TESIS DE LA UNIVERSIDAD DE ZARAGOZA

2022

64

José Ángel Gimeno Alonso

Definición y análisis multinivel de determinantes para el autoconsumo fotovoltaico a pequeña escala: desarrollo metodológico y modelización de procesos decisionales

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EXTRACTO

ISSN 2254-7606

Prensas de la Universidad
Universidad Zaragoza

ISSN 2254-7606

Universidad Zaragoza 1542

Tesis Doctoral [Extracto]

DEFINICIÓN Y ANÁLISIS MULTINIVEL DE DETERMINANTES PARA EL AUTOCONSUMO FOTOVOLTAICO A PEQUEÑA ESCALA: DESARROLLO METODOLÓGICO Y MODELIZACIÓN DE PROCESOS DECISIONALES

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UNIVERSIDAD DE ZARAGOZA
Escuela de Doctorado

Programa de Doctorado en Energías Renovables y Eficiencia Energética

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TESIS POR COMPENDIO DE PUBLICACIONES

La presente Tesis doctoral, con el título "Definición y análisis multinivel de determinantes para el autoconsumo fotovoltaico a pequeña escala: desarrollo metodológico y modelización de procesos decisionales", ha sido realizada por el doctorando José Ángel Gimeno Alonso, codirigida por la Dra. Eva María Llera Sastresa y la Dra. Sabina Scarpellini y desarrollada en el marco del Programa de doctorado de Energías Renovables y Eficiencia Energética de la Universidad de Zaragoza.

Se trata de una Tesis que se presenta como compendio de los artículos previamente publicados que se detallan a continuación, siendo el doctorando autor de todos ellos:

Artículo 1:

Gimeno, J. Á., Llera-Sastresa, E. and Scarpellini, S. (2020a) 'A Heuristic Approach to the Decision-Making Process of Energy Prosumers in a Circular Economy', Applied Sciences, Vol. 10, Page 6869, 10(19), p. 6869. doi: 10.3390/APP10196869.

Artículo 2:

Gimeno, J. Á., Llera-Sastresa, E. and Scarpellini, S. (2020b) 'Determinants and barriers of PV self-consumption in Spain from the perception of the installers for the promotion of distributed energy systems', Economics and Policy of Energy and the Environment, (1), pp. 153–169. doi: 10.3280/EFE2020-001007.

Artículo 3:

Gimeno, J. Á., Llera, E. and Scarpellini, S. (2018) 'Investment Determinants in Self-Consumption Facilities: Characterization and Qualitative Analysis in Spain', Energies, 11(8), p. 2178. doi: 10.3390/en11082178.

Artículo 4:

Scarpellini, S., Gimeno, J.Á., Portillo-Tarragona, P., Llera-Sastresa, E. (2021) 'Financial Resources for the Investments in Renewable Self-Consumption in a Circular Economy Framework', Sustainability, Vol. 13, Page 6838, 13(12), p. 6838. doi: 10.3390/SU13126838.

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Siendo el primer autor del artículo *titulado "A Heuristic Approach to the Decision-Making Process of Energy Prosumers in a Circular Economy'"*, afirmo haber contribuido en todo el proceso de elaboración de este trabajo de investigación, incluyendo la definición del estudio, el diseño de las entrevistas semi-estructuradas, la realización del trabajo empírico de recopilación de los datos y el análisis cualitativo, así como la redacción del manuscrito. Además, hago constar que, siendo todos los demás autores poseedores del título de Doctor, este trabajo de investigación no formará parte de ninguna otra Tesis en modalidad de compendio de publicaciones.

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1542

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Siendo el segundo autor del artículo titulado *"Financial Resources for the Investments in Renewable Self-Consumption in a Circular Economy Framework"*, afirmo haber contribuido en todo el proceso de elaboración de este trabajo de investigación, incluyendo la definición del estudio, el desarrollo del enfoque teórico, el diseño de las encuestas, la realización del trabajo empírico de recopilación de los datos y el análisis cuantitativo, así como la redacción del manuscrito y su posterior revisión en la fase de publicación. Además, hago constar que, siendo todos los demás autores poseedores del título de Doctor, este trabajo de investigación no formará parte de ninguna otra Tesis en modalidad de compendio de publicaciones.

En Zaragoza, a 25 de octubre de 2021

Fdo.: José Ángel Gimeno Alonso

AGRADECIMIENTOS

A mis Directoras, Dra. Eva Llera Sastresa y Dra. Sabina Scarpellini por su paciencia, colaboración y generosidad. Sin su experiencia, impulso y ayuda, esta Tesis no se habría concluido.

A la Dra. Pilar Portillo Tarragona por su aportación, ayuda e ideas especialmente en el marco de la financiación de este tipo de inversiones.

Al Grupo de Investigación “Socio-economía y Sostenibilidad” por su colaboración y ayuda en la publicación de varios artículos y al Instituto de Investigación Mixto CIRCE por las facilidades encontradas en la tramitación de la Tesis.

A mis padres, siempre agradecido y será poco.

A mi mujer, Marisol, por su apoyo incondicional, y a mi hija Inés, y ahora ya lo sabe, porque ha sido mi aliciente para terminar esta Tesis doctoral.

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Resumen

Las instalaciones de autoconsumo fotovoltaico son actualmente soluciones sostenibles y eficaces para acometer el reto de la transición energética hacia un futuro sostenible en el que humanidad está implicada, especialmente en los países de la Unión Europea por los audaces objetivos a los que se han comprometido. Un desarrollo intensivo de plantas de autoconsumo en el territorio favorecería a su vez la aplicación de los principios de la economía circular en el ámbito energético multiplicando sus beneficios. Sin embargo, a pesar de las ventajas que el autoconsumo fotovoltaico ofrece para clientes a pequeña y mediana escala, su despliegue ha sido dispar en muchos Estados miembros donde se constata una implementación aún bastante limitada en número de instalaciones.

La literatura académica ha analizado en los últimos años los distintos factores que pueden impulsar la decisión de instalar este tipo de tecnología y los determinantes que ayudan a incrementar el número de instalaciones para alcanzar la generación de energía eléctrica de forma renovable y sostenible a pequeña escala, en aplicación de las estrategias de transición energética a nivel europeo. Sin embargo, en la actualidad, quedan aún diversos ámbitos de estudio escasamente analizados en la materia. Así, entre otras, las investigaciones centradas en los prosumidores que invierten en este tipo de instalaciones y los recursos financieros disponibles a tal fin son aún poco numerosas hasta la fecha. De igual manera, se destaca la ausencia de trabajos que aborden el papel desempeñado por los profesionales que realizan la instalación de esta tecnología, como actores influyentes en el proceso de decisión por estas inversiones.

A partir de un análisis de la literatura, puede observarse que la mayor parte de los estudios anteriores a esta Tesis doctoral no han examinado en profundidad y de manera holística los factores determinantes de las inversiones y los recursos financieros específicos destinados a la instalación de autoconsumos fotovoltaicos a pequeña escala, incluyendo los segmentos residencial y de pequeñas y medianas empresas, que siguen siendo escasamente explorados en los estudios científicos a pesar de ofrecer numerosas oportunidades de inversión en recursos renovables para los inversores.

Ante estas consideraciones, esta Tesis tiene la finalidad general de ampliar el análisis y el conocimiento en la materia y llenar el *gap* en la literatura anteriormente señalado. En resumen, el objetivo principal de esta investigación es la modelización de los procesos decisionales y los determinantes que subyacen a las inversiones en el autoconsumo fotovoltaico a pequeña

escala. Para alcanzar estos objetivos, en esta Tesis se emplea un doble enfoque metodológico, cualitativo y cuantitativo, así como distintas fuentes de información, primarias y secundarias analizadas a través del análisis estadístico y un estudio de casos múltiples. Los datos empleados se han obtenido a través de diversas herramientas tales como encuestas a instaladores de plantas de autoconsumo fotovoltaico, entrevistas semi-estructuradas a prosumidores y bases de datos que han permitido llevar a cabo tanto un análisis multinivel con enfoques inéditos en la literatura como análisis de casos de estudio múltiple con una categorización técnica y económico-financiera de 35 instalaciones de autoconsumo fotovoltaico en España instaladas entre 2016 y 2017. A través de fuentes secundarias se realiza un análisis comparado de la regulación en materia de autoconsumo en diferentes países de la Unión Europea que permite la elaboración de potenciales escenarios regulatorios que faciliten el despliegue de este tipo de instalaciones.

La Tesis está compuesta por cuatro artículos vinculados con objeto de responder a las principales preguntas planteadas y así poder contribuir a ampliar el conocimiento y llenar el *gap* detectado en la literatura: (a) ¿Cuáles son los factores determinantes en el proceso de decisión para convertirse en prosumidor? (b) ¿Cuáles son las razones que motivan a los prosumidores a invertir? (c) ¿Cómo influyen las características de las instalaciones y las políticas específicas a nivel territorial en el despliegue de instalaciones de autoconsumo fotovoltaico? (d) ¿Cuál es el papel de los instaladores en la toma de decisiones para las inversiones en las instalaciones de autoconsumo fotovoltaico? (e) ¿Cuáles son y qué características tienen las fuentes de financiación empleadas en las inversiones en autoconsumo a pequeña escala?

El primer artículo incorpora un estudio heurístico realizado a partir de las opiniones de propietarios que decidieron invertir en instalaciones de autoconsumo fotovoltaico con el objetivo de dar respuesta a las preguntas a) y b). En este estudio se analiza el enfoque del prosumidor y los factores determinantes, su ponderación y el momento de aparición durante el proceso de decisión.

El segundo artículo se desarrolla en respuesta a las preguntas c) y d), tratándose de un enfoque inédito en la investigación que aporta esta Tesis al incorporar la perspectiva de los profesionales instaladores de sistemas fotovoltaicos de autoconsumo a pequeña escala, como un actor clave que influye en numerosas ocasiones en el proceso decisional.

A partir de un análisis en profundidad de la literatura y junto con las conclusiones de los dos primeros estudios, el tercer artículo, en respuesta a las preguntas a) y c), profundiza en dos de los factores clave en el proceso de decisión: el marco normativo y los determinantes económico-financieros de las instalaciones, a través de un análisis comparado de la legislación en autoconsumo fotovoltaico en cinco países de la Unión Europea. Se analiza particularmente el caso de España y, en base al marco regulatorio nacional, se establecen distintos escenarios para el despliegue de esta tecnología. Adicionalmente, se incluye la caracterización de sistemas de autoconsumo fotovoltaico a nivel territorial y los determinantes en términos de rentabilidad de inversiones.

Finalmente, en el cuarto artículo se profundiza en el estudio de las fuentes de financiación aplicadas a las inversiones en estas instalaciones y en los factores económicos-financieros determinantes para la toma de decisiones de inversión, como una de las aportaciones relevantes de esta Tesis en respuesta a la pregunta de investigación e).

En resumen, esta Tesis representa una contribución tanto teórica como metodológica que amplía el conocimiento para la definición, valoración y jerarquización de los determinantes de las inversiones en autoconsumo fotovoltaico a pequeña escala, así como en la modelización del proceso decisional desde la doble perspectiva de los prosumidores y de los instaladores. Asimismo, se amplía el conocimiento para la definición de escenarios regulatorios que permitirían alcanzar un mayor grado de penetración de este tipo de modelo de provisión de energía eléctrica y cómo dichos escenarios influyen en los parámetros de rentabilidad de los sistemas. Finalmente, otra de las contribuciones científicas de esta Tesis concierne a la definición y clasificación inéditas en la literatura hasta la fecha de los recursos financieros y los canales alternativos para las inversiones en este tipo de tecnología renovable, profundizándose en las características de dichas fuentes sustitutivas y paralelas frente a los canales tradicionales de crédito.

Abstract

Photovoltaic self-consumption installations are currently sustainable and effective solutions to face the challenge of the energy transition towards a sustainable future in which humanity is involved, especially the countries of the European Union for the audacious objectives to which they have committed. In turn, an intensive deployment of self-consumption plants in the territory would favor the application of the principles of the circular economy in the energy field, multiplying its advantages.

Despite the advantages, the photovoltaic self-consumption plant development in domestic clients or in small and medium-sized companies presents an uneven penetration in many Member States where implementation is still quite limited in number of installations.

In recent years the academic literature has analysed the different factors that can drive the decision to install this type of technology and the determinants that would increase the number of facilities to achieve the renewable and sustainable generation of electricity at a low scale, in application of energy transition strategies in European Union. However, at present, there are still various areas of study scarcely analysed. Thus, among others, research focused on prosumers who invest in this type of facilities and the available financial resources are still few to date. Similarly, it stands out the lack of studies that address the role played the installer, as influential actors in the decision process for these investments.

From an analysis of the literature, it can be deduced that most of the studies before this Thesis have not examined in depth in a holistic way the investment determinants and the specific financial resources allocated to photovoltaic self-consumption installations at a low scale, including domestic and small and medium-sized business markets, which remain poorly explored in scientific studies despite offering many investment opportunities.

Given these considerations, this Thesis has the general purpose of broadening the analysis and knowledge on the subject and filling the gap in the previously mentioned literature. In summary, the main objective of this research is the decision-making process modelling and the determinants that underlie photovoltaic self-consumption investments at low scale. In order to achieve these objectives, this thesis uses a double methodology, qualitative and quantitative, as well as different sources of information, primary and secondary, analysed through statistical analysis and a multiple case study.

The data have been obtained through surveys of photovoltaic self-consumption plant installers, semi-structured interviews with prosumers and databases. These have made it possible to carry out both a multilevel analysis with approaches unpublished in the literature and analysis of multiple case studies with a technical and economic-financial categorization of 35 photovoltaic self-consumption facilities in Spain installed between 2016 and 2017. A comparative analysis of self-consumption regulation in different countries of the Union is carried out through secondary sources European that allows the development of potential regulatory scenarios that facilitate the deployment of this type of facilities.

The Thesis is composed of four linked articles in order to answer the main questions posed and thus be able to contribute to broadening the knowledge and filling the gap detected in the literature: (a) What are the determinants in the decision-making process to become in prosumer? (b) What are the reasons that motivate prosumers to invest? (c) How do the characteristics of the facilities and specific policies influence the deployment of photovoltaic self-consumption facilities at the territorial level? (d) What is the role of installers in the decision-making for investments in photovoltaic self-consumption facilities? (e) What are and what characteristics have the financing sources used for investments at low scale self-consumption?

The first article incorporates a heuristic study based on the opinions of investors who have installed photovoltaic self-consumption in order to answer questions a) and b). This study analyses the prosumer position and the determinants, their weighting and the moment of appearance during the decision-making process.

The second article answers questions c) and d), being an unprecedented approach provided by this Thesis by incorporating the perspective of installers at low photovoltaic self-consumption installations, as a key actor that influences on several occasions in the decision-making process.

Based on an in-depth analysis of the literature and the conclusions of the first two studies, the third article answers questions a) and c), deeping two key determinants in the decision-making process: the regulatory framework and the economic-financial factor through a comparative analysis of the legislation on photovoltaic self-consumption in five countries of the European Union. The case of Spain is particularly analysed and, based on the national regulatory framework, different scenarios are designed for the deployment of this technology. Additionally, it includes the characterization of photovoltaic self-consumption systems at the territorial level and the determinants in terms of investment profitability.

Finally, the fourth article delves into the study of the financing sources applied to investments in these facilities, and the determining economic-financial factors as one of the relevant contributions of this Thesis in response to research question e).

In summary, this Thesis represents both a theoretical and methodological contribution that broadens the knowledge for the definition, assessment and ranking of the investment determinants at low scale photovoltaic self-consumption, as well as in the modelling of the decision-making process taking into account the prosumers and installers approaches. Likewise, the knowledge is expanded for the contribution of potential regulatory scenarios that would allow to achieve more intensive development of this technology and how these influence the profitability parameters. Finally, another of the scientific contributions of this Thesis concerns the definition and classification unpublished in the literature to date of financial resources and alternative channels for investments in this type of technology, delving into the characteristics of such substitute and parallel sources. compared to traditional credit channels.

1 Parte primera. Introducción

1.1 Antecedentes de las inversiones en autoconsumo en entornos de sostenibilidad medioambiental y economía circular

La energía eléctrica es el vector energético por antonomasia fundamental en la actividad humana. En la actualidad, es la fuente de energía final indispensable para el accionamiento de equipos y la iluminación y muy relevante en el transporte o en la producción de calor. Desde que la generamos a gran escala, su utilización no ha hecho más que crecer a nivel mundial incluso en años de crisis económicas sistémicas, de pandemias globales o de evidentes peligros medioambientales a escala planetaria. A pesar de la implantación de medidas de eficiencia y de su clara vinculación a los ciclos económicos, el consumo anual de energía eléctrica a nivel mundial en los últimos treinta años tan sólo ha experimentado un esporádico descenso en 2009 y 2020 para repuntar con fuerza al siguiente año. Su imbricación en nuestro modo de vida no ha hecho más que incrementarse por la mayor penetración de la electricidad en nuestra actividad cotidiana y nuestra economía.

No obstante, la utilización masiva de la electricidad supone un coste relevante para particulares, empresas y organizaciones. En la actualidad, la factura eléctrica de las empresas en España constituye más de la mitad de su gasto total en productos energéticos (Banco de España, 2020). A esto se suma una tendencia general de precios crecientes de la electricidad desde hace 20 años en España, segmento industrial incluido, con notables incrementos también en el residencial (Shah and Booream-Phelps, 2015).

Por otra parte, la actual situación de emergencia climática obliga a modificar las pautas de generación y consumo de energía. En los países de la Unión Europea (UE), teniendo en cuenta que la energía que consumimos en Europa es responsable del 75% de los gases de efecto invernadero según la Comunicación "*Stepping up Europe's 2030 climate ambition*" (European Commission, 2020), este cambio se ha proyectado a través de un plan de transición energética, que entre sus pilares incluye una cuota del 32% de energía procedente de fuentes renovables sobre el consumo total de energía de la UE para 2030.

A nivel nacional, el Plan Nacional Integrado de Energía y Clima (PNIEC, 2020) plasma la estrategia de España para cumplir los objetivos medioambientales en el 2030, siendo todavía más ambicioso que los retos de la UE en su conjunto (Linares, 2019), ya que se eleva hasta el 42% la cuota de renovables en el consumo total de energía y una presencia del 74% de energías renovables en el mix eléctrico nacional, con un enfoque a largo plazo de alcanzar la neutralidad climática en 2050 con un 100% de generación eléctrica mediante renovables.

Desde la perspectiva medioambiental, hay que tener en cuenta también la Comunicación "*An EU action plan*" que considera la economía circular (EC) como eje fundamental del plan de acción de la UE para la transición energética (European Commission, 2015a). Las sinergias entre la EC y la generación renovable de energía eléctrica son notorias y comparten objetivos comunes. Así, uno de los principios fundamentales de la EC es la utilización de energías renovables (Moraga *et al.*, 2019) para disminuir el consumo de fuentes fósiles (Pan *et al.*, 2014; Haas *et al.*, 2015) y las emisiones de efecto invernadero (Howard, Hopkinson and Miemczyk, 2019). El tener en cuenta de forma simultánea la sostenibilidad energética y los principios de la EC permitirá conseguir sin duda un efecto multiplicador en la consecución de los retos de transición energética hacia un desarrollo sostenible.

De igual manera, para acelerar dicha transición energética son fundamentales nuevos enfoques que incluyan la posible participación de toda la sociedad (Sanz-Hernández *et al.*, 2020), y especialmente la del consumidor particular, que mediante políticas y medidas de empoderamiento puede interactuar en el mercado contratando y produciendo energía, así como cambiando sus hábitos a consumos más eficientes en un enfoque de abajo arriba y desde una escala local como alude la Comunicación "*Making the internal market work*" (European Commission, 2014).

En este contexto, el autoconsumo de energía proporciona una solución viable e integrada al reto múltiple de la descarbonización, la generación renovable y distribuida y la incorporación de algunos principios de la EC (Scarpellini *et al.*, 2019).

Por la naturaleza multidimensional del reto, la perspectiva multinivel (Grin *et al.*, 2010) junto con la complementariedad de tecnologías renovables constituyen una ventaja porque permiten sumar esfuerzos para alcanzar los objetivos de diversificación (Grubler, 2012). Así, el autoconsumo resulta adecuado en un proceso transicional de entrada y salida de tecnologías y de progresiva madurez de mercados (Geels, 2010), dado que muchos de los sistemas de generación son considerados innovadores y pudieran no tener éxito en algún segmento, a la vez que ayuda, particularmente, a disminuir el riesgo por la intermitencia de las energías renovables.

En resumen, el autoconsumo empodera al consumidor -residencial, comercial o industrial- para producir y consumir su propia energía, actuando como prosumidor (Toffler, 1980), y por otro lado potencia la incorporación de nuevas instalaciones y estimula inversiones dentro de los objetivos de transición energética, a través de inversores que tienen en general menores expectativas de rentabilidad que otros actores financieros. Asimismo, el autoconsumo permite a particulares y empresas hacer previsibles una parte o la totalidad del coste de la energía generada y autoconsumida, despreocupándose en esa cuota de electricidad de la volatilidad del precio del mercado.

Desde una perspectiva de EC, las instalaciones de autoconsumo renovable favorecen la introducción de un modelo circular al mejorar la eficiencia por generar parte del consumo eléctrico de forma local y por realizar también la propia producción del recurso energético que se necesita (autogenerador). De igual manera, el autoconsumo instalado en empresas permite ampliar la base de modelos de negocio sostenibles (SMB) al incrementar el valor del prosumidor entre los *stakeholders* que demandan sostenibilidad, creando e intensificando las relaciones de dependencia mediante un modelo menos lineal de interacción comercial (Witjes and Lozano, 2016). También, desde un enfoque social de la EC, tal y como subraya la Directiva de Energías Renovables (Directiva UE 2018/2001), los sistemas de autoconsumo, como ejemplo de generación distribuida, ayudan al desarrollo y la cohesión comunitaria al suponer ingresos y una fuente de empleo a nivel local.

En la literatura científica el autoconsumo se ha analizado hasta la fecha también con aplicación de mecanismos de flexibilidad mediante almacenamiento descentralizado y permite, a su vez, el despliegue de tecnologías, como el *smart metering*, en diferentes esquemas (*net metering o net billing*) (Dufo-López *et al.*, 2015). Asimismo, han sido objeto de estudio los contratos flexibles ligados a esta tecnología que multiplican las ventajas para el prosumidor, al facilitarle reducir el consumo en determinados horarios o ajustarlo a momentos oportunos siguiendo las señales de precio, y también para el sistema eléctrico, al ayudar a reducir los picos de congestión, por ejemplo en verano, reduciendo costes y pérdidas como se apunta en la Comunicación *"Best Practices on Renewable Self-consumption"* (European Commission, 2015b).

Sin embargo, quedan aún líneas de investigación poco exploradas para modelizar estrategias que ayuden a su despliegue masivo y su posible combinación con sistemas de almacenamiento locales (Cucchiella, D'Adamo and Gastaldi, 2016), y se requiere mayor investigación en lo que se define como *Demande-Side Responde*, adaptando el consumo a la estructura tarifaria o como respuesta a señales de precio del mercado. Otro campo que es aún objeto de investigación es el impacto de las políticas energéticas en el despliegue del autoconsumo.

En la actualidad, esta tecnología ha logrado la paridad de red (no requiriéndose ayudas públicas) en al menos once Estados de la UE, entre ellos España (y, por ejemplo, en 14 Estados de EEUU) e incluso en los segmentos comercial y residencial (Shah and Booream-Phelps, 2015). Este umbral de rentabilidad se ha traspasado por el continuo descenso de costes de las instalaciones desde 1980 (Mints, 2010) y con reducciones medias muy intensas en la última década. Estas reducciones se han producido fundamentalmente por la bajada del coste del módulo fotovoltaico en sus diferentes tecnologías comerciales. No obstante, el impacto de la regulación en el despliegue de estas instalaciones a nivel territorial sigue siendo objeto de análisis y esta Tesis trata de ampliar el conocimiento en tal sentido.

Desde el punto de vista de la caracterización de instalaciones y del análisis de costes, la generación de electricidad mediante un sistema de autoconsumo fotovoltaico debe contemplar todos los costes de generación durante toda la vida útil de la instalación: inversión inicial, coste de capital, reposiciones de equipos, costes de operación, mantenimiento y seguros. Así, un tema de estudio es la caracterización de costes y su análisis a través del LCOE (*Levelized Cost Of Electricity*) que tiene en cuenta los anteriores costes en el ciclo de vida de la instalación. Gracias al análisis y caracterización de instalaciones, en esta Tesis se profundiza en esta línea para demostrar como el autoconsumo representa actualmente una opción tecnológica fiable a un precio razonable de adquisición y con unos costes de operación y mantenimiento previsibles cuando el perfil de carga se adecúa con la curva de generación en el lugar del emplazamiento (Kreifels *et al.*, 2016).

El estudio de la producción fotovoltaica de electricidad a pequeña escala se considera de interés ya que se trata de una tecnología probada con éxito en proyectos de gran escala, mientras que los sistemas de microgeneración están siendo aún objeto de investigación. En la literatura, son mayoritarios los estudios que analizan el potencial de instalaciones fotovoltaicas a gran escala (Girard *et al.*, 2016) y minoritarios, aunque en aumento, los enfocados en la microgeneración (Balcombe, Rigby and Azapagic, 2014; Juntunen and Hyysalo, 2015) o en el autoconsumo fotovoltaico (Colmenar-Santos *et al.*, 2012; Chiaroni *et al.*, 2014; Kästel, P., Gilroy-Scott, 2015; Sarasa-Maestro, Dufo-López and Bernal-Agustín, 2016), siendo en particular poco numerosos los estudios a nivel nacional (Talavera *et al.*, 2014).

Dado que la implantación intensiva de sistemas a pequeña escala, con potencias instaladas inferiores a 500 kW según la *Best practices on Renewable Self-consumption,* (European

Commission, 2015b) ayudará a lograr el cumplimiento de los objetivos climáticos y permitirá que sean los prosumidores los que adquieran un mayor compromiso en sus patrones de consumo energético y lleguen a una mejor y más amplia comprensión del sistema energético, resulta fundamental ampliar el conocimiento de los procesos decisionales que permiten el paso de la *utility scale* al despliegue de pequeñas instalaciones de autoconsumo fotovoltaico o incluso combinada con otras tecnologías (Mendes,Ioakimidis and Ferrão, 2011).

Una modelización de la toma de decisiones, así como de las barreras e incentivos que influyen en el proceso de inversión para la instalación de sistemas de autoconsumo fotovoltaico a pequeña escala, permitirá una adecuada explicación de la desigual penetración de esta tecnología en la UE. Investigar en estas líneas ayuda a dar respuesta a unas preguntas aún abiertas y proporciona herramientas para la mejora de la efectividad en el despliegue a un menor coste de recursos en un proceso de transición energética y de progresiva madurez de la tecnología (Reeves, Rai and Margolis, 2017) en segmentos sociales clave para la consecución y alineamiento con los retos de sostenibilidad, medioambientales y de EC a los que nos enfrentamos.

El marco teórico en el que desarrolla la investigación se describe en el siguiente apartado.

1.2 Marco teórico

La toma de decisión en la que influyen factores a favor y en contra se establece entre dos opciones: no invertir o alternativamente hacerlo e instalar un autoconsumo fotovoltaico, eligiendo la alternativa que maximice ganancias y minimice consecuencias negativas ajustándose a los objetivos seleccionados (Byrne, 1998) mediante un proceso consciente y deliberado (Kahneman, 2003). Los numerosos factores que influyen en el proceso decisional dificultan la elección de un marco teórico único para esta Tesis.

Entre los factores determinantes para la toma de decisiones de inversión en esta tecnología destacan los de tipo económico-financiero y de rentabilidad , tales como el coste de la instalación, el periodo de retorno de la inversión y los que hacen referencia al perfil y al contexto socioeconómico del prosumidor; la tarifa eléctrica, el marco regulatorio y eventuales incentivos junto con elementos psico-sociales, entre los que podemos citar creencias y valores (medioambientales, por ejemplo), la aversión al riesgo del inversor así como su predisposición a la adopción de tecnologías innovadoras, u otras intenciones y expectativas. Estos factores contextuales y psicosociales (o actitudinales) se clasifican en internos (propios del individuo) o externos (entorno, mercado o ambiente) como pueden ser los administrativos, regulatorios y legales, incentivos, impuestos y tasas, entre otros.

En las investigaciones previas a esta Tesis sobre los determinantes para realizar una inversión en una instalación de autoconsumo predomina el estudio del factor económico (Sommerfeld, Buys and Vine, 2017), fundamentado en razones como conseguir ahorro evitando el consumo de la red y percibiendo ingresos por la energía excedentaria, o relacionado con el coste de la instalación (Chiaroni *et al.*, 2014), o al objeto de disminuir la dependencia de la red, y consecuentemente, apantallando en parte el riesgo del incremento del precio (Balcombe, Rigby and Azapagic, 2014).

Desde otra perspectiva, la influencia de la regulación y de las políticas e incentivos públicos también ha sido analizada en la literatura (Orioli and Di Gangi, 2015). En el contexto nacional, España se ha caracterizado por una muy amplia legislación a nivel fotovoltaico (Ibarloza *et al.*, 2018) y también en el autoconsumo (López Prol and Steininger, 2017). Así, la notable influencia de la regulación en el despliegue del autoconsumo en comparación con otros marcos normativos europeos ha sido también de obligado estudio en esta Tesis.

A partir de estas consideraciones y de la literatura previa, en esta Tesis se analizaron distintos marcos teóricos para dar respuesta a los principales objetivos de investigación. Tanto la Teoría institucional (Suchman, 1995) como la evidencia empírica establecen que los factores económicos no pueden explicar completamente la decisión de invertir en autoconsumo. Así, además de factores económicos, financieros y regulatorios, los inversores innovadores o pioneros (*early adopters*) tienen en cuenta la sostenibilidad ambiental y el factor estético (Faiers and Neame, 2006), e incluso pueden valorar el beneficio económico por detrás de otros aspectos como el medioambiental y la afinidad con la tecnología (Leenheer, De Nooij and Sheikh, 2011), o porque la percepción del valor de la inversión tecnología no se basa exclusivamente en el aspecto económico (Rai, Reeves and Margolis, 2016) o porque los consumidores pueden estar a favor del despliegue de productos aun cuando no los vayan a utilizar (Johansson, 2016), o dispuestos a pagar más por sistemas y políticas que disminuyan la generación de electricidad mediante combustibles fósiles (Cheng *et al.*, 2017), o influidas por opiniones y experiencias vitales instigadas por cierta presión institucional. Incluso los incentivos económicos pueden funcionar de manera diferente por razones geográficas, como sostiene

Zhao *et al.*, (2011) al descubrir que son más eficientes en ciudades pequeñas que en grandes, o demográficas según los estudios Engelken *et al.* (2018) que revelan menores motivaciones en las personas de mayor edad para invertir que en las de mediana edad.

Desde otra perspectiva, la opinión pública puede decidir apoyar un crecimiento equilibrado entre lo económico, medioambiental y social, tanto a nivel de ética individual, como a nivel formal y normativo (Breyer, Heinonen and Ruotsalainen, 2017). De igual manera, la emulación de pares cercanos, vecinos o conocidos (Jager, 2006) puede ser influencia suficiente para eliminar gran parte de las barreras, como la falta de familiaridad con la tecnología o la imposibilidad de probarla antes de decidirse (Labay and Kinnear, 1981). Incluso, la decisión puede satisfacer varias necesidades individuales (Max-Neef, 1989), como la subsistencia y protección (frente a la amenaza climática), pertenencia e identidad (junto a otros inversores o incluso pioneros), de creación (de la propia energía) y de libertad (autonomía de la red de suministro).

Asimismo, también la información disponible, su calidad, relevancia, presentación y extensión, y cómo es reunida e interpretada, son factores a tener en cuenta para la toma de decisiones (Wilson and Dowlatabadi, 2007) sobre todo en el momento de despliegue como ya se ha estudiado en Suecia (Palm, 2018). En resumen, podría considerarse que en la decisión puede influir en positivo una ganancia de estatus social y de autosuficiencia, junto con el ahorro económico, y en negativo el riesgo con el que se asociaba la tecnología fotovoltaica junto con su coste (Korcaj, Hahnel and Spada, 2015).

A partir del análisis de la literatura, puede afirmarse que las barreras existentes para el despliegue de la tecnología de autoconsumo fotovoltaico han sido parcialmente estudiadas hasta la fecha. Algunos análisis y supuestos citados ut supra ponen de relieve la necesidad de profundizar en el proceso de decisión inherente a las inversiones en generación de energía distribuida al objeto de definir incentivos coherentes con las motivaciones de los prosumidores (McKenzie-Mohr, 2000). Además, las barreras pueden tener particularidades a nivel país o territorio, cómo muestran Michaels and Parag (2016) en Israel, lo que implica el análisis del mercado a nivel territorial y de la evolución de la madurez del mercado por aumentar, por ejemplo, las trabas por aumento de cargas administrativas en la segunda fase de la implantación (Palm, 2018). Esto pone de manifiesto la necesidad de realizar un análisis dinámico de las motivaciones y barreras que puede ayudar a un mejor despliegue a lo largo del tiempo.

Por todo lo anterior, en esta Tesis se realiza un avance en el conocimiento a través de la modelización del proceso de decisional de inversiones en autoconsumo, profundizándose en el análisis multinivel de los factores que influyen en la toma de decisiones en cuanto a amplitud de factores y en la interrelación entre ellos de una forma holística que no se había acometido en estudios anteriores. A tal fin, en esta Tesis se ha tenido en cuenta diferentes perspectivas teóricas para relacionar la adopción de una tecnología innovadora con los procesos de difusión y los marcos sociales y tiempos (Rogers, 2003; Meade and Islam, 2006), además de analizarse las barreras y el marco de incentivos (Foxon *et al.*, 2005).

La aproximación a esta decisión multinivel ha sido también abordada en la literatura en el marco teórico de la de modelización basada en agente (ABM) que ha simulado la interacción compleja de dichos factores (Zhao *et al.*, 2011; Palmer, Sorda and Madlener, 2015; Robinson and Rai, 2015; Alyousef, Adepetu and de Meer, 2017; Stavrakas, Papadelis and Flamos, 2019). En cualquier caso, un modelo predictivo que facilite una solución factible simple para la comprensión del proceso de decisión del prosumidor puede ser más adecuado para la difusión de este tipo de tecnología a través de diversos actores, los cuales pueden requerir estrategias sencillas y trasparentes y más fácilmente asimilables a sus planes de desarrollo.

1.3 Objetivos, justificación y estructura de la Tesis

Esta Tesis tiene la finalidad general de ampliar el análisis y el conocimiento en la materia y llenar el *gap* en la literatura anteriormente señalado. En resumen, el objetivo principal de esta investigación es la modelización de los procesos decisionales y de los determinantes que subyacen en las inversiones en el autoconsumo fotovoltaico a pequeña escala.

Para alcanzar los objetivos generales de la investigación se abordan objetivos específicos profundizándose en dos factores considerados clave en el proceso de decisión: el marco normativo y los determinantes económico-financieros de las instalaciones. A tal fin se realiza un desarrollo metodológico multinivel para la caracterización de sistemas de autoconsumo fotovoltaico a nivel territorial y de los determinantes en términos de rentabilidad de inversiones. Adicionalmente, otro de los objetivos secundarios de investigación acomete el estudio de las fuentes de financiación aplicadas a las inversiones para estas instalaciones, tanto en su definición y clasificación como en las principales características de las fuentes movilizadas, como una de las aportaciones relevantes de esta Tesis.

La Tesis doctoral analiza experiencias en España puesto que, una vez lograda la paridad de red, dispone de una experiencia de éxito en el despliegue de instalaciones de producción fotovoltaica (Scarpellini and Romeo, 1999) así como de excelentes condiciones de radiación, incluso mejores que Alemania (López Prol, 2018), líder en potencia instalada fotovoltaica en la UE según las Estadísticas de Capacidad Renovable (IRENA, 2020). Sin embargo, desde el comienzo de los estudios que incluyen esta Tesis y a pesar de las indudables ventajas señaladas con anterioridad, se detectó en España un muy modesto despliegue de instalaciones de autoconsumo fotovoltaico, comparado con otros Estados de la UE, que puede comprometer la consecución de sus objetivos climáticos

A diferencia de otros estudios, la Tesis realiza un análisis multinivel de los factores que afectan a las inversiones en instalaciones de autoconsumo fotovoltaico de pequeña escala y no en plantas de producción fotovoltaica a gran escala. Los sistemas a escala doméstica o industriales de pequeña potencia son claves para empoderar energéticamente a potenciales prosumidores en áreas urbanas o rurales y conectarlos con los retos medioambientales a los que nos enfrentamos.

La Tesis está compuesta por cuatro artículos vinculados y conectados con los que se pretende contribuir a ampliar el conocimiento y el *gap* en la literatura detectado resolviendo las siguientes cuestiones: (a) ¿Cuáles son los factores determinantes para que un consumidor decida ser prosumidor? (b) ¿Cuáles son las razones que motivan a los prosumidores a invertir? (c) ¿Cómo influyen las características de las instalaciones y las políticas específicas a nivel territorial en el despliegue de instalaciones de autoconsumo fotovoltaico? (d) ¿Cuál es el papel de los instaladores en el proceso de toma de decisiones para la inversión en instalaciones de autoconsumo fotovoltaico? (e) ¿Cuáles son y qué características tienen las fuentes de financiación empleadas para las inversiones en autoconsumo a pequeña escala?

El primer artículo incorpora un estudio heurístico realizado a partir de las opiniones de inversores que han instalado autoconsumos fotovoltaicos con el objetivo de dar respuesta a las preguntas a) y b). En este estudio se analiza la posición del prosumidor y los factores determinantes, su ponderación y el momento de aparición durante el proceso de decisión.

El segundo artículo se desarrolla en respuesta a las preguntas c) y d), tratándose de un enfoque inédito en la investigación que proporciona esta Tesis al incorporar la perspectiva de los profesionales instaladores de instalaciones de autoconsumo fotovoltaico a pequeña escala, como un actor clave que influye en numerosas ocasiones en el proceso decisional.

A partir de un análisis en profundidad de la literatura y junto con las conclusiones de los dos primeros estudios, el tercer artículo profundiza en dos de los factores que parecen claves en el proceso de decisión: el marco normativo, a través de un análisis comparado de la legislación en autoconsumo fotovoltaico en cinco países de la UE, y los determinantes económico-financieros de las instalaciones, en respuesta a las preguntas a) y c). Se analiza particularmente el caso de España y, en base al marco regulatorio nacional, se definen distintos escenarios para el despliegue de esta tecnología. Adicionalmente, se incluye la caracterización de sistemas de autoconsumo fotovoltaico a nivel territorial y los determinantes en términos de rentabilidad de inversiones.

Finalmente, en el cuarto artículo se profundiza en el estudio de las fuentes de financiación aplicadas a las inversiones para estas instalaciones, al tratarse de uno de los factores económicos-financieros determinantes para la toma de decisiones de inversión, lo que constituye una de las aportaciones relevantes de esta Tesis en respuesta a la pregunta de investigación e).

El resumen esquemático de la Tesis y la relación entre los artículos queda recogido en la siguiente figura:

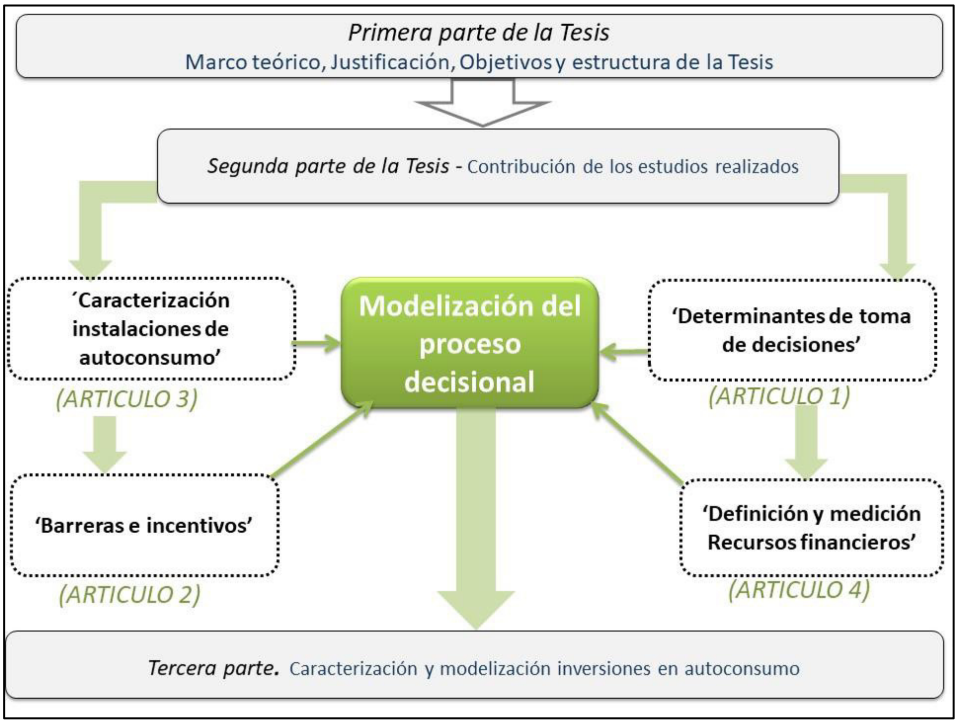

Figura 1.1. Resumen esquemático de la Tesis

Este trabajo doctoral permite añadir más datos e investigaciones sobre el proceso de decisión para instalar autoconsumo fotovoltaico con factores determinantes dinámicos a lo largo del tiempo y en un proceso transicional de largo alcance.

La Tesis busca servir de apoyo a responsables políticos, académicos, empresas y profesionales para el diseño y profundización en políticas e incentivos, investigaciones, estrategias y productos que contribuyan al efectivo y más rápido despliegue de las instalaciones de autoconsumo fotovoltaico.

En los cuatro artículos citados en la figura anterior, se ha utilizado la base teórica e introducido las cuestiones anteriormente descritas según se explica en los siguientes apartados.

1.3.1 Aproximación heurística al proceso decisional para prosumidores en entornos de economía circular

A partir de la revisión de la literatura, podemos deducir que el análisis coste-beneficio es el que predomina frente a otros factores en la decisión de instalar este tipo de tecnología: conseguir ahorros económicos por la energía autogenerada y no consumida de la red e incluso obtener ingresos por la energía excedentaria (Balcombe, Rigby and Azapagic, 2015). Otras investigaciones, teniendo en cuenta esta idea, estudian los incentivos para favorecer la decisión de invertir del potencial prosumidor (Aragonés, Barquín and Alba, 2016).

Sin embargo, existen análisis que se centran, no en el contexto en el que la persona vive, sino en sus motivaciones y actitudes psicológicas. Y así, también se ha tenido en cuenta en este primer artículo que los factores contextuales no siempre explican la implantación de productos tecnológicos (Masini and Menichetti, 2013) o que el valor de la instalación no sólo se configura por su precio monetario (Faiers and Neame, 2006).

Con estos precedentes, en este artículo se busca profundizar en las investigaciones previas desde otro enfoque metodológico: mediante una aproximación heurística evitando análisis fragmentarios, con alternativas sin referencias específicas e incluyendo modelos de elección generales (Tversky, 1972). Dicho enfoque heurístico se realiza a través de dos formas novedosas: en primer lugar, mediante entrevistas semiestructuradas a prosumidores de instalaciones fotovoltaicas, cuyo punto de vista se ha tenido en cuenta de forma más limitada hasta la fecha del artículo y, en segundo lugar, centrado en sistemas de autoconsumo a pequeña escala en España, a diferencia de los más frecuentes estudios a gran escala.

El objetivo es identificar qué factores predominan en la decisión de invertir, mostrando el procedimiento de interacción funcional entre dichos determinantes y cómo "deciden" convertir un consumidor en prosumidor.

Gracias a los resultados obtenidos, se obtienen por orden de valoración los criterios y factores más valorados por los prosumidores a la hora de invertir, así como un modelo secuencial ponderado del proceso de decisión en base a puntuaciones, el cual permite revelar cuándo aparecen y cómo se suceden los determinantes durante el desarrollo de la toma de decisiones.

1.3.2 Determinantes de autoconsumo fotovoltaico en sistemas de generación distribuida

A diferencia de la mayoría de investigaciones académicas anteriores a esta Tesis, el segundo artículo estudia las barreras que dificultan el despliegue del autoconsumo fotovoltaico a pequeña escala desde la percepción de los instaladores de este tipo de sistemas de generación, al tratarse de profesionales que no se limitan al montaje de los equipos, sino que combinan labores comerciales y técnicas, realizando la difusión de información previa a la decisión. En consecuencia, el artículo se enfoca en el papel de los instaladores cuya influencia es hasta la fecha desconocida (Drury *et al.*, 2012).

Así, el artículo utiliza una encuesta con la opinión de una muestra de instaladores para conocer cómo afecta la falta de políticas específicas sobre el autoconsumo, y cuáles son, en su opinión, los barreras e incentivos que influyen sobre la decisión de invertir en este tipo de sistemas. De igual manera, se valora su papel en la difusión y promoción de estas instalaciones en su desempeño profesional y la posible falta de una estrategia específica para el desarrollo del autoconsumo en España junto con los efectos que esta deficiencia pudiera provocar. El perfil del instalador es el de un profesional autónomo o asalariado en una empresa cuyo negocio fundamental es el montaje de instalaciones eléctricas, la venta de electricidad y de productos y sistemas energéticos entre los que se encuentran las instalaciones de autoconsumo fotovoltaico.

Asimismo, la encuesta se diseña contemplando barreras e incentivos antagónicos: esto es, el incentivo antagónico permite comprobar si una situación contraria a la que plantea su correspondiente obstáculo incrementaría el número de instalaciones fotovoltaicas con autoconsumo. Con esta metodología y objetivo se valoran las barreras e incentivos y además se obtiene información sobre si el incentivo antagónico permite una mejora de la situación que plantea actualmente la barrera y la diferencia de percepción entre ambos.

Los resultados permiten evaluar las barreras e incentivos que encuentra el instalador durante el proceso de toma de decisión del consumidor que invierte en estos sistemas, analizando su predominancia y frecuencia, y organizarlos según su carácter regulatorio y administrativo, económico, financiero, técnico y otros. Con los resultados de este artículo, la Tesis contribuye a aportar una visión complementaria sobre los factores determinantes para la inversión, así como la evaluación de la capacidad de los incentivos para contrarrestar las barreras opuestas que aparecen en la decisión según la percepción de este actor relevante. Estas valoraciones, agrupaciones y efectos entre factores antagónicos permiten el diseño de políticas e incentivos para mejorar el desarrollo de este tipo de sistemas.

1.3.3 Caracterización y análisis cualitativo de inversiones en instalaciones de autoconsumo.

Como se ha citado anteriormente, los estudios previos consideran motivaciones y barreras contextuales y actitudinales en la decisión de llevar a cabo este tipo de inversiones. A la hora de decidirse a invertir, los factores económicos (Sommerfeld, Buys and Vine, 2017) y financieros (Karakaya and Sriwannawit, 2015) parecen ser los más importantes junto con los legislativos y de incentivos regulatorios (Aragonés, Barquín and Alba, 2016; Londo *et al.*, 2020). Entre estos últimos podríamos incluir barreras institucionales como la inexistencia de políticas de implantación supervisadas por instituciones confiables, junto con fuentes de información relevantes y suficientes.

Con objeto de ampliar los resultados de los artículos precedentes y teniendo en cuenta la base teórica existente, en el tercer artículo se incorpora un análisis comparativo de la legislación en cinco países de la UE. Para ello, se examinan los marcos regulatorios de 5 países europeos: Alemania, Francia, Italia, Portugal y España. Las razones de esta selección son dos: por una parte, se trata de Estados con una población muy relevante a nivel de la UE; por otra, la mayoría se encuentran en una situación geográfica de alta irradiación solar lo que les permite tener altas expectativas de éxito en la implantación de este tipo de sistemas. Con esta revisión comparada de la legislación, se valora un listado de barreras e incentivos determinantes en la decisión de instalar según el punto de situación de dicho factor respecto al marco normativo en cada uno de los cinco países. Para alinearse con en el objetivo de la Tesis, se analiza particularmente el caso de España y se estudia cómo podría influir la eliminación de barreras en España mediante varios escenarios. De esta manera, el artículo profundiza en la situación legislativa del autoconsumo en España, calificada como muy restrictiva (López Prol, 2018) y que en el momento de la redacción del artículo se amparaba fundamentalmente en el Real Decreto 900/2015.

Además, en el análisis de la legislación se tiene en cuenta que ya existen soluciones empresariales que podrían ayudar a solventar algunas de las barreras a las que se enfrenta el inversor, sobre todo en lo que hace referencia al coste inicial a pagar, al riesgo e incertidumbre en la tecnología y la regulación, y por la dificultad en el acceso a la financiación. Mediante la configuración de Empresas de Servicios Energéticos o ESCO (*Energy Service Company*), las empresas pueden, actuando como un tercero, instalar sistemas de autoconsumo fotovoltaico a su costa en los terrenos o cubierta propiedad del consumidor (u ofrecer una modalidad de arrendamiento financiero), vendiendo la energía generada mediante un precio a largo plazo o PPA (*Power Purchase Agreement*) con descuentos y ahorros desde el primer mes frente a los precios habituales de la energía de red reduciendo las barreras anteriormente comentadas al ser, la Empresa de Servicios Energéticos, titular de la propiedad y operador de la instalación y asumiendo los riesgos planteados. Estas soluciones pueden permitir que incluso sectores demográficos con menos posibilidades en principio de adoptar esta tecnología lo hagan como, por ejemplo, en el sur de California (Drury *et al.*, 2012). A pesar de esta configuración empresarial que permitiría mejorar la implantación, existe la paradoja de países como España con un considerable desarrollo de empresas ESCO, pero con escaso desarrollo de los sistemas de autoconsumo fotovoltaico (Irrek et al., 2013).

Adicionalmente, se incluye el análisis de las características técnicas más comunes (potencia instalada, zona de instalación, conexión o a la red) de 35 plantas de autoconsumo fotovoltaico que se habían instalado en España antes de julio de 2018, así como la muestra de cómo se presentaba el análisis de la rentabilidad de estas inversiones.

Los resultados obtenidos permiten diseñar escenarios regulatorios más favorables al desarrollo del autoconsumo fotovoltaico a pequeña escala, así como exponer el tipo de instalaciones (en relación con su conexión o no a la red, tamaño y tipo de inversor) y los valores de rentabilidad de una muestra de las primeras instalaciones implementadas en España. En este último caso, y en relación con el objetivo de la Tesis, se obtienen valores de referencia aceptados por inversores de un factor clave como es el económico.

1.3.4 Definición y medición de recursos financieros para inversiones en autoconsumo renovable

Este cuarto y último artículo parte de la base del limitado despliegue de los sistemas de autoconsumo fotovoltaico en algunos países de la UE y la influencia que en este hecho pueden tener factores económicos como el coste de la instalación (Frank *et al.*, 2015; Ford *et al.*, 2017) el período de retorno de la inversión (Chiaroni *et al.*, 2014; Talavera *et al.*, 2014) y la financiación de la operación. De hecho, los estudios de Allen, Hammond y McManus (2008), Bergman y Eyre, (2011) y Claudy, Michelsen y O'Driscoll (2011) señalan que, a pesar de los incentivos financieros del global de la operación para el potencial prosumidor, el coste inicial de la instalación es la barrera determinante para la inversión en este tipo de instalaciones, que incluso para un cierto número de hogares puede calificarse de inasumible (Scarpa and Willis, 2010) o bien los ingresos del prosumidor no son considerados garantía suficiente (Claudy *et al.*, 2010).

La dificultad de acometer la inversión afecta tanto a particulares (Lang, Ammann and Girod, 2016), como a PYME y empresas de reciente creación (Allen, Hammond and McManus, 2008; Zhang, 2016) lo cual perjudica la consecución de los retos medioambientales al poner barreras a inversores capaces de movilizar recursos propios y que esperan de la inversión retornos financieros menos exigentes (en TIR o períodos de retorno) que otro tipo de actores financieros.

Dadas estas premisas, en el cuarto y último artículo que integra esta Tesis se amplía el marco de análisis en relación con la posible dificultad en realizar o financiar la inversión con el contexto teórico e investigaciones que existen sobre eco-inversiones (Przychodzen and Przychodzen, 2015) y EC (Aranda-Usón *et al.*, 2019). Además, se tienen en cuenta en el análisis los compendios de los diferentes instrumentos de financiación existentes para sistemas de generación distribuida como fondos propios, préstamos, arrendamientos financieros e incentivos públicos -ayudas, créditos blandos, exenciones y deducciones fiscales- (Mir-Artigues and Del Río, 2014; Satchwell, Mills and Barbose, 2015; Song *et al.*, 2016; Talavera *et al.*, 2019) así como estudios que analizan la proporción y el coste de la financiación adecuada para invertir en este tipo de sistemas (Palmer, Sorda and Madlener, 2015; López Prol and Steininger, 2017).

El núcleo del problema que se plantea en esta fase de la investigación es que el coste de la instalación de autoconsumo fotovoltaico sigue señalándose como un factor determinante a la hora de invertir. Esto implica que la falta de adecuados instrumentos de financiación (Leenheer, De Nooij and Sheikh, 2011) representan una clara barrera para estas instalaciones, en tanto que afecta a la adopción de la tecnología y condiciona la rentabilidad final de los proyectos.

Por otra parte, se expone la importancia de ciertos actores, cercanos o pares, tanto en el proceso de despliegue de la tecnología (Palm and Eriksson, 2018) como en la difusión de canales alternativos de financiación (Mazzucato and Semieniuk, 2018). Así, la figura del instalador se presenta como un elemento clave en la información, comercialización, instalación e incluso vehículo a través del cual se proporciona la financiación de la instalación de autoconsumo fotovoltaico. De hecho, en la decisión sobre invertir en la instalación por parte del potencial prosumidor, y en comparación con otras fuentes de información como Internet o incluso familiares y conocidos (Reeves, Rai and Margolis, 2017), se considera muy influyente el papel del instalador, como profesionales que cuánto menos, montan los sistemas de autoconsumo fotovoltaico y que también son difusores alternativos de financiación.

En este contexto, se exponen también las ventajas de este canal, al vincular el vencimiento del crédito a las características técnicas y económicas del sistema ofertado y, sobre todo, simplificar la calificación del riesgo de impago del cliente, que ha sido previamente analizado al aceptar el pedido de ofertar la instalación, y con el que se dispone de una información y comunicación establecidas (Allen, Qian and Xie, 2018) frente a la que puede construirse por la entidad financiera clásica. Además, el instalador estaría inclinado a dar dicho servicio (Burkart and Ellingsen, 2004) porque la financiación es una palanca que facilita y consolida la operación (Wilner, 2000). Así, este canal es conveniente para el cliente, ya que abrevia la contratación al facilitarle un acceso inmediato a un canal de financiación que tiene ya establecida los canales de comunicación, simplifica los trámites documentales para verificar el riesgo de impago tanto para inversores domésticos como para las pequeñas empresas (O'Shaughnessy, 2018) e incluso facilita la inversión a prosumidores con débil posición crediticia.

En consecuencia, el papel de los instaladores es valioso ya que es cercano tanto al proceso de decisión de invertir en este tipo de sistemas de autoconsumo como a la información sobre la conformación de los recursos financieros utilizados (cuando no es el facilitador).

Ante estas premisas, mediante una encuesta a instaladores con formación y experiencia en autoconsumo, se estudia la información que aportan sobre las características de las fuentes de financiación utilizadas en las inversiones en autoconsumo fotovoltaico que sus clientes han llevado a cabo, así como sobre los factores económicos-financieros que, en su opinión, influyeron en la decisión de invertir. De igual manera, se consulta y analiza la influencia que tuvieron ellos mismos en el proceso de decisión, así como si facilitaron el acceso a la financiación de dichos proyectos. Las encuestas fueron respondidas de forma anónima por 90 de los 243 participantes a los que se les ofreció tomar parte en la investigación (un 37%), cumpliendo los criterios de validez 81 de las 90.

Los resultados obtenidos permiten distinguir que existen fuentes de financiación predominantes (entre fondos propios o externos) que se combinan y exponer los porcentajes de aportación al *capex* de la inversión. Asimismo, se comprueba la existencia y viabilidad de actores de financiación diferentes a los canales tradicionales en las inversiones realizadas, así como el porcentaje medio de aportación de ayudas públicas. De igual manera, se demuestra la involucración del instalador en proporcionar datos de ahorro estimado a sus clientes y el porcentaje medio de dichos ahorros, y, por tanto, se concluye que su papel en la difusión y despliegue de este tipo instalaciones es muy significativo.

1.4 Enfoque metodológico

Para dar respuestas fundamentadas a las preguntas formuladas, se opta por aplicar un doble enfoque metodológico, cualitativo y cuantitativo. Cabe mencionar que antes del desarrollo de esta Tesis no se disponía de indicadores específicos para la definición y medición de los recursos financieros aplicados a las inversiones en instalaciones de autoconsumo y no se había propuesto ninguna metodología de caracterización de instalaciones a pequeña escala que integrara distintos factores con este grado de amplitud y con visión heurística del proceso decisional que incluyese asimismo el papel de los instaladores como agentes relevantes en la toma de decisiones.

Por consiguiente, para la caracterización de las instalaciones y la modelización del proceso decisional, resulta necesario obtener información específica directamente desde los prosumidores y desde los técnicos involucrados en el proceso de financiación de la inversión, siendo esta una de las principales limitaciones existentes para la investigación en este campo al tratarse a menudo de datos confidenciales en cuanto a tecnología, rentabilidad de las instalaciones y recursos financieros movilizados. A su vez, los indicadores aplicados a las instalaciones existentes a menudo no se habían relacionado con la medición espacial de la penetración del autoconsumo a nivel territorial y el relativo impacto de la regulación, representando uno de los campos de investigación aún abierto en la materia.

En esta Tesis se aplica un estudio multinivel sobre las motivaciones y barreras que afectan a las inversiones de autoconsumo fotovoltaico. De igual manera que se ha considerado primordial la complementariedad tecnológica para afrontar los retos climáticos a los que nos enfrentamos, el análisis multinivel de motivaciones y barreras puede ser muy provechoso para el objetivo de la Tesis. Así, en primer lugar, se tiene en cuenta de forma extensiva los antecedentes empíricos e investigaciones sobre factores determinantes para invertir en autoconsumo fotovoltaico. En segundo lugar, se efectúa un análisis comparado de la legislación y regulación administrativa de cinco países de la UE, entre ellos España. En tercer lugar, la Tesis contiene una caracterización técnica y económica de los elementos distintivos de las primeras instalaciones de autoconsumo realizadas en España. Asimismo, la Tesis se ha enriquecido con la opinión del prosumidor, tratando de buscar explicación de su proceso de decisión y analizando también su experiencia tras la puesta en marcha de la instalación en un enfoque novedoso con respecto a trabajos antecedentes más centrados en otros *stakeholders*. Y, finalmente, incorpora también entrevistas con instaladores con experiencia en implantación de sistemas fotovoltaicos.

Por tanto, la Tesis tiene en cuenta perspectivas y experiencias multinivel extraídas mediante herramientas utilizadas usualmente en investigaciones similares, como encuestas (Alsabbaugh, 2019; Faiers, Neame, 2006; Karakay, Sriwannawit, 2015) o entrevistas (Bouly de Lesdain, 2019; Tayal, Rauland, 2016).

Ante estas premisas, en la primera fase de la investigación se realiza un estudio de caso múltiple de instalaciones de autoconsumo en España y así definir sus principales características, los factores que influyen en la decisión a invertir y el impacto de la política energética y la regulación, que se lleva a cabo sobre la base de un *desk research.* El estudio del caso múltiple resulta de utilidad en esta Tesis para proceder a una caracterización que aproveche el poder explicativo del análisis cualitativo con un alcance territorial del autoconsumo a pequeña escala para proporcionar su generalización posterior (ARTÍCULO 3).

Conjuntamente con el estudio del caso múltiple de 35 instalaciones, se llevaron a cabo 16 entrevistas semi-estructuradas a prosumidores para analizar en detalle el proceso decisional y poder modelizar a través de un análisis cualitativo los factores determinantes de la toma de decisiones para inversiones en tecnología de autoconsumo (ARTÍCULO 1).

En una segunda fase de investigación, se realiza una aportación de enfoque metodológico analizando el papel de los instaladores en el despliegue de esta tecnología. Los datos, que se analizan a través de un doble enfoque cualitativo y estadístico-descriptivo, se recolectaron a través de 90 encuestas respondidas por técnicos involucrados en la instalación de esta tecnología en España. Esta fuente de datos permite la definición y medición de los recursos financieros específicos empleados en las inversiones en autoconsumo como una de las aportaciones relevantes de esta Tesis (ARTÍCULO 4) y la definición del papel de los instaladores en la toma de decisiones (ARTÍCULO 2).

En síntesis, las fuentes de los datos empleados para esta Tesis son los que se detallan a continuación:

	Caracterización instalaciones	**Proceso decisional**	**Regulación territorial y *Politicas energéticas***
Características Técnico-económicas	**Caso de estudio múltiples** *(35 instalaciones)*	**Entrevistas semi-estructuradas** *(16 entrevistas a prosumers)*	*Desk research, entrevistas y encuestas*
Recursos financieros	**ENCUESTAS a instaladores** *(90 encuestas a instaladores)*		

Figura 1.2. Fuentes de datos empleados para la investigación

El enfoque metodológico planteado puede describirse gráficamente como sigue:

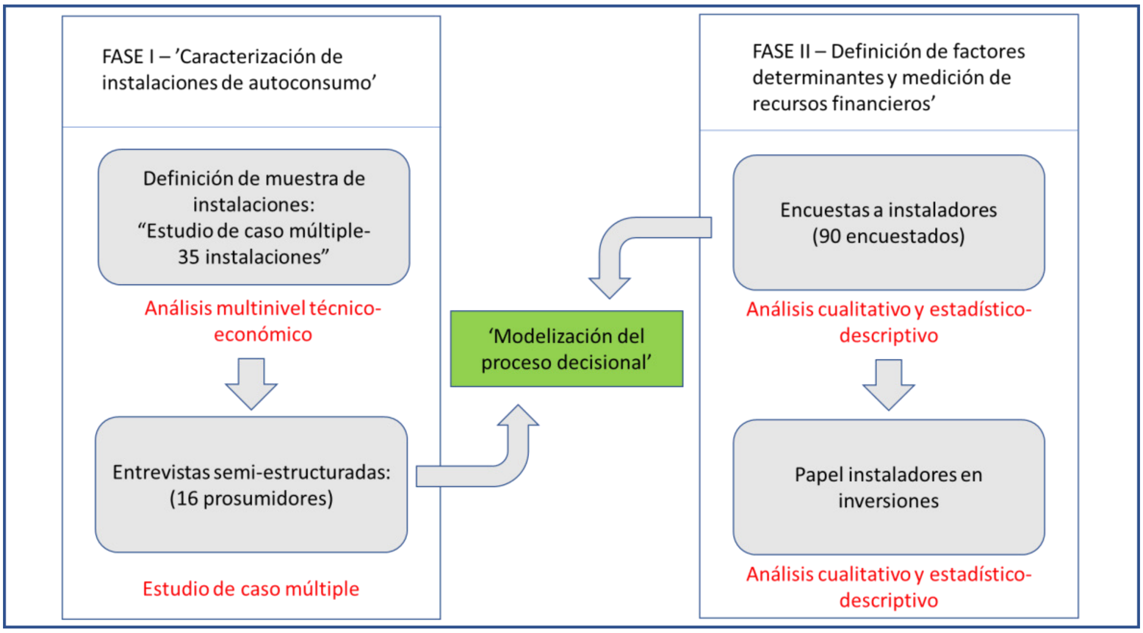

Figura 1.3. Doble enfoque metodológico en las fases de la investigación

Los resultados obtenidos a través de la aplicación de las metodologías descritas en este apartado se detallan en los artículos que integran esta Tesis y que se incluyen en la siguiente sección.

2 Parte segunda. Contribución de los estudios realizados

2.1 A Heuristic Approach to the Decision-Making Process of Energy Prosumers in a Circular Economy (Artículo 1)

ARTÍCULO 1: Gimeno, J. Á., Llera-Sastresa, E. and Scarpellini, S. (2020a) 'A Heuristic Approach to the Decision-Making Process of Energy Prosumers in a Circular Economy', Applied Sciences, Vol. 10, p. 6869. doi: 10.3390/APP10196869.

Editorial: MDPI- ISNN: 2076-3417

Publicación INDEXADA JCR CIENTÍFICO Q2: factor de impacto: 2.679 (2020)

Category Name	Impact Factor (2020)	Quartile Rank	Quartile in Category
JCR CIENTÍFICO- Chemistry, Multidisciplinary	2,679	101/178	Q3
JCR CIENTÍFICO -Physics, Applied	2,679	73/160	Q2
JCR CIENTÍFICO-Engineering, Multidisciplinary	2,679	38/91	Q2
JCR CIENTÍFICO-Materials Science, Multidisciplinary	2,679	201/333	Q3

applied sciences

MDPI

Article

A Heuristic Approach to the Decision-Making Process of Energy Prosumers in a Circular Economy

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Received: 9 September 2020; Accepted: 28 September 2020; Published: 30 September 2020

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Abstract: Renewable distributed energy and self-consumption are promising and sustainable solutions in the energy-transition scenario for moving toward a circular economy. In this future scheme, prosumers are expected to play a leading role in the forthcoming sustainable energy market, facing new technical, economic, and financial challenges as energy producers at a small scale. In fact, the adoption of photovoltaic (PV) self-consumption systems requires mobilizing capital for investment and their interaction with the market. In this scenario, the aim of this paper was to explore insights into the decision-making process of prosumers to enhance the understanding of self-consumption deployment and to support effective policymaking. This study contributes to the state of the art by defining and classifying determinants of the energy prosumers' decision-making process and their relevance using a heuristic approach. Potential measuring tools and methods are analyzed through a specific case study of Spanish prosumers.

Keywords: self-consumption; circular economy; environmental management tools; corporate finance; prosumers

1. Introduction

A key principle of the circular economy (CE) is that energy is powered via renewable sources [1], leading to significant reductions in fossil-fuel consumption [2,3] and greenhouse gas (GHG) emissions [4]. Additionally, some authors argued that the CE also shifts toward the use of waste-derived resources in value chains [5], while companies undertaking activities related to the CE introduced the consumption of renewables [6,7].

Haas et al. (2015) indicated that strategies targeting the CE are shifting from fossil fuel to renewable energy sources and translating efficiency gains into a reduction in the overall level of resource consumption [2]. In the same vein, a shift toward a more efficient and distributed energy generation model based on renewables, as is the case for self-consumption, is appearing [8]. Self-consumption deployment increases energy self-sufficiency within an energy-transition period toward a new, more sustainable, and circular model, and it helps maximize the consumption of locally generated electricity. Thus, self-consumption can increase retail competition and support market transformation, promoting the entry of suppliers capable of offering new services in a circular business model, in response to more rooted levels of public and private green purchases [9].

In a circular model, renewable self-consumption helps achieve two objectives in parallel. Firstly, it very concretely empowers consumers while facilitating a bottom-up deployment of renewables. More importantly, the consumers' involvement in the energy market contributes to the achievement of binding national renewable targets by attracting private capital from actors (i.e., consumers) who have lower expectations in terms of rate of return compared to pure financial investors [10]. In addition, it has to be taken into account that the market for renewable technologies relies on a variety of materials that will evolve in the future depending on their deployment rates and the technology mix, such that the CE has to be considered for recycling and material procurement [11].

In summary, evolution toward a CE depends on structural changes in the management of energy and material flows, especially in a new configuration of economic interactions. Solving technical problems does not guarantee the success of this circular scheme, and economic and social challenges must also be addressed. More recent circularity concepts have shifted the perspective to include consumers that, instead of matching their needs to the product offerings available, would cocreate or coproduce the products and services they actually need; thus, the importance of culture, education, and awareness in achieving circularity has been highlighted [12].

In this scenario, the aim of this study was to explore insights into the decision-making process of energy prosumers to enhance the understanding of self-consumption deployment and to support effective policymaking. This study contributes to the state of the art by defining and classifying determinants of the prosumers' decision-making process and their relevance using a heuristic approach. In particular, a Spanish case study is analyzed to ascertain which factors play a significant role in photovoltaic (PV) self-consumption adoption; these factors are subsequently graded on the basis of the results of a semi-structured interview among a sample of prosumers.

We analyze the results obtained through an explorative study on decision-making in self-consumption facilities, using data collected through semi-structural interviews of prosumers within facilities installed by a Spanish company (please see https://www.fenieenergia.es/ (accessed in August 2020)).

This article is organized as follows: After the introduction, Section 2 provides the theoretical approach to set the basis for the evaluation of the case study, which is described in Section 3, along with an analysis of the results and a discussion. Finally, some recommendations for academics, practitioners, and policymakers are included in Section 4.

2. Background

At present, a reduction in the consumption of nonrenewable resources is especially urgent in the framework of the energy-transition objectives set by the European Union (EU) and for the achievement of the principles of a circular economy (CE) in the territory of the EU [13]. In the context of a CE, if imported energy resources are reduced due to self-consumption, or if the gap between importing and exporting costs is increased, the system would be financially feasible for the average household and it would provide significant benefits in terms of grid balancing [14]. Thus, the circular loops could be closer to investments in small-scale renewables within the framework of a CE [15].

Stakeholder engagement in the energy transition has been a theme throughout the literature in the last decade [16]. However, the role of prosumers from a CE perspective is a relatively novel line of inquiry, and the decision-making process with respect to investment in self-consumption is still under study. In fact, the responsibility for effecting change has been increasingly passed down from large-scale renewables, such as government agencies or industries, toward the individual user in concert with the progress of energy transition [17]. Thus, to understand how prosumers behave is a relevant area of research to establish the complex process of influencing the deployment of sustainable energy.

In self-consumption facilities, the consumer is also a producer that faces many additional questions during the decision-making process before installation. On the one hand, these investors are strongly influenced by socioeconomic factors. Some of them are external factors such as the equipment and installation costs, the electricity tariff, local taxes, and incentives, while others are inner or individual factors such as the demand profile, income, and home value. These contextual factors underpin "rational" or "objective" decisions when dealing with investment in the installation. The socioeconomic context, defined by variables such as income level and demographic characteristics, was shown to be determinant in the effectiveness of policies in the adoption of renewable technologies at the user level.

For instance, Zhao et al. (2011) found that potential customers of photovoltaic installations in big cities are less sensitive to economic incentives such as feed-in tariffs or investment tax credits than customers in small cities [18].

If economic criteria win in the final decision, contextual external factors constitute the economic incentives for investment [14]. A transition scenario of zero emissions and renewable energy is not cost-free, and it raises the need for incentive mechanisms, reflected in energy tariffs and payback schemes [19]. The results indicate that, in spite of the numerous financial incentives, the largest barriers are still the high capital costs, the low cost-effectiveness, and the risk of losing money when moving home [20]. The effects of different parameters related to financial resources and the allocation of public subsidies were demonstrated for eco-innovative investments [21]. In addition, from a CE perspective, similar conclusions were achieved by Aranda-Usón et al. (2019) when analyzing the relationship between the financial resources of firms and their circular scope [15]. Thus, it is relevant to analyze the role of economic parameters in the final decision from a theoretical perspective.

In this context, behavioral change theories attempt to make sense of and model this complex issue, but each differs in its focus, although, as explained by Moloney, Horne, and Fien (2010), the key distinction in the examination of these models for low-carbon energy consumers is that which is made between variables that are "located in the physical, social, and discursive environments in which a person lives" and variables that "influence or shape what goes on inside a person's mind" [22].

Masini and Menichetti (2013) demonstrated that the institutional context does not always affect the technology adoption as long as there are many psychological factors that may have an influence on the prosumers [23]. Following the study of Faiers and Neame (2006), the "value of the installation" is a characteristic of the individual adopter and includes not only monetary but also nonmonetary costs, such as information search costs and uncertainty about future performance, operation and maintenance requirements, and perceptions of quality, sacrifice, and opportunity cost [24]. In addition, environmental beliefs are also a part of this group of attitudinal factors on which the "personal" or "subjective" decision of the investing prosumer relies. All of these attitudinal factors can be modified through dissemination and information campaigns, and it is for this reason that social and communication networks are considered strong determinants in the decision-making of individuals [25].

The complexity of such a predictive model limits its use at the installer level, which was shown as one driver in the promotion of these kinds of installations. In spite of a lower certainty, simpler and more transparent analytical models are desirable for evaluating the sensitivity of strategies to different factors. Furthermore, in the model of a CE, a society is proposed that takes into account environmental criteria, in addition to economic and social ones, which allows predicting a sustainable energy supply in the second half of the 21st century [26]. In this context, some authors used agent-based simulation models (ABMs) to obtain the relationships among factors, showing that it is very complex [27–30].

Table 1 shows a classification of the main factors that could influence on the decision-making process of prosumers using a heuristic approach.

Table 1. Classification of factors that influence the decision-making of prosumers in self-consumption installations.

	Contextual	**Attitudinal**
Internal	Income level Consumption level Demand profile Demographic characteristics Energy access	Risk acceptance Uncertainty tolerance Environmental beliefs Appreciation of technological innovations
External	Price of the technology Electricity rates Tax incentives Environmental taxes Compensation for electricity surplus	The soundness of related policies

The factors classified in Table 1 are usually combined into several decision criteria in order to establish the main motivations for self-consumption PV installations. A brief review of recent European studies focused on this line of research is summarized in Table 2.

Table 2. Recent studies related to European self-consumption adopters. PV: Photovoltaic.

	SCOPE	Reported Criteria for PV Adoption
Balcombe, Rigby, and Azapagic (2014) [20]	United Kingdom	Saving or making money Increasing energy autonomy Protection against a future increase in energy price
Bouly de Lesdain (2019) [31]	France	Electricity autonomy
Engelken et al. (2018) [32]	Germany	Economic benefits Energy autonomy Environmental awareness Affinity with technology
Gautier et al. (2019) [33]	Belgium	Environmental and financial motivations
Gram-Hanssen, Hansen, and Mechlenborg (2020) [34]	Denmark	Financial arguments that underpin self-sufficiency and emission reductions
Korcaj, Hahnel, and Spada (2015) [35]	Germany	As long as costs were low Social status
Leenheer, de Nooij, and Sheikh (2011) [36]	Denmark	Other investor motivations Economic benefits
Palm (2018) [37]	Sweden	Environmental and financial motivations
Vasseur and Kemp (2015) [38]	The Netherlands	Electricity cost-savings and costs of PV system Self-sufficiency and contribution to a better natural environment

The review was focused in Europe and over a short time period because it was assumed that prosumers will operate in similar socioeconomic and normative scenarios. According to the literature review, the recurring thought in the prosumers' judgement was saving or making money with a small investment and short recovery period. Thus, the decision to adopt self-consumption photovoltaic systems is based on a cost–benefit analysis, where the internal and external economic factors listed in Table 1 are considered, with an additional interest in minimizing the effect of possible increases in electricity prices. This decision criterion can be based on objective information, as there are easy ways of estimating the return on investment.

Minor motivations include reducing the energy dependence of the electricity network and contributing to a reduction in environmental impact. In the case of isolated installations, autonomy is a clear and real motivation. However, in connected installations, the subjective perception of risk has an interesting role, and the feeling of insecurity can be reduced if energy storage systems are allowed. Due to difficulties faced in their proper estimation and allocation before installation, environmental benefits can be considered halfway between objective and subjective.

In summary, the encompassing concept of PV self-consumption adoption is energy security, as set out by the International Energy Agency (IEA), applied to particular spheres [39]. This is not new, as experiences in developing countries show a similar motivation, while it is to be expected that the criteria of energy availability, affordability, and environmental sustainability have different effects on the result. In addition, according to the comprehensive study of Amala Devi (2018) in India, "consumer confusion over procedures and delays in approvals due to institutional inconsistencies and lack of coordination" restrains these installations [40].

From an analysis of the literature, we consider it necessary to study the determinants of the decision-making process experimented by prosumers using a heuristic approach, since previous studies offered a fragmented analysis of this line of inquiry. As one of the contributions raised, the role of prosumers in a CE scheme was included in this study because it has been scarcely analyzed to date. In addition, we recognize two gaps in the literature. First, there is a general need of detailed analysis of the motivations that move consumers to become prosumers. Second, the majority of previous studies did not offer a specific analysis of determinants of investments in small-scale PV self-consumption facilities and their influence on the decision-making process of prosumers for the deployment of renewables in a circular model.

On the basis of the previous considerations, the following research questions arise:

RQ1. What are the most widespread self-consumption-related reasons for an energy consumer deciding to become a prosumer?

RQ2. What are the determinants of the decision-making process and how do they influence the prosumers' investments?

In summary, the aim of this paper is to present a simple and transparent procedure to identify how energy consumers become prosumers, as well as a method of classification and measurement of factors influencing the decision-making process. After establishing a heuristic framework for the adoption process, the target is to ascertain the vectors that, in a hypothetical hierarchical decision tree, would transfer the significance of particular factors to the final decision. To this end, we analyze the decision process of a sample of Spanish self-consumption PV adopters as a European case study.

3. Case Study and Method

3.1. Methodology

The research design hinges on a new dataset built through a semi-structured interview of companies and individual users who have already adopted PV self-consumption. Access to the population for the purpose of this study was achieved through a company that installs self-consumption facilities, and semi-structured interviews were conducted with Spanish PV self-consumption owners. A total of 16 out of 35 owners whose installations were commissioned from 2016 to April 2019 by the company agreed to participate in the interview.

The main goal of the interview questionnaire developed by the authors was to understand the owners' decision-making process when adopting solar energy, as well as the experience in selecting and installing a PV self-consumption system. PV adoption is a multicriteria decision process where the different economic, social, and environmental criteria have to be considered. Thus, the interviews, which were carried out in Spain from May to June 2019, included specific questions closely related to these three criteria.

Prosumers were asked to participate in a semi-structured interview composed of four parts. Part A concerned the general information of the prosumer for stratification. In the case of a company, questions were related to the identification of the firm (business name, address, ID number), as well as the number of employees (size), location, and sector. In the case of persons, the focus was on household characteristics. Part B determined the technical and financial aspects of the installations. Parts C (pre installation) and D (post installation) included closed and open questions related to the decision-making process and to the subsequent experience of the prosumer with respect to the installation. The methodological technique adopted in this study involved a nonprobabilistic sample, given that the number of complete interviews was 16.

The profile of the respondents encompasses 37.5% (6 out of 16) of the companies and 62.5% (10 out of 16) of the individual users. The size of the PV systems installed by the companies ranged from 1.56 to 41.6 kW, while the size of the PV systems installed by the individual users ranged from 0.52 to 9.9 kW.

3.2. Main Results and Discussion

Regarding the decision-making process itself, we asked how important the following factors were in the decision to install the PV system:

C1.1 General interest in energy self-generation;
C1.2 Improving value of the company/house;
C1.3 Obtaining savings in energy bill;

C1.4 Avoiding electricity network dependency;
C1.5 Reducing environmental impact using renewables.

For closed questions, answers were structured according to the following Likert scale: 1 "not relevant", 2 "rarely relevant", 3 "relevant", 4 "very relevant", and 5 "totally relevant".

Considering pre-installation (Part C of the questionnaire), respondents considered the five factors as "relevant" (3) at the very least, although some differences were noticeable, as shown in Figure 1, which includes the average values (all above 4 "very relevant") and dispersion.

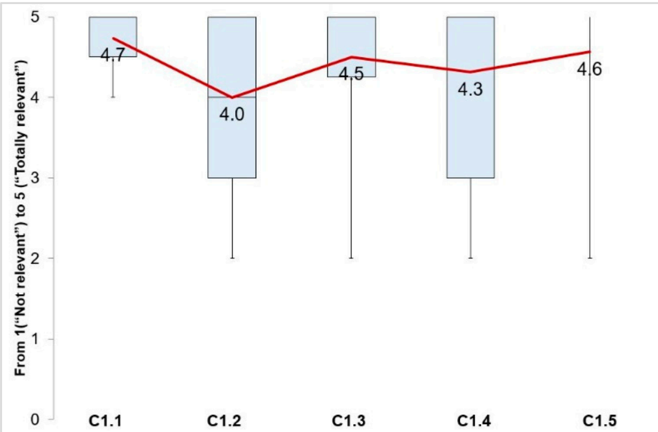

Figure 1. Relevance level (average and range) of global factors in the pre-installation phase.

Using box plots, we could identify the median of all the answer values and graphically illustrate the interval in which the most common and, therefore, most representative values fell. The mean is also included in these figures. Vertical lines show the rank of the obtained answers, and colored boxes allow seeing the dispersion of answers. Colored bars show the 25th and 75th percentiles as a function of the median, i.e., each bar covers the central 50% of data. A larger colored box denotes greater dispersion of the answers. An inexistent colored box means that the values were barely dispersed, although the median could have differed from the average value due to atypical values.

Responses to an open-ended question related to the motivations when installing PV systems revealed that responders considered energy security and energy independence as part of the economic benefits, as they felt that they were "less vulnerable to changes in the electricity tariff". On the other hand, "influence of others in the neighborhood with PV systems" and "influence of a close acquaintance not from the neighborhood" were not considered relevant factors in the decision to install PV systems. This is mainly because the spatial distribution of these systems was sparse; the respondents were largely "innovative" adopters.

Finally, at the end of the interview (Part D in the questionnaire), respondents were asked to rate the performance, operation, maintenance, and financial attractiveness of their systems post installation. The same set of questions as in Part C1 (see Figure 1) was used in order to compare the obtained results. This approach was expected to eliminate the subjectivity seen in pre-installation answers from the average values and data dispersion.

By comparing the average answers shown in Figures 1 and 2, the following conclusions can be drawn:

- Regarding the level of general interest in energy self-generation (C1.1 vs. D1) or environmental concern (C1.5 vs. D5), we can say that internal attitudinal factors were unchanged on average, but dispersion increased in the answers related to the second issue.

- Economic concern was displaced from savings (C1.3 and D3) to home value (C1.2 and D2). After installation, prosumers identified the possibility of improving the value of their home. However, owners did not perceive a reduction in their total electricity consumption post installation of PV systems, and the independence of the grid was not as high as expected.
- Regarding avoiding electricity network dependency (C1.4 vs. D4), the reduction seen in the range of answers could have been due to the fact that any perceptions were now evidenced.

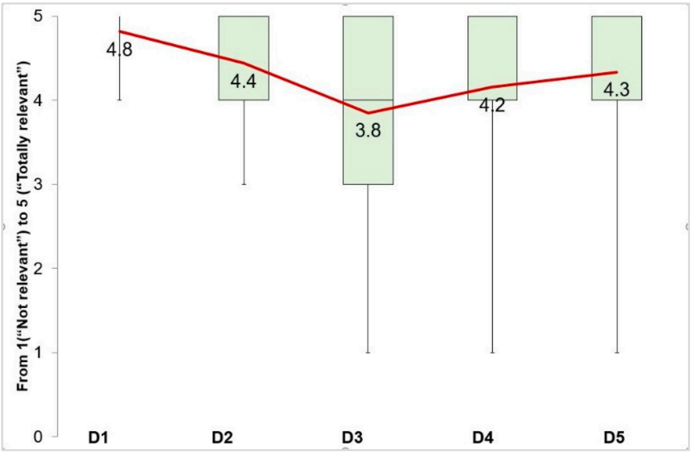

Figure 2. Relevance level (average and range) of global factors in the post-installation phase.

Economic and financial aspects are expected determinants in the adoption of PV self-consumption; thus, Part C.2 was intended to gather the interviewee's thoughts with regard to the relevance of price (C2.1), access to financing (C2.2), payback (C2.3), operation and maintenance costs (C2.4), and regulations (C2.5) in their final decision. Answers are shown in Figure 3.

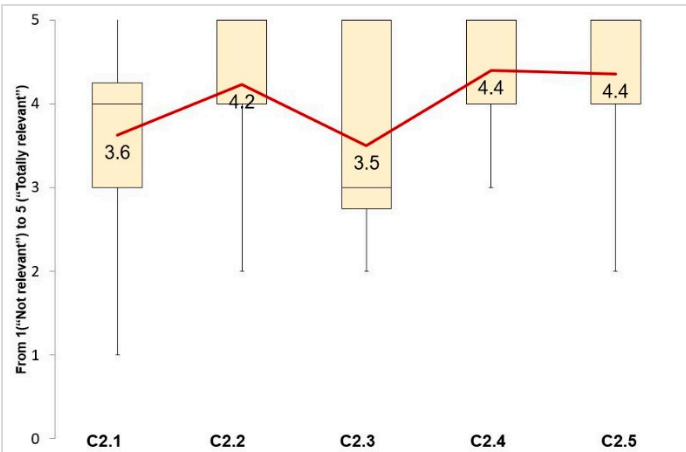

Figure 3. Relevance level (average and range) of economic and financial factors.

Prosumers were asked to select the tool used to establish the economic viability of their installation (internal rate of return, net present value, etc.), revealing that a cost–benefit analysis was implemented by all respondents.

As they were all assisted by installers when calculating financial attractiveness, price (C2.1) and payback (C2.3) displayed the same level of relevance, but the latter featured a wide range of responses. Access to financing (C2.2) appeared more important than the investment level. Moreover, operation and maintenance costs (C2.4) and regulations (C2.5) had a higher weight in the final decision.

Answers to the open-ended questions suggested that the unknown performance of the PV installation and the little trust in future regulations had a high weight in the final decision. As these were noncontrollable variables, their judgement was consequently subjective.

Finally, the degree of relevance in the PV adoption decision with respect to general access to information (C3.1) and other aspects such as maintenance of the installation (C3.2) (notice that this question is a control question which was already included as C2.4), simplicity of the installation (C3.3), employment generation (C3.4), and role of the installer (C3.5) was requested. Answers are shown in Figure 4.

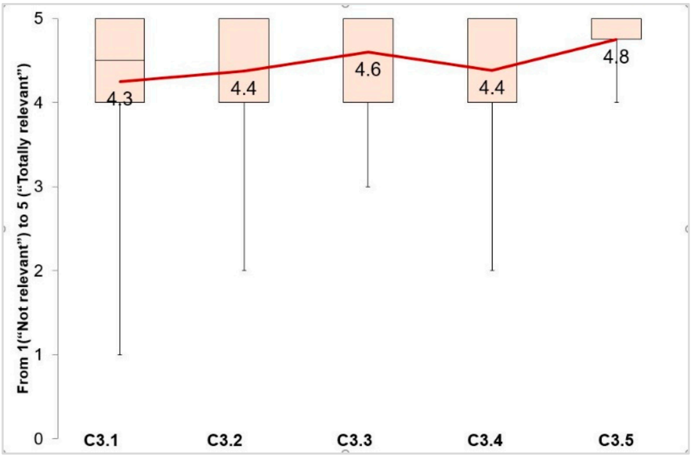

Figure 4. Relevance level (average and range) of information-related factors.

A majority of the responding PV owners considered the five factors to be "very relevant" (4) or "totally relevant" (5), leading to the conclusion that investments in these facilities are highly sensitive to the existence of clear and accessible information that reduces uncertainty in the final decision. In other words, information networks play a significant role in reducing the subjective or attitudinal factors.

As the average values in Figure 1 were not conclusive enough to establish any sort of predominance among the economic, autonomy, and environmental criteria, interviews were examined individually.

For each of the 16 interviews, factors C1.3, C1.4, and C1.5 were ranked to analyze their relevance (Table 3). The relative weight of each factor assigned by the respondents was expressed as a percentage, thereby identifying C1.5 as the factor considered most relevant by most prosumers.

Table 3. Ranking of the relevance of the three factors provided by the prosumers.

Case.	C1.3	C1.4	C1.5
1	33%	33%	33%
2	22%	33%	44%
3	29%	36%	36%
4	33%	33%	33%
5	33%	33%	33%
6	42%	42%	17%
7	38%	38%	25%
8	33%	25%	42%
9	33%	33%	33%
10	42%	17%	42%
11	23%	38%	38%
12	33%	33%	33%
13	38%	23%	38%
14	33%	33%	33%
15	33%	33%	33%
16	23%	38%	38%

In summary, all three factors were taken into account during the decision-making process, with slightly greater relevance afforded to environmental motivation.

Figure 5 shows the factors classified using the heuristic approach outlined in Table 1. The relevance level reported on average by interviewees is also included for consideration. In addition, factors were also grouped according to their natural influence in terms of the three global criteria involved in the final decision.

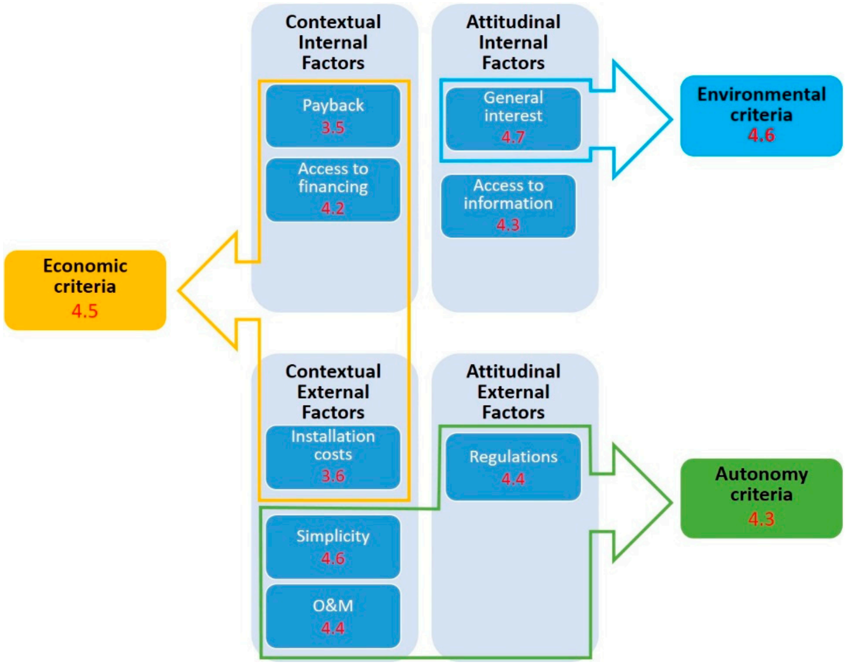

Figure 5. Factors classified using the heuristic approach with respect to the decision criteria.

The following conclusions arise after evaluating the typologies of the factors under study:

- The economic criteria are only based on contextual factors that are known, accessible, and usually accurate, such as installation costs or energy consumption data for the calculation of payback. However, access to financing seemed to be the main economic concern as its relevance level was comparable to the overall economic criteria.
- The autonomy criteria are linked to external factors for which reliability is key for the final decision. The user-friendly operation of installations, particularly the existence of regulatory and institutional frameworks that ensure the sustainability and economic viability of these investments, is very important. In fact, the very useful role of installers was appreciated.
- The environmental criteria depend only on the awareness of the adopter, as attitudinal factors are impacted by information campaigns.

Figure 6 schematically summarizes the factors taken into account by the prosumers throughout the decision process, and it also shows the relevance assigned by interviewees to each factor. As can be observed, longer-term factors that may be influenced by events after the start-up of installation, over which the prosumers lack control, are generally more relevant in decision-making.

Data inherent to the financing of the facilities were obtained through Part B of the interview, which revealed that investment received cofinancing of public funds (40%) in only one case. It was found that three installations were financed entirely by personal resources, while financing provided by retail energy companies was the main source of resources (11 cases). It is worth mentioning that prosumers employed more than one source in many cases, but the role of the retail energy company promoting the facilities was prevalent. Thus, these results did not demonstrate a high relevance of public funds in the decision-making process of prosumers, in line with the results of

Scarpellini et al. (2018) for eco-innovation [21]; furthermore, access to financing seemed to be the main economic concern of these investors. Lastly, we assessed other factors such as demographic and psychological aspects deemed important by prosumers, in line with Hahnel et al. (2020) [41].

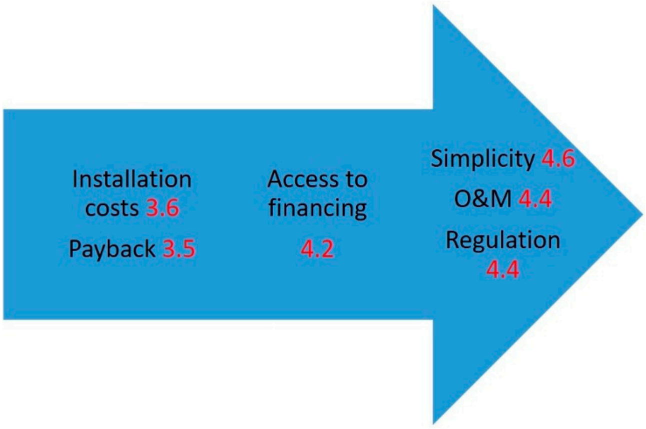

Figure 6. Hypothetical timeline from the beginning to the end of the decision process.

4. Conclusions

Through a qualitative study of the decision-making process of prosumers in Spain, this article provided a heuristic analysis of the influence of economic, environmental, and social criteria for investors. The obtained data allowed a novel analysis of the self-consumption decision process in a circular-economy scenario, which is complementary to prior studies.

As the main consideration, contextual factors influencing the final decisions were mainly related to the investment return and the future performance of the installation in both economic and technical aspects. Initiatives aimed at guaranteeing the reliability of information or access to financing could motivate new adopters. In addition, it was observed that public funds were not essential for the deployment of self-consumption. Attitudinal factors were also found to play a role in the final decision, and dissemination activities such as awareness campaigns and success stories could increase the general interest, by shedding light on environmental concerns and boosting confidence in innovation. In this same vein, installers are expected to play a leading role going forward.

These results partially fill a gap in the literature by providing a heuristic analysis of investment decision-making related to sustainable energy at a small scale, which will involve an increasing number of investors in the short and medium terms. On the one hand, exploring actual insights into the decision-making process of energy prosumers seems to be highly relevant for an understanding of the limitations of self-consumption deployment and for effective policymaking. On the other hand, the acquired knowledge and findings can be extrapolated to similar consumer decisions within the sphere of a circular economy. Policy and industry stakeholders aiming at identifying target groups for self-consumption investment can use these findings.

The main limitations of this study are mainly associated with the territoriality of the analysis and the number of interviewed prosumers. New lines of future research could characterize different factors that influence the decision-making process of prosumers in other regions, applied to different sustainable energy solutions in the framework of a circular economy.

Author Contributions: All authors contributed substantially and equally to the work reported in this paper. Conceptualization, J.Á.G., E.L.-S., and S.S.; formal analysis, J.Á.G., E.L.-S., and S.S.; investigation, J.Á.G., E.L.-S., and S.S.; methodology, J.Á.G., E.L.-S., and S.S.; writing—review and editing, J.Á.G., E.L.-S., and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: This study was cofinanced within the research groups of the Regional Government of Aragón, Ref. S33_20R and T46_20R. The collaboration with FENIE ENERGIA, S.A., for the empirical study is particularly acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

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2.2 Determinants and barriers of PV self-consumption in Spain from the perception of the installers for the promotion of distributed energy systems (Artículo 2)

ARTÍCULO 2: Gimeno, J. Á., Llera-Sastresa, E. and Scarpellini, S. (2020b) 'Determinants and barriers of PV self-consumption in Spain from the perception of the installers for the promotion of distributed energy systems', Economics and Policy of Energy and the Environment, (1), pp. 153–169. doi: 10.3280/EFE2020-001007.

EDITORIAL: Franco Angeli Edizioni - ISSN 22807659, 22807667

Publicación INDEXADA SJR Scimago (2020): 0.19

Category Name	**Impact Factor (2020)**	**Quartile Rank**	**Quartile in Category**
SJR Scimago – Economics and Economerics	0,192	506/661	Q4
SJR Scimago – Renewable Energy, Sustainability and the Environment	0,192	157/195	Q4
SJR Scimago – Management, monitoring, Policy and Law	0,192	280/355	Q4

Artículo no disponible por restricción de publicación por la Editora

2.3 Investment Determinants in Self-Consumption Facilities: Characterization and Qualitative Analysis in Spain (Artículo 3)

ARTÍCULO 3: Gimeno, J. Á., Llera, E. and Scarpellini, S. (2018) 'Investment Determinants in Self-Consumption Facilities: Characterization and Qualitative Analysis in Spain', Energies, 11(8), p. 2178. doi: 10.3390/en11082178.

EDITORIAL: MDPI- ISSN: 1996-1073

Publicación INDEXADA JCR CIENTÍFICO Q3: factor de impacto: 2,707 (2018)

Category Name	**Impact Factor (2020)**	**Quartile Rank**	**Quartile in Category**
ENERGY & FUELS	2,707	56/103	Q3

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Investment Determinants in Self-Consumption Facilities: Characterization and Qualitative Analysis in Spain

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Received: 11 July 2018; Accepted: 9 August 2018; Published: 20 August 2018

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Abstract: Self-consumption energy facilities are presented as viable and sustainable solutions in the energy transition scenario in which many countries are immersed. However, they rely on dispersed and private investments in the territory. Given the uneven growth in the number of self-consumption facilities in Europe, the main objective of this study is to identify and measure the investment determinants in self-consumption facilities. To this end, the main influential incentives and barriers are identified through the aggregate analysis of the regulatory framework for self-consumption in several European countries, and the empirical characterization of Spanish facilities as a multiple case study, to define the common features of the investments made. The technical, economic, and financial characterization of real self-consumption facilities in climatic zones of southern Europe is a significant contribution of the present work. There are few samples of this type in the studies published to date, which have mainly been prepared from case studies or statistical data without identifying particular facilities. Cost-related variables have been identified as the most important variables in private investment decisions, and potential influential factors on these variables that could be regulated have been pointed out as relevant. It is also worth highlighting the elaboration of an analytical framework based on this conceptual approach, which has been proven to be useful to depict regulatory scenarios and to compare the positioning for the development of self-consumption systems in different countries. A model that transfers the influence of the determining factors to the deployment of self-consumption under specific regulatory scenarios has been developed and applied to the case of Spain. As a general reflection, to increase the adoption of this kind of technology and encourage consumers to make private investments, policies for renewable energy must consider self-consumption and microgeneration as the main axis, by increasing the availability of energy when necessary. For instance, the promotion of energy storage from these kinds of facilities could receive priority treatment, as well as rewarding the electricity surplus in the interests of security of supply in a period of energy transition towards a new, more sustainable model. Incentive schemes, aids to compensate for the additional costs resulting from the battery storage or easing restrictions in terms of contracted power would foreseeably increase the rates of adoption of the technology, favoring its faster development in terms of research and development and product innovation.

Keywords: self-consumption; solar energy; investments; remuneration policies; prosumers; drivers and barriers

1. Introduction

The most developed countries are immersed in an energy transition that, in a few decades, will be a new paradigm in energy supply on a planetary scale. In this new scenario, when defining investments in the sector, new elements are added to the usual reliability and price factors, such as the reduction of emission levels, production decentralization, the energy storage capacity at a large scale, changes in consumption patterns, or transport electrification in line with an energy market in a low carbon economy. The progress made by the COP21 (See https://www.un.org/sustainabledevelopment/cop21/ (accessed on June 2018)) agreements reached in Paris reinforces this perspective from the view of a globalized economy and commits the governments of the signatory countries to take it on and promote it with concrete policies.

The complementarity of systems and technologies will be essential to accomplish the sustainability objectives and, given the multidimensional nature of the process, economic and social transformations will acquire higher relevance in view of the need for new technologies, products, services, organizations, norms, and practices to gradually replace the previous ones [1,2].

In the European Union (EU), where the energy transition is largely characterized by global warming, renewable sources are going to be essential [3], as well as the active participation of stakeholders and in particular of consumers, as the European Commission recognizes in its call to develop strategies for its empowerment [4]. Likewise, the consumer will have a relevant role in the evolution of this new energy model, from the choice of supplier in a very competitive market to the production of its own energy supply–also called self-consumption.

According to the general definition [5], self-consumption is considered a process by which a consumer—residential, commercial, or industrial—produces and consumes their own energy (hence the term prosumer), being able to cover their own needs partially or totally. The energy produced is used instantaneously, or later if the installation incorporates storage equipment such as accumulator batteries or other systems such as hydrogen [6]. The self-consumption modality that presents the greatest challenges is that which contemplates the possibility of obtaining a return for the electricity that is produced and not consumed, that is delivered into the grid. These returns can be in the form of income if the injected electricity is considered a commercial transaction (net-billing), or in the form of the right to consume electricity from the grid when it is considered a storage system (net-metering).

Self-consumption solutions allow consumers to participate actively in the energy transition through an effective option for stimulating consumer private capital with lower expectations in terms of rates of return compared to conventional financial investors in the energy sector, which contributes to a sustainable energy transition. In addition to this, self-consumption represents a flexibility mechanism for demand through storage solutions, smart devices, and more flexible contracts for consumers, helping to reduce generation peaks with consequent congestion problems and benefiting the network operators [5].

In this field, the energy policies adopted in the EU have contributed positively to technological renewable energy development and the reduction of their costs.

These policies allow us to analyze the evolution of self-consumption facilities facing specific strategies, to understand the behavior of prosumers as investors, and can partially explain the differences that exist in self-consumption technology penetration among EU countries—a field in which investigations are still required. In fact, the definition and measurement of determinants that motivate investments and their relationship with specific plans for promoting self-consumption, as well as the characterization of facilities or the behavior of investors, are still important subjects of study [7–10].

Previous studies on electric microgeneration in the domestic, commercial, and industrial fields [8,11] provide the basis for the study of investments in self-consumption facilities. Some authors focus their works on European countries where network parity has been achieved [12], so self-consumption with photovoltaic systems can be economically interesting—not only in residential [13] but also in productive sectors, where new incomes could arise [14]. Likewise, competition in the retail market and market transformation has been studied, as well as the entry into the market of suppliers offering new services in a circular business model and in response to more deep-seated levels of private and public green purchases [15]. Nevertheless, it can be said that the research is still needed, and that empirical studies of many facilities are not numerous so far.

On these bases, the main objective of this study is to identify and measure the investment determinants in self-consumption facilities. To this end, the main influential drivers and barriers in self-consumption determinants are classified through a previous analysis of the applicable legislation. For the first time, an analytical framework for the evaluation of the policies as a means of promoting self-consumption systems is proposed. This framework has been proven to be useful to compare the positioning of the development of self-consumption systems in different countries, and the elaboration of scenarios. Then, the characterization of real facilities and a sensitivity analysis of the most determining technical and economic factors of investments in these facilities, in a European country as a case study (Spain), are carried out. The characterization of self-consumption facilities in climatic zones of southern Europe is a significant contribution, with few samples of this type existing in the studies published to date, which have mainly been prepared from case studies or statistical data from unidentified individual facilities.

This paper is structured as follows: Section 2 explains the research methodology and develops the analytical framework to be used for interpreting the data. Section 3 introduces the results of the empirical research and the application of the proposed approach. Finally, Section 4 discusses the influence of the determining factors for private investment in self-consumption in hypothetical scenarios and summarizes the key aspects for the definition of specific promotion plans. Shortcomings of the proposed approach and future lines of research are also introduced.

2. Materials and Methods

As it is represented in Figure 1, the present work is developed first from an analysis of the background from which the research questions and analytical framework are defined. Next, empirical research is carried out through the characterization of self-consumption facilities as a multiple case study, based on the comparative results of many projects to define the common features of the investments made [16]. This combined research allows a conceptual approach that contributes to the establishment of a framework for the analysis of the influence on the investment decision by factors that could be regulated. This framework is included in a model that transfers the influence of the determining factors to the deployment of self-consumption and can be used to forecast the evolution of the self-consumption sector under specific regulatory scenarios.

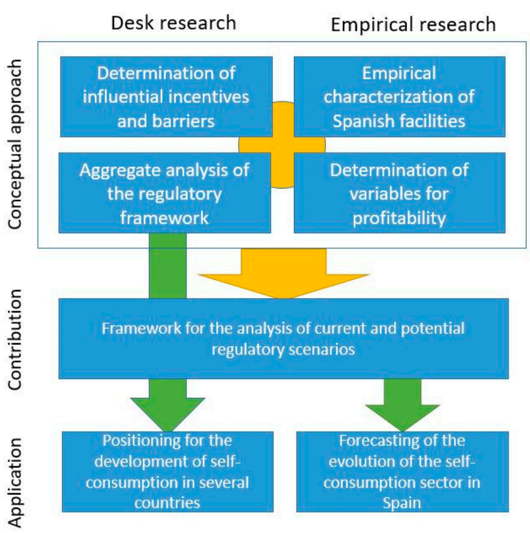


Figure 1. Flow chart depicting the applied methodology and results.

According to the literature, it can be affirmed in general terms that the adoption of innovative systems in a territory is determined by various elements, such as the inherent characteristics of the innovation, the social system structure where the adoption takes place, the diffusion, and the level of information in the territory, and the time frame [17,18].

In the framework of institutional theory [19], several authors postulate that, in addition to the rational decision of the investor, non-financial factors affect the adoption of new energy technologies [20–22], and decision-making to invest in renewable energies [9] or the application of environmental management criteria [23]. To this end, it is essential to analyze the decision-making process of investors with the objective of identifying the main determinants of their choices, particularly for those groups of investors with short-term horizons, as they are especially sensitive to institutional and related agent pressure.

In recent years, agent-based simulation models (ABM) have been widely used to simulate the inherent complexity of the adoption process of innovative photovoltaic installations [7], defining the utility function of these investors as four factors linear one: advertising, social environment, income level, and period of investment recovery [24].

It should also be considered for the benefit-cost analysis of these facilities that, in the environmental literature, it has been found that a household can value a product even if it does not consume it [25] and, therefore, in the case of self-consumption, it may be relevant for the evaluation of the investment to take into account the perception of households of the environmental component of these facilities. It should be noted that even households with a lower income can support environmental activities for a zero-emissions future in a similar way to higher income households [26].

It can be considered as widely accepted that the decision to invest in self-consumption photovoltaic systems would be influenced by economic factors such as household incomes or the investment recovery period, but also by the self-interest of minimizing the effect of possible increases in electricity prices. To these economic motivations, the desire to reduce the energy dependence of the network and to contribute to the reduction of environmental impacts can be added. However, the priority over other criterion appears more clearly in studies based on the answers provided by potential or present investors.

In summary, based on the previous studies and to analyze the possible impact on the future development of self-consumption facilities, the factors that would influence the decision of investors can be classified into attitudinal type factors and contextual type factors. In the first group there would be factors such as the perception of the households, environmental beliefs, uncertainties, and non-monetary costs. All of these can be modified through dissemination and information campaigns. In the second group, social factors such as income level and demographic characteristics, as well as economic factors such as the equipment costs, the electricity tariff, the demand profile, and the compensation of an electricity surplus would be included. Contextual factors configure the framework in which investments can be analyzed from a monetary point of view.

In the scientific literature, the aim of these investments to contribute to improving the environment plays a secondary role in most of the published studies [8,27,28]. Leenheer et al. [29] proposed a different perspective in which the main motivation is not economic, since through a sample of 2000 Danish households surveyed, the obtained economic benefit was less relevant than other investor motivations. However, it is worth mentioning that this was a study on households that did not have the installation yet, and the authors concluded that the economic motivation would be basically moderating the relationship between intention and behavior. Therefore, it is an issue that continues to be the object of study, and while it has motivated the work of some authors, papers are still few in number so far.

In this area, Balcombe et al. [8] used qualitative research through 291 surveys to investors in a microgeneration to identify the main motivations of saving or making money with the installation, increasing independence, and protecting themselves from an increase in the price of energy in the future. Similarly, the 197 respondents of the study of Jager [30], who were all owners of a photovoltaic installation, placed economic and environmental reasons at the same level of priority.

In the work of Engelken et al. [28] on a sample of 395 households in Germany, economic benefits and autonomy were also identified as priority factors, followed by environmental awareness and affinity with technology. Likewise, the majority of the 200 German households surveyed by Korcaj et al. [27] were potentially willing to install self-consumption photovoltaic systems if costs were low. The authors concluded that there was a need to promote energy storage systems that increase independence and economic savings, while reducing the perception of risks through a standardization system.

Social motivations also appear in some studies, with some of the analyzed investment determinants including the obtaining of social status [27], the establishment of networks [30], or the effects of between pairs [31].

The still incipient status of these investments in some countries has motivated the analysis of drivers and barriers in self-consumption. Among the latest investigations, the low rates of return on investment are frequently mentioned as one of the main obstacles to the take-off of these facilities in all EU countries [8]. However, some authors have demonstrated the profitability of photovoltaic systems in the residential sector in various scenarios, depending on the combination of supply and demand involving a significant increase in the self-consumption of energy [32]. These research studies reached the conclusion that, when market maturity is accomplished, a subsequent phase to the incentives can be initiated in which they will no longer pay aids to electricity generated from renewable sources, entailing a reduction in the specific tax burden applied to consumers and companies.

Among the works focused on the barriers, Michaels and Parag [33] analyzed a 509-respondent sample, and although the results showed some peculiarities of the Israeli context, universal barriers were identified including trust in the institutions that supervise the programs, health care and data protection problems, the high initial cost, social norms, the economic incentive structure, and reduction of energy demands. They concluded that financial incentives could solve some of these barriers.

In another quite clarifying study, Palm [34] tried to identify the reasons why the photovoltaic self-consumption facility evolution in Sweden was very different in different municipalities, and identified the role played not only by the prosumers but also by the rest of the stakeholders. They mentioned, for example, the driving role played by the utilities with the purchase of the electricity surplus, and by the installers with the sale and dissemination of turnkey facilities.

It is important to consider that motivations and incentives may vary with the market situation [35]. Thus, Palm [36] showed that at the time when the sale of the generated electricity was permitted in Sweden and the regulation was expanded, the investor in self-consumption facilities perceived new barriers related to an increase in administrative burdens and the difficulty of finding information about the market agents, which led to a higher interest in turnkey facilities. In fact, "planned value" is an individual and intrinsic characteristic of the investor and includes not only the cost of equipment and installation, but also non-monetary costs such as the cost of searching for information and uncertainty about future performance, operation and maintenance needs, and the perception of quality, sacrifice and opportunity cost [37,38].

In any case, we must bear in mind that the inherent business of self-consumption facilities is largely defined by each country's regulations through permitted return schemes, a fact that in principle could be explained by the disparate penetration of self-consumption existing among EU countries. The case of Spain is particularly noteworthy because of the small number of facilities to date.

To classify the corresponding drivers and barriers to self-consumption facilities induced by regulations, the legal framework in several EU countries—specifically Germany, Spain, Italy, France, and Portugal—was analyzed.

The selection of these mentioned countries responds to two criteria: on the one hand, their special relevance in the EU in terms of population, and on the other hand, their expectations of self-consumption investments because of their geographical location, since they are mostly located in center-south Europe and because of the solar radiation levels that make them suitable for these installations.

The analysis was carried out in two phases. Firstly, the existence of a specific legislative framework that allows and orders the implementation of self-consumption facilities. Secondly, the possible extension of this right to third parties is taken into consideration; that is, whether the country regulations allow for solutions in which the owner of the self-consumption facility is different from the holder or holders that consume the generated electricity. In this sense, the idea is to find out specifically if the implementation of facilities based on power purchase agreements (PPA) as well as shared self-consumption facilities would be authorized—a very favorable and feasible solution in countries with mostly horizontal properties. Appendix A Table A1 summarizes the main characteristics of the different policies supporting self-consumption and the schemes they contemplate, especially those related to net-metering and net-billing, in the countries of southern Europe and in Germany as a reference for this type of facility.

In summary, Germany is the country that stands out for installed photovoltaic power because of the reduction of the prices of facilities and the high electricity rates. As a general point, it is worth mentioning that in this country there are progressive surcharges for self-consumption and other renewable facilities calculated on self-generated electricity, though facilities with an installed power of less than 10 kWp and an annual generation of less than 10 kWh are exempt [39].

It can be held that the European country of the Mediterranean Arc that is exemplary in the promotion of self-consumption is Italy, where surcharges are also available to the facilities to contribute to the electrical system costs (except for installations of less than 3 kWp), and with reduced annual fees for the facilities. In addition, in this country the installations connected to the network have the right to receive remuneration for the injected energy that is compensated for by the cost of the consumed electricity from the network [39].

In Portugal, Law 153/2014 allows the connection to the grid of renewable facilities below 200 kW and with an annual limit of 20 MW, facilitating self-consumption by legalizing the sale of an electricity surplus to the grid. The limit of an installed facility capacity is established according to the contracted power. This Law seeks a paradigm shift that helps maximize local electricity production, favoring a more direct market structure free of subsidies. However, the regulation protects the electricity system by a provision of compensation once the self-consumption penetration reaches 1% of the installed capacity. The surplus that is injected into the network is remunerated at 90% of the average price of electricity in the majority market. The remaining 10% is used to compensate for commercial energy costs and the purchase guarantee. The new remuneration mechanism is based on an auction model [40].

The Spanish self-consumption regulatory framework was one of the most restrictive in Europe for quite time, despite Spain having the highest rates of solar radiation in the EU [41]. In 2012, through the so-called "Moratorium on renewable energies", established in Royal Decree law 1/2012, January 27, the pre-assignments of remuneration and the economic incentives were removal of new installations for electricity production from cogeneration, renewable energy sources, and waste.

Later, the regulatory framework for self-consumption in Spain was established fundamentally with the promulgation of the Royal Decree 900/2015, October 9, which regulates the administrative, technical, and economic conditions of the supply of electricity from self-consumption and production from self-consumption [42]. This Royal Decree made possible the legal continuation of self-consumption facilities that had been carried out before its publication. It is worth mentioning that, after the publication of the Royal Decree 900/2015, an incipient jurisprudence (Constitutional Court Sentence 68/2017, 25 May 2017, which estimated the appellant's recourse regarding articles 4, 19, 20, 21 and 22, regarding the so-called "shared self-consumption", and in the needs for National registration of self-consumption facilities. This Sentence annuls the third paragraph of the Fourth article, which prohibited a generator from connecting itself to the internal network of several consumers; Sentence of the Supreme Court 3531/2017 that supports, at the request of the appellants, the existence of fixed and variable charges for self-consumption facilities, for compensating the backup that the electricity system provides to the consumer at the moment that the contribution of the generation is insufficient and must resort to network supply) has been generated in the matter that will let new normative developments in the near future be opened, at the nation level as at the regional level, since the regional registration of this type of facility is required.

To use and interpret the information, an analytical approach is proposed. Having read the different regulations, common aspects were ascertained and classified according to the topic that is taken into account, and if they play as drivers or barriers. Next, with the goal of making a comparative analysis of the legal framework in each country, and in addition to detecting the existence of the previous disaggregated factors, each incentive and barrier is assigned a score according to the level at which the regulation limits or favors self-consumption in each country. The scale selected for this purpose is between −3 and +3, with the lowest score representing the measures that hinder self-consumption with higher intensity, and the highest representing the measures that favor self-consumption implantation (This classification of the qualitative approach has been carried out by the authors as members of the research team through the average of the individual valuations of the legal frameworks).

Regarding the advantages and incentives, the following aspects were considered and categorized as drivers:

- Driver_1: Aspects unrelated to the surplus electricity sale, among which are the economic savings of self-consumption obtained by the installation owner of accreditations for the generated green energy or for the fossil energy savings and, consequently, vouchers, deductions or bonuses that the holder can receive.
- Driver_2: Aspects related to the self-generated electricity surplus sale: if it is possible to inject the electricity surplus, and if it is possible to charge for this injected electricity and what formula is used for calculating the income.

Likewise, the time duration and geographic scope of the incentives and their possible effects are analyzed.

- Driver_3: Regarding the duration of a possible compensation for the generated and injected electricity into the distribution network: whether this compensation is in real time, on a daily basis, or through a net energy or economic balance (that is, if injected energy into the network can be netted at any time without economic liquidation or includes it).
- Driver_4: If the compensation for not consumed and injected self-generated electricity could be demanded in a location different from the place where the self-consumption installation is located.
- Driver_5: Regarding the duration of the compensations and incentives framework that the regulation must promote this type of facility.
- Driver_6: Regarding additional incentives that either facilitate their implementation or represent a certain advantage, such as incentives to incorporate energy storage systems.

Next, factors that may discourage or hinder the implementation of self-consumption facilities were taken into consideration as barriers:

- Barrier_1: Limitations on the self-consumption generation capacity or existence of power ranges with different regulatory implications.
- Barrier_2: Existing limits to incorporation of the new self-consumption installations (for example, annual or as a percentage in reference to the of total generation power of the country).
- Barrier_3: Economic obligations of self-consumers related to the maintenance, operation, and sustainability of the transport and distribution network.
- Barrier_4: Existing general costs, such as rates for self-consumption, or specific costs to each installation such as, for example, the existence of a network backup charge.

- Barrier_5: Restrictive regulatory requirements regarding the connection, regulation, and measurement of facilities, as well as the technical instructions for the electrical installation.

Table 1 classifies the drivers that may influence self-consumption in each country, while in Table 2 the barriers are presented.

Table 1. Regulation impact on the set of drivers for self-consumption.

DRIVERS		Germany	Spain	Italy	France	Portugal	Remarks
Driver_1	Other income	0	0	0	0	1	Green credits
Driver_2	Injection income	2	0	3	2	−1	More positive is considered if income is higher than the whole market price
Driver_3	Third party right extend	3	−1	1	−3	1	More positive is considered when greater extended
Driver_4	Geographic compensation	0	0	0	0	0	
Driver_5a	Framework duration (short term)	0	0	0	0	0	
Driver_5b	Framework duration (long term)	2	3	3	2	2	More positive is considered if longer
Driver_6	Other drivers	1	0	0	1	0	Incentives for accumulation batteries
AGGREGATED SCORE		**8**	**2**	**7**	**2**	**3**	

Table 2. Regulation impact on the set of barriers for self-consumption (own elaboration).

BARRIERS		Germany	Spain	Italy	France	Portugal	Remarks
Barrier_1	Particular limits	0	−1	−1	3	−1	More negative if installation power must be less than or equal to contracted power
Barrier_2	Aggregated limits	−1	1	3	3	−2	More negative if limits
Barrier_3	T&D charges	3	−3	−1	3	−1	More negative if surcharges
Barrier_4	Additional costs and restricted codes	−1	−3	3	−1	−3	
Barrier_5	Others	−1	−1	0	−1	0	If surcharges for accumulation batteries
AGGREGATED SCORE		**0**	**−7**	**4**	**7**	**−7**	

Finally, the result of the previous approach is shown in Figure 2, which displays the aggregate positioning of barriers and drivers in each country in terms of the implementation of self-consumption facilities:

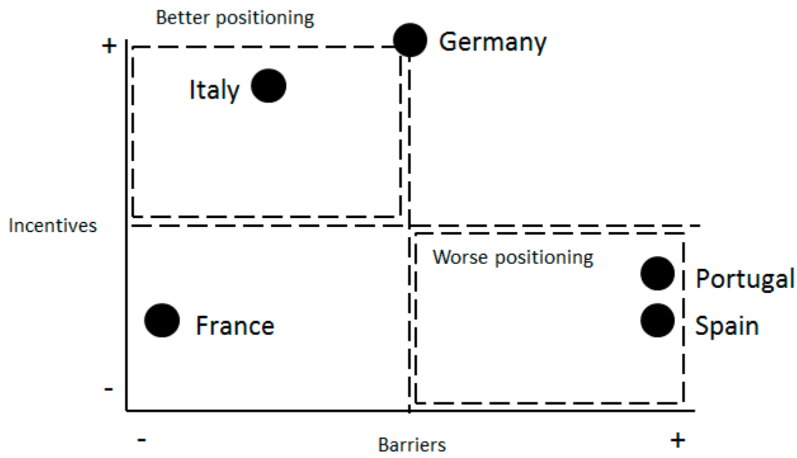


Figure 2. Current positioning for the development of self-consumption systems (own elaboration).

It can be observed that the best position for self-consumption support is accomplished by Italy, as a result of its regulations containing net-metering, feed-in-tariff (FiT) income, and a stable regulatory framework that reduces the effect of possible obstacles to the installation of this type of plant.

Germany has more advantages and incentives for self-consumption plant installation (FiT income, facilities for the realization of PPA and shared self-consumption, and a stable regulatory framework for 20 years), although the introduction of charges for facilities above 10 kWp make its situation worse than Italy.

The comparative analysis of France lets us consider it as a country that hardly imposes obstacles for self-consumption installation (without charges for maintenance of the transport and distribution network, and without limitations or ranges of power) but restrictions on the extension of the rights for self-consumption to third parties make the other advantages provided by France worse, due to accumulator aids and the timing of their incentives.

Portugal and Spain show the worst position because of their transport and distribution network maintenance charges, the imposition of additional costs ("sun tax" in Spain, registration costs in Portugal), and the annual limitation quota for Portugal of 20 MW for new facilities. Revenues for surplus energy injected into the network are paid at the wholesale market price in Spain, and at 90% of the wholesale market price or based on an annual auction in Portugal. Portugal incorporates better treatment of the implementation of facilities by third parties, but nevertheless the duration of the legal framework of self-consumption has a limitation of 20 years that Spain does not impose.

Based on the previous analysis, and to define the self-consumption investment determinants and thus to advance the knowledge in this field to favor the decision-making process, the following research questions are posed:

- (R1) What are the common characteristics of the investments made in self-consumption facilities in Spain, and how can their impact be measured in investors' decision-making?
- (R2) What are the determining factors for profitability and how can they improve the positioning of self-consumption facilities?

Most of the research work on regulation and the impact of self-consumption activity in Spain to date has focused on the comparative analysis of different alternatives in terms of the profitability of the facilities [43], its incidence on public collection [41], the return periods for investments [44], the electricity costs for photovoltaic self-consumption [45,46] or, more generally, the data-based evolution of photovoltaics at the national level [47,48].

In a case study on the profitability of photovoltaics in Spain, a 17–18-year payback period was considered [44]. Likewise, the profitability of self-consumption photovoltaic systems was evaluated for the Italian regulatory framework by carrying out a survey of 750 companies with systems of between

3 kW and 1 MW. Using the discounted payback time as an economic feasibility indicator, return periods from 5 to 6 years were found for residential installations, from 6 to 8 years for large systems (1 MW), and above 12 years for smaller commercial and industrial facilities [49]. Results are also available in Italy for the relevance of aids and incentives for photovoltaic self-consumption [50]. Disparities in these feasibility results could be linked with the different types of installations.

There are many different definitions of net-metering and net-billing schemes depending on the specific economic and engineering criteria involved [51]. Net-metering can be considered as both self-consumed electricity and surplus electricity being valued at the same retail price; or, otherwise, net-billing can be considered the surplus electricity being valued at a price lower than the price at which it is purchased on the network. It is defined as "exclusive self-consumption" when the surplus of electricity is not at all remunerated [52].

Another determining factor is the level of maturity of the market. Some mathematical models define the break-even-point of the increase of self-consumption, which is the point at which residential PV battery systems become economically viable in a mature market. Energy storage systems are useful only when the relationship between supply and demand permits them to induce a significant increase of energy self-consumption [32]. However, the uncertainties in consumption forecasting models must also be taken into account [10]. In general, greater deviations are observed due to the application of an unrealistic consumption profile, and the effect on the forecasts depends mainly on the volume of taxes on self-consumption and the relationship between the production of photovoltaic energy and annual consumption.

As for the application methodology and the variables under study, another topic of interest is the cost of storage. In this area, results achieved through a simulation made from a data sample of 30 households are used to determine the degree of electrical self-consumption, as well as the costs and economic benefits of the facilities, demonstrating that households consume on average 49% of the electricity generated, not including the contribution of batteries [53]. With a subsidy of capital equivalent to the cost of a small battery (2 kWh), it has been demonstrated that these systems would be economically viable without any doubt for the average household. Therefore, small to medium capacity batteries need attention in energy policy aimed to promote microgeneration, in view of the future rise in electricity prices.

In addition, results obtained in previous studies indicate that, under the current conditions in Spain, the direct economic impact of the self-consumption of photovoltaic energy on the total revenues of the government and the electricity system is positive for investments in the residential segment, insignificant for the commercial segment, and negative for the industrial segment [41]. For this reason, the analysis of the determinants of the investments and the legal framework has been carried out, proposing possible actions to increase the number of photovoltaic self-consumption facilities at a minimum cost for the electrical system in accordance with the guidelines of good practices of the European Commission on the self-consumption of renewable energy [54].

Thus, given the complexity of the phenomenon and the interplay of many factors, the application of qualitative methodologies of analysis through facilities as a multiple case study is chosen. This methodology allows us to overcome the limitations of the scope of quantitative information and provides a deeper vision for the analysis of innovative environmental investments [55,56], both in the specific aspects of the case studies analyzed [57] and in the definition of theoretical approaches [58,59].

For this purpose, the data of 35 photovoltaic self-consumption installations in Spain, for which ample information about their technical characteristics and economic and financial aspects is available, are compiled and analyzed (Thanks to the collaboration of the company FENÍE ENERGÍA, 35 self-consumption facilities in Spain that were promoted by this company between 2016 and October 2017 could be analyzed).

In light of this, the selected characteristics of the installations that make up this empirical study are detailed in Appendix A Table A2. They include the climate zone, which is a determinant of solar radiation levels; type of installation; installed capacity; consumer profile (residential, industrial or services); cost of the installation; financing rate; power contracted in the case of installations connected to the grid; and annual electricity production.

It should be highlighted that obtaining information regarding the internal costs and specific operational conditions directly from installed systems is not an easy task, and it means a smaller number of valid observations. Even though the sample was given by a unique company, the analyzed systems are fully identified, and this allows us to integrate all the data for the empirical analysis. In addition, it can be considered a relevant sample of the systems installed in Spain (At present in Spain, approximately 1266 systems are registered in the public register of the Spanish Government. The specific modus operandi of the Company FENÍE ENERGÍA must be considered because it only promotes facilities that are carried out by independent installers. This means that the analyzed sample is heterogeneous with regards to the equipment and operational conditions and can be considered as relevant in the geographical context of the country).

To identify the common features of these installations, a statistical-descriptive analysis has been applied and the results are shown in Section 3.

Once the most important variables in the private investment decisions have been identified, potential influential factors on these variables that could be regulated are apparent and have been described.

However, the impact of these incentives and barriers would not be the same for the different types of self-consumption facilities. To obtain a forecast of the evolution of the self-consumption sector, a model that transfers the influence of the determining factors to the deployment of self-consumption under specific regulatory scenarios has been developed.

3. Results

To figure out the common characteristics of the investments made in self-consumption facilities in Spain, an analysis of a sample of well-documented installations has been carried out.

The installed peak power was lower than 10 kW in 77% of the cases. The cases studied have always been low voltage and with a contracted power of less than 100 kW. Figure 3 shows the size of the installations.

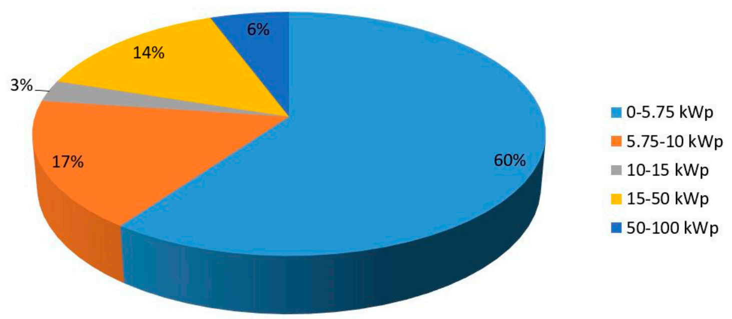


Figure 3. Size distribution of the installations.

By means of a statistical-descriptive analysis, it can be observed that the installations have been mounted in the two climatic zones with the highest solar incidence: 89% in climatic zone IV (from 4.6 to 5 kWh/m^2) and 11% in climatic zone V (more than 5 kWh/m^2).

As shown in Figure 4, the facilities under study were mainly in residential buildings and connected with small and medium companies, although two solar pumps (isolated installations with self-consumption to pump water for later irrigation) were also studied. Installations have been also classified according to consumer profiles: domestic (43%), industrial (20%), and services (37%).

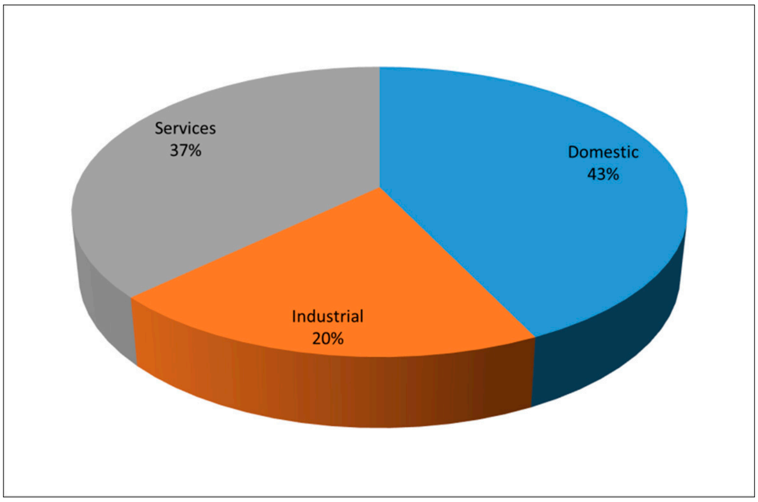


Figure 4. Type of consumer owner of the self-consumption facility.

Regarding the technical execution, as it is shown in Figure 5, the installations studied have been mainly isolated with batteries (43%) and grid-connected without remuneration (40%), with a lower incidence of isolated (14%) or connected with which the surplus electricity is sold to the grid (one installation, 3%).

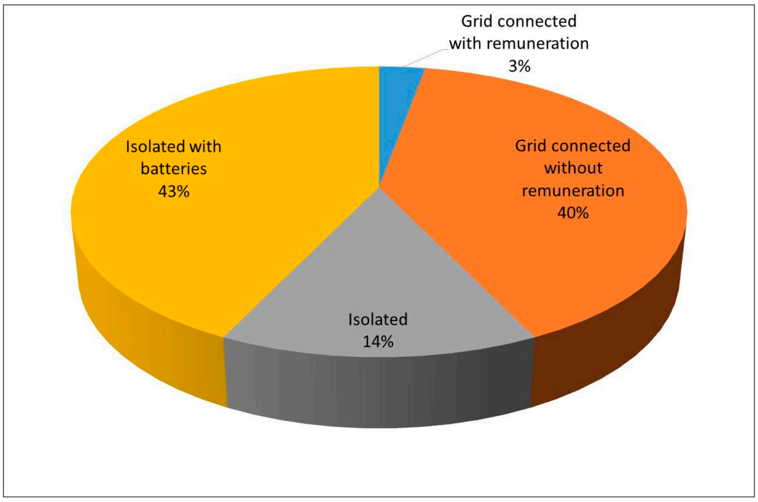


Figure 5. Type of installation.

Installations have had a medium-low investment, from €2200 to €255,000, with an average of €24000. A total of 91% of the installations were financed by the energy company that executed the keys-hand installation, with financing periods between 4, 5 and 8 years.

The profitability of the facilities was evaluated through the calculation of the economic return period of the installation, based on the following data and considerations. The cost of the installation is a known fact of the contract signed between the client and the energy company that carried out the execution of the turnkey project. The total amount includes the cost of materials, equipment, structure, installation, legalization, project or report, financing if applicable, and gross margin of the installation company.

For the characterization, the lifetime of the investment is assumed to be equal to 20 years, although the lifecycle of a PV panel is usually assumed to be 25 years. The inverter of the installation has a useful life of more than 10 years, so it is expected to be replaced, at least once, within the lifetime of the investment. The cost of the investor accounts for 15–20% of the installation, and experiences a relative cost influenced by the scale factor. The accumulators of energy (batteries) have a useful life of about 8–10 years, so the installations must amortize, if necessary, the batteries at half the life of the installation. The cost of the batteries represents approximately 20% of the cost of the installation depending on the type of batteries installed, and on the depth of discharge in the use of the batteries. The lag between the useful life of the installation and that of its components has been contemplated by incorporating the weighting factors on the initial investment, as summarized in Table 3.

Table 3. Weighting factors on the initial investment due to component replacement.

Installation's Components	Factor
Installations with inverter and without batteries	1.2 €/Wp
Installations with batteries	1.1 €/Wp
Installations with inverter and batteries	× 1.2 × 1.1 €/Wp

The loss of efficiency of the photovoltaic modules is introduced in the study by means of an annual decrease factor of 0.8%. Likewise, an increase in the cost of annual electric energy with a value of 3.5% has been factored in. This energy cost is supported by the increase in electricity prices reflected in the Spanish National Statistical Institute reports of the general consumer price index (CPI) and the energy CPI, despite their short-term volatility. It should be mentioned that the analysis does not include any type of maintenance of the facilities, which usually has a lower impact on the cost of the installation and that, in the types of self-consumption studied, is the responsibility of the owner of the installation.

The execution of the self-consumption facilities studied involves avoiding an equivalent amount of energy demanded from the distribution network or generated by generating sets (in isolated installations), or that of an opportunity cost of consumption not implemented due to the technical or financial difficulty of the interconnection with the distribution network. The cost of this energy in the interconnected installations has been realized by means of a valuation of the cost of said energy at the cost regulated by the voluntary price for the small consumer (PVPC, PVPC tariff is a regulated tariff designed for private consumers), during the year 2016 (middle price) for contracted power supplies equal to or less than 10 kW. For powers greater than 10 kW, the corresponding adjustment has been made by applying the corresponding access tariffs. In summary, the prices applied are detailed in Table 4.

Table 4. Price of the avoided energy by power ranges.

Contracted Power (Kw)	Price of the Avoided Energy (€/kWh)
Pc ≤ 10	0.104393
10 kW ≤ Pc ≤ 15 kW	0.117726
Pc > 15 kW	0.072941

The opportunity cost of not implementing activities that involve electricity consumption, and that can be carried out with the self-consumption installation executed, is valued at most as the cost of using the generator set. These costs are affected by the so-called energy CPI explained above (3.5%) during the 20-year life of the facility. For each installation, this includes the energy expected to be generated in 20 years (in kWh), the total updated cost of the installation considering the entire useful life (€), the unit cost (€/Wp), the cost of electricity not acquired from the network (€), and the return period (in years).

This study does not include charges for variable self-consumption to interconnected plants (77% of the facilities analyzed are 10 kW or less of contracted power and are exempt and do not affect isolated installations). The analyzed facilities, except for one of them, are self-consumption plants Type 1 and, therefore, are not remunerated for surplus electricity.

In summary, the results show initial costs of the installation between 0.73 and 10.14 €/Wp, with an average cost of 3.3 €/Wp, and return periods between 3 and 22 years and with an average period of 9 years.

In the next figures, considerable differences can be observed depending on the type of installation, as reflected in the following graphs that show the statistical analysis of the data collected for the 35 facilities.

It can also be observed in Figure 6 that the isolated installations have lower return periods than the installations connected to the network, even though their initial installation costs are higher, since they cover electrical consumption that would otherwise have a high cost for generating energy. In the case of self-consumption facilities in grid-connected supplies, the investment costs are between 0.73 and 3.71 €/Wp (with an average of 1.93 €/Wp), which is substantially lower than those of the isolated facilities given the smaller size of the batteries. However, as it is shown in Figure 7, they have return periods of between 4 and 22 years, with an average of 12 years.

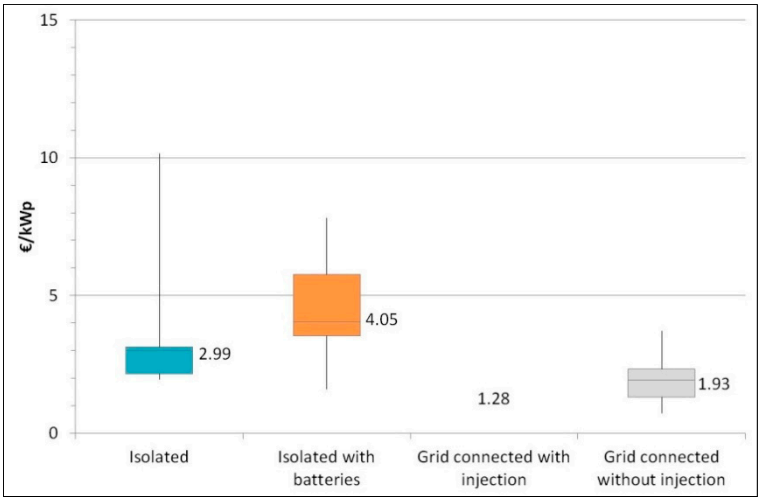


Figure 6. Unit cost of the installation (€/kWp) according to its connection to the network.

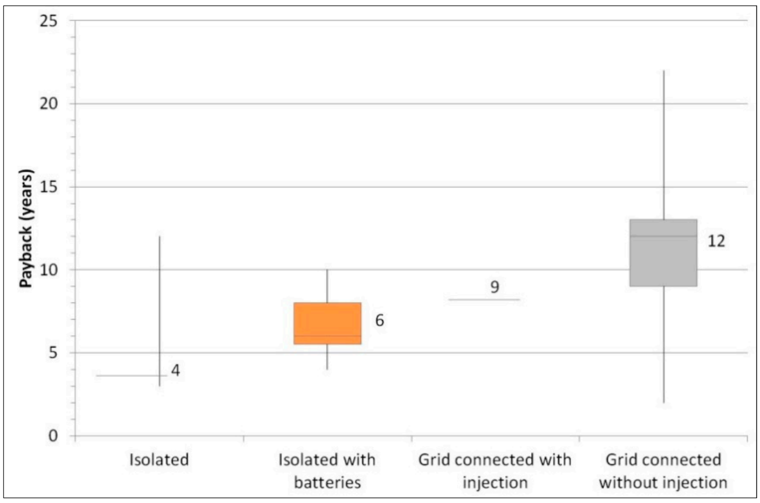


Figure 7. Payback of the facilities according to their connection to the grid.

Additionally, as expected, isolated installations with accumulators have higher return periods and initial investment costs than isolated plants that do not have energy storage elements. The only exception is the case of solar pumping with a return period of 12 years due to the high cost of the installation, which is heavily influenced by the costs of the auxiliary pumping equipment for storage in the tank and subsequent impulsion for irrigation.

As a general result, it can be affirmed that the cost of the avoided electrical energy is of key importance in the economic return of the investment for the considered installations. The profitability is particularly favorable (faster economic return) for those customers who pay for electricity at a higher price (domestic customer or electricity produced in a generator set) and worsens for customers with more power contracted and with an average price of lower electricity.

In short, the improvement of the profitability of self-consumption facilities is related to the possibility of increasing the difference between the levelized cost of the produced electricity (LCOE) and the grid electricity price. In a scenario with stable grid electricity prices and according to the LCOE definition [60], this increase can be achieved by reducing the investment (mainly reducing the cost of batteries), reducing operating costs (basically, decreasing the power contracted or reducing taxes), or by increasing revenues from economic returns through the injection of electricity into the grid, even at wholesale market prices (The producer under the self-consumption modality receives the corresponding financial compensation according to the regulations in force, according to article 14th of Royal Decree 900/2015, which regulates the conditions of self-consumption in Spain. From Decree Law 9/2013, of July 12, and Royal Decree 413/2014, of June 6, no specific remuneration is applied in Spain to the discharge of electric power to the net, so the producer only receives the hourly price wholesale market income. OMIE manages the wholesale electricity market on the Iberian Peninsula and reports the intra-daily market prices at http://m.omie.es/reports/index.php?m=yes&report_id=121&lang=en#).

After identifying that cost-related variables are the most important in the investment decision, potential influential factors on these variables that could be regulated must be pointed out.

To illustrate how a small change in the incentives and barriers related to the above economic variables would encourage self-consumption, the same methodology used for the analysis of the comparative legal framework has been applied. Economic savings and incomes could be favored with policies related to Driver 1 and 2 and would mean a higher score for them. Reducing the cost of batteries would be possible with incentives for the incorporation of energy storage systems, which would mean higher scores for Driver_4 and Barrier_1. Finally, policies aimed to reduce economic obligations related to the transport and distribution network would improve the scores for Barrier_3 and 4. Only one level of improvement (one scoring point) has been considered for Drivers_1, 2 and 4 and Barrier_1, and three levels of improvement have been considered for Barrier_3 and 4.

Ultimately, in this favorable scenario incentives and barriers would take the values shown in Table 5, leading to a better position in the matrix of incentives and barriers as shown in Figure 8.

Table 5. Impact of regulations on the incentives and barriers to self-consumption in current and the favorable scenarios.

Incentives and Barriers		Current Scenario	Favorable Scenario
Driver_1	Other income	0	1
Driver_2	Injection income	0	1
Driver_3	Third party right extend	–1	–1
Driver_4	Geographic compensation	0	0
Driver_5a	Framework duration (short term)	0	0
Driver_5b	Framework duration (long term)	3	3
Driver_6	Other drivers	0	1
Barrier_1	Particular limits	–1	0
Barrier_2	Aggregated limits	1	1
Barrier_3	T&D charges	–3	0
Barrier_4	Additional costs and restricted codes	–3	0
Barrier_5	Others	–1	–1

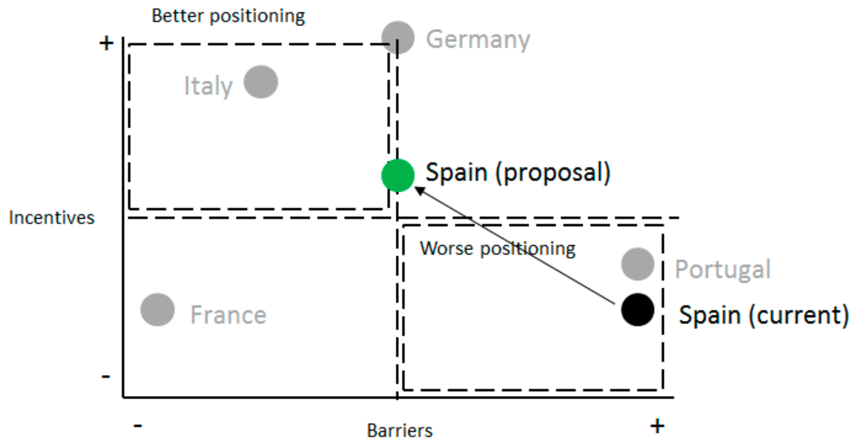


Figure 8. Favorable positioning for the development of self-consumption systems (own elaboration).

However, the impact of these incentives and barriers would not be the same for the four types of facilities identified.

A model that transfers the influence of the determining factors to the deployment of self-consumption under specific regulatory scenarios has been developed and applied to the case of Spain.

Three scenarios (most likely scenario, best-case scenario, and worst-case scenario) have been considered. They incorporate hypotheses regarding the evolution of the variables of influence with respect to a theoretical static scenario, in which there were neither positive nor negative changes—also called "business as usual" (BaU)—that would be the equivalent to the current. Considered factors because of their relevancy are those shown in Table 5: Driver_1, Driver_2, Driver_6, Barrier_1, Barrier_3, and Barrier_4.

Table 6 shows the influence level (low, medium, or high) that each incentive or barrier has on the profitability of each of the considered types of self-consumption facilities:

Table 6. Weight matrix (own elaboration).

Type of Installation	Driver_1	Driver_2	Driver_6	Barrier_1	Barrier_3	Barrier_4
Isolated	Low	Low	Low	Low	Low	Low
Isolated with batteries	Low	Low	High	Low	Low	Low
Grid-connected without injection	Low	Medium	High	High	High	High
Grid-connected with injection	High	High	Medium	High	High	High

Table 7 summarizes the assumptions regarding the evolution occurring in each of the three proposed scenarios. Again, three levels of trend or estimated variation for each variable (incentive or barrier) have been chosen in each of the scenarios. An increase ("+") means a positive evolution, a decrease ("−") implies a negative evolution, and a stagnation ("=") indicates absence of significant variation of the variable with respect to the current situation.

The best scenario for the promotion of self-consumption therefore requires that all the variables evolve positively ("+"), while the worst case will be given by a worsening or stagnation ("−"). As stated above, the "business as usual" scenario is a hypothetical case in which there is no change to the current situation.

The evolution of the influential variables in each scenario will have a greater impact on self-consumption depending on the importance that these variables have for the profitability of the facilities of each type.

Table 7. Definition of scenarios for self-consumption (own elaboration).

Incentives and Barriers	Best Case	Most Likely	Worst Case	Business as Usual	Explanation
Driver_1	+	=	−	=	Positive evolution means rising grid electricity prices
Driver_2	+	=	−	=	Positive evolution means rising prices for injected electricity
Driver_6	+	+	−	=	Positive evolution means reduction in battery costs
Barrier_1	+	+	−	=	Positive evolution means reduction in installation costs
Barrier_3	+	=	−	=	Positive evolution means reduction in T&D charges
Barrier_4	+	=	−	=	Positive evolution means lessening limitations

Assigning values 1, 2 and 3 for the selected resolution level and combining the weight matrix with the evolution matrix for each scenario, a number from 1 to 9 will be obtained regarding the positive or negative influence of each of the variables in each of the subsectors for each scenario, with 9 being the maximum positive influence (greater impulse to self-consumption) and 1 the maximum negative influence (less impulse to self-consumption). From the average values for each variable in the three scenarios, the most probable percentage of relative variation with respect to the static scenario is calculated.

4. Discussion

The present analysis has allowed definition of the variables for the characterization of 35 self-consumption facilities of low voltage supplies with power less than 100 kW in Spain. There are few samples of this type in the studies published to date, which have mainly been prepared from case studies or aggregated data. Given that particular facilities have been identified, this study provides an interesting advance in empirical knowledge because of the geographical scope, the type of investor, the number of facilities, and the scope of the data analyzed—both that which is inherent to the technical characteristics, as well as the economic and financial aspects.

As a general result, it can be affirmed that the cost of the avoided electrical energy is of key importance in the economic return of the investment for the considered installations. This is in line with the results obtained by other authors, thus providing a response to the research question posed (R1).

With regards to the installation costs and return periods obtained, the results can be explained by the separate analysis of two types of configurations: isolated and grid-connected installations. Both types have different implementation and maintenance costs, which are higher for the isolated installations due to the batteries, as well as very different savings. This has a bearing on the payback period and the lowest values were found for the isolated installations in the sample under study.

It is also worth noting the self-consumption facilities carried out in low-power homes (less than 10 kW) or other customers in other sectors with access to the network and therefore, with easy access to the power extension or total coverage of their needs through the distribution network.

Likewise, the presence of isolated installations demonstrates that self-consumption allows the resolution of situations with a lack of access to electricity, even with long periods of return on investment. In this sense, solving a basic need such as the access to electricity can be a priority over the economic cost.

However, it should be noted that the low return periods for isolated installations are linked to the high cost of generating electricity through the generator sets that are the most common equipment for this type of supply (maximum cost is also assigned to the opportunity cost for those customers who, even if they do not make such an investment, do not implement a possible solution with connection to the network). It is reasonable to think that these high generation costs can be avoided in some cases.

In this case, an estimated 12-years payback period for the interconnected facilities seems to be more realistic and similar to results obtained by Chiaroni et al. [49] and could be a more representative value for both types of installations. These long periods of return could justify the low level of implementation of this type of facility, except when other motivations such as the need for electricity, innovation, or environmental sensitivity influence decision-making in terms of investing in these types of self-consumption facilities.

Among the general observations of this study, it can be claimed that the fact of having reached network parity in Spain does not seem to be enough for citizens and companies to decide to become prosumers. This is in line with the report of the IEA Photovoltaic Power System Programme [61], where it is said that the price of photovoltaic electricity would have to fall well below the grid parity, so the assumed financial risk and inertia is overcome. The final price of photovoltaic electricity could be reduced through measures such as net-billing or net-metering.

The case study has made it possible to define the determinants of self-consumption investments, advancing knowledge in this area for its promotion and facilitating the decision-making process where economic profitability is one of the factors with the greatest impact on the deployment of these facilities.

Bearing in mind that some authors consider that energy prices and network access charges should reflect the real costs of supply in order to not distort the consumer incentives when choosing between a photovoltaic installation and the supply of the network, it is of interest to propose a transition framework for a zero emission and renewable environmental energy scenario, even if it is not free of costs. Thus, aligned with Aragonés et al. [39], the convenience of incentives for the deployment of self-consumption may be considered opportune, which in turn requires energy prices and network tariffs that provide the right economic signals.

Table 7 summarizes the response to the second research question (R2), showing the influence level that each driver or barrier has on the profitability of each of the considered types of self-consumption facilities.

Graphically, as it is shown in Figure 9, the variables with the greatest influence are the incentives that reduce the cost of batteries and the barriers related to the monetary and non-monetary costs of the installation, while the typologies with the highest expectations of growth are the installations connected to the grid according results in Figure 10.

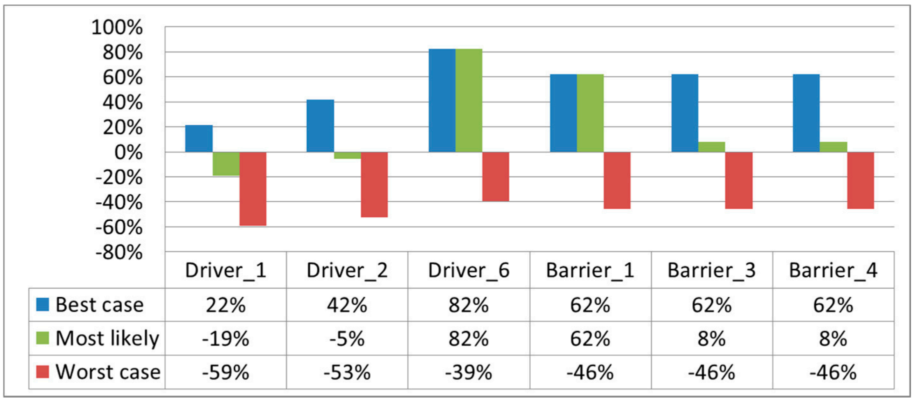
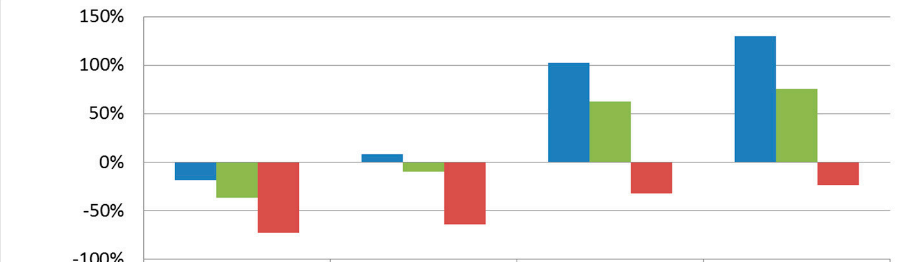


Figure 9. Most likely percentage of relative variation of self-consumption potential in Spain by variable and scenario with respect to static (own elaboration).



	Isolated	Isolated with batteries	Grid connected without injection	Grid connected with injection
Best case	-19%	8%	103%	130%
Most likely	-37%	-10%	62%	76%
Worst case	-73%	-64%	-32%	-23%

Figure 10. Most likely percentage of relative variation of self-consumption potential in Spain by type and scenario with respect to static (own elaboration).

Among the contributions of interest provided by this study, it is worth highlighting the detailed study of the determinants of self-consumption investments, and the elaboration of scenarios based on the analysis of the country's legal framework and the corresponding barriers and incentives.

However, this study has some limitations inherent to the number of installations analyzed and the number of variables. Through a more in-depth study, the influence of the charges associated with the system costs on the return period, or the decision-making process for each type of investor, could be investigated.

As a general reflection, it is worth mentioning that to increase the adoption of this kind of technology and encourage consumers to make private investments, policies for renewable energy must consider self-consumption and microgeneration as the main axis, by increasing the availability of energy when necessary. For instance, the promotion of energy storage from these kinds of facilities could receive priority treatment, as well as the rewarding of energy self-sufficiency in the interests of security of supply in a period of energy transition towards a new, more sustainable model. Incentive schemes, aids to compensate the additional costs resulting from the battery storage or easing of restrictions in terms of contracted power would foreseeably increase the rates of adoption of the technology, favoring its faster development in terms of R&D and product innovation.

Author Contributions: All authors participated equally to the research design, development of the theoretical framework, methodological choices and the analysis. All authors wrote and revised the paper. All authors revised and approved the manuscript. Conceptualization, J.Á.G., E.L. and S.S.; Formal analysis, J.Á.G., E.L. and S.S.; Investigation, J.Á.G., E.L. and S.S.; Methodology, J.Á.G., E.L. and S.S.; Writing—review & editing, J.Á.G., E.L. and S.S.

Funding: This research received no external funding.

Acknowledgments: Part of this study has been developed within the project "ECO-CIRCULAR"—Ref. ECO2016-74920-C2-1-R granted by the Spanish Ministry of Economy and Business Affairs and thanks to the support of the CIRCE Research Institute and the aids for Research Groups of the Aragon Government (S33_17R and T46_17R). Special thanks are expressed to FENIE ENERGIA, S.A. for its collaboration to the empirical study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix

Table A1. Regulatory frameworks in the selected European countries (adapted from [61]) Acronyms: FiT: feed-in-tariff, FiP: feed-in-premium, SSP: Scambio Sul Posto (acronym in Italian, meaning Exchange on Site), ToU: time of use tariff, SeU: Sistema Efficiente di Utenza (acronym in Italian, meaning User Efficiency Systems), EEG: Erneuerbare-Energien-Gesetz (acronym in German, meaning Renewable Energy Act).

Title	Spain	France	Germany	Italy	Portugal
Revenues from self-consumed PV	Savings on the electricity bill	Savings on the electricity bill	Savings on the electricity bill	Savings on the electricity bill	Savings on the electricity bill and right to guarantee of origin from renewable sources
Charges to finance T&D	Yes (“solar tax”)	None	None	Yes, above 20 kW	Yes, above 1.5 kW for 10 years
Revenues from excess electricity	None//Wholesale market price minus taxes	FiT	FiT or FiP	SSP, net-billing based on energy and services; market price for selling	<1.5 kW Wholesale market price minus 10%>1.5 kW Reference tariff, established annually by the government
Maximum timeframe for compensation	Real-time	Real-time	Real-time	Self-consumption, real time; SSP, advance payment twice per year	Real-time
Geographical compensation	None	On-site only	On-site only	On-site (meter aggregation is allowed for some specific SSP cases)	None
Regulatory scheme duration	Unlimited	20 years (FiT)	20 years (FiT)	Unlimited	15 years
Third party ownership accepted	None//Yes (“solar tax”)	None	All	Yes, with conditions for SSP	Yes, with conditions
Grid codes and additional taxes/fees	Above 10 kW//Yes	Possible move towards a higher share of fixed grid costs	Grid codes compliance and partial EEG-surcharge	None	Register costs, metering costs, and Grid codes compliance, civil liability insurance taking out
Other enablers of self-consumption	None	ToU Tariffs	Battery storage incentives	None	None
PV system size limitation	100 kW but below or equal to capacity contracted//Below or equal to capacity contracted	None	Minimum 10% of self-consumption	Self-consumption, none (below 20 MW for SeU); SSP, up to 500 kW	Self-consumption power below or equal to contracted power. Different requirements up to 1.5 kW, between 1.5 and 250 kW, and more than 250 kW
Electricity system limitations	Distributor’s license	None	52 GW of PV installations	None	In all self-consumption below 20 MW on an annual basis
Additional features	Taxes on batteries	Projects to increase the fixed part of grid costs	EEG levy must be paid anyway by the prosumer (above 10 kW)	None	None

Table A2. Main characteristics of the self-consumption installations under study.

Title	Type of Installation	Location	Power(kWp)	Contracted Power (Kw)	kWh per Year	Installation Cost (€)	Financing Rate (%)
1	Isolated with batteries	Apartment block	0.7	N/A	1185	5466	96
2	Grid-connected without remuneration	SME	1.56	4.4	2641	1907	96
3	Isolated with batteries	SME	9.36	N/A	15,847	52,092	96
4	Grid-connected without remuneration	SME	6.76	6.9	12,248	4966	0
5	Grid-connected without remuneration	SME	37.44	41.6	67,837	43,772	0
6	Isolated with batteries	Dwelling	2.25	N/A	3809	7552	96
7	Isolated with batteries	Dwelling	0.9	N/A	1524	4873	0
8	Grid-connected without remuneration	SME	5.1	51	8570	12,044	96
9	Isolated with batteries	SME	6.24	N/A	10,564	10,803	96
10	Isolated with batteries	Dwelling	1.02	N/A	1727	4134	48
11	Isolated with batteries	Dwelling	4.68	N/A	7923	13,163	96
12	Isolated with batteries	Poultry farm	5.76	N/A	9752	9144	96
13	Grid-connected without remuneration	Dwelling	3.64	5.196	6427	8213	96
14	Grid-connected without remuneration	Camping	26	100	48,797	48,924	96
15	Isolated	SME	6.36	N/A	10,768	12,371	96
16	Grid-connected without remuneration	SME	5.3	29.58	9354	13,664	96
17	Grid-connected without remuneration	Funeral parlor	5.2	29.7	9084	10,482	96
18	Grid-connected without remuneration	SME	15.9	92	27,549	31,418	96
19	Grid-connected without remuneration	Catering	18.02	19.8	34,250	30,821	96
20	Isolated with batteries	Dwelling	1.53	N/A	2590	6459	60
21	Grid-connected with remuneration	Catering	50.88	110	94,060	65,189	96
22	Isolated with batteries	Dwelling	3.3	N/A	5587	12,263	96
23	Isolated with batteries	Dwelling	3.18	N/A	5384	20,925	96
24	Isolated with batteries	SME	11.13	N/A	18,843	43,455	96
25	Grid-connected without remuneration	Dwelling	1.06	3.3	2930	3934	96
26	Isolated with batteries	Dwelling	0.52	N/A	880	3645	96
27	Grid-connected without remuneration	SME	2.16	6 928	3068	7391	96
28	Isolated with batteries	Dwelling	1.02	N/A	1727	6078	36
29	Isolated	Dwelling	99.2	N/A	167,946	212,569	96
30	Isolated	Solar pumping	0.4	N/A	677	4057	96
31	Isolated	Dwelling	2.55	N/A	4317	7958	96
32	Isolated	Solar pumping	2.55	N/A	4317	7622	96
33	Grid-connected without remuneration	Dwelling	2.7	6.9	2085	2842	96
34	Isolated with batteries	Dwelling	5.355	N/A	9066	20,172	96
35	Grid-connected without remuneration	SME	35.25	170	38,430	55,686	96

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2.4 Financial Resources for the Investments in Renewable Self-Consumption in a Circular Economy Framework (Artículo 4)

ARTÍCULO 4: Scarpellini, S. et al. (2021) 'Financial Resources for the Investments in Renewable Self-Consumption in a Circular Economy Framework', Sustainability, Vol. 13, p. 6838. doi: 10.3390/SU13126838.

EDITORIAL: MDPI - ISSN: 2071-1050

Publicación INDEXADA JCR CIENTÍFICO Q2: factor de impacto: 3,251 (2020)

Category Name	**Impact Factor (2020)**	**Quartile Rank**	**Quartile in Category**
JCR SCIENCE – Green & Sustainable Science & Technology	3,251	30/44	Q3
JCR SCIENCE – Environmental Sciences	3,251	124/274	Q2

sustainability

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Financial Resources for the Investments in Renewable Self-Consumption in a Circular Economy Framework

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Abstract: The availability of financial resources has been pointed out as one of the determining factors for the investment in renewable self-consumption solutions for the energy transition in the European Union. In economic terms, the barriers to investment are related to low levels of profitability and difficulties in accessing financing in some European regions. These barriers must be overcome to foster a sustainable energy transition. However, this topic of analysis is still underexplored in the literature to date. This study provides a characterisation of the financial resources applied to self-consumption from an economic–financial approach to the decision-making investors in a case study in Spain from a novel focus on the subject. The relevance of alternative financial resources as a mechanism to reduce existing barriers is revealed through the analysis of the active role that installers play in making investment decisions, facilitating the growth of self-consumption. The alternative financial channels and the bank intermediation for renewables are topics of interest to promote the energy transition towards a low-carbon economy.

Keywords: energy transition; circular economy; corporate finance; renewable self-consumption; energy research

Citation: Scarpellini, S.; Gimeno, J.Á.; Portillo-Tarragona, P.; Llera-Sastresa, E. Financial Resources for the Investments in Renewable Self-Consumption in a Circular Economy Framework. *Sustainability* **2021**, *13*, 6838. https://doi.org/10.3390/su13126838

Academic Editor: Andrea Pérez

Received: 6 May 2021
Accepted: 14 June 2021
Published: 17 June 2021

1. Introduction

Economies of the most developed countries are involved in an energy transition, and new models for energy supply based on renewables within a zero-emission economy can be expected in the coming decades in the framework of the sustainable paradigm. Since the beginning of this century, there is no doubt that the connection between renewables and sustainability is intimate [1,2]. This link has led to the search for energy solutions for on-site electricity generation using low-carbon sources, such as photovoltaics (PV) or other renewables, at a scale suitable for a single consumer who owns the installation [3,4].

Self-consumption provides an answer to the multiple environmental sustainability challenges posed for the first half of the 21st century, such as the goal of a low-carbon economy, the energy transition to a fully renewable scenario, a distributed energy model, and the implementation of the circular economy (CE). Furthermore, sustainable energy consumption nowadays is an essential step toward sustainability because of concerns about the effect of current energy production systems [5], facing the energy transition challenge. In addition, the active participation of consumers as producers and the decentralisation of the energy sector also align with the CE framework [6].

Despite the numerous advantages of self-consumption for small and medium enterprises (SMEs)—residential, commercial or industrial—and particular prosumers, small-scale renewable energy facilities entail scattered investments in the territory. Its penetration varies in the different countries of the European Union (EU). This disparity is fundamentally due to the uneven difficulties associated with its financing, the installation costs that can reduce profitability, and the legislative and administrative barriers at the national level [7]. This analysis topic is still underexplored in the literature because profitability and payback are related to the selected technology and the existing local and national regulatory framework [8].

The dissemination of decentralised renewable energy generation with storage and smart metering devices leads to new consumption models in the energy sector [9]. In fact, the relevance of the availability of alternative financial channels (banking disintermediation through the financing of the retail energy company, cost savings in equipment, in addition to the financing provided by public subsidies) as a mechanism to reduce the possible barriers to renewable technologies is a line of inquiry under development. The definition of the compelling reasons for the investments and the impact of specific promotion plans is still being examined in the academic literature, particularly the drivers to mobilise the investments [7,10–14] in the framework of the Trade Credit Theories [15]. Likewise, the detailed study of the financing sources used to carry out these investments and their main characteristics contributes to enhancing the knowledge on the transitional change toward a CE [6,16].

Given these premises, this study investigates the financial resources associated with self-consumption facilities in the EU through a case study in Spain as an interdisciplinary analysis in order to bring sustainable energy consumption, zero-emission goals and renewables in a CE together in a single research framework. In summary, the main objective of this heuristic research is the characterisation of specific financial resources and the analysis of alternative financing channels for investments in self-consumption and the theoretical framework of the trade credit. A new approach is provided as it considers the perspective of installers and their role as drivers in investment decision-making. This work contributes to the collaborative business model operations area for sustainable energy consumption through the incorporation of non-energy services, such as alternative financing channels. The paper is structured as follows. The underlying background is summarised in the following section to introduce the research questions of this study. Subsequently, the applied methodology and the main results obtained are described. A final section summarises the main conclusions that are achieved through a brief discussion of the energy policy.

2. Background

The multidimensional nature of an energy transition towards sustainability triggers the need for new technologies, products, services, organisations, standards and practices of users who gradually replace the previous ones. Along with the complementarity of systems and technologies, deep social transformations are also necessary to achieve the proposed objective [17,18].

Self-consumption with renewable energies is considered one of the most feasible strategies in the short term. On the one hand, it responds to supplying reliable power at affordable prices and low carbon content. On the other hand, it relies on technologies with a high development level, such as photovoltaics, with a demonstrated success in microgeneration projects. The main contribution of self-consumption to the traditional distributed generation is the possibility of making transactions under specific rules with the electricity produced and not consumed.

Households and companies view renewable self-consumption as a solution to assure stable costs in the coming decades and avoid exposure to the volatility of energy prices in the future [19].

From a financial point of view, self-consumption allows consumers to actively participate in energy transition through a real option of revitalising the private capital of lower expectations regarding rates of return compared to conventional financial investors of the energy sector. In addition, the flexibility of self-consumption by supplying demand through storage solutions, smart devices and more flexible contracts for consumers contributes to reducing generation peaks and consequent congestion problems, also benefiting network operators [19].

The requirement to increase the number of photovoltaic self-consumption installations at a minimum cost for the electrical systems in different EU countries is highlighted per the guidelines of good practices on the self-consumption of renewable energy. However, the transition to a zero-emission and renewable energy scenario is not cost-free. It raises the need for incentive mechanisms, reflected in energy tariffs and the payback scheme [20], especially when new stakeholders are involved as prosumers.

Regulations have to make the procedures for self-consumption facilities easy and ensure that renewable energy prosumers, individually or through aggregators, are not subjected to any double charge.

Thus, the detailed study of the required investments for these facilities has a particular interest today.

2.1. Financial Resources and Self-Consumption Investments

To date, the economic–financial analysis of self-consumption has been mainly focused on the determining factors for investments such as the payback period [21–23], their costs [11,15,24], the different billing schemes [24,25], or the volume of public incentives [13,26]. However, there is not a thorough characterisation of the financial resources applied to the investments in self-consumption.

The approach used in this study is not specifically theory-driven. Nevertheless, in this topic, the theoretical framework of the trade credit contextualises the seminal view of trade credit as a type of financing made available by the seller to the buyer introduced by Emery [27].

Previous research has identified some motivations and barriers that affect the adoption of microgeneration, including funding. Despite the numerous financial incentives, the results indicate that the most significant obstacles are still high capital costs, low cost-effectiveness, and the risk of losing money if they moved home [7]. Capital cost has repeatedly been found to be the main barrier to installing microgeneration by different authors [28–30]. The capital cost is often unaffordable [31], or potential owners cannot earn enough money from the installation to warrant the investment [32]. In the United Kingdom, the government has attempted to address the capital cost and house resale value barriers with the introduction of specific incentives (the so-called "Green Deal") so that the risk associated with an upfront outlay is reduced by providing a capital cost loan because the financial barriers were dominating the adoption decision [11].

Regarding photovoltaic self-consumption installations, the main barriers that hinder investment for private investors [33] or younger and smaller companies [34,35] include its high cost, their own insufficient resources to cover the investment and difficulty in accessing other financial resources (in acceptable amount and cost).

Besides these barriers to the widespread investment in renewable systems, some studies identify an inaccurate economic assessment, lack of proper financial appreciation, and administrative bureaucracy related to energy and non-energy services [36].

Masini and Menichetti [12] point out the need for policies to stimulate investments in renewables more effectively by removing barriers and leveraging all the investment decision drivers. Mazzucato and Semieniuk [37] highlight the role that different financial actors can play in developing renewables and their impact on the policies to foment these energy sources.

Due to the previously mentioned parallelism to other related research fields, it is interesting to enlarge the analysis to those financial resources applied in eco-innovation or circular economy [16]. In the literature, the relationship between financial resources and eco-innovation has been explored [38]. Furthermore, the influence of different parameters inherent to these resources on eco-innovative investments has been demonstrated in more dimensions, such as the volume, availability and other qualitative aspects of financing and the allocation of public subsidies [16].

From a CE perspective, similar conclusions were achieved by Aranda-Usón et al. [39] when analysing the relationship between the financial resources of firms and their circular scope. In addition, from a technological innovation systems framework, financial capital has also been added among those complementary resources relevant to system performance [40].

More specifically, private investment has so far played a relatively marginal role in the renewable energy industry. Moreover, mobilising private capital to support investment projects in renewables is challenging, particularly in the current economic context, as investors are reluctant to allocate resources to new technologies that guarantee uncertain returns in the short term [12]. Nevertheless, the installed PV capacity system depends on its investment costs, yearly running costs and financing conditions, the interest rate [12] and other financing costs [13].

According to PV's high upfront capital investment, the adopted financial support measures are often a liability. Therefore, the cost of external financing is a parameter that conditions the economic viability of the projects. If the government can support the emission of "green bonds", it will decrease the interest rate [41]. Tax benefits are also suggested in the case of a PV system installed in conjunction with the purchase or construction of a private home. Moreover, these facilities could attract private capital and investments (especially PV suppliers or investors) to develop rooftop PV power plants, as Song et al. [41] affirm for the case of Hong Kong. Nevertheless, further monetary incentives are required to achieve a reasonable payback period that, in particular, needs to be less than the lifetime of the solar panels [42], and it demonstrates the current character of this research.

As far as the type of resources is concerned, their proportion and the cost of proper financing to fund the PV investments have been the subject of interest in analysing potential viability scenarios for different investment segments [13,24]. The investment volume can be a barrier in the model's decision-making [8,43] and the lack of adequate financing resources.

Investment in self-consumption is a topic for consideration. Prosumers manage private capital having lower expectations in terms of rate of return compared to pure financial investors, and, consequently, they could make the energy transition cheaper.

The idea that the prosumers are partially financing the electricity system is not new. Some analysis on the effects of different regulation schemes on the financial viability of self-consumption systems on residential and industrial prosumers is reported [24]. Moreover, a proper harmonisation between the consumption and production of energy achieves could increase earnings [44]. Still, reducing the specific investment cost is the factor that provides the most remarkable financial results.

It is accepted that the main factors that make easy decision-making are: the availability of own resources, and the accessibility to different formula funding renewables such as loans or public financial incentives (subsidies, soft loans, reduced tax rate, exemptions, etc.) [45–47]. The introduction of financial incentives has improved payback time, and the significant increase in solar PV uptake suggests that the changing economic landscape has further motivated people to adopt [7]. Vilaça Gomes et al. [48] state that financing mechanisms to facilitate access to the capital required to invest in PV systems can be a good path since there are no instruments available in some countries. Balcombe et al. [7] demonstrate that a capital grant of 24% of the installed cost of the whole microgeneration system is required to make the system financially viable for households with a limited average electricity demand (around 3300 kWh/year).

Song et al. [41] provide a complete classification of PV subsidy policies and other financial instruments helping investors to reduce the investment threshold, subsidising PV installations to minimise upfront capital input and reduce the financial cost. The possibility of achieving public funds at a lower cost has become a central issue, making it necessary to examine the efficiency of the instruments used to promote PV [49]. Referential loans and tax incentives are also used to reduce power generation costs from renewables and overcome high upfront project costs [50]. In China, a specific fund was established to provide additional financial support for renewable energy development, including a subsidy of solar photovoltaic application in buildings [41]. In general terms, capital grants provide a valuable subsidy by mitigating the financial burden of renewable energy because they reduce the risk, increase the leverage of the investments, and enhance returns.

In this framework, R&D programs applied to renewable energy technologies are also helpful when they are based on a deterministic forecast of costs and performance of renewables [50]. Some examples can be found in Italy, where a public program provided financial support, up to 75% of the total capital costs, to install a PV system with peak power between 1 and 20 kWp [41]. However, it must be considered that the evolution of technology (installation cost reduction, larger storage capacity devices) will benefit the economic savings, entailing the need to review the financial aids.

Avril et al. [49] pointed out the necessity of a controlled level of expenditures and balanced allocation of the public support for PV when analysing the subsidies in five representative countries (France, Germany, Japan, Spain and the US). They found that subsidies require matching the profitability of the model with minimum standards that make it attractive for potential investors. Thus, it is demonstrated that public funds can promote self-consumption development [51]. As a summary, Table 1 shows the authors that analysed financial decisions and financial resources applied to renewables at a small scale.

Table 1. Main studies focused on investment and financing decisions of financial resources applied to renewables at a small scale.

Investment Decisions	
Investment volumes	[8,11,48,50,51]
Cash Flows: Financial aspects of energy prices and tariff (regulation)	[41,44]
Return of the investments and uncertainty about the cash flows	[12,13,23,25]
Financing Decisions	
Availability of capital	[52–54]
Financing conditions	[13,14,27,36]
Capital cost	[28–31]
Financial incentives and public funds	[12,14,28,43,44,49,50,53,55]
Alternative financial sources	[24]

Balcombe et al. [7] present the results of a simulation of 30 households with different energy demand profiles in the United Kingdom. Gimeno et al. [52] study 35 photovoltaic self-consumption installations in Spain during 2016 and 2017 to analyse information about their technical characteristics and economic and financial aspects.

From another perspective, Li et al. [50] analyse the policy effectiveness of economic instruments for PV using a panel dataset of yearly data from 1996 to 2013 for EU countries. Additionally, in the EU, Mir-Artigues and Del Río [45] propose a financial model to provide an economic analysis of the combinations of investment subsidies and soft loans applied to renewable electricity. In addition, Cucchiella et al. [44] evaluate the profitability of PV systems in the residential sector in Italy using a mathematical model. Finally, in the same country, Palmer et al. assess the evolution of residential PV systems over the 2012–2026 period through a model structure [13].

After this literature review, it can be concluded that there are two main gaps regarding investments in self-consumption. First, there is a general lack of detailed analysis of the characteristics of those specific financial resources needed for the investments in renewables at a small scale that will involve an increasing number of investors in the short term. Second, previous studies have been focused on financial theories and do not offer a specific analysis of the influence that alternative financial sources can display in the decision-making process. Therefore, the following research question is considered:

RQ1. What are the characteristics of the financing sources used to invest in self-consumption?

Based on the characterisation of the financial sources mobilised for self-consumption, these investments′ decision-making will be subsequently analysed.

2.2. Decision-Making Investment

The adoption of innovative systems in a territory is determined by different elements identified in the literature, such as the intrinsic characteristics of innovation, the structure of the social system where adoption occurs, the dissemination and level of information in the territory, and the time frame of the innovation [55,56]. In particular, the decision to invest in self-consumption facilities is influenced by several types of factors. Most of them are linked to the profitability of the investment and the impact on risk [8].

Profitability will be affected by the investment size, the economic horizon and the savings otherwise linked to self-consumption and surplus management.

In a framework of the energy transition, risks will be related to the dependence on the power network, the volatility of electricity prices and environmental impacts. Needless to say, self-consumption is still an immature technology with room for improvement, with more efficient systems and lower cost [51], and regulation is accepted to be influential on the assessment of the expected savings.

At present, motivations for installing microgeneration are a field of debate. The decision to install PV systems in Mediterranean areas is influenced by economic issues such as the volume of household income or the rates of return of the investment and the environmental benefit, communication with other agents, and technology diffusion [8,13]. Therefore, it is necessary to add motivations for the investors in PV other than the energy dependence reduction to minimise the increasing energy supply prices.

In the case of self-consumption, the perception of households of the environmental component of these facilities may be relevant for the investment assessment. In addition, the concern about the risk of an imminent "energy gap" over the following years may further increase the motivation of households to be self-sufficient and avoid increasing power cuts [7,14]. Some authors show that improving the environment is a far greater motivation for adopters than rejecters [7]. In a different position, Palmer et al. [13] affirm that the adoption decision is assumed to be influenced by the payback period of the investment, its environmental benefit, the household's income, and communication with other agents. As a result, small coefficients for the payback period weight indicate that innovators are willing to take more risk. Thus, in a rational evaluation of the economics of the investment opportunities, various non-financial factors affect the decision to invest in renewables [12].

In addition, trade credit financing has a significant positive impact on sustainable growth because private enterprises generally encounter credit constraints and have harder access to bank loans [53]. Unfortunately, the existing literature does not seem to have shed light on all the economic–financial factors that influence investment decisions in self-consumption. This study tries to cover this gap through a second research question that has been defined as follows:

RQ2. What are the economic–financial factors that influence decision-making for self-consumption?

Given that other agents may take part in investment decision-making, a section of this study is proposed to analyse the role played by installers in fostering the investment in self-consumption.

2.3. The Role of Installers and Alternative Sources

Within a restrictive policy of access to new loans context, one of the barriers faced by self-consumption investors is the limitation of the sources of financing to undertake this investment. Furthermore, an inadequate adaptation of the traditional credit instruments offered by financial institutions can affect their final profitability [54]. Thus, the insufficient adjustment between the repayment terms and the return rate of the financed investments [35] can increase its cash flow risk and endanger its survival if the repayment terms focus on the short term and the rates of return are longer.

It should also be mentioned that access to financing formulas offered by financial institutions requires the fulfilment of specific solvency parameters by borrowers [35], whether they are homeowners or SMEs. This financing mechanism is highly exposed to economic recession scenarios in which cash flow restrictions are marked. As numerous public grants depend on the budgetary figures, the possibility of accessing alternative arrangements outside the traditional ways becomes a driver for the transition to the new model. However, the possibility of accessing other channels to finance these investments is still underexplored [57,58]. Thus, the professionals involved in installing self-consumption systems are an enabler of financial resources for investors. The mediation of the installers allows the commercial operation to be temporarily linked to the loan maturity and offers a different and simplified process and scoring compared to the traditional banking model.

Within the financing of trade credit theory framework [59], suppliers are willing to finance the operations to their clients, considering its financial repercussions (financial profitability and impact on the credit risk to the provider). Moreover, trade credit reduces the problem of asymmetric information associated with bank financing since private communication between suppliers and customers is incorporated [34]. Additionally, they could both do it like that if this improves their commercial relationship [60], contributing to its consolidation, taking advantage of the synergies between infrastructure and climate finance [61]. Thus, the different mechanisms applied to self-consumption can contribute to its penetration, even eliminating the barrier of resource scarcity for potential investors and providing alternative financing sources to traditional ones offered by financial intermediaries.

In this line, Burkart and Ellingsen [59] and Mateut and Chevapatrakul [62] associate a negative relationship between the financial strength of customers and the financing use of their suppliers. Thus, simplifying investment resource access favours adopting this technology and models in which the disbursement or ownership of the investment in this type of facility can be deferred and would drive the adoption of this technology [14].

Installers make the process easier for investors, who may have difficulties accessing traditional financing to invest in self-consumption because they have a weaker position to meet credit requirements. This relation allows them to take advantage of both the technical knowledge of the installations financed through the installers and the associated commercial and operation funding terms. O'Shaughnessy [58] points out that the complexity associated with the financial transaction, from a legal, administrative and financial point of view, exceeds the small-scale company capacity, thus contributing to the market concentration. Likewise, requirements of these formulas allow the attraction of new investors [57], and installers can be a driver by becoming a financing enabler as an alternative to bank intermediation.

However, the role of installers contributing to the elimination of financial barriers is still poorly studied in the literature. Thus, given the previous reflections, the following research question is defined to broaden the knowledge about alternative financing sources and how other agents take part in the decision-making in self-consumption investments:

RQ3. What role do installers play in decision-making and accessing financing in self-consumption investments?

The study case that was carried out to obtain the contributions both for academics and practitioners is described in the following section.

3. Methodology

The analysis was carried out in the case of Spain, as an EU country in which self-consumption has experienced some delay compared to other Member States [8]. Spain exemplifies the development of renewable energy, particularly in photovoltaic solar energy, influenced significantly by public regulation [63]. Likewise, this country represents an interesting case due to the entry into force of the national regulation to allow self-consumption in Spain [63,64], and administrative, technical and economic conditions of these facilities are regulated. It is also identified the fundamental role that installers play in the penetration of this type of facility in countries like Spain, where self-consumption development has experienced numerous barriers [8].

At this point, it should be added that the decision-making information of small consumers cannot be collected through databases. Therefore, a qualitative methodology development is required to analyse and collect information in the territory, which can only be obtained through a case study.

To this end, a broad professional network was involved in the empirical work and data collection. In addition, installers who had directly and indirectly promoted self-consumption in the region, either by selling customised electricity supply for customers or budgeting a self-consumption installation provision, were asked to complete a questionnaire (Appendix A).

For this case study, answered questionnaires were collected in 2018 during training activities specifically aimed at professionals and small-scale renewable energy installation companies. The primary purpose of the training sessions was the specific qualification of professionals to contribute effectively to the promotion and installation of self-consumption facilities in the Spanish territory. A total of 8 sessions of 4 h were delivered in the framework of a training programme funded and led by a national retail energy company with an average of 30 participants per session.

The surveys were designed to obtain specific data for an in-depth analysis of the main characteristics of the financial resources used in self-consumption investments and collect primary data about the installers' role in promoting this type of facility (Table 2). In addition, the decision-making investors and the financial barriers faced in Spain were explored.

Table 2. List of variables of the survey of self-consumption installers.

Variable	Variable Type	Description
CODE	Numerical continuous	Survey alphanumeric code
SES	Discrete	Training location
AGE	Numerical continuous	Respondent age
GEN	Dichotomous	Respondent gender
LAB	Dichotomous	Respondent employment situation
TRA	Discrete	Respondent qualification
EXP	Numerical continuous	Respondent professional experience as an installer
POS	Discrete	Respondent job
TYPE	Discrete	Mostly executed installation type
CMAT	Discrete	% average cost dedicated approximately to the material and equipment purchase necessary for the installation
GRA	Continuous	% public aid received on average
COS	Discrete	Average cost EUR/Wp of the total self-consumption facilities executed by the respondent
FIN	Discrete	Primary financing source used by clients for the facilities payment
EXT	Numerical continuous	The average percentage of external financing applied to the facilities
B01–B10	Discrete (Likert from 0 to 5, with 0 being not relevant, 5 highly relevant; NA)	Assessment by the installer of the relevance of barriers in Spain for self-consumption installations: Regulation; Distributor administrative procedures; Installation complexity; Lack of interest of the client; Installation maintenance; Prices of photovoltaic modules; Cost of the batteries; Financing difficulties; Payback period; Investment volume

Table 2. *Cont.*

Variable	Variable Type	Description
I01–I10	Discrete (Likert from 0 to 5, with 0 being not relevant, 5 highly relevant; NA)	Assessment by the installer of the relevance of possible incentives for self-consumption installations in Spain: Regulation changes; Administrative procedure simplification; Installation incentives; Development plans; Environmental awareness; Facilities' price reduction; Tariff reduction; Network connection rate reduction; Public grants and incentives; Electricity price rise; Reduction in maintenance costs
SA	Dichotomous	Economic saving estimates in executed installations
ENV	Dichotomous	Emissions saving estimates in executed installations
C.11-C.15	Discrete (Likert from 0 to 5, with 0 being not relevant, 5 highly relevant; NA)	Assessment by the installer of the relevance of different factors in investment decision-making in self-consumption in Spain: Environmental improvement; Energy/economic savings; Type of building; Property; Technical knowledge; Other facilities nearby

The surveys were delivered at the end of the training sessions. They were answered voluntarily and anonymously by 90 of the 243 participants (37%), which can be considered a representative sample of the analysed group. Eighty-one observations of the collected surveys were valid, and 10% of the respondents were women. Thus, the profile of the respondents combines 84% of self-employed persons and 16% of employees. In terms of training, 52% had a Compulsory Secondary Education Certificate, and 36% were university graduates, aged between 20 and 55 years and with a level of professional experience of more than 20 years in most cases, while 7% of respondents had been working for less than ten years (Table 2).

The installed self-consumption systems by the respondents are distributed among isolated facilities without network connection (77%), connected facilities without selling the surplus to the grid (15%) and other facilities (8%). Their clients were from the agricultural sectors—23%—(mostly isolated facilities for irrigation systems), domestic prosumers—31%—and secondary and tertiary sector companies—46% divided into 30% isolated, 8% connected without selling to the grid and 8% of other types.

4. Results

The first phase of analysis is based on the installers' answer data regarding the barriers in Spain for self-consumption.

The barriers can be classified into two types (Figure 1): technical or regulatory (regulation, administrative procedures, the complexity of the installation, lack of interest of the client, installation maintenance), and economic–financial (PV module price, cost of batteries, financing difficulties, investment rate of return, investment volume).

Barriers for self-consumption	%	Average value	Std. Dev.
B.03) Prices of photovoltaic modules	18%	2.4	1.17
B.04) Cost of the batteries	52%	3.5	1.07
B.05) Financing difficulties	41%	3.1	1.31
B.06) Investment rate of return	53%	3.5	1.16
B.10) Initial investment	71%	3.8	1.06

Figure 1. Results of the survey to gather the installers' opinions about the economic–financial barriers to self-consumption development in Spain.

The average and the frequency of the obtained responses were calculated for each variable. The percentage of answers with the highest levels of relevance (ratings of 4 and 5 on a 0 to 5 scale) was also calculated.

Based on their experience with prosumers, 71% of the surveyed installers consider that the factor that slows down the deployment of these installations the most is the high investment volume (Figure 1). The second relevant barrier set by 53% of respondents is the investment rate of return. It is also noted that the price of the batteries has the most significant impact among the components of investment (52%) and no longer those of PV modules (18%). Finally, the problematic access to financial resources (41%) is also very relevant.

Concerning economic–financial drivers, the analysis shows that any measure that improves the competitiveness, such as tariff modifications (82%), a reduction in the price of the components (67%) or a rise in the cost of the electricity (61%), is a powerful incentive for self-consumption deployment.

Among the drivers with the highest significant impact on these facilities' deployment, the reduction in investment through subsidies is pointed out by 76% of respondents (Figure 2).

Drivers for self-consumption	%	Average value	Std. Dev.
I.03) Facilities prices reduction	67%	4	1.05
I.04) Network connection rates reduction	82%	4.3	0.85
I.05) Public grants and incentives	76%	4.2	1.08
I.06) Electricity price rise	61%	4.9	7.42
I.09) Reduction of maintenance costs.	30%	2.9	1.26

Figure 2. Results of the survey to gather the installers' opinions about the economic–financial drivers to self-consumption development in Spain.

This first approach to the questionnaires confirms the expected relevancy of the economic–financial aspects of the self-consumption investments.

As summarised in Table 3, more than 50% of the prosumers financed their installations with their own sources.

Table 3. Information provided by the installers about the primary financing sources used for self-consumption facility investments in Spain.

Main Financing Source	% Facilities
Own financing	54%
External financing	38%
Others	8%

The requested average external financing from credit institutions is very high (80%), with around 50% provided by the retail energy company when this is considered the primary external source of investment financing. The collected information shows that the facilities receive some public grants or subsidies (38% of the facilities) in more than a third of the cases. This means that the government supports approximately 35% of the self-consumption investment (Table 4). It is worth mentioning that prosumers employ more than one source in many cases during the investment period, in line with Mazzucato and Semieniuk [37].

Table 4. Information provided by the installers about the primary sources of external financing used for self-consumption facility investments in Spain.

Financing Sources	% Facilities	% Funded
External financing (credit institutions)	19%	80%
External financing (retail energy company)	19%	52%
Grants and subsidies	38%	35%

Some differences can be observed among prosumer profiles. As Figure 3 shows, prosumers of the agricultural sector use mostly external financing (credit institutions and instruments provided by the retail energy company); however, domestic prosumers mostly use their own funds. Remarkably, leasing is used in isolated facilities without a network connection (Figure 3).

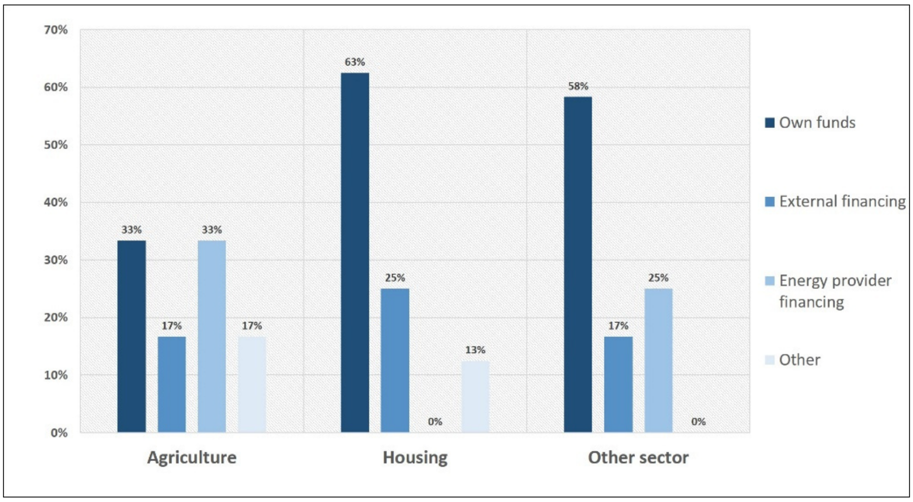

Figure 3. Information provided by the installers about the primary financing sources used for self-consumption facility investments in Spain.

Delving deeper into the first research question posed in this study (RQ1), the primary financial sources for these facilities are their own funds. In other cases, they are externally financed through credit institutions or provided by the retail energy company, subsidies or public aid and, finally, other sources and instruments (for example, leasing).

Interviewees were also asked to rate the main factors that influence the investor decision-making, and Figure 4 summarises the obtained results as the answer to RQ2. As it can be seen, energy savings and economic savings are the major contributing factors to investment decision-making (Figure 4).

Assigned value	Environmental improvement	Energy / economic	Type of building	Technical knowle	Other facilities nearby
0	0	0	0	0	0
1	1	1	0	0	0
2	4	0	4	6	3
3	12	3	9	8	8
4	6	14	8	8	11
5	3	8	5	4	4
Average	3.2	4.1	3.5	3.4	3.6
Median	3	4	3.5	3	4
Mode	3	4	3	3	4
Typ. Dev.	0.99	0.89	0.99	1.02	0.90

Figure 4. Main contributing factors on the investment decision-making in self-consumption.

Through the data collected, the role exercised by the installers in both the promotion of self-consumption systems and in the electricity supply in grid-connected facilities is also remarkable. More specifically, the intervention of the installer is decisive in the prosumer decision-making (RQ3) in terms of the estimated saving that can be obtained with self-consumption, being one of the most relevant aspects for investors (Table 5).

Table 5. Information provided by the installers about energy and estimated economic savings obtained through the self-consumption facilities.

		% Estimated Saving		
Estimated Economic Saving	**Not Calculated**	**20%**	**25%**	**30%**
The prosumer does not require estimated saving	27%			
The prosumer requires estimated saving		35%	31%	8%

In the analysed case study, the function of the collaborative business model operation stands out: installers have continuous participation with the retail energy company promoting the facilities. These installers combine both a commercial and technical job and maintain a relationship with the prosumer over time through contracting energy supplies and facility maintenance. In addition, through the information collected, we can highlight the proactive role exerted by the self-consumption installers, in both technical and economic–financial terms, within the energy company, offering alternative instruments in financing or co-financing.

As detected from the collected information, self-consumption faced several legal barriers in the territory and a traditional need for awareness campaigns for renewables' depletion [65]. Consequently, investors carried out investment in self-consumption facilities using their own funds and external financial resources from the retail energy company, thanks to the installers. These alternative financial mechanisms or ways allow them to solve the lack of financial resources by adapting to the nature of the investment, simplifying the process and reducing the traditional financing procedures (Figure 5).

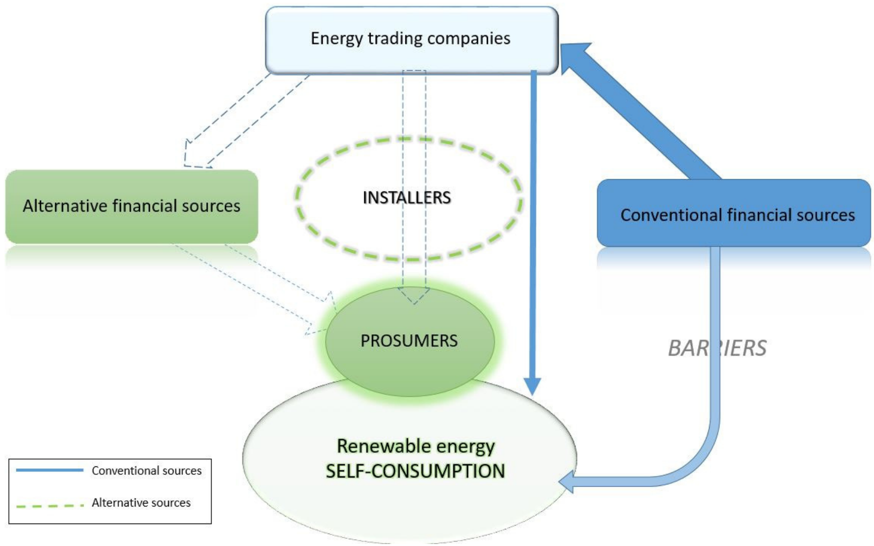

Figure 5. Graphical description of the alternative financing mechanisms.

In a more favourable regulatory framework (than the current one in Spain), the role played by the installers will take on even greater relevance as a mechanism to facilitate the energy transition, allowing a greater expansion of self-consumption facilities in Spain. This growth will also imply the need for retail energy companies to seek alliances to increase the fund volume requested by investors, which could be obtained through new frameworks within collaborative fund management or even through traditional financial institutions. These results are mainly correlated to previous studies focused on financial resources and incentives for renewables of Balcombe et al. [7], Gimeno et al. [8] and Plewnia [9]. In addition, these results are in line with Huang et al. [53], who demonstrate that trade credit can also be used as an effective alternative mechanism of bank credit to ease the financing constraints for the enterprise.

In summary, the main factors determining the profitability of PV installations are solar irradiation intensity, the share of self-consumed electricity, installation costs, financing costs and electricity prices [24]. Not only the resource availability influences the deployment of self-consumption. Thus, the results of the case study analysed could be applied to other European and non-European regions promoting these energy solutions if they want to overcome the financial barriers.

5. Conclusion and Policy Implications

This article analyses the economic–financial problems these small-scale renewable energy systems pose for investors and the active role that installers play in investment decision-making through a qualitative analysis of self-consumption implementation in Spain. The obtained data allow a novel analysis of self-consumption's inherent aspects, previously unexplored and complementary to the prior studies. First, the mediating role of installers is also analysed for the self-consumption installation implementation as an example of small-scale renewables deployment in a territory. Further to this, the incorporation of non-energy services, such as alternative financing channels, into the process of self-consumption expansion for energy sustainability is analysed.

Through the analysis of the information provided by the installers, the relevance of the availability of different financial channels is shown (traditional or alternative) to access the financing sources necessary to undertake the investments. In economic terms, the main barriers of the investment can be summed up in the uncertainty of rates of return, investment volumes (still high due to storage equipment cost), and difficulties in accessing financing for small investors and companies.

The results also highlight that alternative financial sources are a mechanism to reduce the existing barriers and the active role of the installer, helping the energy transition and the deployment of renewables at a small scale. From a theoretical perspective, we can observe that trade credits serve as a significant financing source for the sustainable growth of self-consumption in a circular model. For academics, it is a contribution within the framework of theory regarding the definition of non-financial services as resources for prosumers. Furthermore, it is a new vision of trade credits since a volume of financial resources is made available to prosumers through non-financial channels, increasing the available volume and investment.

Based on the definition of the financial sources applied to self-consumption, its impact on investor decision-making is analysed as one of the contributions of this study. These results partially fill a gap in the literature, providing a detailed analysis of the characteristics of those specific financial resources needed in the decision-making process for investments in sustainable energy at a small scale that will involve an increasing number of investors in the short and medium term. In addition, a clear vision of the influence that alternative financial sources can display in the decision-making process and in the banking disintermediation to withdraw funds from intermediary financial institutions for the deployment of renewables is also provided. Finally, yet importantly, this study tackles other aspects that could hinder the investment in sustainable energies, such as the lack of financial appreciation or inadequate valuation.

As a general reflection, it should be underlined that renewable policies must focus on self-consumption and microgeneration by increasing the availability of financial resources and alternative financing sources appropriated to the investment size and requiring simplified procedures and lower guarantees, when necessary. As a possible priority, self-consumption promotion could be considered through co-financing models such as the analysed one in this case study. The retail energy company could provide financing to prosumers for grid-connected facilities and training the installers.

Regarding public administration, it follows from the analysis that the high cost of some equipment actuates a scheme of incentives or aids to favour the current extra cost derived from storage. On the other hand, actions must ease the access to financial resources from bank intermediation to the extent that they reduce the risk of the operation being financed. In addition, innovative policy measures have to be developed to introduce a sharing culture in the CE model and educational strategies are needed to combine zero-emission technologies with the circular principles.

Our research sheds new light on the economic–financial and behavioural factors that determine the penetration of renewables by increasing the number of retail investors in the territory. The achieved results have important implications for both investors and policymakers, suggesting that distributed renewables still suffer from a series of biased perceptions and barriers that favour status quo financial resources over alternatives. An upgrade for legislation could include specific financing schemes for a household to overcome the barriers to financing the investments in self-consumption.

This study, whose limitations are mainly associated with the territoriality of the analysis and the number of surveyed installers, provides new lines of future research to deepen the characterisation of alternative financing resources in other territorial areas and applied to different sustainable technological solutions. However, this study offers a methodological contribution to the novel approach of analysing decision-making from the perspective of installers and professionals that could be applied to other geographical areas.

Author Contributions: Conceptualization, S.S., J.Á.G., P.P.-T. and E.L.-S.; Formal analysis, S.S. and P.P.-T.; Investigation, S.S., J.Á.G. and P.P.-T.; Methodology, S.S. and E.L.-S.; Resources, J.Á.G.; Writing—original draft, S.S.; Writing—review and editing, S.S., J.Á.G., P.P.-T. and E.L.-S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: This study was cofinanced within the research groups of the Regional Government of Aragón, Ref. S33_20R and T46_20R and was elaborated thanks to the support of the CIRCE Research Institute. The collaboration with FENIE ENERGIA, S.A., for the empirical study is particularly acknowledged. We want to express our gratitude to Miguel Marco-Fondevila and Jesús Valero-Gil for their contribution to the empirical study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Profile

Self-employed ☐ Employed ☐ Age ___ Gender:___ Education ______________________ | Professional experience:____(years)

Position: Director/manager ☐ Eng./technician or similar ☐ Installer ☐ Administration ☐ Other:____________________

Name and family name (optional):________________________ Company (optional):________________________________

Read carefully the following questions and select one of the values, taking into account that "0" means that the described factors are not relevant, and "5" means that they are very relevant ("NA" means that you do not know or do not answer).

BARRIERS		*No relevance or little relevance*				*Very relevant*		
B.1	To what extent is the REGULATION an obstacle to self-consumption installations?	0	1	2	3	4	5	NS
B.2	To what extent do THE FORMALITIES with the electricity distribution company hinder self-consumption?	0	1	2	3	4	5	NS
B.3	To what extent is the PRICE OF THE PHOTOVOLTAIC MODULES an obstacle?	0	1	2	3	4	5	NS
B.4	To what extent is the PRICE OF THE BATTERY an obstacle?	0	1	2	3	4	5	NS
B.5	To what extent is the difficulty of obtaining FINANCING an obstacle to installation?	0	1	2	3	4	5	NS
B.6	To what extent does THE PAYBACK PERIOD OF THE INVESTMENT hinder self-consumption?	0	1	2	3	4	5	NS
B.7	To what extent does the COMPLEXITY of the facilities hinder self-consumption?	0	1	2	3	4	5	NS
B.8	To what extent does the lack of INTEREST on the part of customers hinder self-consumption?	0	1	2	3	4	5	NS
B.9	To what extent does subsequent MAINTENANCE hinder the installation of self-consumption?	0	1	2	3	4	5	NS
B.10	To what extent is the high volume of initial INVESTMENT an obstacle to self-consumption?	0	1	2	3	4	5	NS

INCENTIVES		*No relevance or little relevance*				*Very relevant*		
I.1	To what extent would a substantial change in LEGISLATION encourage self-consumption?	0	1	2	3	4	5	NS
I.2	To what extent would simplification of ADMINISTRATIVE PROCEDURES encourage self-consumption?	0	1	2	3	4	5	NS
I.3	To what extent would lower TECHNOLOGY PRICES increase self-consumption?	0	1	2	3	4	5	NS
I.4	To what extent would the downgrade of network CONNECTION RATES involve more installations?	0	1	2	3	4	5	NS
I.5	To what extent would SUBSIDIES encourage self-consumption?	0	1	2	3	4	5	NS
I.6	To what extent would rising the PRICE OF ELECTRICITY mean more self-consumption?	0	1	2	3	4	5	NS
I.7	To what extent would making easier the INSTALLATION PROCESS increase self-consumption?	0	1	2	3	4	5	NS
I.8	To what extent would INFORMATION CAMPAIGNS encourage self-consumption?	0	1	2	3	4	5	NS
I.9	To what extent would lower MAINTENANCE COSTS increase self-consumption?	0	1	2	3	4	5	NS
I.10	To what extent would greater ENVIRONMENTAL AWARENESS facilitate self-consumption?	0	1	2	3	4	5	NS

FACILITIES *or little relevance* *relevant*

Type) What type of facilities has you installed?

Price) What medium price had facilities you executed?

Costs) What is the % average cost dedicated approximately to the material and equipment purchase necessary for the installation?

Grants) What is the % of public aid received on the average?

Total) Average cost € / Wp of the total self-consumption facilities executed

Average % of external financing received by prosumers: ____________%	Average % of public grants received by prosumers for financing the investments: ____________%	Average size of the installations executed (peak power): ____________kWp

Please indicate if some of the following calculations were performed in the installed facilities				
Economic saving obtained through the facility	☐ Yes - Estimated percentage _____ (% €)		☐ *NO*	☐ *NS*
Emission saving obtained through the facility	☐ Yes - Estimated percentage _____ (%Co_2)		☐ *NO*	☐ *NS*

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3 Parte tercera. Conclusiones

3.1 Consideraciones finales

El autoconsumo de energía proporciona una solución viable al reto de descarbonización y permite a particulares y empresas hacer previsibles una parte o la totalidad del coste de la electricidad, despreocupándose en esa cuota de la volatilidad del precio del mercado. Representa actualmente una opción tecnológica fiable y sencilla para producir energía a un precio razonable de adquisición y con unos costes de operación y mantenimiento previsibles. Por la naturaleza multidimensional del reto climático al que nos enfrentamos, la complementariedad de tecnologías renovables es definitivamente necesaria y el autoconsumo va a tener un papel relevante en la estrategia para alcanzar los objetivos comprometidos de descarbonización y seguridad energética.

En la actualidad, el constante aumento del precio de la electricidad predispone al prosumidor tanto a buscar sistemas que le proporcionen ahorros económicos en la factura como a la instalación de tecnologías que le permitan mayor autonomía de la red.

A partir de los resultados alcanzados en la presente investigación, se corrobora que el factor económico sigue siendo crucial para el proceso de decisión en estas inversiones. No obstante, queda también demostrado que el autoconsumo fotovoltaico permite dotar de electricidad a consumidores que, o bien la generaban con grupos electrógenos o pagaban el coste de oportunidad de no tenerla, aun con altos costes de instalación y largos períodos de retorno. Aunque el criterio económico (consecución de ahorros) siga siendo muy relevante, otros factores influyen cada vez en mayor medida en la decisión, como la rentabilidad basada en el período de retorno, así como los costes iniciales de la instalación debido al acceso a la financiación, que se demuestran determinantes cruciales, una vez superada la barrera económica.

A este respecto, en la Tesis se abarca un ámbito de estudio poco explorado hasta la fecha analizándose los recursos financieros de aplicación en estas inversiones. Por tanto, se pone de relieve la importancia de que se estimulen instrumentos de financiación bien mediante incentivos públicos (con créditos blandos o con ayudas para reducir la inversión inicial), bien facilitando su acceso a través de canales alternativos a las instituciones de crédito habituales, que a su vez, estén simultáneamente comprometidos y conectados en el desarrollo de la instalación y faciliten así la comunicación, reduzcan las condiciones y documentación para validar al cliente ante el riesgo de impago y disminuyan la información asimétrica que puede aparecer al contar con un tercero.

Por otra parte, en la Tesis queda expuesta la financiación movilizada para sistemas de autoconsumo fotovoltaico en España, señalando la falta de ayudas públicas a la inversión en numerosas instalaciones. A su vez, queda patente a través del análisis realizado, el impacto positivo de incentivos económicos específicos en el futuro próximo para fomentar un despliegue intensivo del autoconsumo fotovoltaico a pequeña escala en España, atendiendo a los objetivos fijados por la transición hacia una sociedad descarbonizada en la UE y a los principios de la EC. Esto permite el desarrollo de escenarios para el diseño de una política para el autoconsumo a pequeña escala, como una de las conclusiones significativas de esta Tesis. De igual manera, cabe aquí mencionar la falta de directrices y estrategias nacionales en lo que hace referencia a objetivos de potencia instalada a nivel territorial o por Comunidades Autónomas, o por tecnología, con un marco de incentivos e instrumentos motivadores, entre ellos los financieros, que mejoren la confianza de los inversores.

La falta de políticas específicas para la promoción del autoconsumo fotovoltaico a pequeña escala es clave en muchos aspectos, y en esta Tesis queda demostrada su necesidad y desarrollados sus elementos axiales a tener en cuenta: una regulación estable y facilitadora para la instalación de sistemas fotovoltaicos; una adecuada promoción e información para ayudar a mitigar la barrera de la incertidumbre de la tecnología por su carácter todavía innovador para muchos potenciales prosumidores; el papel desempeñado por los instaladores en demostrar la fiabilidad de las instalaciones, explicando la existencia y estimación de ahorros económicos y la ventaja que otorga el ganar autonomía con respecto a la red apantallando una parte del precio de la electricidad.

Sobre el primer aspecto axial anteriormente citado, la Tesis acredita la importancia del factor regulatorio. Así, y fundamentando en la opinión de los instaladores y prosumidores y del estudio comparado y escenarios evolutivos del marco regulatorio expuesto en el tercer artículo de esta Tesis, se justifica que apoyar mayores facilidades de la legislación y en las condiciones de medida, conexión y acceso a la red son claves para la difusión de esta tecnología. Aun teniendo en cuenta el cambio favorable en la legislación española con la aprobación del Real Decreto-ley 15/2018 y del Real Decreto 244/2019 de Autoconsumo, la Tesis señala también la necesidad de estabilidad y de facilitar la sencillez en las condiciones administrativas de acceso y del indispensable desarrollo en aspectos como el autoconsumo colectivo o sobre la participación en la titularidad y operación de la planta por parte de un tercero.

Como se ha citado anteriormente, la Tesis ha abordado el proceso, ponderación y secuencia de aparición de los factores determinantes en la decisión de invertir y así, tras la aceptación del coste económico y resuelto el acceso a financiación, entran en juego otros factores cuya importancia se considera muy alta en la encuesta a los prosumidores. En consecuencia, esta Tesis acredita que en el proceso de decisión intervienen tanto factores contextuales como actitudinales o psicológicos y, por tanto, el diseño de políticas públicas o estrategias de difusión comerciales tendría que tener en cuenta ambas tipologías de factores sin descuidar ninguna de ellas.

Finalmente, esta Tesis pone de manifiesto la importancia del rol que juega el instalador en la difusión de este tipo de tecnología, para proporcionar información sobre la inversión y la instalación y, por otro lado, su función en el proceso de decisión, desde la misma recomendación y exposición de alternativas de ahorros, planteamiento de propuestas con los criterios de económicos, la difusión de mensajes referentes a la concienciación medioambiental, de fiabilidad y sencillez en la operación y mantenimiento y en el ofrecimiento de canales alternativos de financiación, alcances que encajan con su desempeño y experiencia profesional.

En consecuencia, el incremento e intensificación de marcos formativos sobre este tipo de sistemas tecnológicos combinados con el entendimiento de los factores determinantes y de la secuencia ponderada del proceso de decisión, junto con una regulación facilitadora que permitiera su desarrollo comercial y técnico pueden ayudar a incrementar la difusión del autoconsumo mediante estos actores privilegiados. De igual manera, la Tesis sugiere que el instalador incorpore soluciones de autoconsumo fotovoltaico financiadas dentro de su porfolio técnico-comercial, alineadas con su proceso venta y de comunicación con el potencial prosumidor, sin necesidad de dar entrada a un tercer facilitador del instrumento de financiación.

Estas conclusiones y resultados son aplicables también a procesos de introducción tecnologías y proyectos de eco-innovación o de economía circular por sus similitudes con las tecnologías de energías renovables a pequeña escala.

3.2 Implicaciones de la Tesis

En este contexto, en esta Tesis se realiza un avance en el conocimiento a través de la modelización del proceso decisional de inversiones en autoconsumo, profundizándose en el análisis multinivel de los determinantes que influyen en la toma de decisiones en cuanto a amplitud de factores y en la interrelación entre ellos de una forma holística que no se había alcanzado en estudios anteriores.

Desde un punto de vista teórico, esta Tesis amplía el conocimiento sobre qué factores son los determinantes en la resolución de invertir en una instalación de autoconsumo, su preponderancia y secuenciación durante el proceso decisorio teniendo en cuenta tanto los contextuales como actitudinales. Además, aporta una valoración sobre la predominancia y jerarquía en términos de incentivos y barreras que aparecen en el proceso de decisión de invertir y cómo se contraponen entre ambos.

En el ámbito académico, esta Tesis representa una aportación a la literatura al ampliar el conocimiento sobre los determinantes y barreras a las que se enfrenta un potencial inversor en un sistema de autoconsumo fotovoltaico a pequeña escala en España. Este trabajo doctoral ayuda a posicionar y valorar de forma ponderada los factores de decisión, estableciendo una jerarquía y oportunidad entre dichos determinantes, así como su preponderancia en una categorización organizada, y a evaluar la fuerza de contraposición entre factores antagonistas. Los resultados alcanzados a través de esta Tesis contribuyen a suplir las limitaciones de enfoques y estudios precedentes al incorporar conclusiones sobre cómo mejorar el despliegue del autoconsumo fotovoltaico a pequeña escala en España bajo el prisma de prosumidores e instaladores de esta tipología de instalaciones.

Para los *practitioners* y los prosumidores esta Tesis proporciona un marco de análisis inédito desde una perspectiva holística que toma en consideración la reducción continua de los costes de las instalaciones (especialmente por el descenso en el precio de los módulos fotovoltaicos), el papel desempeñado por los instaladores y los incentivos que pueden introducirse y contrarrestar la barrera inicial que representa el coste de la instalación si se acompaña también con estímulos como campañas de ayudas a la inversión (más de tres de cada cuatro de ellos las consideran entre muy y totalmente relevante). Los resultados obtenidos proporcionan información para empresas y profesionales cuyo sector de negocio incluya la promoción y ejecución de este tipo de instalaciones al ofrecer las claves determinantes e incentivos potenciadores para una resolución positiva de invertir en estos sistemas, explicando cómo, qué y cuándo sucede en el proceso de decisión.

Entre las principales implicaciones de esta investigación se destaca la necesidad de contemplar los determinantes económicos de forma prioritaria en la estrategia de las empresas, mediante una presentación de la información de la rentabilidad y montante de la inversión, junto con aportar un canal alternativo y asequible de financiación o ayuda a la inversión. Adicionalmente, se exponen que factores actitudinales, fundamentalmente basados en la confianza y simplicidad en la operación de la instalación, deben ser incorporados tras haber superado las barreras económicas y financieras en la primera fase de la decisión del inversor.

Para las administraciones públicas, los resultados aquí expuestos implican la necesidad de una definición y publicación de una estrategia nacional para el desarrollo del autoconsumo que aúne la disposición de un marco estable, permisible y más ambicioso en relación con la regulación normativa, técnica y de acceso, junto con la puesta en marcha de programas de incentivos financieros que faciliten la inversión y mejoren las posibilidades de introducción de equipos como los acumuladores. Adicionalmente, esa estrategia debería completar la presentación de los factores contextuales económicos y financieros, informados mediante otros canales, con una difusión y promoción de este tipo de sistemas mediante la información que incentive la confianza ante este tipo tecnologías y coadyuve en la decisión positiva de invertir.

Como última reflexión, la Tesis contiene claves sobre el papel de los instaladores en la facilitación del proceso decisorio que pueden ser utilizadas por las administraciones públicas para incrementar las oportunidades y ayudar a suplir las debilidades de este actor económico, así como por las mismas empresas instaladoras que pueden así mejorar sus estrategias comerciales y descubrir y potenciar sus fortalezas en la implantación de este tipo de sistemas.

3.3 Limitaciones y Perspectivas

La investigación llevada a cabo en esta Tesis presenta limitaciones mayoritariamente ligadas a la información específica de las tipologías de sistemas de autoconsumo fotovoltaico más implementadas a nivel territorial y, en particular, a los datos de tipo económico-financiero y más propios del proceso decisional por parte de los inversores. Se trata en gran medida de datos de carácter confidencial que escasamente se han podido analizar con anterioridad. A pesar de las dificultades que este tipo de análisis cualitativo supone, en esta Tesis se han podido paliar las principales limitaciones encontradas a través del acopio sistemático de datos de una variedad de fuentes complementarias.

Cabe mencionar que, en España, a pesar del cambio normativo que obliga a dar de alta en el Registro de cada Comunidad Autónoma aquellas instalaciones realizadas realizas en su territorio, el Registro Estatal de autoconsumo y su acceso a través del RADNE no incorporan a día de hoy datos actualizados de los sistemas de autoconsumo existentes. El Registro Estatal de Autoconsumo es clave, ya que sirve para poder evaluar si se está logrando la implantación deseada, analizar los impactos en el sistema eléctrico y el cumplimiento del PNIEC. La incompleta creación y puesta al día de dichos registros autonómicos impiden la actualización de datos del Registro estatal desde finales de 2018 lo que en definitiva complica la investigación.

En cualquier caso, a pesar de las limitaciones para conseguir datos estandarizados a través de Registros, en esta Tesis se han podido analizar en profundidad diversas instalaciones para conocer y tipificar sus características, por ejemplo, en lo que hace referencia al segmento prosumidor (doméstico, servicios o industrial), tecnologías utilizadas (fotovoltaica, eólica, cogeneración, combinaciones de ellas), sistemas individuales o compartidos, zonas climáticas, potencias instaladas, si son con conexión a la red o aislados, la posible incorporación de almacenamiento, proporción de titularidad de un tercero, etc.

Por otra parte, las modificaciones en el marco normativo producidas con las publicaciones del Real Decreto-ley 15/2018 y del Real Decreto 244/2019 han permitido pasar de un régimen jurídico muy restrictivo a otro favorable. Así, los cambios referentes a la eliminación del recargo por energía autoconsumida, facilidades en las configuraciones de medida, eliminación de limitaciones de potencia de generación instalada hasta la potencia contratada o los relativos al pago de cargos por la energía autoconsumida, entre otros, facilitan un mayor despliegue de este tipo de instalaciones. A partir de esta situación favorable, se plantea como línea de investigación pendiente la de conocer si dichos cambios han sido así percibidos por el potencial prosumidor o por los instaladores, y qué aspectos legales o normativos permanecen como barreras, y entre ellos, por ejemplo, los relacionados con licencias de obra, trámites de acceso y conexión, limitación de conexión a través de red próxima en menos de 500 m o conectadas a un mismo centro de transformación, complejidad administrativa (alta y registro industrial y con la distribuidora), ausencia de coeficientes dinámicos en sistemas colectivos o los referidos a aprobaciones en caso de instalaciones afectadas por la Ley de Propiedad horizontal. Además, parece conveniente incluir un análisis comparativo a nivel normativo europeo para ver tendencias de evolución próxima y posicionamiento de España.

En lo que se refiere a escenarios regulatorios más ambiciosos y adicionales a los presentados tras el análisis comparativo del tercer artículo de este trabajo de doctorado, cabe mencionar que esta Tesis no analiza las posibilidades y oportunidades de potenciales soluciones fotovoltaicas puesto que el autoconsumo a través de red de distribución se puede plantear actualmente en los tres supuestos que permite el Real Decreto 244/2019, y se da de facto, mayormente, en el de consumidores a menos de 500 m de la instalación de generación, ya que existe la posibilidad de vincular a un consumidor y su punto de generación mediante balances de físicos de energía y financieros. Adicionalmente, y por la tipología de edificación de las viviendas en España, el autoconsumo colectivo puede ser también una solución muy adecuada para dar servicio a clientes domésticos, a los servicios generales de las Comunidades de Propietarios e incluso a otros consumidores cercanos a la instalación. Las instalaciones de autoconsumo colectivo aparecen como un nuevo y segmentado área de interés para realizar un futuro estudio sobre las barreras e incentivos para su implantación, así como para analizar cómo diferentes esquemas de coeficientes de reparto (fijo, variables con distinta variabilidad) pueden afectar o incentivar la rentabilidad de dichos sistemas.

De igual manera, tampoco se analizan en la Tesis las Comunidades de energías renovables, introducidas en la legislación española a través del Real Decreto-Ley 23/2020, y el papel que podrían jugar, con el desarrollo adecuado, al plantear soluciones de autoconsumo hoy en día no permitidas, pero con altas rentabilidades esperadas y con interés explícito de potenciales prosumidores. Entre dichos factores regulatorios la Tesis no se extiende en analizar si por parte del prosumidor o del instalador el modelo de Empresas de Servicios Energéticas (ESCO) representa un enfoque atractivo para evitar al consumidor eléctrico los costes iniciales de la instalación y los recurrentes de mantenimiento, así como algunos de los riesgos inherentes a la titularidad de la instalación (regulatorios, de generación, comerciales, y de deterioro del activo) permitiéndole disfrutar de ahorro económico desde el principio. Además, sería necesario investigar lo paradójico que resulta la existencia de un número relevante de este tipo de empresas en España, mientras los datos de sistemas con esta configuración (un tercero propietario y promotor de la instalación) no tienen paragón con los números de implantación de otros países. A partir de las consideraciones anteriores, las futuras líneas de investigación podrían ser enfocadas en el factor de escala (a mayor tamaño de instalación, menor coste) como posible barrera de entrada, o los efectos que puede tener una propuesta de un contrato a largo plazo y su incertidumbre ya que pueden inhibir la decisión de inversión por parte del inversor.

Asimismo, puede señalarse como futura línea de investigación el análisis de las ayudas públicas que próximamente se irán publicando procedentes fundamentalmente de la UE a través de nuevos instrumentos como por ejemplo el denominado "NextGenerationUE" planteado para paliar los efectos de la pandemia por el COVID-19 e impulsar la recuperación económica, y que se concentrarán primordialmente en la transición climática y digital. Dado que la estrategia climática incluirá medidas del apoyo al autoconsumo, se abre una posible línea de investigación para comprobar la eficiencia de la implantación de los primeros planes en los sistemas que se instalen con el fin de poder impulsar sus ventajas y corregir sus defectos.

También, y relacionado con esta última línea de investigación, cabe exponer que la reducción del precio de las instalaciones de autoconsumo fotovoltaico, y en especial de los módulos, ha venido acompañada también por un descenso de los precios de los acumuladores. Resultaría potencialmente muy interesante incorporar estudios de rentabilidad de estas instalaciones con almacenamiento, actualizados con los costes de estas soluciones junto con las señales de precio que el nuevo sistema de tarifas eléctricas ha puesto en marcha desde el 1 de junio de 2021, analizando los períodos de retorno de la instalación y los ahorros que se producen con estos sistemas combinados. A partir de dichos datos, se pueden elaborar estrategias armonizadas con ayudas e incentivos para la introducción de sistemas con acumuladores, elementos que son una palanca incentivadora para la implementación de la tecnología de autoconsumo fotovoltaico para sistemas a pequeña escala.

4 Referencias

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