2030*. COM(2014)15 Final. Brussels, Belgium: European Commission. Obtenido de https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2014:15:FIN

Consejo de la Unión Europea (2010a). *Europe 2020 - A strategy for smart, sustainable and inclusive growth*. COM(2010)2020 final. Brussels, Belgium: European Commission. Obtenido de https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:52010DC2020

Consejo de la Unión Europea (2010b). *Energy 2020: A Strategy for Competitive, Sustainable and Secure Energy*. COM(2010)639. Brussels, Belgium: European Commission. Obtenido de https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0639:FIN:En:PDF

Consejo de la Unión Europea (2006). *Review of the EU Sustainable Development Strategy (EU SDS) - Renewed Strategy*. Brussels, Belgium: European Commission. Obtenido de https://data.consilium.europa.eu/doc/document/ST%2010917%202006%20INIT/EN/pdf

Consejo de Reguladores Europeos de la Energía (2021). *Status Review of Renewable Support Schemes in Europe for 2018 and 2019*. Brussels, Belgium: Council of European Energy Regulators. Obtenido de https://www.ceer.eu/documents/104400/-/-/ffe624d4-8fbb-ff3b-7b4b-1f637f42070a

Costa-Campi, M.T., Duch-Brown, N. & García-Quevedo, J. (2014). R&D drivers and obstacles to innovation in the energy industry. *Energy Economics*, 46, 20–30. https://doi.org/10.1016/j.eneco.2014.09.003

Criqui, P., Jaccard, M.& Sterner, T. (2019). Carbon Taxation: A Tale of Three Countries. *Sustainability*, 11, 6280. https://doi.org/10.3390/su11226280

De Almeida, A., Fonseca, P., Schlomann, B. & Feilberg, N. (2011). Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations. *Energy and Buildings*, 43, 1884–1894. https://doi.org/10.1016/j.enbuild.2011.03.027

D'Este, P., Iammarino, S., Savona, M &, von Tunzelmann, N. (2012). What hampers innovation? Revealed barriers versus deterring barriers. *Research Policy*, 41, 482–488. https://doi.org/10.1016/j.respol.2011.09.008

Di Maio, F., Rem, P.C., Baldé, K. & Polder, M. (2017). Measuring resource efficiency and circular economy: A market value approach. *Resources, Conservation and Recycling*, 122, 163–171. https://doi.org/10.1016/j.resconrec.2017.02.009

Dogan, E. & Seker, F. (2016). Determinants of CO_2 emissions in the European Union: The role of renewable and non-renewable energy. *Renewable Energy*, 94, 429–439. https://doi.org/10.1016/j.renene.2016.03.078

Dooley, J.J. (1998). Unintended consequences: Energy R&D in a deregulated energy market. *Energy Policy*, 26, 547–555. https://doi.org/10.1016/S0301-4215(97)00166-3

D'Silva, J. & Webster, J. (2017). *The Meat Crisis: Developing More Sustainable and Ethical Production and Consumption*. London:Taylor and Francis.

Drummond, W.J. (2010). Statehouse versus greenhouse: Have state-level climate action planners and policy entrepreneurs reduced greenhouse gas emissions? *Journal of the American Planning Association*, 76, 413–433. https://doi.org/10.1080/01944363.2010.499537

Erdogdu, E. (2013). Implications of liberalization policies on government support to R&D: lessons from electricity markets. *Renewable and Sustainable Energy Reviews*, 17, 110-118. https://doi.org/10.1016/j.rser.2012.09.030

Eurelectric (2013). *Utilities: powerhouses of innovation*. Brussels, Belgium: Eurelectric. Obtenido de https://www.eurelectric.org/media/1799/utilities_powerhouses_of_innovation_findings_and_recommendations_final-2013-104-0002-01-e.pdf

Eurostat (Statistical Office of the European Union) (2021). *Database*. Available online: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en (accessed on 10 August 2021).

Erzurumlu, S. & Yu, W. (2018). Development and deployment dynamics of sustainability-driven innovations in the electric and energy utility industry. *The Journal of High Technology Management Research*, 29(1), 88–97. https://doi.org/10.1016/j.hitech.2018.04.008

Figge, F., Thorpe, A.S., Givry, P., Canning, L. & Franklin-Johnson, E. (2018). Longevity and circularity as indicators of eco-efficient resource use in the circular economy. *Ecological Economics*, 150, 297–306. https://doi.org/10.1016/j.ecolecon.2018.04.030

Gan, Y., Zhang, T.Z., Liang, S., Zhao, Z. & Li, N. (2013). How to deal with resource productivity. *Journal of Industrial Ecology*, 17, 440–451. https://doi.org/10.1111/j.1530-9290.2012.00547.x

García-Álvarez, M.T., Cabeza-García, L. & Soares, I. (2018). Assessment of energy policies to promote photovoltaic generation in the European Union. *Energy*, 151, 864–874. 10.1016/j.energy.2018.03.066

Garcia-Herrero, I., Hoehn, D., Margallo, M., Laso, J., Bala, A., Batlle-Bayer, L., Sarabia, C.(2018). On the estimation of potential food waste reduction to support sustainable production and consumption policies. *Food Policy*, 80, 24–38. https://doi.org/10.1016/j.foodpol.2018.08.007

Gardetti, M.A. & Torres, A.L. (2017). *Sustainability in fashion and textiles: values, design, production and consumption*. London: Taylor and Francis.

Genoese, F., Egenhofer, C. & Wieczorkiewicz, J. (2015). The energy and climate policies of the European Union. *Handbook of Clean Energy Systems*, 1–10. https://doi.org/10.1002/9781118991978.hces179

Green, J., Newman, P. (2017). Citizen utilities: The emerging power paradigm. *Energy Policy*, 105, 283–293. https://doi.org/10.1016/j.enpol.2017.02.004

Haas, W., Krausmann, F., Wiedenhofer, D. & Heinz, M. (2015). How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European Union and the world in 2005. *Journal of Industrial Ecology*, 19(5), 765–777. https://doi.org/10.1111/jiec.12244

Hair, J.F., Anderson, R.E., Tatham, R.L. & Black, W.C. (1998). *Multivariate Date Analysis*. NJ, USA: Prentice-Hall: Englewood Cliffs.

Hale, L.A. (2018). At home with sustainability: From green default rules to sustainable consumption. *Sustainability*, 10(1), 249. https://doi.org/10.3390/su10010249

Harvey, B. & Schaefer, A. (2001). Managing relationships with environmental stakeholders: A study of UK water and electricity utilities. *Journal of Business Ethics*, 30, 243–260. https://doi.org/10.1023/A:1006356928957

Helm, D. (2014). The European framework for energy and climate policies. *Energy Policy*, 64, 29–35. 10.1016/j.enpol.2013.05.063

Herring, H. & Sorrell, S. (2009). *Energy efficiency and sustainable consumption. The Rebound Effect*. London, UK: Palgrave MacMillan.

HM Government (2018). *Encouraging Innovation in Regulated Industries: Consultation*. London, UK: HM Treasury.

Horvath, B., Bahna, M., Fogarassy, C. (2019). The ecological criteria of circular growth and the rebound risk of closed loops. *Sustainability*, 11, 2961. https://doi.org/10.3390/su11102961

Jamasb, T. & Pollitt, M.G. (2015). Why and how to subsidise energy R+ D: Lessons from the collapse and recovery of electricity innovation in the UK. *Energy Policy*, 83, 197–205. http://dx.doi.org/10.1016/j.enpol.2015.01.041

Jamasb, T. & Pollitt, M. (2011). Electricity sector liberalisation and innovation: An analysis of the UK's patenting activities. *Research Policy*, 40(2), 309–324. https://doi.org/10.1016/j.respol.2010.10.010

Jenner, S., Groba, F. & Indvik, J. (2013). Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries. *Energy Policy*, 52, 385–401. https://doi.org/10.1016/j.enpol.2012.09.046

Jiusto, S. (2008). An indicator framework for assessing U.S. state carbon emissions reduction efforts (with baseline trends from 1990 to 2001). *Energy Policy*, 36, 2234–2252. https://doi.org/10.1016/j.enpol.2008.02.034

Kaenzig, J., Heinzle, S.L. & Wüstenhagen, R. (2013). Whatever the customer wants, the customer gets? Exploring the gap between consumer preferences and default electricity products in Germany. *EnergyPolicy*, 53, 311–322. https://doi.org/10.1016/j.enpol.2012.10.061

Kalmykova, Y., Rosado, L. & Patrício, J. (2016). Resource consumption drivers and pathways to reduction: economy, policy and lifestyle impact on material flows at the national and urban scale. *Journal of Cleaner Production*, 132, 70–80. https://doi.org/10.1016/j.jclepro.2015.02.027

Karmellos, M., Kopidou, D. & Diakoulaki, D. (2016). A decomposition analysis of the driving factors of CO_2 (Carbon dioxide) emissions from the power sector in the European Union countries. *Energy*, 94, 680–692. https://doi.org/10.1016/j.energy.2015.10.145

Kim, J., Kim, Y. & Flacher, D. (2012). R&D investment of electricity-generating firms following industry restructuring. *Energy Policy*, 48, 103–117. https://doi.org/10.1016/j.enpol.2012.04.050

Kim, H., Kim, M., Kim, H. & Park, S. (2020). Decomposition analysis of CO_2 emission from electricity generation: Comparison of OECD countries before and after the financial crisis. *Energies*, 13, 3522. https://doi.org/10.3390/en13143522

Klewitz, J. & Hansen, E.G. (2014). Sustainability-oriented innovation of SMEs: A systematic review. *Journal of Cleaner Production*, 65, 57–75. https://doi.org/10.1016/j.jclepro.2013.07.017

Kline, P. (2014). *An Easy Guide for Factor Analysis*. London, UK :Taylor and Francis.

Kowal, B. & Kustra, A. (2016). Sustainability reporting in the energy sector. *E3S Web of Conferences*, 10, 129–132. https://doi.org/10.1051/e3sconf/20161000129

Kounetas, K.E. (2018). Energy consumption and CO_2 emissions convergence in European Union member countries. A tonneau des Danaides? *Energy Economics*, 69, 111–127. https://doi.org/10.1016/j.eneco.2017.11.015

Krajnc, D. & Glaviˇc, P. (2003). Indicators of sustainable production. *Clean Technologies and Environmental Policy*, 5, 279–288. https://doi.org/10.1007/s10098-003-0221-z

Labra, R. & Torrecillas, C. (2014). Guía CERO para datos de panel. Un enfoque práctico. *UAM-AccentureWorkingPapers*, 16, 57. Obtenido de https://www.catedrauam-innova.com/documents/Working%20papers/WP2014_16_Guia%20CERO%20para%20datos%20de%20panel_Un%20enfoque%20practico.pdf

Lakatos, E.S., Cioca, L.I., Dan, V., Ciomos, A.O., Crisan, O.A. & Barsan, G. (2018). Studies and investigation about theattitude towards sustainable production, consumption and waste generation in line with circular economyin Romania. *Sustainability*, 10, 865. https://doi.org/10.3390/su10030865

Lee, S.W., Sarp, S., Jeon, D.J. & Kim, J.H. (2015). Smart water grid: The future water management platform. *Desalination and Water Treatment*, 55, 339–346. https://doi.org/10.1080/19443994.2014.917887

Liao, T.F. (1994). *Interpreting Probability Models*. CA, USA: Sage Publications: Thousand Oaks.

Lieberherr, E. & Truffer, B. (2015). The impact of privatization on sustainability transitions: A comparative analysis of dynamic capabilities in three water utilities. *Environmental Innovation and Social Transitions*, 15, 101–122. https://doi.org/10.1016/j.eist.2013.12.002

Lindberg, M.B. (2019). The EU emissions trading system and renewable energy policies: Friends or foes in the European policy mix? *Politics and Governance*, 7, 105–123. DOI: https://doi.org/10.17645/pag.v7i1.1800

Lucas, H., Carbajo, R., Machiba, T., Zhukov, E. & Cabeza, L. (2021). Improving public attitude towards renewable energy. *Energies*,14, 4521. https://doi.org/10.3390/en14154521

Luo, Z., Dubey, R., Gunasekaran, A., Childe, S.J., Papadopoulos, T., Hazen, B. & Roubaud, D. (2017). Sustainable production framework for cement manufacturing firms: A behavioural perspective. *Renewable and Sustainable Energy Reviews*, 78, 495–502. https://doi.org/10.1016/j.rser.2017.04.069

Mairesse, J. & Mohnen, P. (2010). Using innovation surveys for econometric analysis. In *Hall, B.H. and Rosenberg, N. (Eds), Handbook of the Economics of Innovation*, (pp. 1130–1155). Amsterdam, The Netherlands: Elsevier.

Marino, M., Parrotta, P. & Valletta, G. (2019). Electricity (de) regulation and innovation. *Research Policy*, 48, 748–758. https://doi.org/10.1016/j.respol.2018.11.005

Mancusi, M.L. & Vezzulli, A. (2010). R&D, innovation and liquidity constraints. *KITeS Working Paper*, Università Bocconi (Milano). Obtenido de https://ideas.repec.org/p/cri/cespri/kites30_wp.html

Markard, J., Raven, R. & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41, 955–967. https://doi.org/10.1016/j.respol.2012.02.013

Markard, J. & Truffer, B. (2006). Innovation processes in large technical systems: market liberalization as a driver for radical change? *Research Policy*, 35, 609–625. https://doi.org/10.1016/j.respol.2006.02.008

Markard, J., Truffer, B. & Imboden, D.M. (2004). The impacts of market liberalization on innovation processes in the electricity sector. *Energy & Environment*, 15(2), 201–214. https://doi.org/10.1260/095830504323153405

Marques, A.C. & Fuinhas, J.A. (2012). Are public policies towards renewables successful? Evidence from European countries. *Renewable Energy*, 44, 109–118. https://doi.org/10.1016/j.renene.2012.01.007

Martin, G. & Saikawa, E. (2017). Effectiveness of state climate and energy policies in reducing power-sector CO_2 emissions. *Nature Climate Change*, 7(12), 912–919. https://doi.org/10.1038/s41558-017-0001-0

Mayes, N. (2017). *Digital Utilities: From Behind the Curve to Innovation*. London, UK: CXP Group.

McGowan, F. (2003). *The Struggle for Power in Europe: Competition and Regulation in the EC Electricity Industry*. London, UK: Royal Institute of International Affairs.

Metcalf, G.E. (2008).An empirical analysis of energy intensity and its determinants at the state level. *Energy Journal*, 29, 1–26. 10.5547/ISSN0195-6574-EJ-Vol29-No3-1

Ministerio de Medio Ambiente de Noruega (1994). *Report of the Sustainable Consumption Symposium.* Oslo, Norway: Ministry of the Environment Norway.

Obtenido de https://www.worldcat.org/title/symposium-sustainable-consumption-19-20-january-1994-oslo-norway/oclc/079024864

Mont, O. & Dalhammar, C. (2005). Sustainable consumption: at the cross-road of environmental and consumer policies. *InternationalJournal of Sustainable Development*, 8(4), 258–279. 10.1504/IJSD.2005.009575

Mont, O. & Plepys, A. (2008). Sustainable consumption progress: Should we be proud or alarmed? *Journal of Cleaner Production*, 16, 531–537.https://doi.org/10.1016/j.jclepro.2007.01.009

Munari, F., Roberts, E.B. & Sobrero, M. (2002). Privatization processes and the redefinition of corporate R&D boundaries. *Research Policy*, 31, 31–53.https://doi.org/10.1016/S0048-7333(01)00108-1

Naciones Unidas (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. Paris, France: United Nations.

Naciones Unidas (2012). Rio+20. *United Nations Conference on Sustainable Development*, Rio de Janeiro (Brazil), 20-22 June 2012. Obtenido de https://sustainabledevelopment.un.org/rio20

Naciones Unidas (2002). *Report of the World Summit on Sustainable Development Johannesburg*. South Africa, 26 August-4 September 2002. Obtenido de https://digitallibrary.un.org/record/478154

Nash, H.A. (2009). The European Commission's sustainable consumption and production and sustainable industrial policy action plan. *Journal of Cleaner Production*, 17(4), 496–498. https://doi.org/10.1016/j.jclepro.2008.08.020

Nemet, G.F. & Kammen, D.M. (2007). US energy research and development: Declining investment, increasing need, and the feasibility of expansion. *Energy Policy*, 35(1), 746–755. https://doi.org/10.1016/j.enpol.2005.12.012

Nidumolu, R., Prahalad, C.K. & Rangaswami, M.R. (2009). Why sustainability is now the key driver of innovation. *Harvard Business Review*, 87, 56–64. no veodoi

Niinimäki, K. & Hassi, L. (2011). Emerging design strategies in sustainable production and consumption of textiles and clothing. *Journal of CleanerProduction*, 19(16), 1876–1883. https://doi.org/10.1016/j.jclepro.2011.04.020

Organización para la Cooperación y el Desarrollo Económicos (OECD) (2012). *The future of eco-innovation: The role of business models in green transformation.* Copenhagen, Denmark: OECD/European Commission/Nordic Innovation Joint Workshop. Obtenido de https://www.oecd.org/innovation/inno/49537036.pdf

Organización para la Cooperación y el Desarrollo Económicos (OECD). (2005). *Oslo Manual. Proposed Guidelines for Collecting and Interpreting Technological Innovation Data.* Paris, France: OECD. Obtenido de https://read.oecd-ilibrary.org/science-and-technology/oslo-manual_9789264013100-en#page1

Pellegrino, G. & Savona, M. (2013). Is money all? financing versus knowledge and demand constraints to innovation.*UNU-MERIT Working Paper*, United Nations University, Maastricht. Obtenido de https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2341095

Rabadán, A. & Sáez-Martínez, F.J. (2017). Why European entrepreneurs in the water and waste management sector are willing to go beyond environmental legislation. *Water,* 9, 151. https://doi.org/10.3390/w9030151

Ravšelj, D. & Aristovnik, A. (2018). The impact of private research and development expenditures and tax incentives on sustainable corporate growth in selected OECD countries. *Sustainability*, 10(7), 2304. https://doi.org/10.3390/su10072304

Rehman, E., Ikram, M., Feng, M.T. & Rehman, S. (2020). Sectoral-based CO_2 emissions of Pakistan: A novel Grey Relation Analysis (GRA) approach. *Environmental Science and Pollution Research*, 27, 29118–29129. https://doi.org/10.1007/s11356-020-09237-7

Rehman, E., Ikram, M., Rehman, S. & Feng, M.T. (2021). Growing green? Sectoral-based prediction of GHG emission in Pakistan: A novel NDGM and doubling time model approach. *Environment, Development and Sustainability*, 23, 12169–12191. https://doi.org/10.1007/s10668-020-01163-5

Rodrigues, J. F., Wang, J., Behrens, P. & de Boer, P. (2020). Drivers of CO_2 emissions from electricity generation in the European Union 2000–2015. *Renewable and Sustainable Energy Reviews*, 133, 110104.https://doi.org/10.1016/j.rser.2020.110104

Rodríguez-Jaume, M.J. & Mora-Catalá, R. (2001). Análisis de Regresión Múltiple. *Técnicas de investigación social II*, Alicante, Spain. Obtenido de https://rua.ua.es/dspace/bitstream/10045/8143/1/Regresion%20MUTIPLE.pdf

Sáez-Martínez, F.J., Lefebvre, G., Hernández, J.J. & Clark, J.H. (2016). Drivers of sustainable cleaner production and sustainable energy options. *Journal of Cleaner Production*, 138, 1–7. https://doi.org/10.1016/j.jclepro.2016.08.094

Sagar, A.D. & Holdren, J.P. (2002). Assessing the global energy innovation system: Some key issues. *Energy Policy*, 30, 465–469. https://doi.org/10.1016/S0301-4215(01)00117-3

Sanyal, P. & Cohen, L.R. (2009). Powering progress: Restructuring, competition, and R&D in the US electric utility industry. *The Energy Journal*, 30(2). 10.5547/ISSN0195-6574-EJ-Vol30-No2-3

Savignac, F. (2008). Impact of financial constraints on innovation: What can be learned from a direct measure? *Economics of Innovation and New Technology*, 17, 553–569. https://doi.org/10.1080/10438590701538432

Schmitt, S. & Kucsera, D. (2014). The impact of the regulatory reform process on the R&D investment of European electricity utilities. *Review of Network Economics*, 13(1), 35–67. https://doi.org/10.1515/rne-2012-0021

Scholl, G., Rubik, F., Kalimo, H., Biedenkopf, K. & Söebech, Ó. (2010). Policies to promote sustainable consumption: innovative approaches in Europe. *Natural Resources Forum*, 34, 39–50. https://doi.org/10.1111/j.1477-8947.2010.01294.x

Schroeder, P., Anggraeni, K. & Weber, U. (2019). The relevance of circular economy practices to the sustainable development goals. *Journal of Industrial Ecology*, 23, 77–95. https://doi.org/10.1111/jiec.12732

Seebode, D., Jeanrenaud, S. & Bessant, J. (2012). Managing innovation for sustainability. *R&D Management*, 42, 195–206. https://doi.org/10.1111/j.1467-9310.2012.00678.x

Sorrell, S. (2015). Reducing energy demand: A review of issues, challenges and approaches. *Renewable and Sustainable Energy Reviews*, 47, 74–82. https://doi.org/10.1016/j.rser.2015.03.002

Sterlacchini, A. (2012). Energy R&D in private and state-owned utilities: an analysis of the major world electric companies. *Energy Policy*, 41, 494–506. https://doi.org/10.1016/j.enpol.2011.11.010

Stevens, C. (2010). Linking sustainable consumption and production: The government role. *Natural Resources Forum*, 34(1),16–23. https://doi.org/10.1111/j.1477-8947.2010.01273.x

Stjepcevic, J. & Siksnelyte, I. (2017). Corporate social responsibility in energy sector. *Transformations in Business & Economics*, 16(1), 21–33. nO VEO doi

Streimikiene, D., Siksnelyte, I., Zavadskas, E.K. & Cavallaro, F. (2018). The impact of greening tax systems on sustainable energy development in the Baltic States. *Energies*, 11, 1193. https://doi.org/10.3390/en11051193

Suarez-Perales, I., Garces-Ayerbe, C., Rivera-Torres, P. & Suarez-Galvez, C. (2017). Is strategic proactivity a driver of an environmental strategy? Effects of innovation and internationalization leadership. *Sustainability*, 1870. https://doi.org/10.3390/su9101870

Sun, K., Xiao, H., Liu, S., You, S., Yang, F., Dong, Y., Wang,W.& Liu, Y. (2020). A Review of Clean Electricity Policies—From Countries to Utilities. *Sustainability*, 12, 7946. https://doi.org/10.3390/su12197946

Tanner, C., Kast, S.W. (2003). Promoting sustainable consumption: Determinants of green purchases by Swiss consumers. *Psychology & Marketing*, 20, 883–902. https://doi.org/10.1002/mar.10101

Thomas, S. (1996). Strategic government and corporate issues. In *Surrey, J. (Eds.),The British Electricity Experiment—Privatization: The Record, the Issues, the Lessons* (pp. 255–291). London, UK: Earthscan.

Tuballa, M.L. & Abundo, M.L. (2016). A review of the development of Smart Grid technologies. *Renewable and Sustainable Energy Reviews*, 59, 710–725. https://doi.org/10.1016/j.rser.2016.01.011

Varadarajan, R. (2017). Innovating for sustainability: A framework for sustainable innovations and a model of sustainable innovations orientation. *Journal of the Academy of Marketing Science*, 45, 14–36. https://doi.org/10.1007/s11747-015-0461-6

Vega-Jurado, J., Gutiérrez-Gracia, A. & Fernández-de-Lucio, I. (2009). Does external knowledge sourcing matter for innovation? Evidence from the Spanish manufacturing industry. *Industrial and Corporate Chang*e, 18, 637–670. https://doi.org/10.1093/icc/dtp023

Veugelers, R. (1997). Internal R&D expenditures and external technology sourcing. *Research Policy*, 26, 303–316. https://doi.org/10.1016/S0048-7333(97)00019-X

Vergragt, P.J., Dendler, L., de Jong, M. & Matus, K. (2016). Transitions to sustainable consumption and production in cities. *Journal of Cleaner Production*, 134, 1–12. https://doi.org/10.1016/j.jclepro.2016.05.050

Welford, R., Young, W. & Ytterhus, B. (1998). Towards sustainable production and consumption: A literature review and conceptual framework for the service sector. *Eco-Management and Auditing*, 5, 38–56. https://doi.org/10.1002/(SICI)1099-0925(199803)5:1<38::AID-EMA78>3.0.CO;2-K

Wehn, U. & Montalvo, C. (2018). Exploring the dynamics of water innovation: Foundations for water innovation studies. *Journal of Cleaner Production*, *171*, 1–19. https://doi.org/10.1016/j.jclepro.2017.10.118

Yi, H. (2015). Clean-energy policies and electricity sector carbon emissions in the US states. *Utilities Policy*, 34, 19–29. https://doi.org/10.1016/j.jup.2015.04.001

Young, W., Hwang, K., McDonald, S. & Oates, C.J. (2010). Sustainable consumption: green consumer behaviour when purchasing products. *Sustainable Development*, 18(1), 20–31. https://doi.org/10.1002/sd.394

Zafar, M.W., Shahbaz, M., Hou, F. & Sinha, A. (2019). From nonrenewable to renewable energy and its impact on economic growth: The role of research & development expenditures in Asia-Pacific Economic Cooperation countries. *Journal of Cleaner Production*, 212, 1166–1178. https://doi.org/10.1016/j.jclepro.2018.12.081

5 Artículos publicados

5.1 Utilities: Innovation and Sustainability

Utilities: Innovation and Sustainability[1]

Abstract: Pro-market reforms have disrupted the playing field and strongly affected the innovative behavior of electricity, gas and water utilities. Beyond a significant reduction in sectoral R&D investments, very little is known about how these firms accomplish their innovation strategies in this new scenario. Given this gap in the literature, the first aim of this paper is to identify the internal determinants of both the product and process innovation of utilities in a liberalized environment. Additionally, there is another external force that is also disrupting the specific landscape of utilities: the sustainability challenge. Therefore, the second aim of this paper is establishing whether sustainability-orientation is a driver of innovation in the utilities industries. The empirical study is carried out on a panel of 82 Spanish electricity, gas and water utilities over the period 2005–2012 (Technological Innovation Panel dataset (PITEC)). The main findings are: (i) the acquisition of disembodied knowledge does not play a relevant role for utilities; (ii) non-formal search processes are central to product innovation; (iii) some markets for technology –external R&D and technology embedded in equipment—are determinant factors for process innovation; (iv) sustainability orientation increases the likelihood of generating both, product and process innovations. These firm-level results are novel contributions to the field of utility management.

Keywords: utility; electricity; gas; water; liberalization; innovation; sustainability; PITEC

1. Introduction

Electricity, gas and water utilities face the challenge of digital transformation [1]. The smart grid is just the most obvious example of this huge but promising technological undertaking [2,3]. However, this paper focusses on two other external

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forces that are shaping the environment of utilities—liberalization and sustainability—and how these forces interact with their innovation strategies.

On the one hand, liberalization and other pro-market reforms have changed the playing field of utilities [4]. As a result, the former centralized and cooperative systems of sectoral innovation have passed away. Moreover, in the old monopoly days, innovation in the utilities industries was a relatively peripheral phenomenon [5]. This is no longer the case. Innovation is now a central issue for the different stakeholders of electricity, gas and water utilities [6]. Regulators, for example, are highly concerned about how to encourage innovation in the industries under their supervision, while ensuring the interests of consumers are protected [7]. Paradoxically, our understanding of how utilities undergo the innovation process in a liberalized environment is very limited. Herein lies the motivation for studying the internal determinants of product and process innovation for utilities. On the other hand, energy and water lie at the heart of the sustainability problem. Therefore, utilities must be essential actors in the transition to a sustainable future [5,8]. Innovation is considered a precondition to progress in this path. For this reason, the second aim of this research is establishing whether sustainability-orientation is a driver of innovation in liberalized utilities industries.

It should be stressed that this is an exploratory study for an under-researched issue. Previous literature is scarce [9,10]. No theories are tested, because the purpose of this paper is to generate empirical evidence regarding a highly relevant decision for utilities.

The remainder of the paper is structured as follows. Section 2 describes how utilities have undergone innovation under traditional monopolistic environments and the changes that pro-market reforms have introduced. It also discusses whether sustainability-orientation is a driver of innovation in the utilities industries, and research questions to be addressed in the paper are formally stated. Section 3 carefully describes the data, variables and models of the empirical study. Section 4 presents the results, and finally Section 5 discusses the main contributions.

2. Innovation and Sustainability in a Liberalized Environment

Internal Determinants of Innovation

Under traditional monopolistic environments, electricity, gas and water utilities deployed innovation strategies characterized by incrementalism and path dependencies. Far-reaching technological changes occurred, but they were usually driven by external stimuli [11]. Rate-of-return regulation, direct public intervention and public ownership situated the risk on the customer's side [4,12]. Not surprisingly, in comparison to firms operating in non-regulated environments, utilities showed a low propensity to introduce product innovations. However, process innovations were much more common and were considered a technical issue. Markard, Truffer and Imboden describe this technological regime for the specific case of the electricity supply industry [13] (pp. 204–205): "in monopoly times, decision making was mainly oriented at the technical quality and the security of supply. Investments into the grid, for instance, were carried out according to a fixed, regular schedule and companies tried to achieve the best available technical standard. Costs or financial returns rather played a minor role. Electricity consumers were mainly regarded from a technical point of view". As far as the inputs of the innovation process were concerned, governments led long-term R&D programs, while utilities co-operated in the development of new knowledge through joint technology centers, demonstration projects and different collaborative arrangements [14–16]. New technologies embedded in equipment and advanced services produced a vast array of supplier-driven incremental innovations. Finally, learning-by-doing and the exchange of best practices among utilities were common non-formal search methods [17].

Liberalization processes have disrupted the playing field of traditional electricity, gas and water utilities. Sectoral restructuring, privatization, new regulatory regimes and competition in or for the market have transferred the bulk of the risk from customers to owners. All these pro-market reforms have strongly affected the innovative behavior of utilities [11]. The new scenario eliminates many previous barriers and rewards firm innovation. Therefore, industry-wide cooperation has collapsed, economic issues have gained a central role, projects with shorter payback periods are preferred and customer-oriented product innovations have flourished [18]. Moreover, several authors have consistently confirmed a significant reduction in sectoral R&D investments in different jurisdictions after liberalization experiences [19–26]. However, very little is known about how utilities accomplish their innovation strategies at the firm level in a liberalized environment; i.e., which activities (inputs) are needed to generate innovations (outputs). As stated above, academic attention has been focused almost exclusively on analyzing the changes in the sectoral volume of R&D resources. Paradoxically, the role of both R&D and non-R&D knowledge acquisition activities at the utility level has been almost neglected [27]. Given this gap in the literature, the first research question this paper addresses is as follows:

> *RQ1. What innovation activities do utilities engage in to generate innovations in a liberalized environment?*

Sustainability-Oriented Innovation

However, there is another external force that is also disrupting the specific landscape of utilities: the sustainability challenge. Energy and water supply utilities find themselves in the midst of a sustainability transition: a long-term, multi-dimensional, and fundamental transformation through which the established socio-technical systems are shifting to more sustainable modes of production and consumption [28].

Pressures to adapt to the new situation come from almost all relevant stakeholders: governments and regulators, non-governmental organizations (NGOs), local communities, investors, employees, suppliers or customers. Harvey and Schaefer [29] point out that green stakeholders with an institutional power base—government via legislation, environmental and industry regulators—appear to be the most influential. In the last decades, the legal framework has emphasized the importance of making both the energy and water sectors greener. The well-established energy policy goals of the European Union not only include security of supply and competitiveness, but also environmental protection [30]. The transition to a low-carbon world is now assumed by almost all stakeholders of the energy industries. Regarding the water sector, the European Union implemented the Water Framework Directive to address both water quality and quantity challenges, with the explicit aim of improving water security and pollution [31]. NGOs now have a direct influence on governments and firms, but they also exert a hidden indirect influence on sustainability issues through national and transnational multi-stakeholder standardization bodies [32]. Sustainability compliance and reporting are becoming key communication mechanisms with investors and the general public [33–35]. Liberalization has empowered customers. They are more aware, have more freedom to shop around and are more demanding. They could even become partners under a new paradigm of citizen utilities. This is already happening in the electricity industry, as the sharp cost reduction of solar photovoltaics technology is changing the traditional unidirectional power grid [36].

Product and process innovation are available tools to cope with such profound transformation. Successful product design for green products may provide utilities with a competitive advantage [37]. At the operational level, economic and environmental goals quite often converge: process innovation is usually incremental and is primarily focused on increasing technical efficiency or quality [8]. The initial narrow eco-innovation practices have slowly evolved into a more comprehensive approach under the label of sustainability-oriented innovation [38]: making intentional changes to firm's products or processes to create social and environmental value, in addition to economic returns [39]. Sustainability-oriented innovation aims to alleviate tensions between the environmental, social and financial goals the firm [40,41].

The conventional wisdom is that sustainability-orientation is associated with higher innovation [42]. Utilities increasingly integrate sustainability goals in their innovation processes. However, it remains an open question whether, in the specific case of utilities, this sustainability-orientation is propelling the innovation output. The existing evidence from the utilities' field is limited, based on case studies and far from conclusive [10]. Thus, the second research question can be stated as follows:

RQ2. Is sustainability-orientation a driver of innovation in the utilities industries?

3. Data, Variables and Models

Data

The empirical study will be developed for the Spanish case. Two reasons support this choice. On the one hand, the regulatory framework governing Spanish utilities clearly evolved towards the liberalized paradigm at the end of the 20th century. Both the Electricity Sector Act (Law 54/1997) and the Hydrocarbons Sector Act (Law 34/1998) restructured and deregulated power and gas markets. Although no equivalent regulatory discontinuity was introduced in the water industry, liberalization forces also affected water utilities: privatizations and public-private partnerships spread across the country under the provisions of the Local Government Act (Law 7/1985). On the other hand, firm-level data availability reinforces the choice of Spain for our empirical study. The dataset from the Technological Innovation Panel (hereafter PITEC) contains annual information about the innovation activities of around 12,000 Spanish firms from 2003 onwards. This wide coverage allows disaggregated analyses for certain industries. As far as econometrics is concerned, PITEC provides a viable sample of Spanish firms whose main activity is in the electricity, gas or water supply value chains.

The data are available on a consistent basis for the period 2005 to 2012. According to a recent strand of literature on innovation barriers [43–47], only the subset of potentially innovative firms should be considered. Innovating is not the only viable competitive strategy, and therefore some firms could rationally decide not to innovate, even if no relevant barrier were in place. Following a similar procedure to Costa-Campi, Duch-Brown and García-Quevedo [9], firms that meet three conditions are excluded from the sample: (i) firms that have not introduced product or process innovations, (ii) firms that state that there is no significant need to innovate, and (iii) firms that do not perceive any significant cost, knowledge or market barrier to innovation. After data cleaning, the final sample contains 429 observations from 82 electricity, gas and water utilities. As will be explained below, all independent variables are lagged one year in the causal model. Hence, the observed interval for the dependent variable is limited to seven years (2006–2012) and 349 observations.

Unfortunately, due to statistical secrecy, there is no obvious way to identify in the dataset whether an observed utility is an electricity, gas or water utility. Therefore, it is not possible to disaggregate the sample into different subsamples according to the main activity of the firm. Previous studies using PITEC data that attempted to focus on energy industries (for instance, [9]) fell short of covering all energy activities and only energy activities.

Variables

Variables are defined according to the Oslo Manual [48] and measured as follows.

- Product or process innovation (INNit) (binary variable 0–1): This variable will take the value 1 if utility i has introduced a new product or process in the year t or in the two previous years. The innovation will always be new for the utility, but not necessarily for its industry or market. In some models, this variable will be split into two: product innovation (INNPTit) and process innovation (INNPCit);

- Research & Development (R&Dit) (binary variable 0–1): This variable will take the value 1 if utility i has carried out internal or external research and development activities during the year. These will be, in any case, creative actions focused on increasing the stock of knowledge and its application to develop new or improved products and processes. In some models, this variable will be split into two: internal R&D (IR&Dit) and external R&D (ER&Dit);
- Acquisition of machinery and equipment (EQUIit) (binary variable 0–1): This variable will take the value 1 if utility i has acquired advanced machinery, equipment, hardware or software intended for the production of new products or processes during the year. This category only includes the acquisition of capital goods for innovation that is not included in R&D activities;
- Acquisition of external knowledge (EXKit) (binary variable 0–1): This variable will take the value 1 if utility i has acquired external knowledge for innovation, such as licenses, patents, disclosures of know-how, trademarks, designs or other inventions during the year;
- Non-formal search processes (NFSit) (binary variable 0–1): This variable will take the value 1 if utility i has (i) trained its personnel for innovation activities, (ii) carried out technical operational preparations not included in R&D, or (iii) performed exploratory market research activities for new or significantly improved products during the year;
- Size (SIZEit) (positive decimal number): This variable will take the value of the log of the average number of employees in utility i during the year;
- Business group affiliation (GROit) (binary variable 0–1): This variable will take the value 1 if, during the year, utility i is part of a group as either the parent company, a subsidiary, a joint-venture or an associate;
- Foreign ownership (FOWit) (binary variable 0–1): This variable will take the value 1 if, during the year, 50% or more of the capital of utility i is owned by foreign firms;
- Sustainability goals (SGit) (binary variable 0–1): This variable will take the

value 1 if, during the year, utility i classifies as highly relevant the innovation goals of mitigating environmental impact and/or complying with environmental/health and safety regulations.

Models

In order to answer the first research question (RQ1), the causal model of Equation (1) is proposed.

$$\mathrm{INNit} = f\,(\mathrm{R\&Dit}\text{-}_{1};\ \mathrm{EQUIit}\text{-}_{1};\ \mathrm{EXKit}\text{-}_{1};\ \mathrm{NFSit}\text{-}_{1};\ \mathrm{SIZEit}\text{-}_{1};\ \mathrm{GROit}\text{-}_{1};\ \mathrm{FOWit}\text{-}_{1}) \quad (1)$$

The generation of product or process innovations is the dependent variable and two types of explanatory variables are considered (Equation (1)). On the one hand and according to the Oslo Manual [39], four variables that describe the innovation strategy of the firm are considered: (i) research and development, including both internal and external activities; (ii) acquisition of machinery and equipment; (iii) acquisition of external knowledge; and (iv) other non-formal search processes. On the other hand, three control variables which capture firm characteristics that may influence the innovation process are considered: (v) size, (vi) business group affiliation, and (vii) foreign ownership. In order to strengthen the causality link, all the independent variables are lagged one year vis-à-vis the dependent variable.

The dependent variable has a dichotomous nature and, therefore, a binary response model is chosen. A logistic regression or LOGIT has been used, as it is considered the most adequate for the distribution of data [49]. In addition, the model is estimated with a panel data set (random effects). This allows us to control for unobservable individual heterogeneity: firm-specific characteristics that could influence the dependent variable and were not included in the model [50]. It is worth noting that panel data also makes possible the introduction of lagged explanatory variables, while cross-sectional studies based on a one-wave innovation survey cannot [51]. Year dummy variables have been included in the model in order to control for the potential year effect.

The second research question (RQ2) is addressed with the causal model of Equation (2).

$$\mathrm{INNit} = f\,(\mathrm{R\&Dit\text{-}1};\ \mathrm{EQUIit\text{-}1};\ \mathrm{EXKit\text{-}1};\ \mathrm{NFSit\text{-}1};\ \mathrm{SIZEit\text{-}1};\ \mathrm{GROit\text{-}1};\ \mathrm{FOWit}\text{-}_{1};\ \mathrm{SGit}\text{-}_{1})\ (2)$$

The difference in relation to Equation (1) is the inclusion of “sustainability goals” as an explanatory variable. A utility with a sustainability-oriented innovation process would assign high relevance to the innovation goals of mitigating environmental impact and/or sustainability compliance. As in the previous case, (i) independent variables are lagged one year, (ii) year dummy variables are included, and (iii) LOGIT regression is used for model estimation.

Computations have been done using the software package STATA V12 (StataCorp LLC, Texas, TX, USA).

4. Results

Inputs of the Innovation Process

Table 1 shows the correlation coefficients for the independent variables of Equation (1). Furthermore, variance inflation factors (VIFs) reveal no evidence of multicollinearity among the variables, as all of them are under the threshold of 2 (full results not shown).

Table 1. Correlation matrix (models 1 to 4). IR&D: internal R&D; ER&D: external R&D; EQUI: acquisition of machinery and equipment; EXK: acquisition of external knowledge; NFS: non-formal search processes; SIZE: size; GRO: business group affiliation; FOW: foreign ownership.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. R&D	1								
2. IR&D	–	1							
3. ER&D	–	0.50 ***	1						
4. EQUI	0.13 ***	0.09 **	0.04	1					
5. EXK	0.19 ***	0.12 ***	0.23 ***	0.11 **	1				
6. NFS	0.33 ***	0.26 ***	0.25 ***	0.18 ***	0.16 ***	1			
7. SIZE	0.30 ***	0.37 ***	0.31 ***	0.115 ***	0.14 ***	0.14 ***	1		
8. GRO	0.16 ***	0.16 ***	0.24 ***	0.12 ***	0.13 ***	0.13 ***	0.41 ***	1	
9. FOW	0	0.03	0.03	0.15 ***	−0.08	−0.03	−0.03	0.27 ***	1

n=349

To begin with, four models are estimated using logistic regressions on the full sample of 82 utilities and 349 observations (Tables 2 and 3). Some common issues will be presented before describing the results of the different models. Firstly, the coefficients of year dummy variables are not reported for brevity. Secondly, Wald tests indicate that the four models are significant at the 99% confidence level. Thirdly, we have also tested and rejected that the panel-level variance components are unimportant for these four models (LR test of Rho). Therefore, panel data are preferred to pooling models in all cases. Finally, we have estimated identical models using PROBIT instead of LOGIT. As expected, the results (not shown) were almost the same.

Table 2. Inputs of innovation process.

Variables	Model 1: INN	dy/dx	Model 2: INN	dy/dx
R&D	2.200 *** (0.54)	0.22 ** (0.11)	-	-
IR&D	-	-	1.40 ** (0.71)	0.11 (0.07)
ER&D	-	-	1.34 ** (0.67)	0.10 * (0.06)
EQUI	4.40 *** (1.42)	0.20 *** (0.07)	4.58 *** (1.42)	0.21 *** (0.07)
EXK	1.02 (1.78)	0.05 (0.07)	1.14 (1.8)	0.06 (0.06)
NFS	1.94 ** (0.97)	0.10 * (0.05)	1.93 ** (0.95)	0.10 * (0.05)
SIZE	0.25 (0.25)	0.02 (0.02)	0.20 (0.25)	0.02 (0.02)
GRO	1.78 ** (0.81)	0.16 (0.10)	1.63 ** (0.79)	0.15 (0.10)
FOW	−0.08 (1.30)	−0.01 (0.11)	−0.13 (1.28)	−0.01 (0.11)
Constant	-4.35***(0.63)	-	-3.91***(1.39)	-
Year effect considered	Yes	Yes	Yes	Yes
Goodness of fit statistics				
Log-likelihood	-121.18	—	-121.33	–
Wald (χ^2)	35.88 ***		35.52 ***	
Sigma_u	2.57		2.50	
Rho	0.67 ***		0.66 ***	
Z_1	31.33 ***		31.02 ***	
Z_2	17.27***		15.43**	
No observations	349		349	
No firms	82		82	

(Standard errors) ***, **, *: Significant at 1%, 5% and 10%; Z1 is a Wald test for the reported coefficients of the explanatory variables, asymptotically distributed as χ^2 under the null hypothesis of no relationship for all the explanatory variables; Z_2 is a Wald test of the joint significance of the time dummies, asymptotically distributed as χ^2 under the null hypothesis of no relationship.

Model 1 represents the general case: the innovation outcome (product or process) depends on the innovation activities and the control variables. Here, R&D is included as an aggregate variable, without discriminating between internal and external categories. All innovation activities but one have been proven to be determinants for generating innovations. The exception is the acquisition of external knowledge (EXK). It seems that utilities do not rely on this source of disembodied technology. Conversely, just one of the coefficients of the control variables is positive and statistically significant: group affiliation (GRO).

Model 2 explores whether splitting the aggregate R&D variable into in-house and outsourced R&D introduces any change. The new variables are named internal R&D (IR&D) and external R&D (ER&D). However, results are very similar. Internal and external R&D coefficients are positive and statistically significant. Again, the acquisition of capital-embodied technology (EQUI) prevails over the purchase of disembodied knowledge (EXK). Downstream non-formal search processes (NFS) keep complementing the other of innovation activities.

As far as marginal effects (dy/dx) for Model 2 are concerned, the acquisition of machinery and equipment (EQUI) is the input with the strongest significant impact on the generation of innovations (0.21). Non-formal search processes (NFS) and external R&D (ER&D) show much lower coefficients (0.10). This amalgamated view of the internal determinants of innovation in utilities could be hiding a more complex reality. To be more precise, it could be expected that managers will establish different innovation strategies when the desired outcome is either a new product or a new process. Models 3 and 4 follow this approach (Table 3).

Table 3. Inputs of product and process innovation process.

Variables	Model 3: INNPT	dy/dx	Model 4: INNPC	dy/dx
IR&D	1.11 ** (0.47)	0.20 ** (0.08)	0.85 (0.59)	0.14 (0.10)
ER&D	0.59 (0.44)	0.10 (0.08)	1.46 ** (0.59)	0.21 ** (0.09)
EQUI	0.60 (0.44)	0.11 (0.09)	3.29 *** (0.84)	0.33 *** (0.08)
EXK	−0.81 (0.86)	−0.11 (0.09)	1.23 (1.68)	0.14 (0.12)
NFS	2.71*** (0.51)	0.57*** (0.10)	1.50** (0.72)	0.18** (0.08)
SIZE	0.27 (0.19)	0.05 (0.03)	0.22 (0.22)	0.04 (0.04)
GRO	0.13 (0.57)	0.02 (0.10)	1.13 (0.71)	0.19 (0.13)

Variables	**Model 3: INNPT**	**dy/dx**	**Model 4: INNPC**	**dy/dx**
FOW	1.05 (0.79)	0.22 (0.18)	-2.03* (1.21)	-0.43* (0.25)
Constant	-5.05*** (1.12)	-	-3.64*** (1.26)	-
Year effect considered	Yes	Yes	Yes	Yes
Goodness of fit statistics				
Log-likelihood	-152.30		-140.38	
Wald (χ^2)	49.77**		39.34***	
Sigma_u	1.55		2.32	
Rho	0.42***		0.62***	
Z_1	47.21***		34.81***	
Z_2	10.06		14.32**	
No observations	349		349	
No firms	82		82	

(Standard errors) ***, **, *: Significant at 1%, 5% and 10%; Z_1 is a Wald test for the reported coefficients of the explanatory variables, asymptotically distributed as χ^2 under the null hypothesis of no relationship for all the explanatory variables; Z_2 is a Wald test of the joint significance of the year dummies, asymptotically distributed as χ^2 under the null hypothesis of no relationship.

In Model 3, the dependent variable is the generation of product innovations (INNPT). In this case, the innovation activities that come out positive and statistically significant are internal R&D (IR&D) and non-formal search processes (NFS). Product innovation in utilities is not based on external contracts: neither ex-ante contracts for R&D, nor ex-post contracts for existing technology. Next, model 4 takes process innovation (INNPC) as the dependent variable. Now, external R&D (ER&D) and acquisition of machinery and equipment (EQUI) come out positive and statistically significant at 1%. Again, non-formal search processes (NFS) complete the portfolio of relevant innovation activities. Among the control variables, foreign ownership (FOW) is the only statistically significant variable, though with a negative sign.

The need for a disaggregated analysis is reinforced when examining the marginal effects (dy/dx), as they behave very differently in Models 3 and 4. Marginal effects provide relevant information about the influence of individual inputs in the dependent variable. In the case of product innovation, non-formal search processes (NFS) show the highest positive coefficient (0.57), while internal R&D (IR&D) follows with a coefficient of 0.20. However, capital-embodied technology (EQUI) achieves the highest positive coefficient (0.33) among the inputs of product innovation, while foreign ownership (FOW) has a strong negative impact (−0.43).

Sustainability-Orientation as a Driver of Innovation

To address the second research question, a subsample of 71 utilities (86.6% of the total sample) with 262 observations (76.4% of the total sample) was selected. This subsample contains observations of utilities that answer the section of the questionnaire related to sustainability innovation goals. Missing values in this section in a particular year imply that the observation for this utility in this year is not considered.

Table 4 shows the correlation coefficients for the explanatory variables of Equation (2) and 262 observations. Again, to deal with the issue of multicollinearity, the variance inflation factors (VIFs) were examined, and the highest value was 1.38 (other results not shown). Therefore, multicollinearity does not constitute a problem in our data.

Two additional LOGIT models are estimated for product and process innovations (Table 5). As explained in Section 4.1, (i) the coefficient of year dummy variables are not reported, and both models are significant at the 99% confidence level (Wald tests); (iii) panel data models are preferred over pooling models (LR test of Rho); and (iv) the PROBIT and LOGIT estimation results are almost the same. In Model 5, the dependent variable is the generation of product innovations (INNPT). In this analysis, the innovation activities that come out positive and statistically significant are internal R&D (IR&D) and non-formal search processes (NFS). Marginal effects for these variables are 0.23 and 0.62, respectively. The variable sustainability goals (SG) offers a positive and significant coefficient in the logistic regression, but the marginal effect for sustainability goals is not significant. In Model 6, the dependent variable is process innovation (INNPC). The innovation inputs that the model reveal as significant are the acquisition of capital-embodied technology (EQUI) and non-formal search processes (NFS). Marginal effects are low for both internal innovation activities: 0.14 for EQUI and 0.08 for NFS. The variable sustainability goals (SG) shows positive and significant coefficients in both the logistic regression and the marginal (0.08).

Finally, to establish the robustness of these results of sustainability orientation, model 5 (product innovation) and model 6 (process innovation) were re-estimated using a lower threshold for the binary variable sustainability goals (SG_{it}). This variable takes now the value 1 if, during year t, utility i classifies the innovation goals of mitigating environmental impact and/or complying with environmental/health and safety regulations at least as "relevant" (instead of "highly relevant"). The new results (not shown) did not differ from those already presented in Table 5.

Table 4. Correlation matrix (models 5 and 6).

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. SG	1								
2. IR&D	0.05	1							
3. ER&D	0.17 ***	0.50 ***	1						
4. EQUI	−0.03	0.09 **	0.04	1					
5. EXK	−0.10 *	0.12 ***	0.23 ***	0.11 **	1				
6. NFS		0.26 ***	0.25 ***	0.18 ***	0.18 ***	1			
7. SIZE	0	0.37 ***	0.30 ***	0.15 ***	0.15 ***	0.13 ***	1		
8. GRO	0.05	0.16 ***	0.24 ***	0.12 ***	0.13 ***	0.13 ***	0.41 ***	1	
9. FOW	−0.14 **	0.03	0.03	0.15 ***	−0.08	−0.03	−0.03	0.27 ***	1

n = 262.

Table 5. Effect of sustainability orientation in product and process innovation.

Variables	**Model 5: INNPT**	**dy/dx**	**Model 6: INNPC**	**dy/dx**
SG	0.97 * (0.57)	0.22 (0.14)	1.54 * (0.83)	0.08 * (0.04)
IR&D	1.15 ** (0.58)	0.23 ** (0.10)	0.15 (0.70)	0.01 (0.05)
ER&D	−0.15 (0.51)	−0.03 (0.11)	0.46 (0.63)	0.03 (0.05)
EQUI	0.23 (0.48)	0.05 (0.11)	2.97*** (0.94)	0.14** (0.06)
EXK	-0.59 (1.00)	-0.12 (0.17)	0.14 (1.72)	0.01 (0.10)
NFS	2.92*** (0.56)	0.62*** (0.09)	1.57** (0.77)	0.08* (0.04)
SIZE	0.21 (0.21)	0.05 (0.05)	0.31 (0.26)	0.02 (0.02)
GRO	0.52 (0.69)	0.11 (0.14)	0.25 (0.82)	0.02 (0.06)
FOW	1.25 (0.89)	0.30 (0.21)	-1.54* (1.13)	-0.17 (0.19)
Constant	-4.70*** (1.28)	-	-2.47** (1.39)	-
Year effect considered	Yes	Yes	Yes	Yes
Goodness of fit statistics				
Log-likelihood	-121.92		-98.16	
Wald (χ^2)	40.36***		26.38**	
Sigma_u	1.66		2.17	
Rho	0.46***		0.59***	
Z_1	36.21***		19.10**	
Z_2	13.10**		13.41**	
No observations	262		262	
No firms	71		71	

(Standard errors) ***, **, *: Significant at 1%, 5% and 10%; Z_1 is a Wald test for the reported coefficients of the explanatory variables, asymptotically distributed as χ2 under the null hypothesis of no relationship for all the explanatory variables; Z_2 is a Wald test of the joint significance of the year dummies, asymptotically distributed as χ2 under the null hypothesis of no relationship.

5. Discussion

This paper has identified the internal determinants of the product and process innovation of utilities operating in a liberalized environment. It has also highlighted the propelling role of sustainability orientation to generate these innovations. These are significant contributions to the field of utility management. As a matter of fact, it is the first quantitative causal paper that considers the full menu of knowledge acquisition activities for innovation as defined by the Oslo Manual [48]. Moreover, it is also worth mentioning that the PITEC questionnaire is aligned with the Community Innovation Survey (CIS). Therefore, the country (Spain) and sectoral (electricity, gas and water utilities) results are directly comparable with a large body of international/multi-industry empirical innovation literature. The main findings will be discussed below.

Regarding Identification of the Inputs of the Innovation Process

First, the acquisition of external disembodied knowledge—licenses, patents, and other inventions—does not play a relevant role for utilities. Paradoxically, however, Jamasb and Pollit [52] have identified a growth in electricity-related patenting activity in the post-liberalization period due to the increased commercialization of the sector. Marino, Parrotta and Valletta [53] have found similar results for countries that have experienced a relatively weak deregulation process. Therefore, inventions are increasingly patented in liberalized environments, but utilities are not acquiring disembodied knowledge as such.

Second, the remainder innovation activities—R&D, acquisition of machinery and other non-formal knowledge search methods—are important inputs for the success of the innovation process. This result holds for both product and process innovation.

Third, as far as the dichotomy product versus process innovation is concerned, utility managers use different combinations of activities. Product innovation demands internal R&D capabilities and downstream non-formal search processes. The marginal effect is much higher for these unformalized, soft, downstream activities. Take the examples of green power labeling or dual-fuel (electricity and gas) offers—product innovations that could be design just from reverse engineering. On the contrary, some markets for technology—external R&D and technology embedded in equipment—are determinant factors for process innovation. According to the marginal effects, the acquisition of equipment has a higher capacity to generate process innovations. For example, investments in technical equipment and IT infrastructure are needed for the deployment of smart grids and networks. All in all, Vega-Jurado, Gutiérrez-Gracia and Fernández-de-Lucio [54] posed a similar idea for manufacturing firms: product and process innovations may be independent of each other and, even more importantly, they could be associated with different knowledge-sourcing strategies.

Fourth, there is no clear evidence supporting the complementarity hypothesis between internal R&D and external knowledge acquisition. Product innovation relies on in-house capabilities. Process innovation, on the contrary, demands knowledge from outside the firm. All in all, there could be complementarity effects between them, but they are not obvious from the data; a stream of innovation literature claims that internal R&D increases the absorptive capacity [55] of the firm to incorporate external knowledge [56,57].

Regarding the Propelling Role of Sustainability Orientation

Given the external pressures from the different stakeholders, sustainability orientation is considered by many authors to be a key driver of firm innovation [58–60]. Our study confirms that sustainability orientation does increase the likelihood of generating innovations. As mentioned in the sensitivity analysis, utilities declaring that sustainability goals are relevant or highly relevant tend to be more innovative. Electricity, gas and water utilities activate innovativeness when searching for solutions that (i) mitigate environmental impact or (ii) comply with environmental and health and safety regulations. However, marginal effects indicate that sustainability orientation is not the most important driver. This holds for both product and process innovation.

Limitations and Future Research

The paper has several limitations, but also sets the foundations for some future research lines. First, we have already mentioned in Section 3.1 that it is not possible to disaggregate the utilities sector into three different industries—electricity, gas and water. Although the three exhibit common features of network industries, they have different technological and regulatory characteristics. Therefore, a separate study for each industry would be valuable, but must be based on other information sources. Second, the database PITEC does not allow the researchers to identify the firms. Therefore, it is not possible to complement the information of the firm with other sources for refining the analysis. Third, the paper has focused on product and process innovation. Marketing, organizational and even business model innovations are other areas that could be worth exploring. Fourth, external determinants of innovation were not considered. For example, subsidies and other support mechanisms strongly affect the willingness to innovate. Thus, including external factors could enrich the results. Finally, due to their traditional monopolistic organizational cultures, utilities are relative newcomers in the open innovation paradigm [61]. Nevertheless, many large utilities are now common players in the external corporate venturing market. They actively seek for ideas and startups that could complement their knowledge portfolio. This new reality opens a promising window for future research.

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References

1. Mayes, N. *Digital Utilities: From Behind the Curve to Innovation, 2017*; CXP Group: London, UK, 2017.
2. Lee, S.W.; Sarp, S.; Jeon, D.J.; Kim, J.H. Smart water grid: The future water management platform. *Desalin. Water Treat.* **2015**, *55*, 339–346. [CrossRef]
3. Tuballa, M.L.; Abundo, M.L. A review of the development of Smart Grid technologies. *Renew. Sustain.Energy Rev.* **2016**, *59*, 710–725. [CrossRef]
4. IEA. *Electricity Supply Industry. Structure, Ownership and Regulation in OECD Countries*; OECD: Paris, France, 1994.
5. Eurelectric. *Utilities: POWERHOUSES of Innovation*; Eurelectric: Brussels, Belgium, 2013.
6. Lieberherr, E.; Truffer, B. The impact of privatization on sustainability transitions: A comparative analysis of dynamic capabilities in three water utilities. *Environ. Innov. Soc. Transit.* **2015**, *15*, 101–

122. [CrossRef]

7. HM Government. *Encouraging Innovation in Regulated Industries: Consultation*; HM Treasury: London, UK, 2018.
8. Wehn, U.; Montalvo, C. Exploring the dynamics of water innovation: Foundations for water innovation studies. *J. Clean. Prod.* **2018**, *171*, S1–S19. [CrossRef]
9. Costa-Campi, M.T.; Duch-Brown, N.; García-Quevedo, J. R&D drivers and obstacles to innovation in the energy industry. *Energy Econ.* **2014**, *46*, 20–30.
10. Erzurumlu, S.; Yu, W. Development and deployment dynamics of sustainability-driven innovations in the electric and energy utility industry. *J. High Technol. Manag. Res.* **2018**, *29*, 88–97. [CrossRef]
11. Markard, J.; Truffer, B. Innovation processes in large technical systems: Market liberalization as a driver for radical change? *Res. Policy* **2006**, *35*, 609–625. [CrossRef]
12. Munari, F.; Roberts, E.B.; Sobrero, M. Privatization processes and the redefinition of corporate R&D boundaries. *Res. Policy* **2002**, *31*, 31–53.
13. Markard, J.; Truffer, B.; Imboden, D.M. The impacts of market liberalization on innovation processes in the electricity sector. *Energy Environ.* **2004**, *15*, 201–214. [CrossRef]
14. Bell, R.A.; Schneider, T.R. Balkanization and the future of electricity R&D. *Electr. J.* **1999**, *12*, 87–98.
15. McGowan, F. *The Struggle for Power in Europe: Competition and Regulation in the EC Electricity Industry*; Royal Institute of International Affairs: London, UK, 1993.
16. Thomas, S. Strategic government and corporate issues. In *The British Electricity Experiment—Privatization: The Record, the Issues, the Lessons*; Surrey, J., Ed.; Earthscan: London, UK, 1996; pp. 255–291.
17. Sagar, A.D.; Van der Zwaan, B. Technological innovation in the energy sector: R&D, deployment, and learning-by-doing. *Energy Policy* **2006**, *34*, 2601–2608.
18. Jamasb, T.; Pollitt, M. Liberalisation and R&D in network industries: The case of the electricity industry. *Res. Policy* **2008**, *37*, 995–1008.
19. Dooley, J.J. Unintended consequences: Energy R&D in a deregulated energy market. *Energy Policy* **1998**, *26*, 547–555.
20. Erdogdu, E. Implications of liberalization policies on government support to R&D: Lessons from electricity markets. *Renew. Sustain. Energy Rev.* **2013**, *17*, 110–118.
21. Kim, J.; Kim, Y.; Flacher, D. R&D investment of electricity-generating firms following industry restructuring. *Energy Policy* **2012**, *48*, 103–117.
22. Nemet, G.F.; Kammen, D.M. US energy research and development: Declining investment, increasing need, and the feasibility of expansion. *Energy Policy* **2007**, *35*, 746–755. [CrossRef]
23. Jamasb, T.; Pollitt, M. Why and how to subsidise energy R+D: Lessons from the collapse and recovery of electricity innovation in the UK. *Energy Policy* **2015**, *83*, 197–205. [CrossRef]
24. Sanyal, P.; Cohen, L.R. Powering progress: Restructuring, competition, and R&D in the US electric utility industry. *Energy J.* **2009**, *30*, 41–79.
25. Schmitt, S.; Kucsera, D. The impact of the regulatory reform process on the R&D investment of European electricity utilities. *Rev. Netw. Econ.* **2014**, *13*, 35–67.
26. Sterlacchini, A. Energy R&D in private and state-owned utilities: An analysis of the major world electric companies. *Energy Policy* **2012**, *41*, 494–506.
27. Sagar, A.D.; Holdren, J.P. Assessing the global energy innovation system: Some key issues. *Energy Policy* **2002**, *30*, 465–469. [CrossRef]
28. Markard, J.; Raven, R.; Truffer, B. Sustainability transitions: An emerging field of research and its prospects. *Res. Policy* **2012**, *41*, 955–967. [CrossRef]
29. Harvey, B.; Schaefer, A. Managing relationships with environmental stakeholders: A study of UK

water andelectricity utilities. *J. Bus. Eth.* **2001**, *30*, 243–260. [CrossRef]

30. Council of the European Union. *Review of the EU Sustainable Development Strategy (EU SDS)—Renewed Strategy*; 10917/06; European Commission: Brussels, Belgium, 2006.
31. European Commission. *Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for the Community Action in the Field of Water Policy*; European Commission: Brussels, Belgium, 2000.
32. Boström, M.; Hallström, K.T. NGO power in global social and environmental standard-setting. *Glob Environ. Politcs* **2010**, *10*, 36–59. [CrossRef]
33. Kowal, B.; Kustra, A. Sustainability reporting in the energy sector. *E3S Web Conf.* **2016**, *10*, 129–132. [CrossRef]
34. Rabadán, A.; Sáez-Martínez, F.J. Why European entrepreneurs in the water and waste management sector are willing to go beyond environmental legislation. *Water* **2017**, *9*, 151. [CrossRef]
35. Stjepcevic, J.; Siksnelyte, I. Corporate social responsibility in energy sector. *Transform. Bus. Econ.* **2017**, *16*, 21–33.
36. Green, J.; Newman, P. Citizen utilities: The emerging power paradigm. *Energy Policy* **2017**, *105*, 283–293. [CrossRef]
37. Kaenzig, J.; Heinzle, S.L.; Wüstenhagen, R. Whatever the customer wants, the customer gets? Exploring the gap between consumer preferences and default electricity products in Germany. *Energy Policy* **2013**, *53*, 311–322. [CrossRef]
38. Klewitz, J.; Hansen, E.G. Sustainability-oriented innovation of SMEs: A systematic review. *J. Clean. Prod.* **2014**, *65*, 57–75. [CrossRef]
39. Adams, R.; Jeanrenaud, S.; Bessant, J.; Denyer, D.; Overy, P. Sustainability-oriented innovation: A systematic review. *Int. J. Manag. Rev.* **2016**, *18*, 180–205. [CrossRef]
40. Carrillo-Hermosilla, J.; Del Río, P.; Könnölä, T. Diversity of eco-innovations: Reflections from selected case studies. *J. Clean. Prod.* **2010**, *18*, 1073–1083. [CrossRef]
41. OECD. *The Future of Eco-Innovation: The Role of Business Models in Green Transformation*; OECD: Paris, France, 2012.
42. Suarez-Perales, I.; Garces-Ayerbe, C.; Rivera-Torres, P.; Suarez-Galvez, C. Is strategic proactivity a driver of an environmental strategy? Effects of innovation and internationalization leadership. *Sustainability* **2017**, *9*, 1870. [CrossRef]
43. Savignac, F. Impact of financial constraints on innovation: What can be learned from a direct measure? *Econ. Innov. New Technol.* **2008**, *17*, 553–569. [CrossRef]
44. Mancusi, M.L.; Vezzulli, A. *R&D, Innovation and Liquidity Constraints*; KITeS Working Paper; UniversitàBocconi: Milano, Italy, 2010.
45. D'Este, P.; Iammarino, S.; Savona, M.; von Tunzelmann, N. What hampers innovation? Revealed barriersversus deterring barriers. *Research Policy* **2012**, *41*, 482–488. [CrossRef]
46. Blanchard, P.; Huiban, J.P.; Musolesi, A.; Sevestre, P. Where there is a will, there is a way? Assessing the impact of obstacles to innovation. *Ind. Corp. Chang.* **2013**, *22*, 679–710. [CrossRef]
47. Pellegrino, G.; Savona, M. *Is Money All? Financing Versus Knowledge and Demand Constraints to Innovation*; UNU-MERIT Working Paper; United Nations University: Maastricht, The Netherlands, 2013.
48. OECD. *Oslo Manual. Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*; OECD: Paris, France, 2005.
49. Liao, T.F. *Interpreting Probability Models*; Sage Publications: Thousand Oaks, CA, USA, 1994.
50. Baltagi, B. *Econometric Analysis of Panel Data*; John Wiley & Sons: Chichister, UK, 2008.
51. Mairesse, J.; Mohnen, P. Using innovation surveys for econometric analysis. In *Handbook of the Economics ofInnovation*; Hall, B.H., Rosenberg, N., Eds.; Elsevier: Amsterdam, The Netherlands,

2010; pp. 1130–1155.

52. Jamasb, T.; Pollitt, M. Electricity sector liberalisation and innovation: An analysis of the UK's patenting activities. *Res. Policy* **2011**, *40*, 309–324. [CrossRef]
53. Marino, M.; Parrotta, P.; Valletta, G. Electricity (de) regulation and innovation. *Res. Policy* **2019**, *48*, 748–758. [CrossRef]
54. Vega-Jurado, J.; Gutiérrez-Gracia, A.; Fernández-de-Lucio, I. Does external knowledge sourcing matter for innovation? Evidence from the Spanish manufacturing industry. *Ind. Corp. Chang.* **2009**, *18*, 637–670. [CrossRef]
55. Cohen, W.M.; Levinthal, D.A. Absorptive capacity: A new perspective on learning and innovation. *Adm. Sci.Q.* **1990**, *35*, 128–152. [CrossRef]
56. Veugelers, R. Internal R&D expenditures and external technology sourcing. *Res. Policy* **1997**, *26*, 303–316.
57. Cassiman, B.; Veugelers, R. In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition. *Manag. Sci.* **2006**, *52*, 68–82.
58. Nidumolu, R.; Prahalad, C.K.; Rangaswami, M.R. Why sustainability is now the key driver of innovation. *Harv. Bus. Rev.* **2009**, *87*, 56–64.
59. Seebode, D.; Jeanrenaud, S.; Bessant, J. Managing innovation for sustainability. *R&D Manag.* **2012**, *42*, 195–206.
60. Varadarajan, R. Innovating for sustainability: A framework for sustainable innovations and a model of sustainable innovations orientation. *J. Acad. Mark. Sci.* **2017**, *45*, 14–36. [CrossRef]
61. Chesbrough, H.W. *Open Innovation: The New Imperative for Creating and Profiting from Technology*; Harvard Business Press: Boston, MA, USA, 2003.

5.2 Sustainable Consumption and Production: Exploring the Links with Resources Productivity in the EU-28

Sustainable Consumption and Production: Exploring the Links with Resources Productivity in the EU-28[2]

Abstract: In the framework of the European Union's Sustainable Development Policy, the promotion of sustainable consumption and production patterns has been a key issue. The explanation is given by their capacity to address social and economic development within the carrying capacity of ecosystems and decoupling economic growth from environmental degradation. The EU has established an extensive range of proposals on sustainable consumption and production (SCP), which include an energy- and resource-efficient economy, circular economy, waste prevention and recycling, among others. This paper contributes, by using both factorial and regression analysis, to the identification of fundamental constructs that define SCP in the EU-28, their links with resource productivity and the role of governments and enterprises in its improvement by means of investment in research, development and innovation over the period 2001–2018. Some recommendations to policy-makers are proposed in the paper in order to take actions directly on SCP, such as promoting the use of recycled raw materials in public works, or imposing the need for Ecolabel certification to contract with public administration.

Keywords: sustainable consumption; sustainable production; research and development; factorial analysis; regression analysis

1. Introduction

1.1. Literature Review

The importance of developing both sustainable consumption and production (SCP) patterns has already been shown, within the framework of the European Roundtables for Cleaner Production, in the Oslo Symposium 1994. It defined SCP as "the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as

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well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of further generations" [1].

The concept of SCP was subsequently recognized in the Johannesburg Plan of Implementation, enacted in 2002, at the World Summit on Sustainable Development. On that occasion, the need for implementing important changes in the way societies consume and produce is emphasized in order to be able to achieve sustainable development. More specifically, it highlighted "the encouragement and promotion of a 10-year framework of programmes (10YFP) in support of regional and national initiatives to accelerate the shift towards sustainable consumption and production to promote social and economic development within the carrying capacity of ecosystems" [2] (p. 7). This 10 year framework of programs on sustainable consumption and production patterns was adopted at the Rio+20 Conference [3].

The 2030 Agenda for Sustainable Development was adopted in 2015, with 17 goals and 169 targets. Goal number 12 aims to ensure sustainable consumption and production patterns. For this, the document pointed out "We (Countries) commit to making fundamental changes in the way that our societies produce and consume goods and services" [4]. The objective was to achieve, among others, the following priority aimed by 2030: the sustainable management and efficient use of natural resources, the reduction of waste generation by means of prevention, reduction, recycling and reuse as well as the provision of relevant information for the sustainable development and the adoption of lifestyles in harmony with nature.

In order to carry out specific actions that promote SCP patterns, a better understanding of the factors that contribute to SCP is important. In this context, Bengtsson et al. [5] identified two approaches: efficiency and systemic. The efficiency approach is focused on technological improvement and informed consumer choice, in which the promotion of more efficient production methods and products is the basis. On the other hand, the systemic approach emphasizes overall volumes of consumption, distributional features, as well as, institutional and related social changes.

Haas et al. [6] pointed out the importance of increasing the circularity of the economy, with the aim of achieving SCP, by means of the following strategies: recycling and reuse, the switch from fossil fuels to renewable energies, and the reduction of the overall level of resource consumption. Recycling entails end-of-life waste reprocessing into products, materials or substances that can be reused in the chain of production and consumption. This contributes to the reduction of resources consumption in the economy, priority issue in the present environment of limited resources in the nature. On the other hand, fossil fuels are converted, in production processes, into greenhouse gas emissions and other residues which cannot be recycled into the economy, with the consequent environmental problems related to global warming and climate change. Hence, the importance of turning towards renewable sources characterized by being widely available, naturally replenished and involving a lower environmental impact. Finally, the resources consumption reduction is essential, as it has been established previously, in the present context of resources limitation.

Similarly, Nash [7] pointed out that resource use, available technologies, product design, and consumer demand as the main challenges in order to achieve SCP. In this context, smarter consumption, learner production, and global action were the main actions developed by the European Union (EU). Smarter consumption is related to promoting producers' and consumers' awareness of the environmental effects of their production and consumption choices (eco-design and labelling). In the case of learner production, it is based on life cycle thinking which requires the development of tools to promote resource efficiency (eco-management and audit schemes). Finally, global action makes reference to investment programs that support the global market for environmental outputs (for example, the International Partnership for Cooperation on Energy Efficiency).

Regarding sustainable consumption, it is considered as the main challenge in EU´s environmental policy. In this context, important advances in sustainable production have taken place, as several outputs have become more resource and energy efficient, whilst total resources consumption was increased [8]. In this context, Scholl et al. [9] and Mont and Dalhammar [10] showed the importance of national eco-labels in order to develop a more comprehensive approach that integrates social sustainability into sustainable consumption instruments, as well as the development of a user-friendly database that provides information about the life-cycle-related environmental, social and economic impacts of products. Mont and Plepys [11] suggested that government intervention was required to change the present framework in order to encourage producers to seek business opportunities based on less resource-intensive product-service offers. Hale [12] showed consumers´ environmental awareness as the main driver to create sustainable consumption and pointed out the need to strengthen policies related to this issue.

In addition to the aforementioned aspects, multiple studies have pointed out the importance and need for investment in research, development and innovation, both from the governmental point of view and from the business point of view, for the effective development of measures aimed at the achievement of SCP. Thus, Adedoyin et al. [13] showed that expenditures on research and development (R&D), especially those destined to the enhancement of renewable energies, improve environmental sustainability, while Stevens [14] denoted the relevance of the government's role in the development of SCP patterns through investment and incentives for R&D. Similarly, private investment in R&D can make a significant contribution to sustainable economic growth [15,16].

In this context, it can be concluded that there is not unanimity about the main drivers of sustainability in the EU-28. Factors related to specific actions were identified in previous literature (for example, circular economy in Haas et al. [6], Figge et al. [17], Di Maio et al. [18]; smarter consumption and learner production in Nash [7]; and governmental intervention in Hale [12] and Mont and Plepys [11]) but there is still not a global framework.

As explained in the next section, as a novelty this paper provides an empirical study, from a global point of view, of the relationship between the factors previously identified as drivers of sustainability and resource productivity, one of the main indicators used by the EU to measure sustainability.

1.2. Objective of the Paper

The objective of this paper is to deepen this research field from a global point of view, due to the previous literature been mainly focused on specific sectors. Thus, we can find several studies related to sustainable production and consumption in sectors such as energy [19,20], textiles [21,22], food [23,24], urban planning [25], construction [26], service sector [27], etc., as well as analyses focused on consumer behavior and attitude towards sustainability [28–30]. By considering the literature review, and the identification of resources productivity as one of the main traditional indicators for achieving SDG 12: Responsible Consumption and Production in the EU, according to the Statistical Office of the European Union (Eurostat), Figure 1 shows the proposed model to study the factors that impact sustainability. It is based on three pillars: circular economy, sustainable consumption patterns and sustainable production patterns.

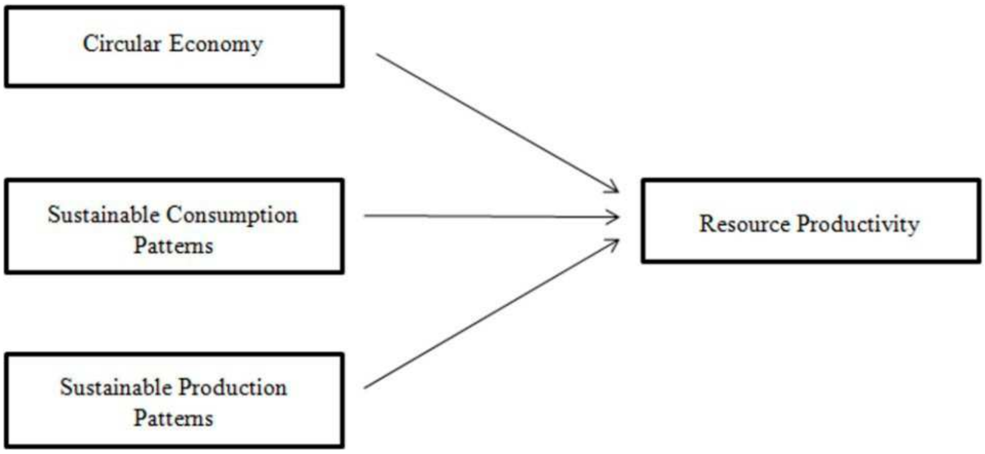

Figure 1. Proposed model in sustainability.

1.3. Hypotheses Proposed

The establishment of the hypotheses is based on previous literature, on those factors that previous research has identified as possible drivers of sustainability.

As mentioned above, several authors ([6,17,18]) have identified the increase in the circularity of the economy as one of the key factors in achieving SCP. Given that a circular economy entails resources' reuse as well as recycling in the chain of production and consumption, and this entails a reduction in the consumption of raw materials, an improvement in resource productivity would be expected. The first hypothesis proposed is:

Hypotheses 1 (H1). *The greater circularity of the economy, the higher resource productivity.*

Secondly, previous research ([7,9–11,31]) has pointed out the importance of less resource-intensive production, of more efficient technologies and design, with a lower environmental impact throughout the product life cycle, in order to achieve sustainability objectives. In this sense, it was hypothesized that sustainable production patterns (cleaner technologies, more efficient in the use of resources) will result in improved resource productivity, with the consequent sustainability improvements:

Hypotheses 2 (H2). *Sustainable production patterns will lead to higher resource productivity.*

Finally, the importance of establishing sustainable consumption patterns for achieving sustainability goals has been raised ([11,12,31]). In this sense, it has been pointed out that the producers' and consumers' awareness of the environmental effects in their production and consumption choices is a key issue. This environmental awareness should lead to a more efficient use of resources, which would entail improvements in resource productivity and allow reducing resource scarcity risk, with the consequent lower environmental impact. The proposed hypothesis is therefore:

Hypotheses 3 (H3). *Sustainable consumption patterns will lead to higher resource productivity.*

2. Materials and Methods

2.1. Sample and Variables

This study was developed for the EU-28 over the period 2001–2018. The unit of analysis is the EU in global terms, without going into an in-depth analysis of the institutional differences between countries. Those cases for which there was no information on any of the variables were not considered in the study in order to avoid missing values in the estimates. In this sense, the analysis were performed taking the data as a pool instead of using panel data methodology due to the high number of missing values in the explanatory variables. As a result, instead of the possible 504 observations (28 countries, 18 years), we ended up with 99 observations that were extracted from Eurostat database.

The variables included in this study were chosen from a previous literature review, as well as from available data in Eurostat. They are based on a circular economy, sustainable consumption patterns and sustainable production patterns.

With regard to sustainable production, as pointed out by Krajnc and Glavicˇ [32] or Azapagic and Perdan [33], there are a series of measurable factors or elements that we can consider as key, such as energy use, materials use, water consumption, products, wastes, and air emissions.

On the other hand, according to Caeiro et al. [34], there are significant environmental and sustainability aspects or pressures directly related to household sustainable consumption to be taken into account: water, materials and energy consumption, pollutant emissions, waste disposal or land use patterns produced by the household activities, products and services.

In order to analyze the circularity of the economy, previous studies such as the one developed by Horvath et al. [35] consider the variables circular material use rate, recycling rate, domestic material consumption and resource efficiency, all of them available in Eurostat, considered as relevant. Taking into account what was mentioned above, and the availability of data, the selected variables aim to collect these main aspects by measuring the consumption and use of energy, the share of energy from renewable sources, the consumption of materials, the reuse or recycling of waste (domestic and construction and demolition) and the emission of greenhouse gases.

Finally, in order to take into account the effect of the investment in R&D proposed by Adedoyin et al. [13], the expenditure data collected by Eurostat were included in the analysis. All the variables selected are shown in Table 1.

Table 1. Variables included in the model.

Variable	Code	Source
Circular material use rate	CIRC-MAT-USE	Eurostat (cei_srm030)
Recycling rate of municipal waste	RECRAT-MWAST	Eurostat (t2020_rt120)
Recovery rate of construction and demolition waste	RECOV-RAT-WAST	Eurostat (cei_wm040)
Primary energy consumption per capita	PRIM-ENER-CONS	Eurostat (sdg_07_10)
Final energy consumption per capita	FIN-ENERG-CONS	Eurostat(sdg_07_11)
Final energy consumption in households per capita	FIN-ENERG-CONS-HOUS	Eurostat(sdg_07_20)
Share of energy from renewable sources	QUOT-ENERG-RES-E	Eurostat(sdg_07_40)
Greenhouse gas emissions per capita	GHG	Eurostat(t2020_rd300)
Greenhouse gas emissions intensity of energy consumption	GHG-ENERG	Eurostat (sdg_13_20)
Domestic material consumption per capita	DMC	Eurostat(t2020_rl110)
Intramural R&D expenditure (GERD—Government	RDEXP-GOV-D	Eurostat(rd_e_gerdtot)
Intramural R&D expenditure (GERD)—business	RDEXP-BUS-D	Eurostat(rd_e_gerdtot)
Resource productivity	RES-PROD-DMC	Eurostat(t2020_rl100)

2.1.1. Variables Explanation

Circular material use rate measures the share of material recovered and fed back into the economyin overall material use (in %) (CIRC-MAT-USE).

Recycling rate of municipal waste reflects the treatment of national waste. This measures the share of recycled municipal waste in the total municipal waste generation. Recycling includes material recycling, composting and anaerobic digestion. The ratio is expressed in percent (%) (RECRAT-MWAST).

Recovery rate of construction and demolition waste makes reference to the ratio that is related to construction and demolition waste (prepared for re-use, recycled or subject to material recovery, including through backfilling operations), and the construction and demolition waste treated (in %) (RECOV-RAT-WAST).

Primary energy consumption per capita considers the energy consumption by end users (such as industry, transport, households, services and agriculture), plus the energy consumption of the energysector itself, losses taking place in energy transformation and distribution (in kg of oil equivalent percapita) (PRIM-ENERG-CONS), divided by the population of the country.

Final energy consumption per capita measures the energy consumed by end users (such as industry,transport, households, services and agriculture), although it excludes the energy consumption of the energy sector itself and the losses occurring during energy transformation and distribution.This variable is divided by the population (in kg of oil equivalent per capita) (FIN-ENERG-CONS).

Final energy consumption in households per capita measures how much electricity and heat (excluding the energy used for transportation) every citizen consumes at home. This variable considers only theenergy used by end consumers (in kg of oil equivalent per capita) (FIN-ENERG-CONS-HOUS).

Share of energy from renewable sources measures the renewable energy consumption share in grossfinal energy consumption (in %) (QUOT-ENERG-RES-E).

Greenhouse gas emissions per capita makes reference to the total national emissions (including carbon dioxide, methane, nitrous oxide, and the F-gases (hydrofluorocarbons, perfluorocarbons, nitrogen triflouride and sulphur hexafluoride)), divided by the population (in kilograms per capita) (GHG).

Greenhouse gas emissions intensity of energy consumption is calculated as the ratio that relates to energy-related greenhouse gas emissions and gross inland energy consumption (index (2000 = 100))(GHG-ENERG).

Domestic material consumption per capita makes reference to the total material amount directly used in an economy. It is calculated as direct material input minus exports, divided by the population(in kilograms per capita) (DMC).

Intramural R&D expenditure (GERD)—Government makes reference to all current expenditures for research and development performed by governments during a specific period (in Euro per inhabitant) (RDEXP-GOV-D).

Intramural R&D expenditure (GERD)—Business makes reference to all the current expenditures for research and development performed by enterprises during a specific period (in Euro per inhabitant)(RDEXP-BUS-D).

Finally, according to the Statistical Office of the European Union (Eurostat), the *resource productivity* variable is the lead indicator for measuring the resource efficiency, so it is used subsequently as the dependent variable of the regression analysis. The indicator is defined as the gross domestic product (GDP) divided by domestic material consumption (DMC) (in Euro per kilogram) (RESPROD-DMC).

2.2. Method

Principal component factorial analysis was the first method used in the present research. It is a multivariate analysis technique of data reduction. This method allows to transform and reduce the initial set of variables in a new set of variables (without losing any information), lineal combination of the original set of variables, called principal components (factors). Principal component factorial analysis seeks to find these components or factors, which are characterized by being uncorrelated with each other, which successively explains the greater part of the total variance. As Kline [36] explains, the meaning of these factors has to be deduced from the factor loadings, computed in the factor analysis. These factor loadings, correlations of the initial variables with the factors, are usually considered as high if they are greater than 0.6, and moderately high if they are above 0.3, ignoring other loadings [36]. This is the selection criterion that was applied in the present research.

Subsequently, once the factorial analysis allowed us to compute the factors, the correlation between each of the three mentioned factors and the dependent variable was analyzed, evaluating the Spearman correlation coefficient. Later, a stepway regression analysis was used to assess the relationships between the selected factors and the dependent variable, namely the resource productivity. In order to check the robustness of the results obtained, several additional analyses were carried out, whose results were mentioned in the following sections.

Both analyses were performed using IBM® SPSS® Statistics (v 25.0).

3. Results

3.1. Factorial Analysis

The results obtained from principal component factorial analysis, summarized in Table 2, shows three factors that explain 74.609% of the variance. These factors were called: resource consumption (RESO-COMPS), sustainable use of resources (RESO-SUST-USE) and recycling-circulareconomy (REC-CIRC-ECO).

Table 2 shows factorial loadings that represent the correlation coefficients among the variables (rows) and factors (columns). Factorial loadings with values greater than 0.6 can be considered high, according to Kline [36] and Hair et al. [37]. These values allow confirming that independent variables, which were identified a priori, belong to a specific factor.

Table 2. Results of principal component factorial analysis.

Variable Code	RESO-COMPS	RESO-SUST-USE	RESO-CIRC-ECO
PRIM-ENERG-CONS	0.960		
FIN-ENERG-CONS	0.947		
FIN-ENERG-CONS-HOUS	0.805		
DMC	0.610		-0.509
RECOV-RAT-WAST			0.554
CIRC-MAT-US			0.741
RECRAT-MWAST	0.480		0.666
GHG	0.819	-0.434	
GHG-ENERG		-0.626	
QUOT-ENERG-ERS-E		0.857	
RDEXP-BUS-D	0.699	0.518	

Variable Code	RESO-COMPS	RESO-SUST-USE	RESO-CIRC-ECO
RDEXP-GOV-D	0.793		

*Convergence in 6 interactions. **Analysis of Principal Component Analysis. Varimax with Kaiser normalization, 74.609% of the variance explained. Test KMO = 0.744, statistical significance p=0.000, acceptable if p < 0.05. Barlett´s Sphericity Test: Chi Square = 1036.34

Previously, the Kaiser–Meyer–Olkin measure of sampling adequacy (KMO) was calculated in order to verify the suitability of the analysis. This should have a value of 0.6 or above. The KMO for this study was 0.744 which fit within acceptable limits. The Bartlett’s Test of Sphericity should be significant (less than 0.05) and in this study met this criterion as the test showed a significant p value($p = 0.000$). According to Hair et al. [37], in the study field of social sciences, a solution that explains more than 60% of the variance is valid. In this study, this variable has a value of 74.609%. Therefore, as the prerequisite values for model fit were achieved, the factor model can be considered reasonably fit.

The estimates of the variables, as well as the overall adjust assessment were developed by means of the principal component analysis. According to Kline [36] and Hair et al. [37], this method is suitable to summarize the original information of the factors in future analysis.

The results of Varimax rotation suggest that especially the variables that make reference to sustainable consumption patterns (PRIM-ENERG-CONS, FIN-ENERG-CONS, FIN-ENERG-CONS-HOUS, DMC),expenditure on research and development (RDEXP-BUS-D, RDEXP-GOV-D) and, to a lesser degree, sustainable production patterns (GHG) and circular economy (RECRAT-MWAST), are combined by creating the first factor, that has been called resource consumption (RESO-COMPS).

On the other hand, the results reinforce the expected pattern: circular material use rate (CIRC-MAT-USE), recycling rate of municipal waste (RECRAT-MWAST), recovery rate of construction and demolition waste (RECOV-RAT-WAST) and, to alesser degree and reverse direction, domestic material consumption (DMC), are all variables that make reference to circular economy factor (REC-CIRCECO).

Finally, the variables that make reference to sustainable production patterns, especially in terms of energy (QUOT-ENERG-RES-E, GHG and GHG-ENERG), and, to a lesser degree, expenditure on research and development (RDEXP-BUS-D, RDEXP-GOV-D) are combined by creating the third factor, that has been called sustainable use of resources (RESO-SUST-USE).

3.2. Correlations between factors and dependent variable

Once the new variables have been obtained from the aggrupation of homogeneous criteria by means of the factorial analysis, a study of bivariate correlations between these factors and the dependent variable has been carried out. An analysis of the Spearman correlation coefficient, given that the factors obtained do not respond sufficiently to a normal distribution, has been used. Table 3 shows the results obtained in this analysis.

Table 3. Correlation analysis

		RESO-COMPS	**RESO-SUST-USE**	**REC-CIRC-ECO**
RES PROD-DMC	**Spearman's Rho**	0.242*	-0.155	0.741**
	Sig. (bilateral)	0.016	0.127	0.000
	N	99	99	99

*correlation is significant at 0.05 level (bilateral) **correlation is significant at 0.01 level (bilateral)

The study of Spearman's correlation allows us to extract some relevant ideas for further analysis. Thus, we can already see that there is an important and significant correlation between the factor linked to circular economy (REC-CIRC-ECO) and resources productivity (RES PROD-DMC) (Spearman's Rho = 0.741; Sig. = 0.000 < 0.01). To a lesser extent, there is a certain correlation between the factor related to resources consumption (RESO-COMPS) and their productivity (Spearman's Rho = 0.242; Sig. = 0.016 <0.05). On the contrary, there does not seem to be a significant correlation between the factor linked to a sustainable use of resources (RESO-SUST-USE), especially in terms of energy production, and its productivity in economic terms (Spearman's Rho = -0.155; Sig. = 0.127 > 0.05). For this reason, for the subsequent regression analysis, factors 1 (RESO-COMPS) and 3 (REC-CIRC-ECO) will be used. These results will be analyzed later.

3.3. Regresion Analysis

Once the factorial analysis allowed us to compute the factors and the correlation analysis allowed us to select them in relation to their significance, a Stepway Regression Analysis has been applied. As it is well known, in the multiple linear regression model we look for a relationship like the following

$$Y_i = \beta_0 + \beta_1 \cdot X_{i1} + \beta_2 \cdot X_{i2} + \cdots + \beta_n \cdot X_{in} + \varepsilon_i$$

where

Y_i is the observed value of the dependent variable

β_0 represents the effects due to constant factors

$\beta_1, \beta_2, \ldots \beta_n$ are the weights of each of the *n* independent variables in the model.

ε_i are errors due to uncontrolled factors

The construction of the equation has been done by selecting the variables step by step, as explained by Rodríguez-Jaume and Mora-Catalá [38]. The aim of this methodology is to find, among all the possible explanatory variables, those that best explain the dependent variable without any of them being a linear combination of the others. In each step is introduced only that variable that meets the input criteria, analyzing the *p-value* associated with the statistic *t* (if $p<0.05$ the variable is introduced). Once introduced, it is assessed if any of the variables meet the output criteria, also analyzing the *p-value*. Finally, in each step, in which a variable is introduced or eliminated, the regression goodness-of-fit statistics, the analysis of variance (ANOVA) and the estimation of parameters are obtained, considering the variables introduced in each model. For obtaining the regression coefficients β_1, β_2, ... β_n, the criterion of least squares is used.

Regarding the goodness of the linear regression model, as pointed out by Rodríguez-Jaume and Mora-Catalá [38], the analysis of variance allows us to assess if this model is adequate to estimate the values of the dependent variable. The ANOVA table provides the F statistic from which we can contrast the null hypothesis that the two variables are unrelated. If the *p-value* associated with the F statistic is less than the level of significance (0.05), we will reject the null hypothesis. In our case of multiple regression analysis, the analysis of variance table (table 4) indicates the *p-values* associated with the F statistic in each of the two models generated.

Table 4. Analysis of variance (ANOVA) of the two models

Model		Sum of squares	df	Meansquare	F	p-value
1	Regression	55.537	1	55.537	121.572	0.000*
	Residual	44.312	97	0.457		
	Total	99.848	98			
2	Regression	65.590	2	32.795	91.899	0.000**
	Residual	34.258	96	0.357		
	Total	99.848	98			

Dependent variable: RES PROD-DMC *Predictors: (Constant), REC-CIRC-ECO **Predictors: (Constant), REC-CIRC-ECO, RESO-COMPS

Since the *p-value* associated with the F statistic is lower than the significance level ($p<0.05$), it indicates that the model proposed is adequate for estimating the values of the dependent variable.

In the same way, the goodness of the adjustment can be verified by the values of R and the coefficient of determination (R^2 and adjusted R^2). According to Abuín [39], with a value of the coefficient of determination R^2 between 0.5 and 0.85 it is considered that the adjustment is good.

The results obtained in the regression analysis are summarized in Table 5 for both models, and show that the adjustment of model 2 can be considered good.

Table 5.Results of Regression Analysis

Model		Coeficients[1]						
		Non standarized		Standarized				
		β	Dev. Error	β	t	p-value	R^2	AdjustedR^2
1[2]	(Intercept)	1.695	0.068		24.956	0.000	0.556	0.552
	REC-CIRC-ECO	0.753	0.068	0.746	11.026	0.000		
2[3]	(Intercept)	1.695	0.060		28.236	0.000	0.657	0.650
	REC-CIRC-ECO	0.753	0.060	0.746	12.475	0.000		
	RESO-COMPS	0.320	0.060	0.317	5.308	0.000		

[1] Dependent variable: RES-PROD-DMC [2] Predictors: (Intercept), REC-CIRC-ECO [3] Predictors: (Intercept), REC-CIRC-ECO, RESO-COMPS

The following expression is obtained for the dependent variable (resource productivity)

RES-PROD-DMC = 1.695 + 0.753 * REC-CIRC-ECO + 0.320 * RESO-COMPS

The model with the best fit and that best explains the dependent variable (RES-PROD-DMC), as noted above, is model 2, in which both independent variables are introduced (REC-CIRC-ECO, RESO-COMPS). It can be observed that circular economy (REC-CIRC-ECO) (factor 3) and resource consumption (RESO-COMPS) (factor 1) have a positive and statistically significant impact on resource productivity (RES-PROD-DMC) (β= 0.753 p=0.000 and β=0.320 p=0.000, respectively).

In order to check the results obtained in the Spearman correlation study, the factor linked to a sustainable use of resources (RESO-SUST-USE) has been introduced in a model with the other two factors (REC-CIRC-ECO, RESO-COMPS), obtaining again that this factor is not significant (β = -0.216 p = 0.117), so it does not seem to be a good predictor of the dependent variable. On the other hand, to verify that, with the data used, there are no clear differences between countries that could affect the results, a pooled OLS regression using the cluster option at country level has been developed, using STATA 13, obtaining similar results, with a very slight variation in the coefficients of the explanatory variables (Intercept β=1.655; REC-CIRC-ECO β=0.739; RESO-COMPS β=0.323).

4. Discussion

Environmental pollution prevention and reduction as well as SCP promotion have been set as essential issues in the framework of the European Union´s Sustainable Development Strategy. These actions are especially relevant in order to secure, in the long-term, the physical basis of society and economy in a way that respect the tolerable limits of the planet´s resources and improve the environmental protection.

This paper provides an empirical analysis of the identification of fundamental constructs that define SCP in the EU-28 over the period 2001- 2018. The results obtained from Principal Component Factorial Analysis have allowed us to identify three factors that explain 74.609% of the variance: resource consumption (RESO-COMPS), recycling-circular economy (REC-CIRC-ECO), and sustainable use of resources (RESO-SUST-USE). Analyzing each of these factors separately we can conclude the following, in order of significance:

The study of correlation and the regression analysis suggest that the factor called recycling-circular economy (REC-CIRC-ECO) has a positive and significant impact on resources productivity (RES-PROD-DMC), which validates the Hypothesis 1. In this point, we must remember that this factor summarized the variables *Circular material use rate*, *Recycling rate of municipal waste*, *Recovery rate of construction and demolition waste*, and in the opposite sense *Domestic material consumption per capita.* Reuse and recycling convert waste into usable products and materials in the production chain or in the domestic sphere, which contributes to reducing the consumption of resources in the economy, which in turn increases its productivity. This result agrees with that stated by Hass et al. [6] and by Schroeder et al. [40]. Therefore, it is possible to move towards sustainable modes of production and consumption (SCP) and increase resource productivity by promoting practices related to circular economy and recycling. These practices, as defined by the European Environment Agency [41] can be: Eco - design, repair, reuse, refurbishment, remanufacture, product sharing, waste prevention and waste recycling.

Secondly, the analysis carried out suggests that the factor called resource consumption (RESO-COMPS) has a positive and significant effect, although to a lesser extent, on their productivity (RES-PROD-DMC), which would validate the Hypothesis 3. This result agrees with that stated by Hale [12] and Mont and Plepys [11], in the sense that an efficient use of resources will tend to increase resource productivity and allow reducing resources scarcity risk, with the consequent lower environmental impact. In the same way, it is observed that public and private investment in research and development, present in the factor in a relevant way with the variables *Intramural R&D expenditure (GERD) - Government* and *Intramural R&D expenditure (GERD) - Business*, allows us to face the uncertainty behind climate change in a manner consistent with sustainable economic growth, supporting the rapid technological change necessary as indicated by Baker and Solak [42].

Finally, the factor called sustainable use of resources (RESO-SUST-USE) encompasses the variables related to sustainable production, especially those related to energy. According to Zafar et al [15], a positive effect of sustainable production on economic growth, and therefore, on the resource productivity variable, would be expected to validate Hypothesis 2. However, from the analysis carried out, no significant relationship emerges, since there is no correlation between the RESO-SUST-USE factor and resources productivity (RES-PROD-DMC). However, the factorial loadings clearly indicate the positive effect of the increase in the share of renewable energies in the decrease of greenhouse gases, and the investment from the private sphere in research and development to promote these clean energies, which does agree with previous research of Zafar et al. [15].

The results obtained have a number of implications related to the orientation of the policies followed to achieve the objectives of sustainable development, both in the EU in general and in its member countries in particular. On the one hand, it seems clear that it is essential to make a decisive commitment to the development of practices of circular economy, recycling and reuse, both in the public administration itself (giving priority to the use of recycled raw materials in public works, for example), as in industry (for example, by promoting the visibility and recognition by consumers of Ecolabel certifications, so that companies are encouraged to obtain them, or by requiring them for contracting with the administration), as in homes (for example, by promoting school campaigns on responsible consumption, reuse and recycling). These practices result on the one hand in the reduction of the import of necessary raw materials, reducing dependence on third countries, and on the other hand in the reduction of waste generated that cannot be incorporated back into the production chain, reducing the impact on the environment. At the same time, it is necessary to maintain the commitment to the use of renewable energies, which allow the reduction of dependence on the import of fossil fuels and at the same time reduce the emission of greenhouse gases. All this should imply an increase in investment in research, development and innovation by the EU, but specifically focused on the practices of circular economy, since it is supported in part on the continuous technological improvement of processes, from design to manufacturing and ultimate recovery of materials.

These ideas are in line with the approaches made by the European Commission in its European Green Deal, the plan to make the EU's economy sustainable. They fit in with what the Commission proposes in its Communication *A new Circular Economy Action Plan for a Cleaner and More Competitive Europe* [43], in terms of empowering consumers and public buyers, circularity in production processes, establishing requirements for the use of recycled materials in construction, or coordinating innovative initiatives on the circular economy through the European Institute of Innovation and Technology. Similarly, this study contributes to one of the objectives set by the Commission, which is to analyze how the impact of circularity on climate change mitigation and adaptation can be measured in a systematic way [43].

To conclude, we must mention some limitations of the study carried out, which will be analyzed in future research. The field of research is complex, with multiple interrelated factors. Although in order to obtain homogeneous measures of the initial data, it was decided to take into account the per capita values and not the absolute values of each of the member countries, the study does not include possible institutional, structural or policy differences between countries, which may have a particular influence on the results. On the other hand, given that the availability of data is limited, it has been decided to consider the relationship between the variables without taking into account their evolution over time. One possible field for future research, depending on the availability of data, would be to carry out the analysis, even if it were qualitative, of the influence on the results of the country variable on the one hand, and the time variable on the other, in order to determine whether the relationship obtained is consistent.

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References

1. Ministry of Environment Norway.1994. *Report of the Sustainable Consumption Symposium.* Ministry of the Environment Norway, Oslo.
2. United Nations. *Johannesburg Plan Of Implementation.* Report of the World Summit on Sustainable Development, South Africa, 26 August-4 September 2002.
3. United Nations. *Rio+20.* United Nations Conference on Sustainable Development, Rio de Janeiro (Brazil), 20-22 June 2012.
4. United Nations. *Transforming our world: the 2030 Agenda for Sustainable Development.* United Nations, 2015, Paris.
5. Bengtsson, M., E. Alfredsson, M. Cohen, S. Lorek and P. Schroeder. “Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency”. *Sustainability Science* **2018** *13*, No 6, p.1-15.
6. Haas, W., F. Krausmann, D. Wiedenhofer and M. Heinz. “How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European Union and the world in 2005”. *Journal of Industrial Ecology* **2015,** *19*, No 5, p.765-777.
7. Nash, H.A. “The European Commission's sustainable consumption and production and sustainable industrial policy action plan”. *Journal of Cleaner Production* **2009,** *17*, No 4, p.496-498.

8. Kalmykova, Y., L. Rosado and J. Patrício. “Resource consumption drivers and pathways to reduction: economy, policy and lifestyle impact on material flows at the national and urban scale”. *Journal of Cleaner Production* **2016,** *132*, p.70-80.

9. Scholl, G., F. Rubik, H. Kalimo, K. Biedenkopf and O. Söebech. “Policies to promote sustainable consumption: Innovative approaches in Europe”. *Natural Resources Forum*,**2010,** *34*, No 1, p.39-50.

10. Mont, O. and C. Dalhammar. “Sustainable consumption: at the cross-road of environmental and consumer policies”. *International Journal of Sustainable Development* **2005,** *8*, No 4, p.258-279.

11. Mont, O. and A. Plepys. 2008. “Sustainable consumption progress: should we be proud or alarmed?”. *Journal of Cleaner Production* **2008,** *16*, No 4,p.531-537.

12. Hale, L.A. 2018. “At home with sustainability: from green default rules to sustainable consumption”. *Sustainability*,**2018,** 10, No 1, p.249-257.

13. Adedoyin, F. F., Alola, A. A., and Bekun, F. V."An assessment of environmental sustainability corridor: The role of economic expansion and research and development in EU countries". *Science of The Total Environment*, **2020,** *713*, p.136726.

14. Stevens, C. "Linking sustainable consumption and production: The government role." *Natural Resources Forum.*,**2010** ,Vol. *34*. No. 1. Oxford, UK: Blackwell Publishing Ltd.

15. Zafar, M. W., Shahbaz, M., Hou, F. and Sinha, A. "From nonrenewable to renewable energy and its impact on economic growth: the role of research & development expenditures in Asia-Pacific Economic Cooperation countries*." Journal of cleaner production,* **2019,** 212, p.1166-1178.

16. Ravšelj, D. and Aristovnik, A. "The impact of private research and development expenditures and tax incentives on sustainable corporate growth in selected OECD countries". *Sustainability*, **2018**, 10(7), p.2304.

17. Figge, F., Thorpe, A. S., Givry, P., Canning, L., and Franklin-Johnson, E. "Longevity and circularity as indicators of eco-efficient resource use in the circular economy". *Ecological Economics*,**2018**, 150, p.297-306.

18. Di Maio, F., Rem, P. C., Baldé, K., and Polder, M. "Measuring resource efficiency and circular economy: A market value approach". *Resources, Conservation and Recycling,* **2017,**122, p.163-171.

19. Herring, H. and Sorrell, S. *"Energy efficiency and sustainable consumption. The Rebound Effect",* Hampshire, 2009

20. Sáez-Martínez, F. J., Lefebvre, G., Hernández, J. J. and Clark, J. H."Drivers of sustainable cleaner production and sustainable energy options". *Journal of cleaner production*,**2016**, 138, p.1-7.

21. Niinimäki, K. and Hassi, L. (2011). "Emerging design strategies in sustainable production and consumption of textiles and clothing". *Journal of cleaner production*, **2011**, 19(16), p.1876-1883

22. Gardetti, M. A. and Torres, A. L. (Eds.). "*Sustainability in fashion and textiles: values, design, production and consumption*". Routledge, 2017.

23. Garcia-Herrero, I., Hoehn, D., Margallo, M., Laso, J., Bala, A., Batlle-Bayer, L., ...and Sarabia, C. (2018). "On the estimation of potential food waste reduction to support sustainable production and consumption policies". *Food Policy*, **2018**, 80, p.24-38.

24. D'Silva, J. and Webster, J. (Eds.). "*The meat crisis: Developing more sustainable and ethical production and consumption*". Routledge, 2017.

25. Vergragt, P. J., Dendler, L., de Jong, M. and Matus, K. "Transitions to sustainable consumption and production in cities". *Journal of Cleaner Production*,**2016**, 134, p.1-12.

26. Luo, Z., Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., Hazen, B. andRoubaud, D. "Sustainable production framework for cement manufacturing firms: A behavioural perspective". Renewable and Sustainable Energy Reviews, **2017**, 78, p.495-502.

27. Welford, R., Young, W. and Ytterhus, B. "Towards sustainable production and consumption: a literature review and conceptual framework for the service sector". *Eco-Management and Auditing*, **1998,**5(1), p.38-56

28. Lakatos, E. S., Cioca, L. I., Dan, V., Ciomos, A. O., Crisan, O. A. and Barsan, G. "Studies and investigation about the attitude towards sustainable production, consumption and waste generation in line with circular economy in Romania". *Sustainability*, **2018,**10(3), p.865.

29. Young, W., Hwang, K., McDonald, S. and Oates, C. J. (2010). "Sustainable consumption: green consumer behaviour when purchasing products". *Sustainable development*, **2010,** 18(1), p.20-31.

30. Tanner, C. and Wölfing Kast, S. "Promoting sustainable consumption: Determinants of green purchases by Swiss consumers". *Psychology & Marketing*, **2003,**20(10), p.883-902

31. Gan, Y., Zhang, T., Liang, S., Zhao, Z., and Li, N. "How to deal with resource productivity: Relationships between socioeconomic factors and resource productivity". *Journal of industrial ecology*, **2013**, 17(3), 440-451.

32. Krajnc, D. and Glavič, P. "Indicators of sustainable production". *Clean technologies and environmental policy*, **2003,**5(3-4), p.279-288.

33. Azapagic, A. and Perdan, S. (2000). "Indicators of sustainable development for industry: a general framework". *Process Safety and Environmental Protection*, **2000**, 78(4), p.243-261

34. Caeiro, S., Ramos, T. B. and Huisingh, D. "Procedures and criteria to develop and evaluate household sustainable consumption indicators". *Journal of cleaner production*, **2012**, 27, p.72-91

35. Horvath, B., Bahna, M., and Fogarassy, C. "The Ecological Criteria of Circular Growth and the Rebound Risk of Closed Loops". *Sustainability*, **2019**, *11*(10), p.2961

36. Kline, P. "*An Easy Guide for Factor Analysis"*, Routledge, 2014

37. Hair, J.F., R.E. Anderson, R.L. Tatham and W.C. Black. *Multivariate Date Analysis*. Prentice-Hall, 1998, Englewood Cliffs, New Jersey.

38. Rodríguez-Jaume, M. J., and Mora-Catalá, R. "*Análisis de regresión múltiple".* Técnicas de investigación social II, 2001

39. Abuín, J. R. "*Regresión lineal múltiple*". IdEyGdM-Ld Estadística, Editor,*32,* 2007

40. Schroeder, P., Anggraeni, K. and Weber, U. "The relevance of circular economy practices to the sustainable development goals". *Journal of Industrial Ecology*, **2019,** *23(*1), p.77-95.

41. EEA (European Environment Agency). *Circular Economy in Europe—Developing the Knowledge Base*. EEA Report No 2/2016. Copenhagen: European Environment Agency.

42. Baker, E. and Solak, S. "Management of energy technology for sustainability: How to fund energy technology research and development". Production and Operations Management, **2014**, 23(3), p.348-365.

43. EC (European Commission). "*A new Circular Economy Action Plan for a Cleaner and More Competitive Europe".* COM(2020) 98, Brussels

5.3 Impact of Clean Energy Policies on Electricity Sector Carbon Emissions in the EU-28

Impact of Clean Energy Policies on Electricity Sector Carbon Emissions in the EU-28[3]

Abstract: The European Union (EU) has developed important efforts in enacting various clean energy policies in order to reduce greenhouse gas (GHG) emissions in the last decades. Both supply-side and demand-side changes are required in the energy systems in the period of 2020–2030 and going towards 2050. In this context, a better understanding of the effects of these specific clean energy actions on reducing GHG emissions may be especially of interest for allowing policymakers to know the strengths and weaknesses of various climate-related power sector policies. This paper adds to the literature by presenting the effects of both supply-side and demand-side policies and empirical evidence of the impact of these policies on the reduction in carbon emissions. This analysis was done by means of a panel data set and several regression models that contribute to explaining the link between clean energy policies applied in the EU and carbon emissions over the period of 2000–2019. The results show that while supply-side policies have shown a positive and effective impact on the reduction in GHG emissions, on the demand side, more aggressive policy efforts are needed.

Keywords: clean energy policies; carbon dioxide emissions; energy sector; renewable energy; energy taxes; panel data

1. Introduction

The EU has implemented different policies in order to reduce the impact of climate change in the last decades. The reduction in CO_2 emissions from the energy sector has been a key issue in the European energy and climate change policies, as this sector has been the main producer of greenhouse gas (GHG) emissions (more than 80%) [1]. In this context, climate policies and energy have been greatly integrated into the EU, where policies related to the use of efficient energy and the development of clean production technologies have been greatly used in the climate change framework [2].

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In 2007, the EU highlighted the importance of ensuring that global average temperature increases do not exceed pre-industrial levels by more than 2 ◦C [3]. Subsequently, the 2020 Climate and Energy Package [4] was approved, which set the strategies and policies related to energy and climate policies up to 2020. It was based mainly on the development of renewable energies (RES-E), complemented by measures of energy efficiency. More specifically, it established the following three key targets: (i) 20% cut in GHG emissions (from 1990 levels), (ii) 20% of EU energy from renewables, and (iii) 20% improvement in energy efficiency.

Although climate change was the main driver of the 2020 Climate and Energy Package, energy policy challenges were also extensively treated in this context. The following three main goals were set in the EU energy policy: supply security, sustainability, and competitiveness. Thus, different actions were developed, such as the promotion of RES-E in order to achieve their large-scale deployment, the promotion of technologies of carbon capture, and storage of the investment or investment in nuclear energy in member states that wished to do so [5]. Likewise, from the side of the demand, energy efficiency has been an essential issue for achieving 2020 targets. These targets should be achieved from all economic sectors, but the power sector has been expected to play a main role in the achievement of both (GHG emissions and RES-E) [6].

Subsequently, the EU adopted the 2030 Framework for Climate and Energy [7], the aim of which is to meet a more secure, sustainable, and competitive energy system and to help the EU to achieve its long-term 2050 GHG reduction target. In this context, the following goals were set: (i) 40% cut in GHG emissions (from 1990 levels), (ii) (at least) 27% of EU energy from renewables, and (iii) (at least) 27% energy savings. Policies related to RES-E development, energy efficiency, and sustainability were emphasized again. This framework was developed on the basis of the 2020 Climate and Energy Package and it is also in line with the longer-term perspective established in the roadmap for moving to a competitive low-carbon economy by 2050 [8] and the Energy Roadmap 2050 [9].

More recently, in December 2019, the EU presented the European Green Deal [10], which aims to make Europe climate neutral by 2050. In order to achieve its decarbonisation objectives, the European Commission adopted a set of proposals to make the EU's climate, energy, transport, and taxation policies fit for reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels. Additionally, the Commission proposed to increase the binding target for renewable sources in the EU's energy mix to 40% and to increase energy efficiency targets and make them binding to achieve an overall 36–39% reduction in final and primary energy consumption. Figure 1, extracted from the report *Trends and projections in Europe 2020* prepared by the European Environment Agency (EEA) [11], shows the evolution of GHG emissions in the EU since 1990, and the different reduction objectives set.

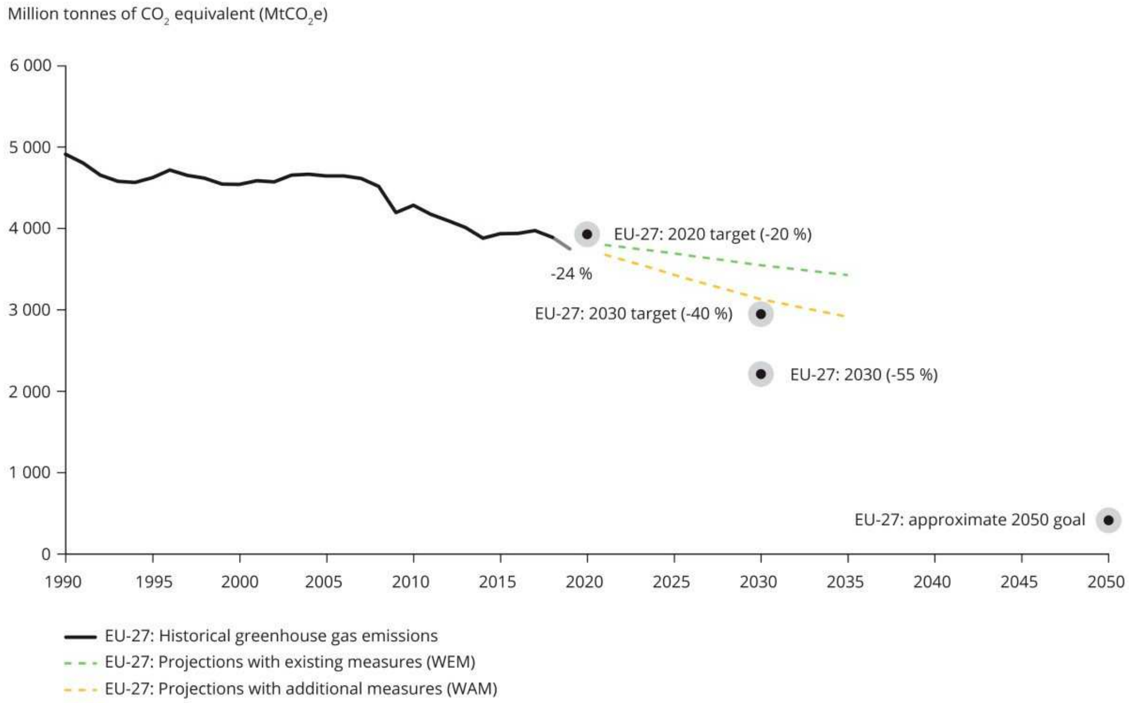

Figure 1. Greenhouse gas emission targets, trends, and member states' MMR projections in the EU, 1990–2050. Reprint with permission [11]; 2020, Publications Office of the European Union.

From a global point of view, different studies have focused on determining the key factors for a reduction in GHG emissions. Rehman et al. [12] studied the effect of energy consumption, economic development, and population growth on CO_2 emissions in Pakistan by means of a grey relational analysis. They concluded that the increase in GHG emissions, especially those related to the transportation sector, is strongly linked to population growth. In addition, ref. [13], by means of a non-homogenous discrete grey model, analysed which sectors will be the main generators of GHG emissions in the medium term.

Furthermore, ref. [14] analysed the relationships among GHG emissions, income level, and consumption of renewable and non-renewable energy in Mexico for the period of 1990–2015. The study showed a strong relationship between economic growth (related to GDP) and the use of non-renewable energies, with increasing GHG emissions.

Regarding the situation of the United States, characterised by being one of the main GHG emitters in relative terms (carbon dioxide emissions per person), ref. [15] studied the impacts of clean energy policies on total carbon emissions, electricity consumption, and carbon intensity. Its conclusion, after a study with a panel data set for 48 continental states from 1990 to 2008, is that more aggressive demand-side policies are needed.

Sun et al. [16] reviewed the clean electricity policies of the EU, Australia, China, India, and the United States, since the power industry and policymakers in almost all countries are focused on clean energy development. The study showed the diversity of the scope, intensity, and comprehensiveness of clean energy policies.

With regard to the role of carbon taxation, several studies [17,18] have analysed its effectiveness worldwide. They have shown that although carbon and fuel taxes seem to be effective in reducing CO_2 emissions in various countries, the implementation of these policies entails serious difficulties in many cases.

Focusing on the case of the EU, and since the energy sector is the one that has contributed the most to GHG emissions, the analysis of the effects of climate change policies in this sector can be of interest for obtaining a better understanding of what specific policies involve a reduction in GHG emissions. As explained below, previous literature has shown that the analyses have mainly been based on climate policies related to the supply side, and consequently, had too narrow a focus. In addition, dynamic approaches do not precisely provide the effects of each specific policy.

In this context, the main contribution of this paper, and where its novelty lies, is the approach to both the supply and demand energy policies in the EU and their impact on the reduction in GHG emissions and electricity consumption. This information could allow policymakers to know the strengths and weaknesses of various climate-related power sector policies and will be especially relevant in future climate change policymaking in order to achieve the targets set.

Much of the previous literature, in order to assess the effectiveness of climate and energy policies, has presented the effects of different policies on RES-E investments or RES-E capacity [19]. As shown in Figure 2, according to [20], there is wide diversity regarding support schemes in the EU. Some countries, such as France, Germany, and Spain, have different types of support schemes operating in combination (for example, for different types of renewable technology). In this context, ref. [21] studied the effects of RES-E support policies on the development of these clean production technologies in 23 member states over the period of 1990–2007 by using a panel-corrected standard error estimator. The conclusion was that some RES-E support policies (quota obligations, product labelling, research, and development programs) were not drivers towards RES-E development. Nevertheless, incentives/subsidy policies (including feed-in systems (FISs)) were effective in promoting RES-E. On the other hand, ref. [22] analysed the effects of FIS policies on promoting leader RES-E in 26 member states for the period between 1992 and 2008. Using the panel data method, they did not find robust evidence that the mere existence of this policy had driven wind energy development.

García-Álvarez et al. [23] studied the effects of FISs and quota obligation policies on the solar photovoltaic installed capacity in the EU-28 for the period between 2000 and 2014. The method was a pooled ordinary least square regression clustered on the country level. Their results indicated that only FISs had significant impacts on the solar photovoltaic installed capacity. Nevertheless, the main design features of this policy—tariff size and contract duration—did not have a significant effect on the development of this RES-E. However, ref. [24] investigated the effect of feed-in systems (FISs) on the investment in wind and solar photovoltaic energy by means of the panel data method in the EU-27 over the period of 1992–2015. Their results indicated that the mere existence of an FIS policy did not necessarily increase wind and solar photovoltaic investment, but policy design features were often more important for increasing RES-E investment.

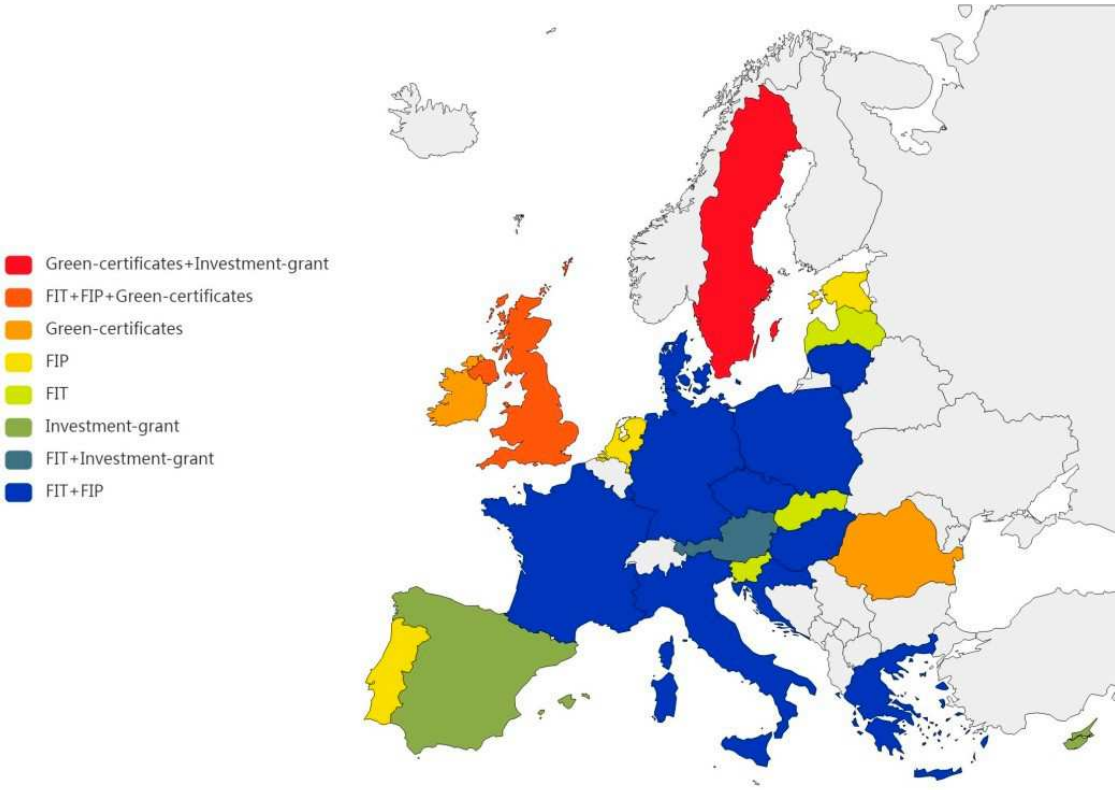

Figure 2. Diversity of RES-E support schemes in the EU. Source: Own elaboration from [20].

Therefore, there is no unanimity about the effects of RES-E support policies on RES-E development in the EU. Moreover, a suitable proxy of the decarbonisation in the power sector cannot be given by increased RES-E capacity, greater RES-E generation, or higher RES-E investment. Thus, a mere increase in RES-E capacity without reducing electricity generation based on fossil fuels cannot be a solution to climate change [19].

Ultimately, from a climate change perspective, what matters is if the policies are effective in reducing GHG emissions rather than if they increase RES-E. In this context, as several interdependent variables affect electricity market behaviour, and therefore, CO_2 emission evolution, various approaches have been used with the aim of analysing the contribution of different technical and socio-economic factors.

Karmellos et al. [6] studied, by means of a decomposition analysis model, the driving factors of CO_2 emissions from the electricity sector in the EU-28 in the period of 2000–2012. They considered five driving factors—activity level, electricity intensity, electricity generation efficiency, fuel mix, and electricity trade. Their results showed that electricity intensity reduction was the main factor in times of economic growth, whilst the contribution of the rest of the factors happened later. Similarly, ref. [25] analysed the effects of RES-E and non-RES-E, real income, and trade openness on CO_2 emissions on the environmental Kuznets curve model for the EU between 1980 and 2012 by using panel estimation tech- niques robust to cross-sectional dependence. They concluded that RES-E and trade reduced CO_2 emissions, while non-RES-E contributed to environmental degradation.

Furthermore, ref. [26] studied, by means of the panel data method, the effects of both environmental regulation and awareness on CO_2 emissions in 17 EU countries (Austria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Poland, Portugal, the Slovak Republic, Spain, Sweden, and the United Kingdom) over the period from 1995 to 2017. Environmental tax revenue was used as a proxy of the stringency of environmental regulation, and the accumulated number of RES-E support policies was used as a proxy of environmental awareness. The results showed that both variables (environmental regulation and awareness) were effective in reducing CO_2 emissions.

By means of index decomposition analysis, ref. [27] studied the drivers of CO_2 emissions for electricity generation in the EU over two subperiods, 2000–2007 and 2007–2015. Their results showed that changes in the fossil fuel mix, by means of the replacement of coal by gas, and efficiency improvements in electricity use were the main drivers of CO_2 reductions in the period of 2000–2007. However, in the period of 2007–2015, RES-E development, as well as efficiency improvements in both fossil electricity production and use became the main drivers of the decrease in CO_2 emissions.

More generally, ref. [28] estimated, over the period of 2000–2019, the impact of RES-E energy, bioenergy efficiency, biofuels, urbanization, population, and real gross domestic product (GDP) per capita on CO_2 emissions in EU countries by using the panel data method. The results showed that clean production technologies, as well as bioenergy factors, were negatively correlated with CO_2 emissions. However, urbanization, population, and real GDP per capita were positively correlated with such emissions.

In addition, dynamic approaches were also developed in order to study dynamic changes. In this context, ref. [29] investigated the distribution dynamics of energy consump- tion and CO_2 emissions, their intensities, as well as the carbonization index, over the period of 1970–2010 in 23 European member states. The method was based on the dynamics of cross-section distributions. The results showed that the convergence patterns hypothesis was not valid. Thus, major differences were observed in member states according to cli- mate type with respect to the analysed variables. Hence, the importance of national and European energy and climate policies can be implemented in terms of the non-convergence paradigm. Similarly, ref. [30] determined, by means of hierarchical methods, the tendency of changes related to energy decarbonisation, as well as distinguished typological groups of EU member states with similar dynamics in this research field. The analysis was applied to 26 member states (except Malta and Great Britain) between 2000 and 2018. Their results showed that the implementation of climate policy by the individual countries was the main factor in reducing CO_2 emissions. Nevertheless, they found two groups of member states—those that were reluctant to dynamically reduce CO_2 emissions (Central and Eastern European countries) and those member states that supported a strong climate policy (the rest of the EU countries).

At this point, and as mentioned above, previous literature [6,26–29] has shown that the analyses were mainly based on climate policies related to the supply side, and dynamic approaches do not precisely provide the effects of each specific policy. Therefore, the objective of this study was to go a little further in the study of the supply and demand energy policies in the EU, analysing their impact on the reduction in GHG emissions and on electricity consumption. This information will allow policymakers to have a better understanding of the effectiveness of the aforementioned policies in order to achieve the targets set.

2. Materials and Methods

In this section, the sample, the hypotheses, the variables, and the methodology used in the empirical assessment are discussed.

2.1. Sample

In order to develop the empirical analysis, the database of the Statistical Office of the European Commission (Eurostat) was examined for the period between 2000 and 2019 (28 countries, 560 observations). The data were chosen from previous literature in both clean energy supply-side and demand-side policies on GHG emissions, presented in Section 1. The period of analysis starts in 2000, as the European Union's clean energy policies related to reducing carbon emissions in the electricity sector acquired great relevance in this decade. More specifically, most supply-side policies, related to RES-E support policies, were introduced in the EU early on in the decade. Similarly, demand-side policies related to energy taxes have acquired great relevance from the early 2000s in order to promote more responsible energy consumption. The study period ends in 2019 because most of the data were provided by Eurostat until that year.

With the aim of avoiding missing values in the estimates and to have the same sample size in all models, the cases for which there was no information on any of the variables were not considered in the analysis. As a result, an unbalanced panel of countries and observations was obtained.

2.2. Hypothesis

Taking the arguments of previous literature into consideration, the research hypotheses were proposed.

Both supply-side and demand-side policies are potentially relevant to reducing car- bon emissions. These emissions can be divided into electricity consumption and carbon intensity, where the latter variable is defined as carbon emissions per unit of energy con-sumed [31].

The objective of supply-side policies is to modify the generation fuel mix from a carbon-intensive portfolio to a low-carbon portfolio by means of an increase in RES-E sources [32]. In the last decades, RES-E support policies have been implemented in the EU with the aim of encouraging these clean production technologies, which are characterised by having zero or few GHG emissions.

There are two main RES-E support policies in the EU—FISs and renewable portfolio standards (RPSs). An FIS sets a fixed payment for electricity produced from RES-E, which can be a retribution based on a pre-set price (feed-in tariff) or based on the wholesale electric- ity price plus an incentive. An RPS sets the obligation of producers/distributors/consumers to maintain a specific RES-E quota in their energy consumption. This study considered both policies of the two main RES-E in the EU—wind energy and photovoltaic (PV) solar energy. The effect of RES-E support policies on GHG emissions from the generation of electricity is based on a two-step causal chain—the fuel mix is affected by the FIS/RPS and the sectors' carbon intensity is shaped by the fuel mix [15].

In this context, the first hypothesis proposed is as follows:

Hypothesis 1 (H1). *Support policies (FIS and quota obligation) of the two main RES-E (wind and PV) reduce carbon intensity in the electricity sector.*

Likewise, demand-side policies can also have an impact on carbon emission reductions. These policies reduce global energy demand by facilitating a shift towards more sustainable consumption patterns [33].

The European Energy Efficiency Directives have established various instruments in order to reduce energy consumption, in which energy taxes have been highlighted due to their potential to encourage energy savings and conservation from the consumption side [34]. Their functioning is based on surcharges for electricity consumption, which is expected to affect individual consumption behaviour.

Taking the above-mentioned arguments into account, the following hypotheses are proposed:

Hypothesis 2 (H2). *Energy tax policies reduce carbon intensity.*

Hypothesis 3 (H3). *Energy tax policies reduce electricity consumption.*

Finally, the effect of these clean energy policies on carbon emission reduction was considered by proposing the following hypothesis:

Hypothesis 4 (H4). *Clean energy policy tools reduce electricity carbon emissions.*

2.3. Variables

Dependent Variables

A total of three models were developed in order to obtain a better understanding of the effects of both supply-side and demand-side policies on GHG emissions, which are explained in Section 2.4. In this context, the following dependent variables were used:

Per capita carbon emissions and carbon intensity were considered proxy variables of GHG emissions [15,35,36]. Per capita carbon emissions were measured as GHG emissions in the energy sector divided by the population (tonnes per capita) (EMISSIONS). Carbon intensity was measured as the ratio between energy-related GHG emissions and the gross inland consumption of energy (index, 2000 = 100) (CARBINTENSITY).

Electricity consumption per capita was also used as a dependent variable in other spec- ifications of the models, following the method of [15]. Electricity energy consumption per capita (MWh per capita) refers to the energy needs of a country (ELECT_CONSUMPTION).

Explanatory Variables

The explanatory variables were grouped into three types—policy variables, fuel mix variables, and economic variables.

Policy variables make reference to clean energy policies from both the supply side and the demand side—wind energy support policies (WIND_FIS, WIND_RPS), PV solar energy support policies (PV_FIS, PV_RPS), and energy tax policies (TAX_POL). These clean energy policies were measured with five binary variables (with 1 indicating the adoption of the policy in that year, and 0 otherwise) [15].

Fuel mix variables make reference to the contribution of different energy sources (coal, natural gas, RES-E, hydro, nuclear) in total gross electricity supply (in %) (CONTRIBUTION_COAL, CONTRIBUTION_GAS, CONTRIBUTION_RESE, CONTRIBUTION_HYDRO,

CONTRIBUTION_NUCLEAR). In this context, it is necessary to consider that clean energy policies (especially FISs and RPSs) seek to change the power generation portfolio, towards a “carbon-light” portfolio, especially in the long run. The coefficients obtained in the models ought to capture the direct impact of these policies. However, these clean energy policies can also affect the fuel mix of power generation by means of their indirect impacts on GHG emissions (or electricity consumption and carbon intensity) [6,27].

Economic variables make reference to economic activity measures. In this context, gross domestic product (GDP) was considered, as economic growth determines electricity demand and consumption patterns. GDP per capita was considered in the model and makes reference to the total value of all goods and services produced less the value of goods and services used for intermediate consumption in their production (Eurostat) (GDP) (in Euros per capita). A prosperous economy can involve an increase in electricity demand and, therefore, GHG emissions will not be reduced without specific clean energy actions. Nevertheless, an economic contraction will result in both consumption and GHG emissions reductions [28]. Likewise, the unemployment rate was considered a proxy of business vitality (in percentage) (UNEMPLOYMENT), for which a high rate is related to underused production capacity, with a consequently reduced electricity demand [15].

Finally, the control variables are related to socioeconomic factors linked to electricity demand. In this context, heating degree days, cooling degree days, and electricity prices variables were introduced in the models.

Heating degree days were calculated as the weather-based technical index used to describe the need for the heating energy requirements of buildings (from Eurostat) (number) (HEATING_DAYS). Cooling degree days were based on a weather-based technical index used to describe the need for the cooling (air-conditioning) requirements of buildings (from Eurostat) (number) (COOLING_DAYS). Both heating degree and cooling degree days are greatly related to energy demand [35–37].

Industrial electricity prices make reference to the average national price for medium- sized industrial consumers (annual consumption between 500 and 2000 MWh) (Euros per kilowatt hour) (ELECT_PRICES). Greater electricity prices can result in more sustainable consumption patterns. It is expected that electricity prices are negatively related to electricity consumption and carbon intensity [15].

2.4. Models

In order to test the hypotheses previously proposed, a panel data set for the 28 coun- tries with a time range from 2000 to 2019 was used with the STATA13 program. In addition, with the aim of controlling problems of endogeneity in the proposed models, explanatory and control variables were lagged by one year. Before going in depth with the models to verify the hypotheses, Hausman tests were performed to decide whether it was more appropriate to use fixed-effect or random-effects models [38].

In this context, three models were estimated to analyse the influence of clean energy policies, along with other variables, on GHG emissions per capita, carbon intensity, and electricity consumption per capita. Fixed-effect regression models were employed to test the hypotheses. The use of a fixed-effect model generated consistent estimations when unobserved country-level variables and the error term were correlated. The model is formulated as follows:

$$Y_{it} = a_i + \beta X_{it} + \varepsilon_{it}, \qquad (1)$$

where “i” is the country and “t” is the year of the observation. Y_{it} is the dependent variable—GHG emissions per capita in Model 1; electricity sector carbon intensity in Model 2; electricity consumption per capita in Model 3.

X_{it} denotes the explanatory and control variables, ε_{it} is the error term, and a_i is a country-specific intercept.

In the three models studied, the three types of explanatory variables were used—policyvariables, fuel mix variables, and economic variables.

3. Results

The descriptive statistics are shown in Table 1. Once the non-normality of the explanatory and continuous control variables was confirmed, and considering that Pearson’s correlation coefficient did not work well for discrete variables as it was very sensitive to violations of normality assumptions, Spearman’s rank correlations were calculated. When there is a perfect linear relationship among the predictors, the estimates for a regression model cannot be uniquely computed. Given this, a multicollinearity study (analysis of the variance inflation factors (VIF)) was carried out in order to rule out, if necessary, any of the predictors. As a result, the variable RPS_PV (related to PV solar support policies) shows significant collinearity, and therefore, it was discarded.

Table 1. Descriptive statistics.

Variable	**Obs[1]**	**Mean**	**Std. Dev.**	**Min**	**Max**
EMISSIONS	560	7.453	3.424	2.879	24.77
CARBINTENSITY	560	93.459	9.220	57.6	124.5
ELECT_CONSUMPTION	560	5.973	3.118	1.839	16.546
ELECT_GENERATION	560	6.098	2.991	1.179	17.746
ELECT_PRICES	512	82.168	26.330	0	221.65
FIS_WIND	560	0.687	0.463	0	1
RPS_WIND	559	0.1466	0.354	0	1
FIS_PV	560	0.630	0.483	0	1
RPS_PV	560	0.126	0.333	0	1
TAX_POL	336	208.304	78.462	77.53	454.67
GDP	308	27,027.89	17,807.49	4930	102,200
UNEMPLOYMENT	537	8.778	4.413	2	27.5
CONTRIBUTION_COAL	560	0.359	0.300	0	0.963
CONTRIBUTION_GAS	560	0.353	0.274	0	0.984
CONTRIBUTION_RESE	448	16.947	11.531	0.102	56.391
CONTRIBUTION_HYDRO	504	0.255	0.289	0	1
CONTRIBUTION_NUCLEAR	504	0.178	0.234	0	0.819
HEATING_DAYS	520	2745.075	1079.274	322.36	6179.75
COOLING_DAYS	520	121.008	182.323	0	812.18

[1] Observation after discarding missing values: 259.

As mentioned above, Hausman tests were conducted in order to select between fixed- effects or random-effects models. The null hypothesis established that there is no systematic difference between the coefficients estimated by the two methods. According to the results (X_2 (13d.f.) = 316.75 for Model 1, X_2 (13d.f.) = 34.78 for Model 2, X_2 (13d.f.) = 37.53 for Model 3), in the three models, this hypothesis was rejected, indicating the suitability of a fixed-effects model. To control for possible heteroscedasticity problems, the proposed models used robust standard errors.

A summary of the results of the three fixed-effects panel regression models is included in Table 2.

Table 2. Results of the fixed-effects panel regression analysis.

Variables	**Model 1** [1]	**Model 2** [2]	**Model 3** [3]
	Coef. (Std. Err.)	**Coef. (Std. Err.)**	**Coef. (Std. Err.)**
ELECT_PRICES	0.0076 (0.0071)	0.0376 (0.0468)	−0.0006 (0.0013)
FIS_WIND	−0.7501*** (0.2058)	−6.7478*** (1.1495)	−0.1817** (0.0705)
RPS_WIND	−1.1225*** (0.1648)	−4.8025*** (1.0255)	−0.3243*** (0.0618)
FIS_PV	−0.3883** (0.1625)	−0.6199 (1.2852)	−0.0812* (0.0469)
TAX_POL	−0.0021 (0.0023)	0.0033 (0.0118)	0.0003 (0.0011)
GDP	−0.0001 (0.00004)	−0.0001 (0.0002)	−0.00001 (0.00001)
UNEMPLOYMENT	−0.0924*** (0.0242)	0.1816 (0.1326)	−0.0613*** (0.0139)
CONTRIBUTION_COAL	0.7388 (0.9798)	2.8162 (7.5818)	0.6535*** (0.2276)
CONTRIBUTION_GAS	−0.1190 (0.6440)	−7.9525 (5.9808)	0.4490*** (0.1219)
CONTRIBUTION_RESE	−0.1477*** (0.0301)	−1.4057*** (0.2345)	−0.0084 (0.0104)
CONTRIBUTION_HYDRO	−5.3265*** (1.7361)	−10.5319 (10.7604)	−1.8567*** (0.3186)
CONTRIBUTION_NUCLEAR	−0.3234 (0.3569)	−6.9023* (3.8825)	0.2755* (0.1561)
HEATING DAYS	0.0007*** (0.0001)	0.0019* (0.0011)	0.0002** (0.0001)
COOLING DAYS	0.0003 (0.0007)	0.0083** (0.0039)	8.702e−06 (0.0003)
CONSTANT	12.1219*** (1.7580)	119.2596*** (10.6770)	6.4437*** (0.5780)
Observation	259	259	259
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
R-squared (within)	0.693	0.695	0.610

[1] DV: emissions; [2] DV: carbon intensity; [3] DV: electricity consumption.*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$ (two-tailed). Standard errors are given in parentheses.

Regarding the support policies (FIS and quota obligation) of the two main RES-E (wind and PV solar energy) and their impact on carbon intensity in the electricity sector, the results of Model 2 support Hypothesis 1 in the case of wind energy, as both FIS_WIND (β = −6.748 p = 0.000) and RPS_WIND (β = −4.802 p = 0.000) have a negative and statistically significant influence. In the case of PV solar energy, although the sign of the coefficient goes in the direction that would be expected, the analysis shows that Hypothesis 1 is not supported, as the variable FIS_PV is not statistically significant (*p* = 0.634). This means that a reduction in carbon intensity might be expected through the introduction of support policies of RES-E. The significance of the support policies for wind energy, compared to those developed for photovoltaic solar energy, may come from the fact that its installed power is considerably higher. The results obtained in this study, for the case of the EU, are in line with those obtained by [15] for the case of the United States.

Regarding energy taxes policies and their link with carbon intensity and electricity consumption, both Hypotheses 2 and 3 are not supported by the analysis. According to the results obtained from Models 2 and 3, the variable TAX_POL is not statistically significant (*p* = 0.782 in Model 2 and *p* = 0.809 in Model 3). Similar results have been obtained in previous studies in the case of the EU [39,40], as well as Latin America [41] and the United States [15]. On the other hand, results obtained by [18] for the Netherlands showed a slight difference, in the sense that an energy tax has a small impact on household energy demand in the short term.

Finally, Hypothesis 4 raised a possible relationship between the establishment of clean energy policies and the reduction in electricity carbon emissions. In this sense, according to Model 1, support energy policies have a negative (in the sense of reduction) and statistically significant effect on electricity carbon emissions (FIS_WIND, β = −0.750 *p* = 0.001; RPS_WIND, β = −1.123 *p* = 0.000; FIS_PV, β = −0.388 *p* = 0.025). This result leads us to accept Hypothesis 4. On the contrary, this hypothesis is not supported in the case of energy taxes policies, as the variable TAX_POL is, again, not statistically significant (*p* = 0.384). Both results indicate a relationship analogous to the one proposed by [6,27] for the EU, and the one indicated by [15] for the United States, reinforcing its validity.

Other interesting results can be extracted from the analysis of the proposed models, examining what was obtained in the case of the control variables. A more in-depth discussion of these results is presented in Section 4.

4. Discussion and Conclusions

The EU has developed important efforts in enacting various clean energy policies in order to reduce GHG emissions in the last decades. In this context, actions related to the development of RES-E, the encouragement of energy efficiency, and sustainable development have been highlighted [3,4,7,8]. Thus, both supply-side and demand-side changes are required in the energy systems in the period of 2020–2030 and going towards 2050 [42].

Obtaining a better understanding of the effects of these specific clean energy actions on reducing GHG emissions may be especially of interest. This information could be incorporated into policymaking in order to facilitate the achievement of the climate change goals set by the EU.

Nevertheless, the previous literature has been mainly focused either on analysing a specific policy in particular (when GHG emissions are conditioned by both the supply side and the demand side) or studying its effectiveness on alternative measures (such as the growth of clean energy industries) but not its ability to decrease carbon emissions. In this context, this paper adds to the literature by presenting the effects of both supply-side (FIS, RPS) and demand-side (energy taxes) policies and empirical evidence of the impact of these policies on the reduction in carbon emissions.

In this context, the objective of this study was to analyse both supply and demand policies in order to obtain a better understanding of what specific measures are successful in curbing GHG emissions. This information could allow policymakers to know the strengths and weaknesses of various climate-related power sector policies and will be especially relevant for future climate change policymaking in order to achieve the targets set.

At this point, we address in more depth the interpretation of the results obtained, focusing especially on the key findings regarding the impact of clean energy policies.

Model 1, where GHG emissions were used as the dependent variable, revealed interesting effects. As mentioned in Section 3, Hypothesis 4 stated that the implementation of clean energy policies leads to a reduction in GHG emissions. According to the results obtained, it can be concluded that the adoption of support policies for renewables from the supply-side point of view, at least in terms of the types used in the EU (FIS and RPS), has a significant impact on the reduction in total carbon emissions. In this sense, in the case of wind energy, there is a greater incidence than in the case of photovoltaic solar energy since the installed wind power and contribution is much higher. On the other hand, if we focus on the fuel mix of power generation, we can conclude that the share of RES-E and hydro has a significant impact on the reduction in emissions.

Additionally, we can verify the influence, to a much lesser degree, of the unemploy- ment rate and the demand for energy for heating in the variation of GHG emissions. In this sense, an increase in the unemployment rate is associated with less economic activity and, in addition, with a reduction in electricity demand and, therefore, in carbon emis- sions [15,28]. In the case of the increase in the demand for energy for heating, a slight effect is observed in the increase in GHG emissions, in line with the results from [35,37].

Model 2 considered carbon intensity as a dependent variable. This model was used to test the effectiveness and influence of RES-E support policies (supply side) on the objective of reducing carbon intensity, as proposed in Hypothesis 1. The results lead us to conclude that the introduction of RES-E support policies in the EU has had a very significant impact on reducing carbon intensity in the period of 2000–2019. These policies have been particularly effective in the case of wind energy. In the case of PV solar energy support policies, it can be concluded that they have also had a certain impact but to a lesser degree due to the lower contribution of this technology to the mix of power generation (5% in 2020 compared to 14% for wind energy).

In addition, Models 2 and 3 were used to test the impact of energy taxes policies (demand side) on the achievement of two different objectives, namely the reduction in carbon intensity in Model 2 and the reduction in energy consumption in Model 3. In both cases, we can conclude that, up to now, energy tax policies from the demand-side point of view do not seem to have a relevant impact on reducing GHG emissions, carbon intensity, or energy consumption. It seems that energy taxes alone cannot promote more sustainable energy consumption patterns or substantially modify household behaviour that can lead to a significant reduction in energy consumption or in carbon emissions.

In summary, it can be stated that when comparing the performance of both supply and demand policies in the EU, it can be observed that supply-side policies have been clearly more effective in terms of reducing carbon intensity, but not so much in terms of global emissions, as the global consumption of electricity has increased.

Therefore, considering these results and those obtained in other countries, as a first recommendation for stakeholders, we can hope that the maintenance and strengthening of the supply-side policies can help the EU to achieve the objectives set out in the European Green Deal. In this sense, it is necessary to continue with policies to promote renewable energy generation and enhance energy efficiency if effective climate mitigation is to be achieved. Previous studies [6,15,27] have reflected on the impact of FISs and RPSs in the development of clean energy industries. The purposes of these clean energy policies include the mitigation of carbon emissions, to stimulate green economic development, and to secure a diversified energy supply. This research makes a contribution to the literature by means of empirical evidence of the carbon reduction effects of these policies. Another measure that could contribute to strengthening the impact of RES-E would be a commitment to technological improvement through investment in research, development, and innovation. This could result in improving the energy efficiency of generation facilities and reducing their environmental impact.

As another recommendation, it could be necessary to rethink energy tax policies due to their lack of effectiveness in reducing energy demand (as it has been shown in [15,40,41] and in the results obtained in this paper). Reinforcing actions and more aggressive policy efforts might, therefore, be necessary to mitigate carbon emissions in the EU. Hale [43] showed that consumers' environmental awareness is the main driver for creating sustainable consumption and pointed out the need to deepen policies related to this issue. In this sense, the adoption of public policies to promote environmental awareness (for example, by promoting school campaigns on responsible energy consumption) might be an effective complementary measure for energy taxes. Likewise, ref. [44] showed that in terms of communication, significant gaps persist when addressing public concerns, and a way to promote consumers' awareness is through communication improvement. The message should be easy to read, simple to understand, and succinct. Other measures could be the maintenance and improvement of subsidies for the energy efficiency of existing buildings, the promotion of passive houses, or an increase in investment for the replacement of inefficient appliances.

Regarding the limitations of this study, it is necessary to acknowledge that the sample did not include a large number of countries, which may have affected the results by using the panel data method. Likewise, the analysis of the effects of supply-side policies related to RES-E support policies might be more exhaustive, as the choice of design elements in these policies could be as important for promoting RES-E as the choice of the specific policy. Further research should consider these issues by expanding the analysis to a larger sample, such as the case of the (Organization for Economic Co-operation and Development (OECD) countries in order to increase the number of observations. Moreover, regarding supply-side policies, the analysis should incorporate two additional design elements (amount and contract duration) in order to obtain a better understanding of the main strengths and/or weaknesses of each policy in reducing CO_2 emissions.

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References

1. Eurostat (Statistical Office of the European Union). Database. Available online https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en (accessed on 10 August 2021).
2. Helm, D. The European framework for energy and climate policies. *Energy Policy* **2014**, *64*, 29–35.
3. Commission of the European Communities. *Communication from the Commission to the Council, The European Parliament, the European Economic and Social Committee and the Committee of the Regions: Limiting Global Climate Change to 2 Degrees Celsius, The Way ahead for 2020 and beyond*; Commission of the European Communities: Brussels, Belgium, 2007.
4. Council of the European Union. *Energy 2020: A Strategy for Competitive, Sustainable and Secure Energy. COM(2010)639*; European Commission: Brussels, Belgium, 2010.

5. Genoese, F.; Egenhofer, C.; Wieczorkiewicz, J. The Energy and Climate Policies of the European Union. *Handb. Clean Energ. Syst.* **2015**, 1–10. https://doi.org/10.1002/9781118991978.hces179.
6. Karmellos, M.; Kopidou, D.; Diakoulaki, D. A decomposition analysis of the driving factors of CO_2 (Carbon dioxide) emissions from the power sector in the European Union countries. *Energy* **2016**, *94*, 680–692.
7. Council of the European Union. *Energy 2020:A Policy Framework for Climate and Energy in the Period from 2020 to 2030. COM(2014)15 Final*; European Commission: Brussels, Belgium, 2014.
8. Council of the European Union. *A Roadmap for Moving to a Competitive Low Carbon Economy in 2050. COM(2011)112*; European Commission: Brussels, Belgium, 2011.
9. Council of the European Union. *Energy Roadmap 2050. COM(2011)885 Final*; European Commission: Brussels, Belgium, 2011.
10. Council of the European Union. *The European Green Deal. COM(2019) 640 Final*;European Commission: Brussels, Belgium, 2019.
11. European Environment Agency. *Trends and Projections in Europe 2020. Tracking Progress towards Europe's Climate and Energy Targets*; Publications Office of the European Union: Luxembourg, 2020.
12. Rehman, E.; Ikram, M.; Feng, M.T.; Rehman, S. Sectoral-based CO_2 emissions of Pakistan: A novel Grey Relation Analysis (GRA) approach. *Environ. Sci. Pollut. Res.*, **2020**, *27*, 29118–29129.
13. Rehman, E.; Ikram, M.; Rehman, S.; Feng, M.T. Growing green? Sectoral-based prediction of GHG emission in Pakistan: A novel NDGM and doubling time model approach. *Environ. Dev. Sustain.* **2021**, *23*, 12169–12191.
14. Alonso, H.C. Impact of renewable energies on greenhouse gas emissions in Mexico. *Probl. Desarro.* **2021**, *52,* 59–83.
15. Yi, H. Clean-energy policies and electricity sector carbon emissions in the US states. *Util. Policy***2015**, *34*, 19–29.
16. Sun, K.; Xiao, H.; Liu, S.; You, S.; Yang, F.; Dong, Y.; Wang, W.; Liu, Y. A Review of Clean Electricity Policies—From Countries to Utilities. *Sustainability* **2020**, *12,* 7946.
17. Criqui, P.; Jaccard, M.; Sterner, T. Carbon Taxation: A Tale of Three Countries. *Sustainability* **2019**, 11, 6280.
18. Berkhout, P.H.G.; Ferrer-i-Carbonell, A.; Muskens, J.C. The ex post impact of an energy tax on household energy demand. *Energy Econ.* **2004**, 26, 297–317.
19. Martin, G.; Saikawa, E. Effectiveness of state climate and energy policies in reducing power-sector CO_2 emissions. *Nat. Clim. Chang.* **2017**, *7*, 912–919.
20. Council of European Energy Regulators. *Status Review of Renewable Support Schemes in Europe for 2018 and 2019. C-20-RES-69-04*; Council of European Energy Regulators asbl: Brussels, Belgium, 2021.
21. Marques, A.C.; Fuinhas, J.A. Are public policies towards renewables successful? Evidence from European countries. *Renew. Energy* **2012**, *44*, 109–118.
22. Jenner, S.; Groba, F.; Indvik, J. Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries, *Energy Policy* **2013**, *52*, 385–401.
23. García-Álvarez, M.T.; Cabeza-García, L.; Soares, I. Assessment of energy policies to promote photovoltaic generation in the European Union. *Energy* **2018**, *151*, 864–874.
24. Alolo, M.; Azevedo, A.; El Kalak, I. The effect of the feed-in-system policy on renewable energy investments: Evidence from the EU countries. *Energy Econ.* **2020**, *92*, 104998.
25. Dogan, E.; Seker, F. Determinants of CO_2 emissions in the European Union: The role of renewable and non-renewable energy. Renew. *Energy* **2016**, *94*, 429–439.
26. Almeida Neves, S.A.; Marques, A.C.; Patrício, M. Determinants of CO_2 emissions in European Union countries: Does environmental regulation reduce environmental pollution? *Econ. Anal. Policy* **2020**, *68*, 114–125.

27. Rodrigues, J.F.; Wang, J.; Behrens, P.; de Boer, P. Drivers of CO_2 emissions from electricity generation in the European Union 2000–2015. *Renew. Sustain. Energy Rev.* **2020**, *133*, 110104.

28. Busu, M.; Nedelcu, A.C. Analyzing the renewable energy and CO_2 emission levels nexus at an EU level: A panel data regression approach. *Processes* **2021**, *9*, 130.

29. Kounetas, K.E. Energy consumption and CO_2 emissions convergence in European Union member countries. A tonneau des Danaides? *Energy Econ.* **2018**, *69*, 111–127.

30. Bąk, I.; Barwińska-Małajowicz, A.; Wolska, G.; Walawender, P.; Hydzik, P. Is the European Union Making Progress on Energy Decarbonisation While Moving towards Sustainable Development? *Energies* **2021**, *14*, 3792.

31. Kim, H.; Kim, M.; Kim, H.; Park, S.. Decomposition analysis of CO_2 emission from electricity generation: Comparison of OECD countries before and after the financial crisis. *Energies* **2020**, *13*, 3522.

32. Lindberg, M.B. The EU emissions trading system and renewable energy policies: Friends or foes in the European policy mix? *Politics Gov.* **2019**, *7*, 105–123.

33. Streimikiene, D.; Siksnelyte, I.; Zavadskas, E.K.; Cavallaro, F. The impact of greening tax systems on sustainable energy development in the Baltic States. *Energies* **2018**, *11*, 1193.

34. Broin, E.Ó.; Nässén, J.; Johnsson, F. Energy efficiency policies for space heating in EU countries: A panel data analysis for the period 1990–2010. *Appl. Energy* **2015**, *150*, 211–223.

35. Drummond, W.J. Statehouse versus greenhouse: Have state-level climate action planners and policy entrepreneurs reduced greenhouse gas emissions? *J. Am. Plan. Assoc.* **2010**, *76*, 413–433.

36. Jiusto, S. An indicator framework for assessing U.S. state carbon emissions reduction efforts (with baseline trends from 1990 to 2001). *Energy Policy* **2008**, *36*, 2234–2252.

37. Metcalf, G.E. An empirical analysis of energy intensity and its determinants at the state level. *Energy J.* **2008**, *29*, 1–26.

38. Labra, R.; Torrecillas, C. Guía CERO para datos de panel. Un enfoque práctico. *UAM-Accent. Work. Pap.* **2014**, *16*, 57.

39. Sorrell, S. Reducing energy demand: A review of issues, challenges and approaches. *Renew. Sustain. Energ. Rev.* **2015**, *47,* 74–82.

40. De Almeida, A.; Fonseca, P.; Schlomann, B.; Feilberg, N. Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations. *Energy Build.* **2011**, *43*, 1884–1894.

41. Bersalli, G.; Menanteau, P.; El-Methni, J. Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America. *Renew. Sust. Energ. Rev.* **2020**, *133*, 110351.

42. Capros, P.; Kannavou, M.; Evangelopoulou, S.; Petropoulos, A.; Siskos, P.; Tasios, N.; Zazias, G.; DeVita, A. Outlook of the EU energy system up to 2050: The case of scenarios prepared for European Commission's "clean energy for all Europeans" package using the PRIMES model. *Energy Strategy Rev.* **2018**, *22*, 255–263.

43. Hale, L.A. At home with sustainability: From green default rules to sustainable consumption. *Sustainability* **2018**, *10*, 249.

44. Lucas, H.; Carbajo, R.; Machiba, T.; Zhukov, E.; Cabeza, L. Improving public attitude towards renewable energy. *Energies* **2021**, *14,* 4521.