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Potencialidad de la energía geotérmica en España: Hibridación y aplicación en la industria

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Agradecimientos

A mi familia y a mi pareja

Resumen y Objetivos

Para acelerar la transición hacia un futuro energético sostenible y cumplir con el Objetivo de desarrollo sostenible número 7, energía asequible y no contaminante, en adelante SDG7, establecido por las Naciones Unidas, es necesario duplicar la cuota mundial de energía renovable para el año 2030. La sustitución de los combustibles fósiles por una proporción cada vez mayor de energías renovables tiene un efecto resultante en la reducción de las emisiones de gases de efecto invernadero, en adelante, GEI y de contaminantes atmosféricos.

En los últimos años debido entre otros factores a los avances en la tecnología y a los mayores volúmenes de producción se ha reducido el coste de las energías renovables en general, especialmente de las tecnologías de energía eólica y solar fotovoltaica. Ambas tecnologías recibieron apoyo político, en diversa medida, y experimentaron un rápido aprendizaje tecnológico que condujo a una creciente confianza por parte de los inversores. No ha sido el caso de otras tecnologías renovables como la geotérmica que en los últimos años ha sido de las que menos desarrollo ha tenido pese a su gran potencial.

Precisamente la presente tesis pretende dar visibilidad a esta fuente de energía mediante el estudio de su potencialidad bien sola o en combinación con energía solar poniendo el foco en la aplicación industrial y de esta forma cubrir esa brecha de conocimiento.

Como punto de partida de esta tesis se identifican las barreras que dificultan la implantación de la energía geotérmica en España y en la Unión Europea y las medidas a adoptar para conseguir su difusión y su uso de forma habitual. Se ha seleccionado España dentro del contexto europeo debido a su escaso 0,1% [1] de mercado geotérmico en la demanda de energía primaria.

A continuación, y dado que el sector industrial es uno de los mayores emisores de GEI del mundo, se estudia cómo dicha energía geotérmica podría contribuir en este sector y en la industria de la desalinización en particular (dado su alto consumo energético y su necesidad en aquellas zonas donde el agua es un bien escaso].

Los resultados de la presente tesis arrojan unas cifras de 76% del tiempo anual se alimentaría una desalinizadora tipo MED con ambos recursos (solar y geotérmico) y el 100% del tiempo solo con geotermia para un pozo a mayor profundidad. Aplicando los resultados a las plantas desalinizadoras existentes del proyecto A.G.U.A, se obtiene un plazo de amortización de seis años y 510 387 920 kg/año CO_2 evitadas a la atmósfera por el conjunto de todas las plantas.

Más allá de la industria de la desalinización, se demuestra por medio de esta tesis que casi el 85% de los procesos industriales de toda la industria en España pueden llevarse a cabo con recursos geotérmicos de muy baja, baja y media temperatura. De esta forma se evitarían 80 millones de toneladas de CO_2 al año a la atmósfera y se

[1] En adelante en todo el documento de tesis los decimales se expresan con coma (,) en la parte escrita de texto en español atendiendo a la discrecionalidad recogida en *The international Systems of Units (Bureau international des Poids et Measures,2018)*

podría amortizar en un plazo razonable de 15 años la inversión en geotermia para los procesos industriales de hasta 45 °C.

Los resultados presentados en esta tesis demuestran que la energía geotérmica como fuente de energía renovable debe ser tenida en cuenta en cualquier actuación empresarial local más allá del mundo doméstico y especialmente ligada al mundo industrial por ser un gran consumidor energético. Esta tesis supone una transferencia de conocimientos y de tecnología en sectores y aplicaciones hasta ahora inexplorados. Además del beneficio social proyectado a la sociedad se demuestra también que económicamente es viable su implantación pese a la falta de ayudas o de economías de escala ligadas a esta tecnología comparadas con otras tecnologías renovables de mayor implementación sobre todo en España. En este sentido, se abre un abanico de posibilidades de nuevos modelos de negocio sostenibles basados en energías minoritarias hasta ahora como la geotermia (bien por sí misma o en hibridación con otras fuentes de energía). Atendiendo a las condiciones del entorno, a los resultados de la exploración y a la viabilidad técnica pero siempre con un gran potencial comercial de las innovaciones aquí presentadas, las cuales si además tuvieran fondos públicos conseguirían un mayor desarrollo empresarial.

Summary and Aims

To accelerate the transition to a sustainable energy future and to meet Sustainable Development Goal 7, affordable and clean Energy, hereafter SDG7, set by the United Nations, the global share of renewable energy needs to double by 2030. The replacement of fossil fuels by an increasing share of renewable energies has a resulting effect on the reduction of greenhouse gas emissions, hereinafter referred to as GHGs, and air pollutants.

In recent years, due to, among other factors, advances in technology and higher production volumes, the cost of renewable energies in general, especially wind and solar photovoltaic technologies, has been reduced. Both technologies received political support, to varying degrees, and experienced rapid technological learning leading to growing investor confidence. This has not been the case for other renewable technologies such as geothermal energy, which in recent years has been among the least developed despite its great potential.

Precisely, the present doctoral thesis aims to give visibility to this energy source by studying its potential either alone or in combination with solar energy, focusing on its industrial application and thus filling this knowledge gap.

The starting point of this doctoral thesis is to identify the barriers that hinder the implementation of geothermal energy in Spain and in the European Union and the measures to be adopted to achieve its diffusion and regular use. Spain has been selected within the European context due to its scarce 0.1 % of the geothermal market in primary energy demand.

Next, and given that the industrial sector is one of the largest GHG emitters in the world, it is studied how geothermal energy could contribute to this sector and to the desalination industry in particular (given its high energy consumption and its need in areas where water is a scarce commodity].

The results of the present doctoral thesis show that 76 %[2] of the annual time a MED type desalination plant would be powered with both resources (solar and geothermal] and 100 % of the time only with geothermal energy for a deeper well. Applying the results to the existing desalination plants of the A.G.U.A. project, we obtain a payback period of six years and 510 387 920 kg/year of CO_2 avoided in the atmosphere for all the plants.

Beyond the desalination industry, this doctoral thesis demonstrates that almost 85 % of the industrial processes of all industry in Spain can be carried out with very low, low and medium temperature geothermal resources.

[2] En adelante en todo el documento de tesis los decimales se expresan con punto (.) en la parte escrita de texto en inglés y además se deja una separación entre el valor numérico y el símbolo % según el criterio de *The international Systems of Units (Bureau international des Poids et Measures,2018) y de The guide for the use of Intenational Systems of Units (NITS: National institute of Standard and technology US Department of commerce, 2008).Esto no aplicaría para los gráficos en Excel cuyos decimales se expresarían con coma y no hay separación entre número y símbolo %.*

In this way, 80 million tons of CO_2 per year would be avoided and the investment in geothermal energy for industrial processes up to 45 °C could be amortised within a reasonable period of 15 years.

The results presented in this doctoral thesis demonstrate that geothermal energy as a renewable energy source should be taken into account in any local business action beyond the domestic world and especially linked to the industrial world as a major energy consumer.

This doctoral thesis involves a transfer of knowledge and technology in sectors and applications hitherto unexplored. In addition to the social benefit projected to society, it also demonstrates that its implementation is economically viable despite the lack of aid or economies of scale linked to this technology compared to other renewable technologies that are more widely implemented, especially in Spain.

It opens up a range of possibilities for new sustainable business models based on hitherto minority energies such as geothermal energy (either on its own or in hybridisation with other energy sources).

Depending on the environmental conditions, the results of exploration and the technical feasibility, but always with a great commercial potential of the innovations presented here, which, if they also had public funding, would achieve greater business development.

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NOMENCLATURA

ACS: Agua caliente sanitaria.

A.G.U.A.: Acciones para la gestión y utilización del agua.

AIE: Agencia Internacional de la Energía.

BCG: Bomba de Calor Geotérmica.

BEI: Banco Europeo de Inversiones

COP25: 25 ª conferencia de las partes de la Convención Marco de las Naciones Unidas sobre el Cambio Climático.

DEHP: Bomba de Calor de Absorción de Doble Efecto.

EEA: Agencia Europea de Medio Ambiente.

EIB: European Investment Bank

EIDUNED: Escuela Internacional de Doctordado de la UNED.

ERAR: Estaciones de Regeneración de Aguas Refinadas.

EU: European Union.

FECYT: Fundación Española para la Ciencia y la Tecnología.

FER-H&C: Fuentes de energía renovable para calefacción y climatización.

FER-E: Fuentes de energía renovable para electricidad.

GEI: Gases de Efecto Invernadero.

GHG: Greenhouse Gas Emissions.

GOR: Gained Output Ratio.

GREEN NEW DEAL: Nuevo Pacto Verde.

inh: Habitantes

IEA: International Energy Agency.

IGA: International Geothermal Association

INE: Instituto Nacional de Estadística.

I+D+i: Investigación, desarrollo e innovación.

MED: Planta Desalinizadora Multiefecto.

NDC: Contribuciones Determinadas a nivel Nacional.

NREAP: Plan de Acción Nacional de Energías Renovables.

ONU: Organización de las Naciones Unidas.

ORC: Ciclo Rankine Orgánico

PANER: Plan de Acción Nacional de Energías Renovables.

PTC: Colectores Cilindro Parabólicos.

PV: Fotovoltáica.

$q_:$ Caudal (m^3/día).

q_d: Consumo medio planta desalinizadora (kWh/m^3).

*Qe***:** Consumo de energía de la industria española (GWh)

REDII: Directiva Europea Renovable.

RES: Sistemas de Energía Renovable.

RES-E: Sistemas de Energía Renovable (Eléctrico).

RES-H&C: Sistemas de Energía Renovable (Calor y Frío).

SCI: Science Citation Index.

SDG: Objetivos de Desarrollo Sostenible.

SDG7: Objetivos de Desarrollo Sostenible número 7.

SEforALL: Fundación Energía Sostenible para Todos.

SHIP: Solar Heat for Industrial Processes.

SSCI: Social Science Citation Index.

UE: Unión Europea.

UE28: Unión Europea de los 28 Estados Miembros.

UN: United Nations.

UNED: Universidad de Educación a Distancia.

UNFCCC: Convención marco de las Naciones Unidas sobre el cambio climático.

UPR: Relación de rendimiento universal.

TRT: Test de Respuesta Térmica.

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1.INTRODUCCIÓN/INTRODUCTION

1.a Introducción

El objetivo central del Acuerdo de París consistió en reforzar la respuesta mundial a la amenaza del cambio climático manteniendo el aumento de la temperatura mundial en este siglo por debajo de los 2 °C respecto de los niveles preindustriales y proseguir los esfuerzos para limitar el aumento de la temperatura a más de 1,5 °C. El Acuerdo de París exige que todas las Partes se esfuercen al máximo mediante "contribuciones determinadas a nivel nacional" (NDC) y que refuercen esos esfuerzos en los años venideros (UNFCCC 2015) [1].

Para 2030, los Estados miembros y la UE deben intensificar sus esfuerzos en materia de clima y energía para alcanzar los objetivos y convertirse en una economía sostenible y con bajas emisiones de carbono para 2050. Los Estados miembros deben superar una serie de importantes desafíos. A corto plazo, éstos se refieren a la formulación de objetivos nacionales adecuados de descarbonización y respuestas políticas para 2030 que permitan alcanzar colectivamente los objetivos de la UE y los compromisos contraídos en el marco del Acuerdo de París. A medio plazo, los Estados miembros deben mejorar sus capacidades nacionales de innovación para aumentar los beneficios de la transición energética en curso en Europa. Para mantener este impulso, la UE y sus Estados miembros deben reforzar y construir los conocimientos especializados y la capacidad de innovación existentes, de origen nacional, en materia de energía renovable y soluciones de eficiencia energética. Esto también ayudará a mantener la competitividad mundial de Europa en estos sectores cada vez más intensivos en conocimiento. Con ese fin, en 2018, las instituciones de la UE acordaron una cooperación y coordinación más sistemática de las políticas y medidas nacionales entre los Estados miembros mediante la adopción de la RED II. La Comisión Europea también ha presentado recientemente una visión del clima para 2050, que confirma la voluntad de la UE de liderar los esfuerzos mundiales de mitigación del clima y apoyar el objetivo de la plena neutralidad del carbono para 2050 [1]. Más recientemente, en la COP25 celebrada en Madrid, la dimensión social de la agenda climática ha tenido por primera vez un papel protagonista. Las discusiones en Madrid han reflejado que en el centro de la respuesta a la crisis climática deben estar las personas, sus preocupaciones y su futuro [2].

La UE ha logrado, en los menos de 15 días transcurridos desde que se formó la nueva Comisión, activar un paquete de medidas ambicioso para afrontar la emergencia climática, a través de su Nuevo Pacto Verde (Green New Deal); comprometerse con la neutralidad climática en 2050 y convertir al Banco Europeo de Inversiones (BEI) en un “Banco Climático”, lo que permitiría desbloquear un billón de euros de inversión durante la próxima década. Además, el BEI ha anunciado que dejará de financiar proyectos relacionados con las energías fósiles en 2021. Una veintena de bancos españoles, algunos de los cuales tienen un peso global destacado, acordaron alinearse con el Acuerdo de París. La Coalición de Ministros de Finanzas por la Acción Climática formada por 51 países, entre ellos España, firmó el Plan de Acción de Santiago, por el que se comprometen a introducir el cambio climático en sus políticas económicas y financieras hacia un crecimiento bajo o nulo en emisiones. El Banco Interamericano de Desarrollo anunció la creación de una Red de Bancos Centrales y Supervisores: una plataforma internacional para lograr un sistema financiero verde a nivel global. El Fondo de Adaptación logró movilizar un total de 89 millones de dólares durante esta COP de varios países, entre ellos España. En la COP25 se ha duplicado el número de fondos de inversión que se han comprometido a que sus carteras sean neutras en emisiones tan pronto como sea posible, pasando de carteras que suman 2,4 millardos de dólares durante la Cumbre del Clima de Nueva York a 4 millardos de dólares en la COP25. El número de multinacionales comprometidas a ser neutras en carbono en 2050 se ha duplicado, pasando de 90 en la Cumbre del Clima de Nueva York a 177 en la COP25. En tamaño, estas empresas emplean a más de 5,8 millones de personas. La cifra de grandes ciudades comprometidas con la neutralidad climática en 2050 ha pasado de 100 en la cumbre de Nueva York a 398 durante la COP25. Aunque el Acuerdo de París fijó el año 2020 para la presentación de compromisos más ambiciosos por parte de los países, este año, 2020, 73 Estados se han comprometido a ser neutros en carbono en 2050, entre ellos, España. Para lograrlo, como ejemplo, en España, se ha fijado reducir una de cada tres toneladas de CO_2 en la próxima década, duplicando el consumo final de energía renovable en 2030. Más de 80 países han anunciado ya que presentarán compromisos de lucha contra el cambio climático (NDC) más ambiciosos que los referentes al Acuerdo de París en 2020 [2].

Junto con la eficiencia energética, la energía renovable es un pilar clave de descarbonización en la transición de Europa hacia una economía y una sociedad con bajas emisiones de carbono. Cumplir los compromisos del Acuerdo de París requerirá que la UE reduzca sus emisiones de gases de efecto invernadero entre un 80% y un 95% para 2050 (en comparación con los niveles de 1990) y que se descarbonice casi por completo el sector de la generación de energía [3].

La Agenda 2030 para el Desarrollo Sostenible, adoptada por todos los Estados Miembros de las Naciones Unidas en 2015, incluye los 17 Objetivos de Desarrollo Sostenible (SDG) [4], que constituyen un llamamiento urgente a la acción de todos los países (desarrollados y en desarrollo) en una asociación mundial (ONU 2019a).

El SDG7 hace un llamamiento a "una energía asequible, fiable, sostenible y moderna para todos" para 2030. Sin embargo, 840 millones de personas en el mundo actual no tienen acceso a la electricidad, y aproximadamente el triple de esa cifra utiliza combustibles sucios para cocinar (ONU 2019b).

El papel de la energía renovable en el logro del SDG7 está bien reconocido. Uno de los tres objetivos fundamentales de la Fundación Energía Sostenible para Todos, (SEforALL), una iniciativa internacional que apoya el SDG7, ha sido sobre la energía renovable, "para acelerar nuestra transición hacia un futuro energético sostenible y cumplir los objetivos del SDG7, es necesario duplicar la cuota mundial de energía renovable para el año 2030".

Con la rápida disminución de los costes de instalación de la energía solar fotovoltaica, las poblaciones sin acceso a la red central de electricidad pueden beneficiarse de la energía solar fuera de la red y de otras soluciones descentralizadas, que pueden proporcionar acceso a la energía a un coste menor.

Los países en desarrollo con graves deficiencias en el acceso a la energía han empezado a adoptar enfoques integrados de suministro de electricidad, combinando redes eléctricas centralizadas mejoradas con soluciones de energía renovable distribuidas. En un estudio realizado por Smart Power India, un programa de la Fundación Rockefeller, se informó de la existencia de 106 mini-redes que utilizan generadores basados en energía renovable que funcionan en zonas rurales de toda la India para proporcionar acceso a la electricidad a las personas (SmartPowerIndia 2017).

Según las Perspectivas Mundiales de la Energía 2019 (AIE 2019b), la proporción de las energías renovables (bioenergía moderna + electricidad32) en el consumo total mundial de energía final fue del 10% en 2018. Si bien la generación de electricidad a partir de fuentes renovables está aumentando a un ritmo rápido, su uso en los sectores de la calefacción y el transporte también se está expandiendo [3].

La innovación tecnológica acelerada sigue siendo fundamental para sacar adelante tecnologías más avanzadas, mejorar el rendimiento de la tecnología y reducir los costes mediante el aprendizaje de la tecnología (AIE 2017) [3].

Por suerte, los avances tecnológicos, el aumento de los volúmenes de producción mundial y la reducción de los costes de capital también han desempeñado un papel importante en la reducción de los costes de las energías renovables, especialmente de las tecnologías de energía eólica y solar fotovoltaica [5,6]. No ha ocurrido así con otras tecnologías renovables como las geotérmicas y las basadas en biomasa sólida [3].

Es sabido de los beneficios colaterales del creciente consumo de RES en Europa, en particular la sustitución de los combustibles fósiles por una proporción cada vez mayor de energías renovables y los efectos resultantes en la reducción de las emisiones de GEI y de contaminantes atmosféricos [3].

En toda la UE, en términos absolutos, el mayor sector del mercado para el uso de energía renovable sigue siendo el de la calefacción y la refrigeración. Las energías renovables representan cerca de una quinta parte de toda la energía final consumida para calefacción y refrigeración en la UE.

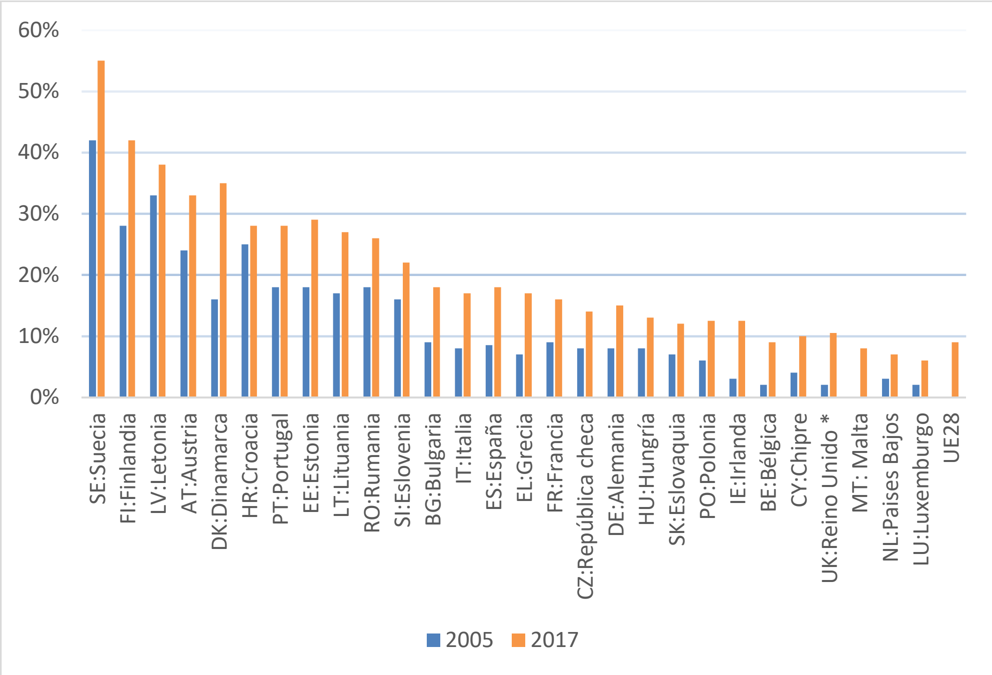
La electricidad es el segundo mayor sector del mercado para el uso de energía renovable en la UE (la cuota de la electricidad RES-E es del 30,7% en 2017 y del 32,1% en 2018 según las primeras estimaciones del EEA). -El transporte es el tercer y más pequeño sector del mercado de las energías renovables (7,6% en 2017 y 8,1% en 2018, según las primeras estimaciones del EEA). El uso de energía renovable en el transporte (incluidos únicamente los biocombustibles certificados de conformidad con los criterios de sostenibilidad existentes) varió considerablemente entre los Estados miembros. Algunas tecnologías de energía renovable ya han superado los niveles de despliegue previstos para 2020 en el Plan de acción nacional de energías renovables, en adelante, PANER, en particular las de biomasa sólida y las de energía solar fotovoltaica y biogás.

El cambio interanual más espectacular en Europa vino de España. La inversión allí se disparó en un 859% a 6,3 mil millones de euros, como una nueva generación de energía solar de bajo coste, las nuevas inversiones en energía renovable en 2017 siguieron estando dominadas por la energía solar (principalmente la energía fotovoltaica solar), que representa el 49% del total de las inversiones en energías renovables, sin embargo, en una proporción muy inferior a la del año anterior (55%). La energía eólica ocupa el segundo lugar, con una participación ligeramente superior en 2017 (46%) que en años anteriores [3]. Ambas tecnologías recibieron apoyo político, en diversa medida, experimentaron un rápido aprendizaje tecnológico que condujo a una creciente confianza por parte de los inversores.

La inversión en otras tecnologías renovables, por ejemplo, biomasa/residuos para la producción de energía, energía hidroeléctrica en pequeña escala y energía geotérmica, siguió siendo relativamente pequeña durante el período 2005 a 2018 con cifras de inversión entre 1000 millones y 2000 millones de €.

En la figura 1 se muestra el reparto de RES per cápita en la UE y sus Estados miembros en el periodo 2005 y 2017.

España en el puesto 14 de 28 ha conseguido duplicar su cuota del año 2005 al año 2017 siendo para el año 2020 por encima del 20%.

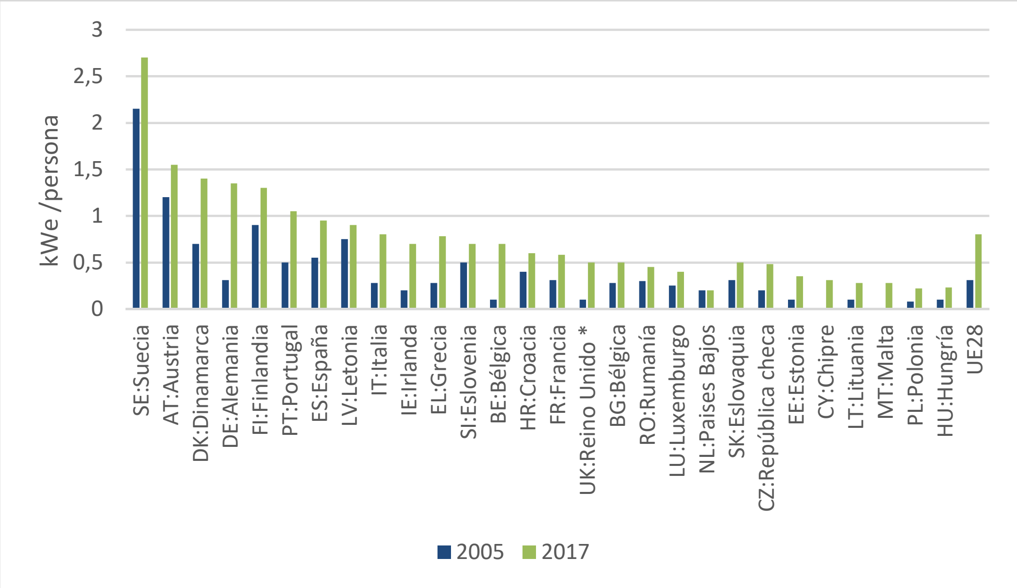


(*) En el momento de redacción de esta tesis Reino Unido pertenecía a la UE28

Figura 1: Reparto de RES en la UE y sus Estados miembros. Comparativa años 2005 y 2017. Fuente: Adaptado de [5]

En la figura 2 se muestra el reparto de RES-E en los Estados miembros de la UE para el año 2005 y 2017.

La media UE28 supera la media mundial (se triplica) y en el caso de España del año 2005 al año 2017 casi se duplica ocupando la posición 7º en la EU28 en el año 2017.



(*) En el momento de redacción de esta tesis Reino Unido pertenecía a la UE28

Figura 2: Capacidades de RES-E excluida la bomba de calor, per cápita en la UE y sus Estados miembros, 2005 y 2017. Fuente: Adaptado de [5]

A la vista de la figura 3, en 15 años (del 2005 al 2020) se ha duplicado el consumo de RES-E en la UE.

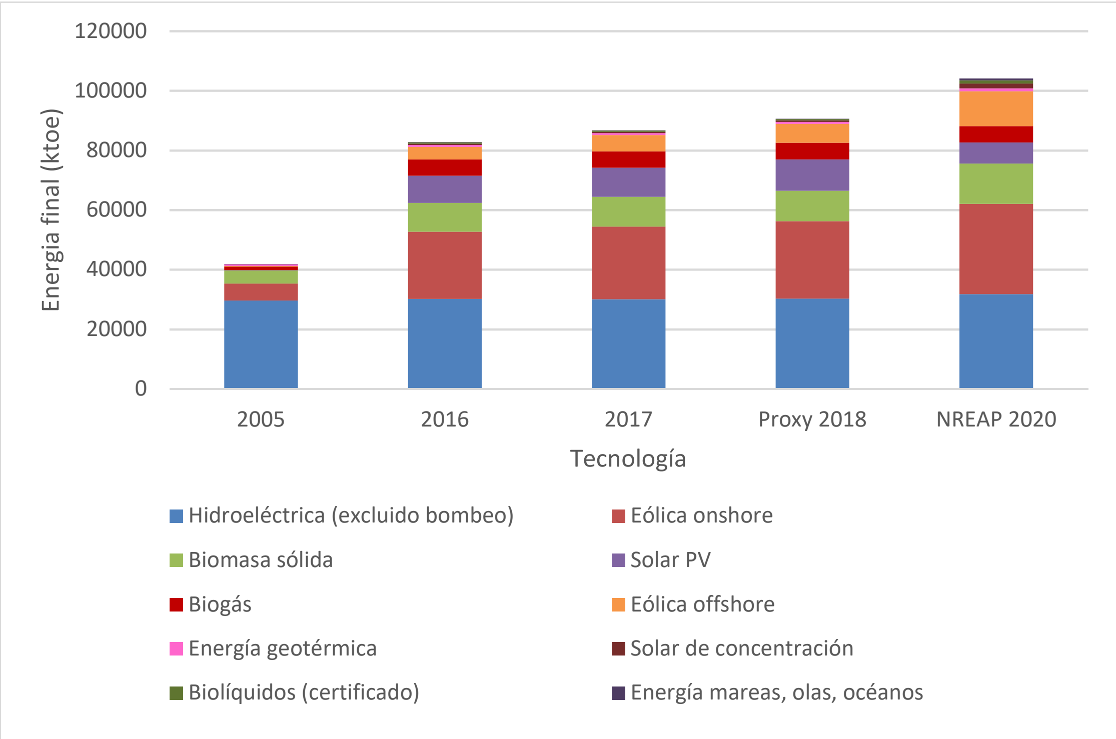


Figura 3: RES-E en la UE. Fuente: Adaptado de [5].

Por tipo de energías renovables, la hidroeléctrica se ha mantenido constante mientras que todas las demás han crecido, especialmente la eólica onshore y en los últimos años la offshore.

La solar fotovoltaica tras el crecimiento fuerte de los primeros años se ha mantenido e incluso ha descendido, pero en el caso por ejemplo de España ha aumentado durante el año 2019 estando a la cabeza de Europa y se prevé que en los años venideros siga haciéndolo. La biomasa y el biogás han ido ganado cuota de mercado en el periodo 2005 a 2020 como se aprecia en la figura 3. La energía geotérmica junto con la de biolíquidos, la concentración solar y la de las mareas es la que menos desarrollo ha tenido durante estos 15 años, aunque parece que se espera un crecimiento en los próximos. Análogo razonamiento se expresa en la tabla 1 y dada la potencialidad de dos de las energías minoritarias para los próximos años, geotermia y solar de concentración, son parte integrante de la presente tesis.

Tabla 1: RES-E por tecnología en la UE. Fuente: Adaptado de [5].

	Energía final (ktoe)					Porcentaje de incremento por año		
Tecnología	**2005**	**2016**	**2017**	**Proxy 2018**	**NREAP 2020**	**2005-2017**	**2016-2017**	**2017-2020**
Hidroeléctrica (excluido bombeo)	29 587	30 176	30 002	30 248	31 786	0%	-1%	2%
Eólica onshore	5667	22 483	24 374	26 017	30 303	28%	8%	8%
Biomasa sólida	4473	9713	10 041	10 211	13 460	10%	3%	11%
Solar PV	126	9101	9760	10 469	7062	637%	7%	-9%
Biogás	1105	5443	5515	5599	5493	33%	1%	0%
Eólica offshore	273	4267	5441	6362	11 740	158%	28%	39%
Energía geotérmica	464	584	583	586	943	2%	0%	21%
Solar de concentración	0	480	506	530	1633	n.a.	5%	74%
Biolíquidos (certificado)	0	440	415	415	1096	n.a.	-6%	55%
Energía mareas, olas, océanos	41	43	45	48	559	1%	5%	381%
Total, RES-E (normalizado, biofueles certificados)	42 007	82 730	86 682	90 483	104 075	9%	5%	7%
Total RES-E (normalizado, incluyendo todos los biofueles)	42 159	82 745	86 696	90 498	104 075	9%	5%	7%

En la tabla 2 se presentan las energías renovables térmicas en la UE.

Tabla 2: RES-H&C en la UE: Fuente: Adaptado de [5].

	Energía final (ktoe)			Porcentaje de incremento por año				
Tecnología	**2005**	**2016**	**2017**	**Proxy 2018**	**NREAP 2020**	**2005-2017**	**2016-2017**	**2017-2020**
Biomasa sólida	61 700	82 784	84 431	85 372	80 886	3%	-2%	-1%
Energía renovable de Bombas de calor	2285	9930	10 467	10 615	12 289	30%	5%	6%
Biogás	744	3586	3918	4085	5108	36%	9%	10%
Solar térmica	698	2169	2307	2411	6455	19%	6%	60%
Geotérmica	560	777	829	870	2646	4%	7%	73%
Biolíquidos (certificado)	0	224	237	241	4416	n.a.	6%	588%
Total calor renovable [certificado biofueles)	65 987	99 470	102 189	103 594	111 801	5%	3%	3%
Total calor renovable (incluido todos los biofueles)	66 156	99 656	102 345	103 759	111 801	5%	3%	3%

La energía geotérmica para usos térmicos que también había tenido un tímido crecimiento en años anteriores se espera que aumente en los próximos años, más que la generación de electricidad.

Una vez vistos los objetivos climáticos a alcanzar como consecuencia de las últimas cumbres realizadas y la situación de las distintas energías renovables por países miembros de la Unión Europea y por usos propiamente dichos de esas energías (eléctricos y/o térmicos) se pretende estudiar por medio de esta tesis la potencialidad de la energía geotérmica bien por sí misma o bien en hibridación con la energía solar dado que no ha tenido el desarrollo esperado en las últimas décadas pese a su gran potencial. Se analizará su situación a una escala global (UE) y a un nivel local en España.

1.b Introduction

The central objective of the Paris Agreement was to strengthen the global response to the threat of climate change by keeping the global temperature increase this century below 2 °C above pre-industrial levels and to continue efforts to limit the temperature increase to no more than 1.5 °C. The Paris Agreement requires all Parties to do their utmost through "Nationally Determined Contributions" (NDCs) and to strengthen these efforts in the years to come (UNFCCC 2015). [1]

By 2030, Member States and the EU must step up their climate and energy efforts to meet the targets and become a sustainable, low-carbon economy by 2050. Member States must overcome a number of important challenges. In the short term, these relate to the formulation of adequate national decarbonisation targets and policy responses for 2030 to collectively achieve the EU's targets and commitments under the Paris Agreement. In the medium term, Member States need to improve their national innovation capacities to enhance the benefits of the ongoing energy transition in Europe. To maintain this momentum, the EU and its Member States must strengthen and build on existing, home-grown expertise and innovation capacity in renewable energy and energy efficiency solutions. This will also help to maintain Europe's global competitiveness in these increasingly knowledge-intensive sectors. To this end, in 2018, the EU institutions agreed on more systematic cooperation and coordination of national policies and measures between Member States through the adoption of RED II. The European Commission has also recently presented a 2050 climate vision, which confirms the EU's willingness to lead global climate mitigation efforts and support the goal of full carbon neutrality by 2050 [1]. More recently, at COP25 in Madrid, the social dimension of the climate agenda has for the first time taken centre stage. The discussions in Madrid reflected that people, their concerns and their future must be at the centre of the response to the climate crisis [2].

The EU has managed, in the less than 15 days since the new Commission was formed, to activate an ambitious package of measures to tackle the climate emergency, through its Green New Deal; commit to climate neutrality by 2050; and turn the European Investment Bank (EIB) into a 'Climate Bank', which would unlock one trillion euros of investment over the next decade. In addition, the EIB has announced that it will stop financing fossil energy projects in 2021. A score of Spanish banks, some of which have a prominent global weight, agreed to align themselves with the Paris Agreement. The Coalition of Finance Ministers for Climate Action, made up of 51 countries, including Spain, signed the Santiago Action Plan, committing to introduce climate change into their economic and financial policies towards low or zero-emission growth. The Inter-American Development Bank announced the creation of a Network of Central Banks and Supervisors: an international platform for a global green financial system. The Adaptation Fund managed to mobilise a total of 89 million dollars during this COP from several countries, including Spain. COP25 saw a doubling of the number of investment funds that have committed to make their portfolios emission neutral as soon as possible, from portfolios totalling $2.4 billion during the New York Climate Summit to $4 billion at COP25. The number of multinationals committed to becoming carbon neutral by 2050 has doubled from 90 at the New York Climate Summit to 177 at COP25. In size, these companies employ more than 5.8 million people. The number of large cities committed to climate neutrality in 2050 has increased from 100 at the New York summit to 398 during COP25. Although the Paris Agreement set 2020 as the year for countries to present more ambitious commitments, this year, 2020, 73 states have committed to becoming carbon neutral by 2050, including Spain. To achieve this, Spain, for example, has set itself the target of reducing one out of every three tonnes of CO_2 over the next decade by doubling its final consumption of renewable energy by 2030. More than 80 countries have already announced that they will submit climate change commitments (NDCs) that are more ambitious than those of the Paris Agreement in 2020 [2].

Together with energy efficiency, renewable energy is a key decarbonisation pillar in Europe's transition to a low-carbon economy and society. Meeting the Paris Agreement commitments will require the EU to reduce its greenhouse gas emissions by 80 %-95 % by 2050 (compared to 1990 levels) and to almost completely decarbonise the power generation sector [3].

The 2030 Agenda for Sustainable Development, adopted by all UN Member States in 2015, includes the 17 Sustainable Development Goals (SDGs) [4], which are an urgent call for action by all countries (developed and developing) in a global partnership (UN 2019a).

SDG7 calls for "affordable, reliable, sustainable and modern energy for all" by 2030. However, 840 million people in the world today have no access to electricity, and roughly three times that number use dirty fuels for cooking (UN 2019b).

The role of renewable energy in achieving SDG7 is well recognised. One of the three key targets of the Sustainable Energy for All Foundation, (SEforALL), an international initiative supporting SDG7, has been on renewable energy, "to accelerate our transition to a sustainable energy future and meet SDG7 targets, the global share of renewable energy needs to double by 2030".

With the rapidly decreasing installation costs of solar PV, populations without access to the central electricity grid can benefit from off-grid solar and other decentralised solutions, which can provide access to energy at a lower cost.

Developing countries with severe energy access gaps have begun to adopt integrated approaches to electricity supply, combining improved centralised electricity grids with distributed renewable energy solutions. A study by Smart Power India, a programme of the Rockefeller Foundation, reported 106 mini-grids using renewable energy-based generators operating in rural areas across India to provide electricity access to people (SmartPowerIndia 2017).

According to the World Energy Outlook 2019 (IEA 2019b), the share of renewables (modern bioenergy + electricity32) in total global final energy consumption was 10 % in 2018. While electricity generation from renewable sources is increasing at a rapid pace, its use in the heating and transport sectors is also expanding [3].

Accelerated technological innovation remains critical to bring more advanced technologies forward, improve technology performance and reduce costs through technology learning (IEA 2017) [3].

Fortunately, technological advances, increased global production volumes and reduced capital costs have also played an important role in reducing the costs of renewables, especially wind and solar PV technologies [5]. This has not been the case for other renewable technologies such as geothermal and solid biomass-based technologies [3].

The co-benefits of increasing RES consumption in Europe, in particular the substitution of fossil fuels by an increasing share of renewables and the resulting effects on the reduction of GHG emissions and air pollutants, are well known [3].

Across the EU, in absolute terms, the largest market sector for renewable energy use remains heating and cooling. Renewables account for about one fifth of all final energy consumed for heating and cooling in the EU.

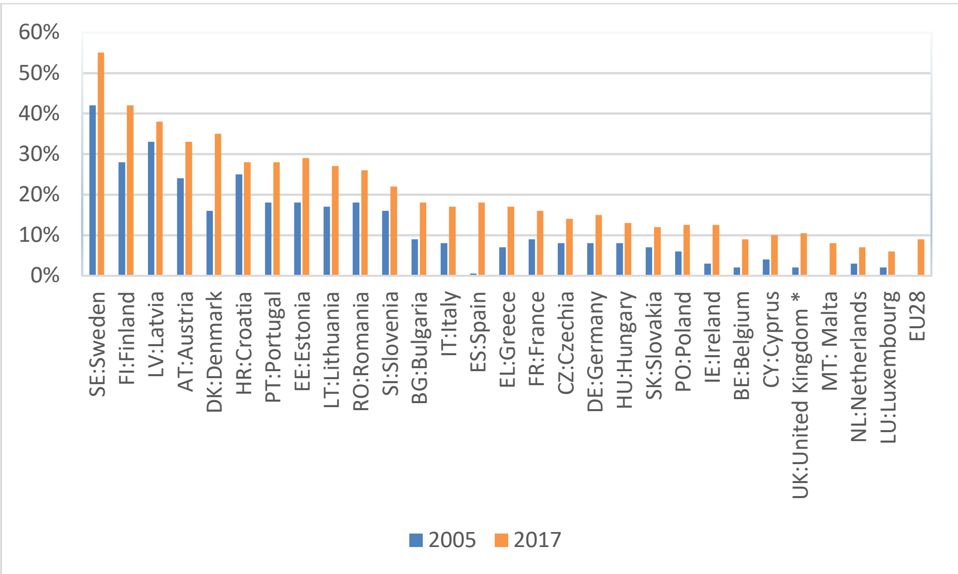
Electricity is the second largest market sector for renewable energy use in the EU (RES-E electricity share is 30.7 % in 2017 and 32.1 % in 2018 according to first EEA estimates). -Transport is the third and smallest sector of the renewable energy market (7.6 % in 2017 and 8.1 % in 2018, according to first EEA estimates). The use of renewable energy in transport (including only biofuels certified according to existing sustainability criteria) varied considerably between Member States. Some renewable energy technologies have already exceeded the deployment levels foreseen for 2020 in the National Renewable Energy Action Plan, hereafter NREAP, in particular solid biomass, solar PV and biogas.

The most dramatic year-on-year change in Europe came from Spain. Investment there soared by 859 % to EUR 6.3 billion, as new low-cost solar power generation, new investments in renewable energy in 2017 continued to be dominated by solar power (mainly solar PV), accounting for 49 % of total renewable energy investments, however, at a much lower share than in the previous year (55 %). Wind energy is in second place, with a slightly higher share in 2017 (46 %) than in previous years [3]. Both technologies received political support, to varying degrees, experienced rapid technological learning leading to growing investor confidence.

Investment in other renewable technologies, e.g. biomass/waste-to-energy, small-scale hydropower and geothermal energy, remained relatively small during the period 2005 to 2018 with investment figures between €1 billion and €2 billion.

Figure 1 shows the distribution of RES per capita in the EU and its Member States in the period 2005-2017.

Spain, in 14th place out of 28, has managed to double its share from 2005 to 2017 and by 2020 it will be above 20 %.

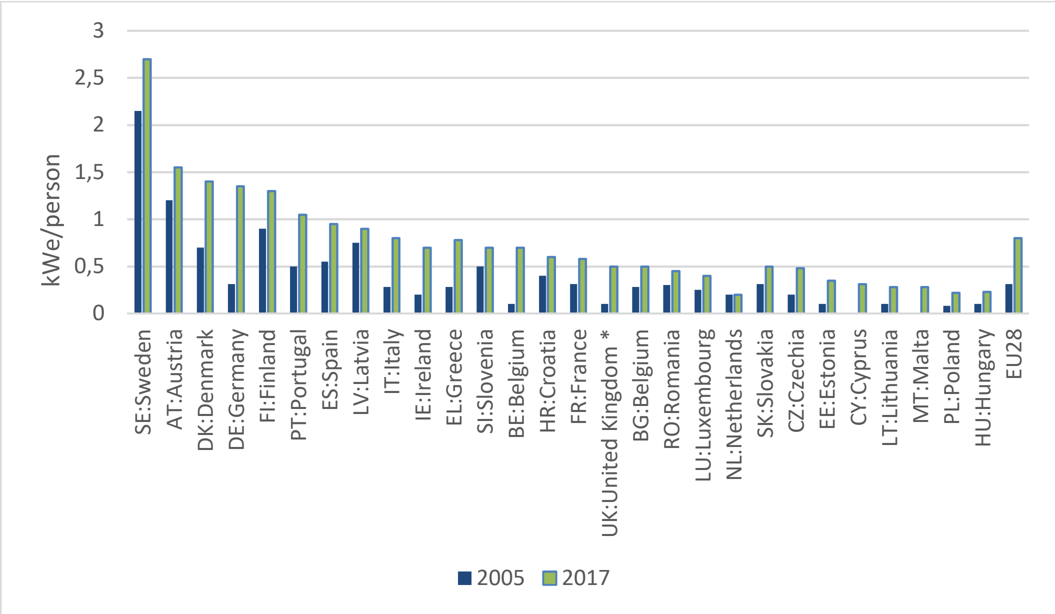


(*) At the time of writing, UK was a member of the EU28.

Figure 1: Share of RES in the EU and its Member States in the period 2005-2017. Source: Adapted from [5].

Figure 2 shows the distribution of RES-E in the EU Member States for the year 2005 and 2017.

The EU28 average exceeds the world average (it triples) and in the case of Spain from 2005 to 2017 it almost doubles, occupying the 7th position in the EU28 in 2017.



(*) At the time of writing, UK was a member of the EU28.

Figure 2: RES-E capacities excluding heat pump, per capita in the EU and its Member States, 2005 and 2017. Source: Adapted from [5]

In view of Figure 3, in 15 years (from 2005 to 2020), RES-E consumption in the EU has doubled.

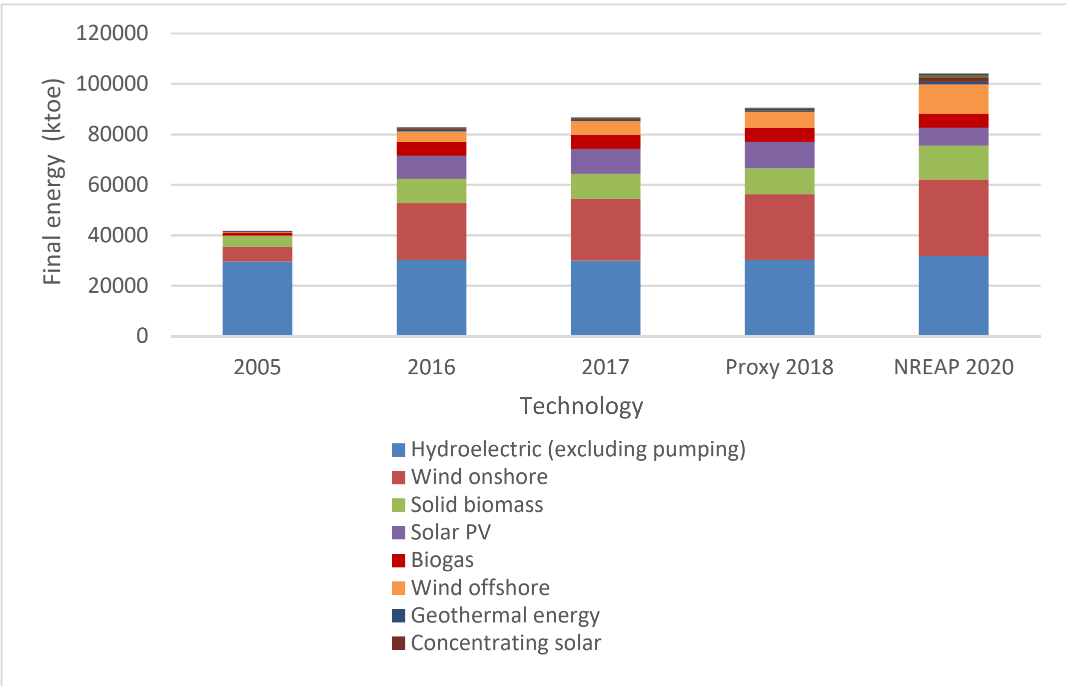


Figure 3: RES-E in the EU. Source: Adapted from [5].

By type of renewable energy, hydropower has remained constant while all others have grown, especially onshore wind and in recent years offshore wind.

Solar photovoltaic, after the strong growth of the first years, has remained constant and even decreased, but in the case of Spain, for example, it has increased during 2019, being at the top of Europe and is expected to continue to do so in the coming years. Biomass and biogas have been gaining market share in the period 2005 to 2020, as can be seen in Figure 3. Geothermal energy, together with bioliquids, concentrated solar power and tidal energy, has seen the least development during these 15 years, although it seems that growth is expected in the coming years. Similar reasoning is expressed in table 1 and given the potential of two of the minority energies for the coming years, geothermal and concentrating solar power, they are an integral part of this doctoral thesis.

Table 1: RES-E by technology in the EU. Source: Adapted from [5].

	Final energy (ktoe)			Percentage increase per year				
Technology	**2005**	**2016**	**2017**	**Proxy 2018**	**NREAP 2020**	**2005-2017**	**2016-2017**	**2017-2020**
Hydroelectric (excluding pumping)	29 587	30 176	30 002	30 248	31 786	0 %	-1 %	2 %
Wind onshore	5667	22 483	24 374	26 017	30 303	28 %	8 %	8 %
Solid biomass	4473	9713	10 041	10 211	13 460	10 %	3 %	11 %
Solar PV	126	9101	9760	10 469	7062	637 %	7 %	-9 %
Biogas	1105	5443	5515	5599	5493	33 %	1 %	0 %
Wind offshore	273	4267	5441	6362	11 740	158 %	28 %	39 %
Geothermal energy	464	584	583	586	943	2 %	0 %	21 %
Concentrating solar	0	480	506	530	1633	n.a.	5 %	74 %
Bioliquids (certified)	0	440	415	415	1096	n.a.	-6 %	55 %
Tides, waves and oceans energy	41	43	45	48	559	1 %	5 %	381 %
Total RES-E (normalized, biofuels certified)	42 007	82 730	86 682	90 483	104 075	9 %	5 %	7 %
Total RES-E (normalizado, incluyendo todos los biofueles)	42 159	82 745	86 696	90 498	104 075	9 %	5 %	7 %

Table 2 presents thermal renewables in the EU.

Table 2: RES-H&C in the EU: Source: Adapted from [5].

Technology	Energía final (ktoe) 2005	2016	2017	Percentage increase per year Proxy 2018	NREAP 2020	2005-2017	2016-2017	2017-2020
Solid biomass	61 700	82 784	84 431	85 372	80 886	3 %	-2 %	-1 %
Renewable energy with heat pump	2285	9930	10 467	10 615	12 289	30 %	5 %	6 %
Biogas	744	3586	3918	4085	5108	36 %	9 %	10 %
Thermal solar	698	2169	2307	2411	6455	19 %	6 %	60 %
Geothermal energy	560	777	829	870	2646	4 %	7 %	73 %
Bioliquids (certified)	0	224	237	241	4416	n.a.	6 %	588 %
Total Renewable heat [certified biofuels)	65 987	99 470	102 189	103 594	111 801	5 %	3 %	3 %
Total renewable heat (included all biofuels)	66 156	99 656	102 345	103 759	111 801	5 %	3 %	3 %

Geothermal energy for thermal uses, which had also shown a timid growth in previous years, is expected to increase in the coming years, more so than electricity generation.

Having seen the climate objectives to be achieved as a result of the latest summits and the situation of the different renewable energies by member countries of the European Union and by the actual uses of these energies (electrical and/or thermal), this doctoral thesis aims to study the potential of geothermal energy, either on its own or in hybridisation with solar energy, given that it has not had the expected development in recent decades despite its great potential. Its situation will be analysed on a global scale (EU) and on a local level in Spain.

2. OBJETIVOS DE LA TESIS

Los objetivos a alcanzar por medio de la presente tesis se pueden resumir en:

1. Identificar de las barreras que dificultan la implantación de la energía geotérmica en España y en la Unión Europea y las medidas a adoptar para conseguir su difusión y su uso de forma habitual.

2. Valorar la conveniencia de la hibridación de la energía geotérmica con otras fuentes de energía como la solar o bien valorar su uso por sí misma para la aplicación de su energía en plantas desalinizadoras (dado su alto consumo energético) en aquellas zonas donde el agua es un bien escaso y preciado.

3. Fomentar el uso de la geotermia como fuente de energía para los procesos industriales de todas las industrias al ser éstas también grandes consumidoras de energía.

Para la consecución de dichos objetivos se realiza por un lado un trabajo de campo con preguntas a expertos internacionales y nacionales en el campo de las energías renovables en general y de la energía geotérmica en particular sobre las barreras y medidas a implementar para generalizar el uso de la energía geotérmica y que alcance el nivel de otras energías renovables como la solar o la eólica tanto en España como en la UE. A nivel práctico y dada la ubicación geográfica y la climatológica de buena parte de España y de su escasez de agua de lluvia se elige una industria muy intensiva a nivel energético como es la de la desalinización y la conveniencia del uso de la energía geotérmica para paliar dicho consumo energético el cual procede mayoritariamente de fuentes de energías no renovables. Se elige un emplazamiento determinado del sur de España alimentando una planta desalinizadora tipo con energía geotérmica y en hibridación con energía solar y se extrapolan sus resultados en términos medioambientales y económicos a un conjunto de plantas desalinizadoras ya existentes de la costa mediterránea. Por último y dados los resultados a nivel de desalinización se hace un estudio más extensivo al resto de industrias en España para que usen la energía geotérmica como fuente de alimentación para sus procesos industriales obteniendo unos resultados económico-medioambientales los cuales se pueden extrapolar a su vez a otros países que se encuentren en situación similar a España por climatología.

2.1 Líneas de desarrollo del objetivo de la tesis y justificación con la unidad temática de la tesis

La unidad temática de la tesis se desarrolla bajo tres líneas de desarrollo coherentes y consecutivas con la potencialidad de la energía geotérmica a nivel local y global analizando la casuística de cada zona y de cada sector de actividad con el uso más adecuado. Partiendo de las barreras y acciones a implementar se analiza un caso práctico muy representativo por ser gran consumidor de energía y fundamental en zonas áridas y con escasez de lluvias como es el de una planta desalinizadora del sureste español y por último se analiza la situación a nivel más global siendo deseable la aplicabilidad de esta fuente de energía a los procesos industriales de la Industria dado que algunos procesos industriales trabajan en los rangos deseables de la energía geotérmica para usos directos.

2.2 Sobre la modalidad de presentación de la tesis

La presente tesis doctoral se presenta bajo la modalidad de **Tesis por compendio de publicaciones.** Esta modalidad de presentación de la tesis doctoral está regulada por el documento aprobado por el Comité de Dirección de la Escuela Internacional de Doctorado de la Universidad Nacional de Educación a Distancia (EIDUNED), en su reunión de 16 de enero de 2017, y por la Comisión de Investigación y Doctorado de la UNED, con fecha 21 de febrero de 2017.

Conforme lo determinado en dicha regulación, la tesis doctoral presentada por compendio de publicaciones deberá estar constituida por una serie de trabajos publicados y/o aceptados, justificados por su unidad temática, de acuerdo a la siguiente estructura.

- Introducción, en la que se justifique la unidad temática de la tesis.
- Hipótesis y objetivos a alcanzar, indicando en qué publicación o publicaciones se abordan.
- Marco teórico en el que se inscribe el tema de la tesis y herramientas metodológicas o remisión a las publicaciones.
- Copia completa de las publicaciones, ya sean publicadas o aceptadas para publicación, donde conste el nombre y adscripción de la autoría y coautoría, en su caso, así como la referencia completa de la revista o editorial en la que los trabajos hayan sido publicados o aceptados para su publicación, en cuyo caso

se aportará justificante de la aceptación de la revista o editorial. En todos estos casos siempre deberá constar de forma explícita la filiación del doctorando o doctoranda a la UNED.

- Conclusiones, indicando de qué publicación o publicaciones se desprenden.
- Resúmenes en español y en inglés o, en su defecto, en el idioma habitual para la comunicación científica en su campo de conocimiento científico, técnico o artístico.
- Otras aportaciones científicas derivadas directamente de la tesis doctoral.
- Informe con el factor de impacto y cuartil del *Journal Citation Reports* (SCI y/o SSCI), *SCOPUS*, Sello de Calidad FECYT o de toda base de datos selectiva y con factor de impacto de referencia del área en el que se encuentran las publicaciones presentadas.
- Fuentes y/o Bibliografía.

La regulación determina tres opciones para la clase y número de publicaciones que deben formar el compendio. Para la presentación de esta tesis doctoral se ha optado por la primera de las opciones, según el cual:"…*el compendio de publicaciones estará formado por un mínimo de 3 artículos (al menos, dos ya publicados y el tercero aceptado) en revistas de índices de impacto en los dos primeros cuartiles de la relación de revistas del ámbito de la especialidad del Programa en el que está inscrita dicha tesis y referenciadas en la última relación publicada por el Journal Citation Reports (SCI y/o SSCI) y de SCOPUS. Todos los artículos deben estar publicados con fecha posterior a la primera matrícula de tutela académica en la EIDUNED. El doctorando o doctoranda debe ser primer firmante o segundo, en este último caso, el primero debe ser el director o directora de la tesis".*

"Atendiendo a los ***NUEVOS CRITERIOS PARA LA PUBLICACIÓN ASOCIADA A LA TESIS DOCTORAL y en concreto al punto 3) de CLAUSULAS COMUNES A TODOS LOS PROGRAMAS DE DOCTORADO:*** *Para verificar si la revista o editorial en la que se publique el trabajo cumple con los criterios indicados, se tomará en cuenta una ventana temporal amplia que incluye el año de publicación (o de aceptación del trabajo, si este no fuera publicado todavía), así como los dos (2) años anteriores y los dos (2) posteriores a la publicación".*

2.3 Hipótesis y objetivos de las líneas de desarrollo del trabajo de investigación: Publicaciones en que se abordan.

Partiendo de una serie de hipótesis se ha llegado a los objetivos de la tesis doctoral plasmados en cada uno de los tres artículos científicos publicados en revistas del sector de alto factor de impacto. A continuación, se indican las hipótesis y los objetivos de cada una de las líneas de desarrollo del trabajo de investigación.

2.3.1 Medidas para eliminar las barreras a la energía geotérmica en la Unión Europea

Numerosos indicadores hoy en día muestran que todavía se sigue apostando por energías fósiles en detrimento de las energías renovables y de los proyectos de eficiencia energética como se muestra en los resultados de la cumbre de Madrid [7-10]. En el caso de las micro-redes, la falta de una regulación específica y el hecho de que es todavía una tecnología incipiente es a menuda una opción costosa como recurso energético no tanto por las barreras técnicas (incluso cuando este aspecto podría mejorarse) sino por los vacíos regulatorio, legislativo y económico a los que se enfrentan [11].

El incremento en la demanda de energía mundial hace imprescindible dar una respuesta en un marco de energía sostenible.

Numerosos estudios hablan de la identificación de barreras para la introducción de energías renovables en el panorama mundial. Estas barreras, sin embargo, se espera que difieran según los diferentes tipos de energía renovable, factores ambientales y sector de actividad. En lo relativo a la energía geotérmica, a pesar de su disponibilidad por todo el mundo y de su independencia de factores climatológicos externos, está infrautilizada tanto por sí misma como en el mix energético. Por tanto, hay una necesidad de realizar estudios más específicos sobre las barreras que le afectan y las acciones a implementar para alcanzar su máximo potencial siendo por tanto uno de los objetivos de esta tesis.

Uno de los principales retos a los que se enfrenta la energía geotérmica tanto para usos térmicos como eléctricos es el desconocimiento por el público general [12]. En el caso de la generación de energía geotérmica, la ausencia de un marco regulatorio favorable da como resultado la falta de plantas para uso eléctrico en España a pesar de los esfuerzos empresariales aislados para realizarlo [12].

Como punto a favor, salvando la barrera de la inversión inicial y la regulatoria para los proyectos de geotermia de alta entalpía, decir que se ha mejorado mucho en el conocimiento y en la investigación del subsuelo en aquellas zonas con potencial en España y eso supone una mayor implicación en el desarrollo del sector para la proliferación de proyectos [12]. En el caso de la geotermia somera, el freno de los últimos años ha venido dado porque se requiere una inversión inicial superior a la de una instalación convencional y eso no ha ayudado en un contexto de crisis como la que se ha vivido en la última década. No obstante, son numerosas las iniciativas privadas que se han ejecutado (sobre todo de rehabilitación de edificios) por toda la geografía española [12].

En el caso de las micro redes, dentro de las barreras técnicas existentes destacan la necesaria implementación de cambios en los sistemas de contadores, de protecciones, de tierra y de comunicaciones con la red eléctrica actual, así como la gestión entre la generación y el consumo a nivel local y la agregación de fuentes de energía [11].

En cuanto a la energía geotérmica en España, habría que trabajar en el contexto de no solo implantar medidas regulatorias sino también trabajar en programas demostrativos, de gestión del conocimiento del potencial geotérmico, del desarrollo de programas de I+D+i que consigan reducir los costes de generación y aumenten la eficiencia, así como en el desarrollo de un modelo formativo y de certificación [12].

Hay numerosas referencias que confirman que la principal desventaja de las energías renovables es su discontinuidad como es el caso de la lluvia, el sol, el viento [13,14]. Por contra, esa es la principal ventaja de la energía geotérmica tanto en su forma aislada como en hibridación al estar disponible durante todo el año no siendo necesario sobredimensionar los sistemas por la falta de energía. Además, no afectaría al paisaje al ir oculto en el terreno [13,14]. Es necesario implementar energías renovables y eficiencia energética en áreas remotas tales como algunas islas no solo desde el punto de vista medioambiental para la reducción de CO_2 y gases de efecto invernadero sino porque se ha demostrado ser más rentable que las fuentes energéticas contaminantes cuando parte de los costes son subsidiados [7,8,13,14].

La contribución de los recursos renovables a la sostenibilidad de la energía es más que relevante en dichas zonas remotas e insulares [15]. Por tanto, las islas Canarias se han seleccionado a propósito para este estudio.

Uno de los temas más recurrentes es la importancia de la implementación de las energías renovables a nivel local. Desafortunadamente, las políticas europeas muestran poco soporte en esta materia [16]. Se pueden destacar algunos casos de estudio en áreas insulares tales como el de Menorca como ejemplo de potencial de suficiencia energética a través de energía solar fotovoltaica [8]. En otra isla, Mikonos, en Grecia, estudios sobre la producción de energía solar y eólica [13] pero es difícil encontrar estudios basados en geotermia.

Algunos estudios proponen la desalinización de agua de mar mediante energías renovables en zonas insulares, de nuevo haciendo uso de recursos solares y del viento [14] pero con una necesidad de sobredimensionar instalaciones en ausencia de dichos recursos. Una opción interesante sería instalar una línea de geotermia que pudiera garantizar recursos energéticos todo el año sin necesitar sobredimensionar los sistemas y en esto va a consistir el segundo objetivo de la tesis.

El propósito de las plantas de desalinización usando el mix energético se presenta como una opción interesante para áreas costeras, insulares o desérticas donde los recursos del agua son escasos y beneficiaria tanto al consumo de agua humano como a la irrigación de cultivos. En este último caso ayudaría en la evolución del sector agrícola de una forma sostenible.

Además, el acoplamiento de solar y geotermia en regiones con gran cantidad de irradiación es una opción muy interesante para las plantas de cogeneración basadas en un Ciclo Rankine Orgánico (ORC), alimentado por un recurso geotérmico y un campo solar de colectores parabólicos [17]. Algunos estudios muestran la importancia de la gestión de la tierra por un lado (planificación, agricultura, conversación) y estudios geográficos por otro para implementar estrategias energéticas [18].

La energía geotérmica puede tener una infinidad de usos y muchos de ellos ya han sido estudiados, aunque la mayoría de ellos están todavía en una fase piloto. Desde la producción de electricidad hasta calefacción urbana o aplicaciones agrícolas, tales como invernaderos, calefacción de instalaciones de ganadería junto a aplicaciones industriales a través del uso de infraestructuras del suelo como calentamiento de edificios residenciales y públicos, así como piscinas, solo por mencionar algunos.

Un análisis geotérmico y medioambiental de diferentes sistemas de *District Heating* ayudado por energía geotérmica se analizó en unos edificios de la provincia de León en el norte de España. La comparación de datos reales de los diferentes escenarios revelan que la opción más apropiada desde un punto de vista medioambiental y económico fue claramente el uso de geotermia frente al resto de escenarios [19].

La mayoría de casos estudiados a nivel mundial son para usos residenciales y domésticos y asociados a una bomba de calor geotérmica, por tanto, hay un sinfín de aplicaciones y sectores susceptibles de evolucionar e implementar.

En el sector agrícola, por ejemplo, el empleo de geotermia para desecado de fruta en Grecia y el de desecado de bacalao en Islandia [18]. En el caso de España, se realizaron estudios para un posible District heating para calentamiento y ACS en Madrid así como calentamiento de invernaderos en Cartagena, Murcia y en los campos de Dalías en Almería [18].

Ejemplos residenciales en otros lugares como Okotoks en Canadá [20], en Holanda [21] o Crailsheim en Alemania son también objeto de mención [22], ambos casos consisten en la hibridación de energía solar térmica con energía geotérmica a través de un almacenamiento geotérmico en el terreno. De forma similar, se propone un innovador sistema de acondicionamiento de espacio y una evaluación del ciclo de vida se presenta para un edificio industrial. Una bomba de calor geotérmica y un almacenamiento térmico atemporal son analizados para reducir el tamaño de la instalación geotérmica [23].

Se puede concluir que la energía geotérmica tiene un enorme potencial tanto para proyectos pequeños de calefacción de casas e invernaderos como para grandes District heating con acumulación del calor en el terreno capaz de suministrar de energía a toda una ciudad [24]. Desafortunadamente, parámetros de mercado tales como aceptación por parte de los inversores, marco regulatorio, restricciones de planificación e impacto medioambiental necesitan ser encauzados para que este tipo de tecnología consiga un desarrollo efectivo [24].

El punto de partida de esta tesis se basa en explorar las barreras a la introducción de la energía geotérmica y/o su mix porque hasta la fecha solo se mencionan como objeto de exploración en algunos artículos [8]. La mayoría de las referencias consultadas son sobre energía solar y eólica [8,25]. Hay algunas referencias teóricas en Turquía, donde diferentes tipos de energía renovable fueron contrastadas con cinco criterios teniendo en cuenta consideraciones de tipo: técnico, económico, político,social y medioambiental.Según esto, la energía geotérmica obtiene la mayor puntuación [26]. Asímismo, seis plantas de producción en ese país se analizaron basados en una serie de criterios tecnológicos y sostenibles,económicos, de calidad de vida y aspectos socioeconómicos. Aquí, las plantas geotérmicas obtuvieron la tercera posición.

Hay algunas investigaciones que se focalizan en las principales barreras y acciones a implementar en la introducción de energías renovables en diferentes usos, contextos, regiones y paises [23]. Sin embargo, la novedad de este estudio reside en el escrutinio de las barreras y medidas a adoptar para introducir una energía con una gran potencialidad y poco conocida como la geotermia.

En otros estudios sobre energías renovables parece que los paises del norte de Europa tiene mayor tradición financiera que los del sur y llevan más tiempo estableciendo cooperativas para este tipo de proyectos lo que hace que esté más extendido su uso [27].

En lo relativo a las barreras culturales y sociales, parece que la falta de sensibilización de los paises del sur de Europa contraria a un activismo energético en el norte ha posibilitado la creación de pueblos de bioenergía como en Alemania, por tanto las barreras son menores que en los paises del sur [27]. Otros estudios muestran que los precios del petróleo y la inversión inicial son barreras financieras significativas [28].

En un estudio de un proyecto híbrido que comprendía energía solar, geotermia y eólica para un invernadero en Turquía [29], la inversión inicial a diferencia de los sistemas de calentamiento establecidos para la agricultura y los edificios resultó ser la barrera más importante. Sin embargo, este estudio concluye que con suficiente carga de viento el sistema es preferible a los convencionales.

De forma similar, otros estudios muestran que, en algunos casos, las instituciones contribuyen significativamente al mix energético y a las políticas energéticas probando que la calidad de las instituciones y la renta son de gran importancia en el desarrollo de las energías renovables en cualquier país [30]. En lo relativo a las barreras culturales y sociales, merece la pena destacar que la falta de aceptación social puede ser un gran impedimento para la consecución de los objetivos deseados en Europa [31].

Estudios más genéricos sobre energías renovables [18] consideran la promoción como una medida clave para el desarrollo junto al establecimiento de regulaciones nacionales en lo relativo a licencias, permisos y procedimientos. También son necesarias estrategias de energías renovables a nivel local basadas en el conocimiento, entrenamiento y monitorización. Algunos estudios sugieren que una vez que el uso de una tecnología es explicada, entonces la intención de uso se incrementa [32]. Esto está directamente unido a la importancia de la promoción como parte del esfuerzo de introducir nuevas tecnologías. En artículos que analizan la situación de las compañías industriales en Alemania en términos de implementación de la eficiencia energética, la inversión pública se destaca también como un elemento clave.

En el estudio de Michalena y Hills, la seguridad y la diversificación del suministro eléctrico se mencionan como elementos a tener en consideración debido por un lado a la alta dependencia de los combustibles fósiles en muchas regiones y por otro lado, al alto coste del petróleo [18].

El artículo de Lin y Omoju destaca que, en el corto plazo, los incrementos en los precios del petróleo afectan al desarrollo de las energías renovables pero en el largo plazo la financiación juega un papel importante y por tanto solo una adecuada planificación puede contribuir al cambio hacia la transición energética [33].

El artículo que dio lugar de esta línea de investigación fue ***"Measures to remove Geothermal energy barriers in the European Union"*** en septiembre de 2018 en la revista *Energies.*

2.3.2 Potencial de desalinización térmica con colectores cilindro-parabólicos y energía geotérmica en el sureste español.

El escenario de Desarrollo Sostenible de la Perspectiva Mundial sobre la Energía, en adelante, SDG, se inspira en los objetivos de desarrollo sostenible de las Naciones Unidas más estrechamente relacionados con la energía: lograr el acceso universal a la energía, reducir los efectos de la contaminación atmosférica y hacer frente al cambio climático. Establece lo que se necesitaría para alcanzar estos objetivos de la manera más rentable. El Escenario incluye ahora también una dimensión para el agua, centrándose tanto en las necesidades de agua del sector energético como en las necesidades de energía del sector hídrico.

Este extracto del World Energy Outlook 2018 revela los beneficios de un enfoque integrado del SDG sobre el acceso a la energía y del SDG sobre el agua limpia y sobre el saneamiento: Las energías renovables descentralizadas [34] desplegadas en las zonas rurales para el acceso a la energía también pueden proporcionar agua potable limpia. Lograr el acceso universal al agua limpia y al saneamiento añadiría menos del 1% a la demanda energética mundial en 2030 [35].

Para el 2030, se pretende aumentar sustancialmente la eficiencia en el uso del agua en todos los sectores y garantizar la extracción y el suministro sostenibles de agua dulce para hacer frente a la escasez de agua y reducir sustancialmente el número de personas que sufren de escasez de agua [36].

En un mundo cada vez más globalizado, los efectos de las decisiones relacionadas con el agua atraviesan las fronteras y afectan a todos. Los fenómenos extremos, la degradación del medio ambiente, el crecimiento demográfico, la rápida urbanización, las pautas de consumo insostenibles e injustas, los conflictos y los disturbios sociales y las corrientes migratorias sin precedentes figuran entre las presiones interconectadas a las que se enfrenta la humanidad, que a menudo afectan con mayor dureza a las personas en situación vulnerable por sus repercusiones en el agua.

Para hacer frente a las desigualdades a las que se enfrentan los grupos desfavorecidos se requieren soluciones adaptadas que tengan en cuenta las realidades cotidianas de las personas y las comunidades en situación de vulnerabilidad. Las políticas debidamente diseñadas y aplicadas, el uso eficiente y apropiado de los recursos financieros, así como los conocimientos basados en pruebas sobre los recursos hídricos y las cuestiones relacionadas con el agua también son vitales para eliminar las desigualdades en el acceso al agua potable y al saneamiento [37].

La mejora de la gestión de los recursos hídricos y el acceso al agua potable y al saneamiento para todos es esencial para erradicar la pobreza, construir sociedades pacíficas y prósperas y garantizar que "nadie se quede atrás" en el camino hacia el desarrollo sostenible [37].

En el contexto de la correcta gestión de los recursos hídricos, el papel de la energía solar es crucial para lograr esos objetivos. La energía solar se considera una de las fuentes de energía renovable más importantes y existen muchas aplicaciones en el sector industrial más allá de la desalinización, especialmente mediante el uso de colectores cilindro-parabólicos, en adelante PTC, debido a sus altas temperaturas adecuadas para determinados procesos industriales como los sistemas de energía solar: Refrigeración y aire caliente, secado, limpieza, pasteurización, etc. [38].

Sin embargo, debido a su carácter intermitente, es imprescindible combinarlo con otras fuentes de energía renovable, si es posible, y estudiar la línea de almacenamiento de los diferentes tipos de energía: electroquímica, mecánica, eléctrica y térmica y, por supuesto, los aspectos legislativos y económicos que la afectan [39] para sustituir precisamente la energía intermitente mencionada.

Algunos estudios proponen sistemas de hibridación renovable con el uso de recursos solares y eólicos para desalinizar [40]. La planta desalinizadora de Perth, en Australia, es un ejemplo [41]. Otros proponen la hibridación de la energía solar mediante PTC con biomasa y el almacenamiento de energía térmica en aquellas épocas del año en que la radiación solar es escasa [42]. Mención especial en zonas insulares como las Islas Canarias [43] para los sistemas de desalinización debido a la falta de agua del grifo y también en las Islas Canarias se analiza que los potenciales tecnológicos disponibles localmente son suficientes para un suministro totalmente renovable de las demandas energéticas de las islas en cuanto a energía, calor y transporte terrestre [44].

Otros ejemplos en la revisión de la literatura son mediante el acoplamiento de una bomba de calor a una planta desalinizadora donde se analiza la "Gained output ratio", en adelante GOR, y es uno de los indicadores más importantes en las plantas de este tipo [45]. Acoplando una planta desalinizadora de multiefecto, MED, a una compresión de vapor térmico, en adelante TVC en áreas con diferente radiación solar y diferente temperatura del agua [46] e incluso mediante el análisis de la Relación de Rendimiento Universal, en adelante UPR, para una mejor comparación de todos los métodos de desalinización y la importancia de la integración con las energías renovables [47].

En lo que respecta al UPR, cabe mencionar el artículo de Kim Choon Ngz y Muhammad Wakil Shahzad en el que se aprovecha la energía de la termoclina del mar para alimentar una MED y lograr un valor de UPR de 158 [el más alto visto hasta ahora en la literatura] [48].

Además, se utilizan técnicas de optimización estocástica para analizar el tamaño de los recursos de energía renovable, en adelante denominados RES, para alimentar una planta de desalinización por ósmosis inversa de la manera más rentable posible [47]. Numerosos estudios muestran el aumento de la producción de agua destilada con el aumento de la temperatura y el flujo de masa [49].

La importancia de los costes de desalinización es evidente en numerosas referencias y algunos de ellos van más allá cobrando costes más específicos pero también influyentes como el coste de la tierra, los estudios previos de implementación y los impuestos asociados [50].

Se propone la energía solar y geotérmica de hibridación para alimentar una planta de desalinización, para la producción de electricidad, así como para calentar y enfriar espacios en pequeñas ciudades como la isla de Pantelleria [51, 52]. También hay artículos que hablan de la hibridación de ambas energías [solar y geotérmica] utilizando PTC para aumentar la temperatura del recurso geotérmico y así mejorar la producción de una planta de ciclo binario existente [53] o se demuestra que mediante la tecnología de hibridación se aumenta la potencia neta pero se disminuye la eficiencia de la planta [54].

La hibridación de una central geotérmica con energía solar de concentración y almacenamiento térmico para aumentar la generación de energía y la despachabilidad se analiza en el campo geotérmico Coso [55].

A nivel doméstico, vale la pena hablar de la investigación de un sistema integrado de destilación de membranas impulsado por energía solar para la purificación de agua y la generación de energía [56].

Poniendo el foco en España, se dirá que es uno de los líderes mundiales, tanto en el marco normativo [hay pocos países que regulen esta materia], como en las tecnologías de regeneración de aguas residuales. España tiene una capacidad de reutilización instalada de 500 hm^3/año en las más de 320 Estaciones de Regeneración de Aguas Refinadas, en adelante, ERAR y una capacidad de desalación cercana a los tres millones de m^3/día, siendo el quinto país en capacidad instalada a nivel mundial [57].

En el caso concreto de Almería, existen actualmente tres plantas desalinizadoras: Del Bajo Almanzora, Carboneras y Campo de Dalías, produciendo entre tres las más de 90 hm^3/año y beneficiando a más de 640 000 habitantes, en adelante inh y más de 31 000 hectáreas de regadío [58]. Conociendo la población de inh de la provincia de Almería [704 297 inh] [58] y que el consumo medio por inh y día es de 132 l/d, [59], se cubre el consumo de agua potable así como el de agua para riego en esta región.

Estas plantas formaban parte de un plan más ambicioso denominado A.G.U.A. (Acciones para la Gestión y Utilización del Agua) que surgió a raíz de la derogación del trasvase del Ebro por el Real Decreto 2/2004 y la promulgación de la Ley 11/2005 de modificación del Plan Hidrológico Nacional. Este plan reorientó la política de aguas en España para satisfacer las nuevas necesidades del Arco Mediterráneo peninsular mediante la desalación. A través de este programa se propuso la construcción de 16 nuevas plantas para producir 350 hm^3 y el coste medio de cada una de ellas fue de 68,7 millones de €. El suministro fue del 54% para el consumo urbano y del 46% para el riego. El coste principal fue la energía que representó el 36% de los costes totales [60].

A pesar de la amplia experiencia en España con este tipo de plantas desalinizadoras, hasta ahora no se ha tenido en cuenta el coste energético y es imprescindible un enfoque innovador para producir energía [térmica y/o eléctrica] a través de energías renovables.

A nivel estatal (España] en las últimas líneas estratégicas para el sector del agua definidas por el Ministerio de Agricultura, Alimentación y Medio Ambiente, ya se habla de la necesidad de mejorar la eficiencia energética y el uso de las energías renovables en ese sector [57].

Como se ha indicado anteriormente, uno de los principales problemas de las plantas desalinizadoras es el alto coste de producción de agua potable debido al elevado coste de la energía y al alto coste de la propia instalación.

Como se está viendo, se conoce la hibridación de la energía solar con geotérmica, sin embargo, parte de la novedad de esta tesis y como segundo objetivo de la misma tras analizar las barreras y proponer medidas correctoras a la implantación de la energía geotérmica será demostrar su potencialidad en un caso práctico donde se combina el recurso solar mediante PTC y el recurso geotérmico existente en la zona de Almería -una zona árida con escasez de agua en el sudeste de España para alimentar térmicamente una planta desalinizadora teórica de tipo MED. Como complemento, verificar la rentabilidad de su implantación en las plantas de tratamiento de agua existentes del proyecto A.G.U.A.

Hasta ahora, el principal reto asociado a las energías renovables con las plantas desalinizadoras es optimizar su variabilidad con la demanda continua de agua potable, por lo que se buscan energías limpias y permanentes a lo largo del tiempo, como la geotérmica. Disponer de una energía limpia continua, cercana al punto de desalación es lo que se pretende en el segundo objetivo de esta tesis además de analizar un marco económico y una amortización razonable a lo largo del tiempo.

Por medio de este trabajo se destaca la importancia de la desalinización en el planeta, pero sobre todo en zonas áridas e insulares y su relación con la energía. El foco será España y en concreto el sureste español (Almería) con el estudio de una planta teórica desalinizadora tipo MED de 9000 m^3/d en hibridación con energía solar y geotermia con ocho posibles configuraciones.

El artículo que dio lugar de esta línea de investigación fue ”Thermal desalination potential with parabolic trough collectors and geotermal energy in the Spanish southeast” publicado en la revista *Applied energy en marzo del 2020, volumen 262.*

2.3.3 Beneficios económicos y medioambientales de la energía geotérmica en los procesos industriales

A pesar de los esfuerzos realizados a lo largo de los años, según la Agencia internacional de la Energía, en adelante IEA, a nivel global, la demanda de energía en la Industria sigue siendo predominantemente fósil [61]

Esto también sucede en España, donde el consumo industrial energético se distribuye de la siguiente forma: gas 40%, seguido de electricidad 32%, productos petróleo (14%), energías renovables (7%) y 6% carbón [62].

Entre las energías renovables, la energía geotérmica es una minoría y el IGA (International Geothermal Association) discrimina por uso directo o eléctrico para este recurso.

A nivel mundial, para usos directos de la energía geotérmica, los usos industriales solo suponen el 2,7% [63]. La mayoría de usos de la energía geotérmica es para bombas de calor, piscinas y baños, y calentamiento de espacios como se muestra en la figura 4.

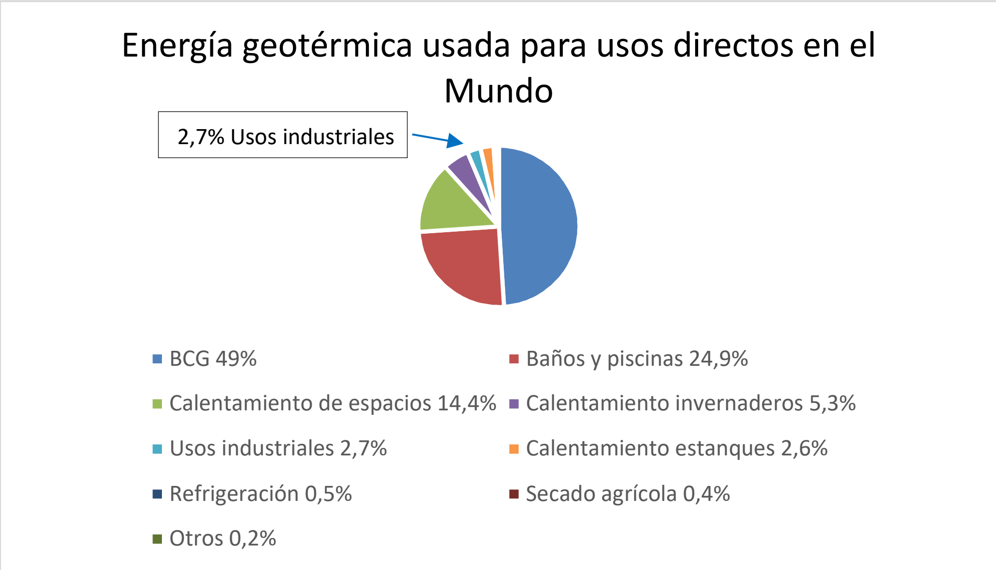


Figura 4: Energía geotérmica usada para usos directos en el Mundo: Adaptado de [63].

En la literatura, hay numerosos casos de calentamiento de espacios con energía geotérmica donde es la mejor opción para algunas municipalidades como la de Alberta (Canadá) [64] y de zonas urbanas como solución más eficiente energética y económicamente [65].

En el caso de España, el porcentaje con respecto a usos industriales es incluso más bajo que la media mundial porque no se consideran los procesos industriales. Solo calentamiento de Spas y piscinas, bombas de calor geotérmicas, invernaderos y calentamiento de espacios como usos directos (Tabla 3)

Tabla 3: Capacidad instalada y uso anual de la energía geotérmica en España. Año 2015. Fuente: Adaptado de [66]

	Capacidad instalada (MW)	Uso anual (GWh)
Baños y piscinas	2,59	52,5
Bomba de calor geotérmica	43 087	121,67
Invernaderos	14,93	94,42
Calentamiento espacios	3,52	76,26
Total	43 108,04	344,85

En España y según la tabla 4, la potencia instalada para usos directos de la energía geotérmica solo representa el 0,09% de la potencia mundial y el 0,06% de la energía mundial (ver figuras 5 y 6). La situación es incluso peor con respecto a la potencia instalada para la energía geotérmica para usos eléctricos en España ya que no existe como se muestra en la tabla 3.

Tabla 4: Potencia y energía geotérmica para usos directos: Comparación a nivel mundial y España. Fuente: Adaptado de [66].

Año 2015

Localización	Potencia (MWt)	Energía (TJ/año)
Mundial	70 329	587 786,40
España	64,1	344,9

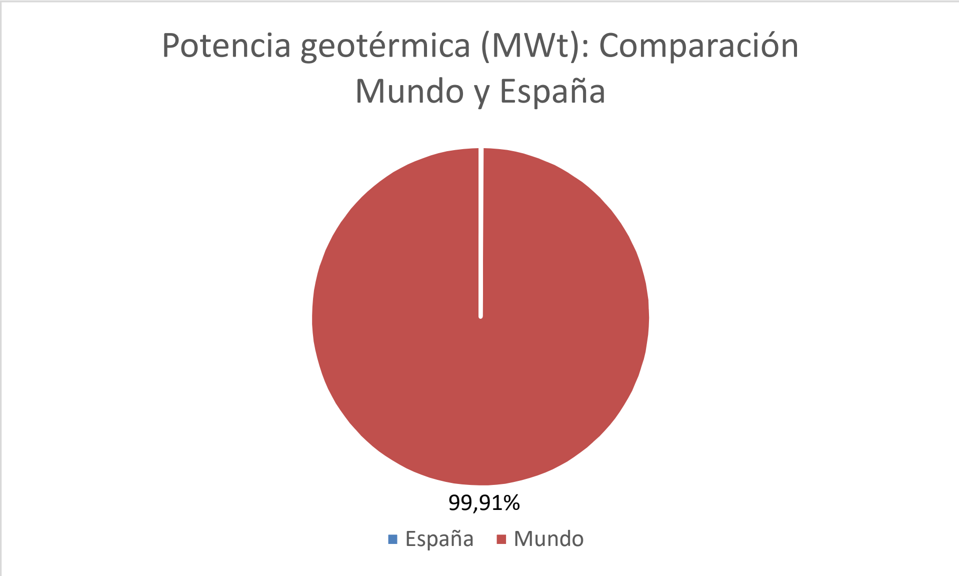


Figura 5: Potencia geotérmica para uso directo: Comparación España y escala mundial. Recurso: Adaptado de [66].

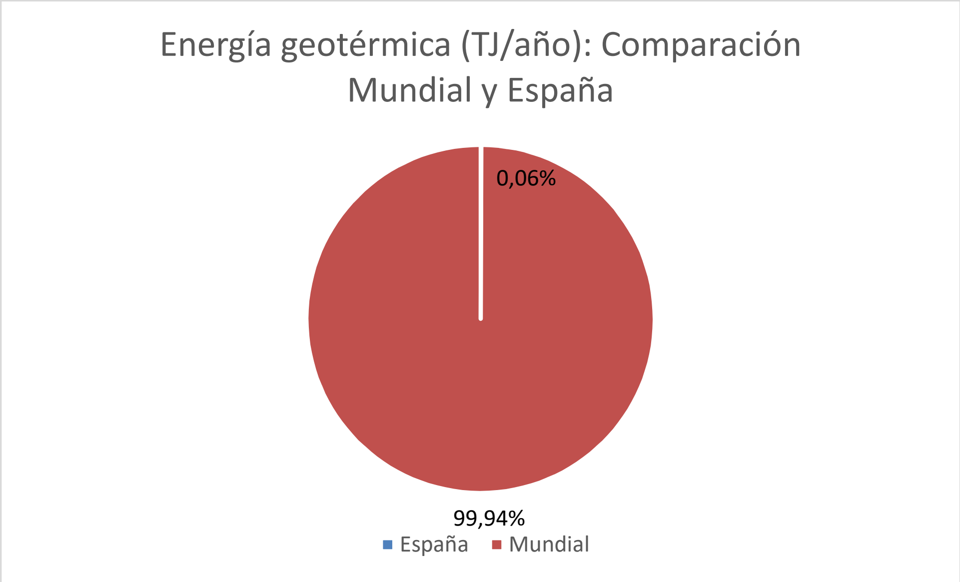


Figura 6: Energía geotérmica para usos directos: Comparación mundial y España. Recurso: Adaptado de [66].

Tabla 5: Generación eléctrica geotérmica por país. Fuente: Adaptado de [66].

	Año 2015
Localización	Potencia (MWe)
Mundial	12 636.10
España	0

En vista de la tabla 5, no hay procesos industriales alimentados con energía geotérmica en España y por tanto será objeto de investigación en este campo y tercer objetivo a conseguir en esta tesis.

Para la energía geotérmica, esas operaciones industriales tienen a ser grandes y con un consumo energético muy alto [67]. Además, tienen el factor de capacidad más alto (horas de operación anual a carga completa en la instalación) entre los usos directos (0,70, o 70 por ciento).

Se trata de procesos industriales que operan durante una gran parte del año [63]. Ésta es una buena razón para implementar el uso en la Industria de la energía geotérmica si se compara con el factor de capacidad de las bombas de calor (0,27) o incluso con la media mundial (0,15).

Curiosamente, a pesar de la falta de uso, el potencial de la energía geotérmica de baja y media entalpia en

España cubriría ampliamente las necesidades de su industria como se muestra en la Tabla 6.

Tabla 6: Comparación del potencial de uso de los recursos geotérmicos en España y baja y media temperatura y el consumo de energía en las industrias españolas. Año 2018.Fuente: Adaptado de [63] y [62].

	Potencial de uso y explotación de los recursos geotérmicos (GWh)	Coste energético de las industrias españolas (€)	Tipo de fuel	Consumo energético de las industrias españolas (GWh)
Baja	15 990 000	78 653	Electricidad	
Media	5 423 000	96 726	Gas	
		34 622	Diésel ,petróleo ,otros derivados del petróleo	
		15 398	Carbón y coque	
		17 119	Energías renovables	
Total	21 413 000			242 508

A la vista de la tabla 6, el consumo de energía de la industria española, en adelante, *Qe*, solo representaría el 1,13% del potencial de uso y explotación del recurso geotérmico en España. Por tanto, el potencial es enorme en este sentido.

Es cierto que hay algunas industrias en España (especialmente las más potentes) que han llevado a cabo recientemente iniciativas para reducir el consumo de energía [68,69,70] pero el nivel de mejora en este sentido es enorme considerando las cifras del consumo de energía en España por tipo de recurso energético del Instituto nacional de estadística, en adelante INE [71].

Al contrario que la geotermia, otras energías renovables han sido más afortunadas como es el caso de la energía solar especialmente en España.

La energía solar es considerada como una de las más limpias y por tanto una de las más importantes en el mundo para aplicaciones domésticas y del sector industrial [72-75]. La energía solar como recurso energético renovable para procesos industriales es bien conocida en numerosos estudios e informes [76, 77, 78] pero no tantos con calor geotérmico, motivo por el cual será objeto de esta tesis.

Hay numerosos estudios de aplicaciones en el sector industrial tales como el de Solar Concentra [79], que une los procesos industriales con energía solar; el estudio de Lilliestam J[80], el cual muestra la importancia de la energía solar térmica para generación de electricidad incluso en invierno, y el cual puede suministrar carga base a bajo coste en algunos casos; el estudio de Sharmaa AK, et.al [81], el cual une procesos industriales con calor solar térmico como uno de los recursos más limpios del planeta.

Otros estudios [82-84] muestran que la conversión de energía solar en energía térmica es mucho más eficiente [hasta el 70%] que la conversión en electricidad.

Procter D, et. al [85] dirige un estudio en una industria de procesado de alimentos en Australia donde se concluye que la mitad de la energía requerida para procesos de entre 40 °C y 60 °C puede ser suministrada por colectores solares.

Como barreras a la energía solar térmica para calentamiento de procesos industriales destaca la falta de apoyo para solar térmica de generación de electricidad y fotovoltaica como se menciona en numerosa literatura [86-90].

Otra desventaja de la solar térmica es que el entramado empresarial español está compuesto principalmente de empresas de tamaño pequeño y mediano las cuales tienen mayor dificultad en hacer una inversión inicial en este tipo de sistemas. Esto último sería reproducible a la geotermia donde la mayoría de instalaciones en España [y en la UE) son con bomba de calor geotérmica y lideradas por pequeñas empresas [63].

Vargas Payera [91] destaca con respecto a la energía geotérmica las barreras sociales en Chile tales como la falta de confianza, la relación espiritual con los volcanes y la incertidumbre sobre el impacto medioambiental como factores que afectan a la percepción pública.

También en el estudio de Cagno et al. [92] se mencionan las barreras y drivers pero en este caso para la eficiencia energética en algunas industrias de Holanda.

En el estudio de Ilic and Trygg [93] llega a ser claro los beneficios económicos y medioambientales de los procesos industriales a District Heating.

El uso de energía geotérmica como parte integral del modelo energético es esencial para solucionar los problemas de espacio de los colectores solares y su naturaleza intermitente en días sin suficiente radiación solar. Otros estudios como el de Mahmoud et al. [94] consideran sistemas de almacenamiento de energía mecánica como una solución.

Es esencial ser capaz de evaluar el mejor recurso de energía sostenible para cada área en cuestión. Esto significa tener en cuenta a la energía geotérmica sola o en hibridación como se comenta en algunos artículos [95-101] dado que puede ser la más apropiada.

De la misma forma que se indica en algunos artículos, una vez se hayan superado las barreras económicas a la energía geotérmica [95], se haya enfatizado el valor de la hibridación de los sistemas renovables [102], se haya considerado la reconversión de las minas inundadas como pozos geotérmicos cuando sea posible [103] y se tenga un mejor conocimiento de las técnicas de simulación para reducir las incertidumbres tecno-económicas [104], entonces la energía geotérmica tendrá el lugar que le corresponde como fuente de energía limpia y renovable.

La forma en que se aborda la energía geotérmica como fuente renovable para procesos industriales es novedosa en esta tesis ya que se asocia a cada proceso industrial que trabaja en un rango de temperatura concreto el más apropiado tipo de energía geotérmica según la localización de la Industria en cuestión en el sentido de aprovechamiento del terreno y concentración de empresas. También es novedoso el cálculo de emisiones de

CO_2 evitadas a la atmósfera y los años de amortización calculados por la implementación del modelo energético geotérmico a las industrias españolas. Se hace además una comparativa con las empresas pertenecientes a la base de datos del "SHIP-plant" (Solar Heat for Industrial Processes) si fueran alimentadas con geotermia en vez de con energía solar.

El artículo que dio lugar de esta línea de investigación fue ***"Economic and enviromental benefits of geothermal energy in industrial processes"*** publicado en Renewable Energy, volumen 174, en agosto del 2021.

3. MARCO TEÓRICO EN EL QUE SE INSCRIBE EL TEMA DE LA TESIS Y HERRAMIENTAS METODOLÓGICAS. REMISIÓN A LAS PUBLICACIONES

3.1 Publicación 1: "Measures to Remove Geothermal Energy Barriers in the European Union

La metodología de esta parte del trabajo de la tesis que dio lugar a esta publicación ha consistido en enviar un cuestionario sobre las barreras de entrada a 54 expertos internacionales y nacionales sobre la materia. Cada cuestionario contiene 20 preguntas lo más elaboradas posibles sobre las barreras para la introducción a la energía geotérmica en la UE, en España y en las islas Canarias como localizaciones de más global a más local y en el sector agrícola como sector de actividad concreto y las medidas para eliminarlas. Un total de 11 respuestas de los expertos se han recibido con una tasa de éxito del 20%.

La metodología sigue el "método no probabilístico" al tratarse de una muestra pequeña pero representativa al ser bien conocidos los expertos que respondieron

La validación se hace por tanto mediante juicio de expertos en energías renovables en general y en energía geotérmica en particular tanto de España como de la Unión Europea por el envío de formularios durante el período de tres meses de octubre del 2017 a diciembre del 2017. El estudio se estructura en 4 bloques principales para cubrir cada una de las tres tecnologías en los cuatro escenarios planteados en la Figura 7.

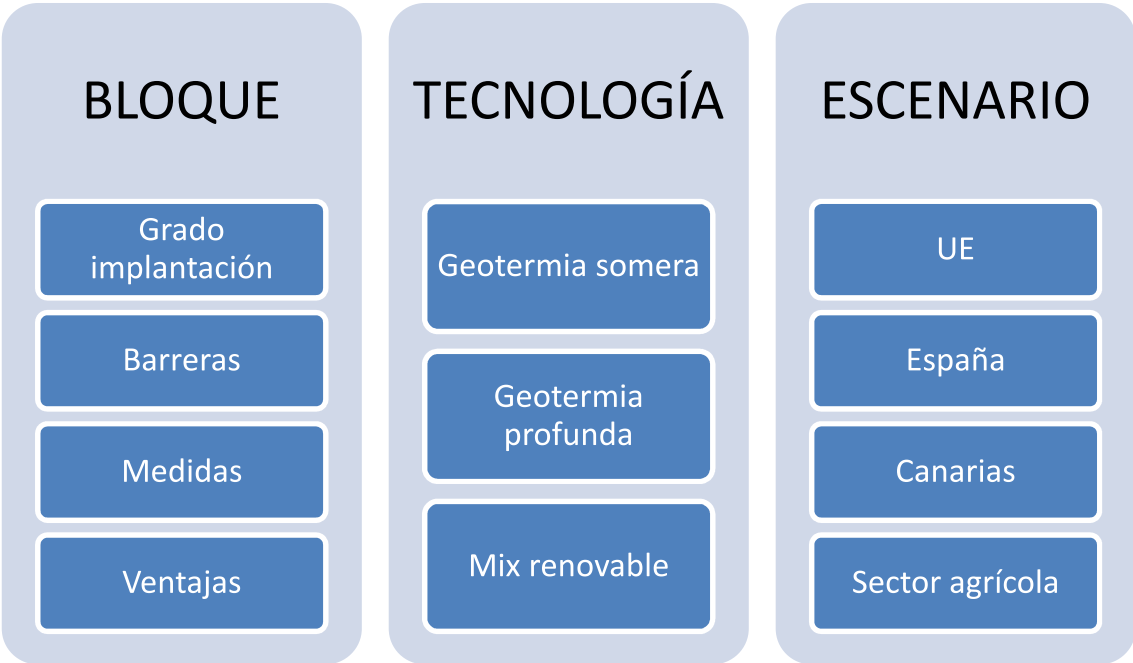


Figura 7: Representación de los bloques, tecnología y escenarios estudiados. Fuente: Elaboración propia.

3.2 Publicación 2: "Thermal desalination potential with parabolic trough collectors and geothermal energy in the Spanish southeast.

La metodología de esta parte del trabajo de la tesis que dio lugar a esta otra publicación pretende combinar el recurso solar mediante colectores cilíndrico parabólicos (PTC) y el recurso geotérmico para alimentar una planta desalinizadora tipo MED obteniendo varias configuraciones posibles.

La metodología seguida comienza tomando como punto de partida una planta teórica desalinizadora con capacidad para 9000 m^3/d. La elección de este tamaño es debido a estudios previos donde se conoce que el coste de desalinizar es óptimo para este flujo con una MED de tres evaporadores. La situación geográfica de la desalinizadora es en la provincia de Almería en el sureste español.

Con las dos premisas anteriores, por un lado, la elección de una MED parece factible comparado con otras técnicas de desalinización al tratarse de una planta de tamaño medio en términos de capacidad de desalinización. Por otro lado, teniendo en cuenta los perfiles climatológicos de la provincia de Almería parece factible hacer uso del recurso solar como opción de energía renovable para alimentar a dicha desalinizadora.

El tipo de colector elegido ha sido PTC (solo capturan radiación directa). Sin embargo, como es esperado, el recurso solar no es suficiente para proveer el 100% de la energía requerida por la planta desalinizadora por lo cual se propone combinar con el recurso geotérmico.

Comenzando con el histórico de irradiación y temperaturas de la provincia de Almería desde el año 1994 hasta el año 2016 proporcionado por la base de datos de Solargis [105], se hace una discriminación del perfil de temperaturas obtenido a la salida de los paneles solares dimensionando el área de colectores para irradiación máxima.

Se parte de un consumo medio de la planta desalinizadora de q_d = 2,9 kWh/m^3 [106] y tomando el valor inicial del caudal para la MED , q = 9000 m^3/d, se obtienen una serie de resultados relativos a la potencia de la planta desalinizadora. A continuación, se calcula el área requerida de paneles solares y luego las temperaturas a la salida de los PTC. Se hace una discriminación según el perfil de temperaturas de salida de los PTC obteniendo un porcentaje de días/año con determinado intervalo de temperaturas.

Por otro lado, se hace uso de la temperatura de un pozo de geotermia en las inmediaciones de Níjar a determinada profundidad. De la combinación del perfil de temperaturas a la salida de los PTC y de la temperatura que se puede obtener del pozo de Níjar (Almería) surgen una serie de configuraciones posibles en hibridación o aisladas para alimentar con energías renovables la planta teórica desalinizadora tipo MED.

3.3 Publicación 3: “Economic and enviromental benefits of geothermal energy in industrial processes”.

Cada tipo de industria lleva asociado una serie de procesos industriales que requieren unos niveles determinados de temperatura. En este caso, la metodología de esta última parte del trabajo de la tesis que dio lugar a esta otra publicación ha consistido en poder suministrar la energía requerida por dichos procesos por medio de fuentes naturales y sostenibles. Para ello, nos vamos a centrar en un recurso como el geotérmico. En particular, se evaluará el potencial geotérmico para el consumo energético industrial español y se hará un estudio que vincule el criterio térmico de los procesos industriales en la industria en España con el criterio geotérmico y con el criterio empresarial.

Como criterio térmico que vendrá definido por el rango de temperatura de los procesos industriales estableceremos cinco a saber, procesos de menos de 30 °C, de entre 30 °C y 45 °C , de entre 45 °C y 100 °C, de entre 100 °C y 150 °C y de más de 150 °C.

Como criterio geotérmico se establecen también cinco zonas geotérmicas en España con perfiles de muy baja (hasta 30 °C), baja (entre 30 °C y 45 °C), baja (entre 45 º C y 100 °C), media (entre 100 °C y 150 °C) y alta temperatura geotérmica (más de 150 °C).

Por último, como criterio empresarial se definen tres criterios, a saber, el mayor grado de concentración empresarial, la mayor cifra de negocios y por último la mayor inversión en activos materiales dando lugar a un ranking de regiones en España que cumplen con este criterio empresarial.

A continuación, calcularemos el ahorro esperado tanto en emisiones de CO_2 a la atmósfera como en años de amortización si fuésemos capaces de suministrar solo con esa fuente de energía la mayoría de los procesos industriales requeridos para la industria en España y se hará extensible a escala global. También se estudiará como caso práctico la reconversión de las plantas solares pertenecientes al SHIP-plant y su ahorro esperado por la reconversión a energía geotérmica.

4. TRABAJOS PUBLICADOS

Las publicaciones que integran la presente tesis cumplen con los requisitos establecidos en el Documento aprobado por el Comité de Dirección de la Escuela Internacional de Doctorado de la Universidad Nacional de Educación a Distancia (EIDUNED), en su reunión de 16 de enero de 2017 y por la Comisión de Investigación y Doctorado de la UNED, con fecha 21 de Febrero de 2017 para ser considerados válidas en la tesis doctoral presentada por compendio de publicaciones. Dichos requisitos son los siguientes:

El compendio de publicaciones estará formado por un mínimo de 3 artículos. Al menos dos de ellos debes estar publicados y el tercero aceptado. En este caso, los tres artículos han sido publicados con anterioridad a la presentación de esta tesis.

Los artículos han de ser publicados en revistas de índices de impacto en los dos primeros cuartiles de la relación de revistas del ámbito de la especialidad del Programa en el que está inscrita dicha tesis y referenciadas en la última relación publicada por el *Journal Citation Reports* (SCI y/o SSCI) y de *SCOPUS.* Los tres artículos han sido publicados en revistas con índices de impacto en los dos primeros cuartiles.

*"Atendiendo a los **NUEVOS CRITERIOS PARA LA PUBLICACIÓN ASOCIADA A LA TESIS DOCTORAL y en concreto al punto 3) de CLAUSULAS COMUNES A TODOS LOS PROGRAMAS DE DOCTORADO:** Para verificar si la revista o editorial en la que se publique el trabajo cumple con los criterios indicados, se tomará en cuenta una ventana temporal amplia que incluye el año de publicación (o de aceptación del trabajo, si este no fuera publicado todavía), así como los dos (2) años anteriores y los dos (2) posteriores a la publicación".*

Todos los artículos deben estar publicados con fecha posterior a la primera matrícula de tutela académica en la EIDUNED. En este caso, la primera matrícula se produjo en el curso académico 2017-2018 y los artículos se han publicado entre noviembre del 2018 y agosto del 2021 (el último artículo aprobado en abril del 2021).

El doctorando o doctoranda debe ser primer firmante o segundo, en este último caso, el primero debe ser el director o directora de la tesis. En todas las publicaciones que integran la tesis doctoral, el doctorando es primer o segundo firmante, siendo en este caso, D. Antonio Colmenar Santos, director de la tesis, el primer autor.

A continuación, en los siguientes apartados se muestran todos los datos correspondientes a cada una de las publicaciones incluidas en esta tesis por compendio.

4.1 Publicación 1: "Measures to Remove Geothermal Energy Barriers in the European Union

- **Autores**: Colmenar-Santos A, Palomo-Torrejón E, Rosales-Asensio E y Borge-Diez D.
- **Título**: Measures to remove geothermal energy barriers in the European Union.
- **Revista**: Energies
- **Factor de impacto** (año 2020): 3,004
- **Factor de impacto últimos 5 años:** 3,085

- **Cuartil en la categoría Energy&Fuels:** Q3 (ranking 70 de 114; en año 2017 y anteriores era Q2).
- **Estado**: Aceptado y publicado Noviembre 2018

4.1.1 Resumen de la publicación

Resumen en español

El artículo examina las principales barreras de mercado que lastran la introducción de la energía geotérmica a nivel local, nacional y europeo, así como las medidas necesarias a adoptar para erradicarlas y su contribución al uso general de esta fuente de energía. La novedad del estudio descansa en la descripción detallada de cuatro escenarios: La Unión Europea, España, Islas Canarias y el sector agrícola para los tres tipos de energía geotérmica y sus usos a continuación expuestos: Baja entalpia o usos térmicos, alta entalpia o usos eléctricos y el mix energético renovable. Los resultados son de esperar que difieran unos de otros en términos de nivel de introducción, barreras y medidas a adoptar. Se ha seleccionado España dentro del contexto europeo debido a su escaso 0,1% de mercado geotérmico en la demanda de energía primaria y las Islas Canarias en particular dado su carácter insular. Se ha seleccionado también a propósito el sector agrícola debido a su escaso desarrollo en energías renovables en general y en energía geotérmica en particular.

Resumen en inglés

This article examines the main market barriers that hamper the introduction of geothermal energy at local, national and European levels as well as the necessary steps that need to be taken to eradicate them, thus contributing to the general use of this renewable source of energy. The novelty of this study lies in the detailed description of four different scenarios: the European Union (EU), Spain, the Canary Islands and the agricultural sector for the three types of geothermal energies and their uses: Low-enthalpy or thermal uses, high-enthalpy or electrical uses and renewable energy mix. The results are expected to differ in terms of level of introduction, barriers and measures to be taken. We have selected Spain within the European context due to its meagre 0.1 % geothermal market share in primary demand for renewable energy, and the Canary Islands in particular, given its insular nature. We have likewise picked the agricultural sector due to its underdevelopment as far as renewable energies are concerned, including geothermal energy.

4.1.2 Conclusiones de la publicación

El hecho de ser capaz de discriminar en este estudio según los diferentes usos de la energía geotérmica (térmica o eléctrica o mix) dependiendo de la región a examen (isla, país o continente) o incluso según un sector específico de actividad, en este caso el sector agrícola, permite poner el foco de atención donde realmente se necesita para identificar las acciones más adecuadas según el caso.

El trabajo contempla cuatro grandes bloques enumerados como el grado de implementación, las barreras, las medidas y las ventajas para las tres tecnologías y los cuatro escenarios mencionados. Por tanto, abarcaría desde una perspectiva más global a otra más específica con análisis de sus resultados.

Los principales resultados de este estudio son:

Primero, relativo al nivel de implementación de la energía. Un nivel de implementación más bajo en España que en la UE se ha identificado al examinar todos los escenarios excepto el relativo a la energía geotérmica de baja entalpia. Es incluso menor en las Islas Canarias para todos los escenarios excepto para el mix energético. En un nivel general, el grado de desarrollo es de dos en una escala de uno a cinco (de la más baja a la más alta). La situación es incluso peor en lo relativo a la energía geotérmica de alta entalpia y en lo relativo al sector agrícola.

Segundo, relativo a las barreras, cuando se separan las energías renovables por tipos y por tanto la energía geotérmica del resto e incluso se discrimina por usos térmicos o eléctricos, se obtiene que para la energía geotérmica de baja entalpia las barreras económicas no son tan importantes como cabría esperar y de hecho la puntuación obtenida es menor que la de sus socios europeos.

Por otro lado, en lo relativo a la producción de energía eléctrica de alta entalpía, las barreras económicas son importantes tanto en España como en la UE. A escala global, el estudio concluye que para la energía geotérmica eléctrica las principales barreras son económicas o financieras mientras que para la energía geotérmica térmica son culturales o sociales. A escala local, en la UE, las barreras económicas o financieras son aún las más importantes para ambos la energía geotérmica de baja y alta entalpia. Esto también se cumple en España, pero en el caso de la de alta entalpía aún es más acusado.

En el caso de las Islas Canarias las principales barreras son las culturales o sociales junto con las regulatorias o institucionales para el caso de la energía geotermia de baja entalpia y de tipo económico o financiero para la energía geotérmica de alta entalpía.

Como se ha dicho anteriormente, uno de los temas más citados en numerosos artículos es la necesidad de implementar energías renovables a escala local, aunque las políticas europeas (y no solo europeas) dan un escaso apoyo a este tema.

Según las investigaciones de este estudio, las barreras institucionales o regulatorias ocupan la tercera posición en la escala general tanto para la geotermia de alta como de baja entalpía, siendo más importante en la UE que en España especialmente para usos eléctricos. Como ya se ha indicado, la importancia de las Islas Canarias también merece la pena mencionarlo en este caso.

En tercel lugar,relativo a las medidas a adoptar, este estudio concluye que a nivel regional, la UE considera que las acciones a implementar son la inversión privada en el caso de energía geotérmica de alta entalpia y la promoción para la energía geotérmica de baja entalpía. En el caso de España, para la energía geotérmica de alta entalpía,sería la inversión pública y , de nuevo, la promoción para usos térmicos. En el caso de las Islas Canarias, la inversión pública para geotermia de baja y alta entalpía; formación, y promoción para baja entalpía. En el caso del sector agrícola,formación y promoción serían las medidas más representativas para ambos, energias renovables en general y energía geotérmica en particular. Relativo a acciones globales,dependiendo de si es baja geotermia, alta geotermia o mix serían inversión pública, promoción y marco regulatorio en este orden.

Las cifras indican que cuando se examinan las barreras a la introducción de las energías renovables poniendo el foco en la energía geotérmica en particular y su mix energético, no solo promoción y marco regulatorio cambian a la primera posición sino también inversión pública y privada siendo más o menos importante dependiendo de la región estudiada y del tipo de tecnología geotérmica.

Por último,relativo a las ventajas, la seguridad energética no parece ser el asunto principal de los expertos por cuanto se cubriría con otras fuentes de energía en el corto plazo (renovable y no renovable. Esto es más importante en las Islas Canarias debido a su carácter aislado e insular. No obstante, este estudio comparte con otros, la importancia de la independencia energética de recursos externos [37].

El caso de Canarias no es diferente del resto de áreas insulares de Europa y del mundo donde la generación distribuida y las microrredes llegan a ser un asunto fundamental. Para las tres tecnologías estudiadas aquí, baja,alta y mix, el escenario de la UE es el más positivo. Esta circunstancia se repite en todos los cuestionarios.

Un estudio con más expertos en la materia sería deseable en un futuro cuando esta tecnología sea más conocida para poder compararlo con el actual. De la misma forma, se espera que futuras investigaciones incluyan en la línea del indicado aquí otras tecnologías tales como roca seca, sistemas geotérmicas estimulados y/o yacimientos supercríticos.

4.2 Publicación 2: "Thermal desalination potential with parabolic trough collectors and geothermal energy in the Spanish southeast"

- **Autores:** Colmenar-Santos A, Palomo-Torrejón E, Mur-Pérez F y Rosales-Asensio E.
- **Título**: Thermal desalination potential with parabolic trough collectors and geothermal energy in the Spanish southeast
- **Revista**: Applied Energy
- **Factor de impacto** (año 2020): 9,746
- **Factor de impacto últimos 5 años**: 9,953
- **Cuartil en la categoría Energy&Fuels :** Q1 (ranking:9 de 114).
- **Estado**: Aceptado en Diciembre 2019 y publicado en Marzo 2020.

4.2.1 Resumen de la publicación

Resumen en español

La industria de la desalinización es esencial para la supervivencia de la población en lugares con escasez de agua fresca. Debido a que es un proceso costoso, la búsqueda constante de la mejor fuente de energía renovable local es una necesidad.

Una planta desalinizadora teórica multiefecto (MED) de 9000 m^3/día localizada en el sureste español (Almería) se pretende alimentar térmicamente con energía solar (colectores cilíndricos parabólicos) y energía geotérmica.

Comenzando con el histórico de irradiación solar y el perfil de temperaturas de la provincia de Almería desde el año 1994 hasta el año 2016 aportado por la base de datos Solargis, se obtiene a la salida de los paneles solares una discriminación del perfil de temperaturas. Poniendo en común dicho perfil y la potencialidad del recurso geotérmico a la profundidad del área estudiada, se obtienen una serie de posibles configuraciones.

Los resultados teóricos del estudio indican que durante el 76% del tiempo anual se alcanzan con ambos recursos (solar y geotérmico) a la profundidad del pozo de la zona climatológica especificada (490 m, t = 41,8 °C).

Dado que el gradiente térmico en la zona es de 8,87 °C por 100 m de profundidad según los estudios indicados, solo la energía geotérmica sería necesaria a la profundidad de 790 m para obtener las temperaturas de trabajo de la planta desalinizadora a 70 °C.

Aplicando los resultados a las plantas desalinizadoras existentes del proyecto español llamado Acciones para la gestión y utilización del agua (proyecto A.G.U.A), se obtiene un plazo de amortización de 6 años y 510 387 920 kg/año CO_2 evitadas a la atmósfera por el conjunto de todas las plantas.

Resumen en inglés

Desalination industry has become essential for the survival of the population in places with shortages of fresh water. Because is a costly process, the constant search for the best local renewable energy sources is a necessity.

A theoretical Multi-effect distillation plant of 9000 m^3/d located in the southeast Spanish (Almería) is intended to fed thermally with solar (parabolic trough collectors) and geothermal energy.

Starting from the history of solar irradiation and temperatures of the province of Almería from 1994 to 2016 provided by Solargis database, a discrimination of the profile of temperatures is obtained at the exit of the solar panels. Putting in common the profile exit temperatures and the potentiality of the geothermal resource at the depth in the area under study, a series of possible configurations are obtained.

The theoretical results of the study indicate that during 76 % of the annual time is achieved with both resources (solar and geothermal) at that depth of the well in that specific climatological zone (490m, t = 41.8 °C).
Since the thermal gradient in the area is 8.87 °C per 100m depth according to the studies carried out, only geothermal energy would be necessary at deep of 790 m to obtain working temperatures of the desalination plant at 70 °C.

Applying the results to the existing desalination plants of the Spanish project named Actions for the Management and Utilization of Water is obtained 6 years of amortization and 510 387 920 kg/y CO_2 avoided to the atmosphere for all of these plants.

4.2.2. Conclusiones de la publicación

El potencial de mejora para la industria de la desalinización es enorme desde el punto de vista de la sostenibilidad energética debido a la gran cantidad de energía requerida para su operación.

La búsqueda de recursos energéticos renovables locales son una necesidad para reducir dicho consumo al máximo y por tanto es el objetivo de este trabajo.

Los principales resultados de este estudio indican que:

Alimentar a una planta desalinizadora multiefecto, - MED-, de 9000 m^3/d que opera a 70 °C con solo energía solar procedente de colectores cilíndrico parabólicos en la región objeto de estudio es una pérdida de tiempo porque solo se podría conseguir durante el 9% de los días anuales.

La situación mejora si se añade una bomba de calor de absorción de doble efecto, -DEHP-, la cual bajaría la temperatura de salida para alimentar la planta desalinizadora tipo MED consiguiendo alimentar con dicha energía durante un 29% del tiempo anual.

La situación es incluso mejor si se añade un pozo de geotermia donde pueda ir la energía sobrante de los colectores cilíndrico parabólicos en cuyo caso la planta desalinizadora tipo MED podría trabajar durante un 76% del tiempo anual en las condiciones geológicas de la tierra en la localización de los campos de Níjar que es t = 41,8 °C a 490 m de profundidad.

Además, el hecho de tener una temperatura de 70 °C a 790m en estos campos de Níjar, abre la posibilidad de alimentar una planta desalinizadora multiefecto, -MED-, con solo energía geotérmica de una forma continua lo cual sería más que deseable y uno de los temas más críticos de las energías renovables en general porque se aseguraría su no intermitencia.

Como una extensión del estudio teórico que nos acaece, se ha realizado también una extrapolación de los resultados a las plantas desalinizadoras ya existentes no renovables del proyecto A.G.U.A localizadas en el sureste de España. El propósito es evaluar el impacto económico y ecológico de las mismas por el uso de energías renovables en general y del mix solar-geotermia en particular. Los resultados teóricos de dicha extrapolación arrojan unas cifras nada despreciables de 6 años aproximadamente de amortización y 510 387 920 kg/CO_2 anual evitado a la atmósfera para todas las plantas

Hay que tener en cuenta también que una buena parte del territorio español (no solo el sureste o sur) está afectado por un gran número de horas de sol anual pero con unos recursos geotérmicos de baja temperatura (30-100)°C [107]. Este hecho no es un inconveniente para la desalinización, especialmente para la desalinización térmica como se ha visto. De hecho, se resaltarán dos factores: Por un lado, es posible reducir el exceso de temperatura de los colectores cilindro parabólicos por medio de una bomba de calor de absorción de doble efecto y energía geotérmica por un lado, y por otro lado, esta clase de recurso de baja entalpía son apropiados para plantas desalinizadoras tipo destilación multiefecto, -MED. Como comentario, el área de los campos de Níjar es uno de los 22 en la región de Andalucía y solo representa el 2,5% del potencial geotérmico disponible en esta zona [107].

Como es lógico, la localización de las plantas de desalinización cercanas a la costa, la localización del campo de colectores solares y la realización de las prospecciones para los pozos geotérmicos son factores a tener en cuenta para una mayor proximidad a los puntos de consumo energético y la posible evaluación de las pérdidas de transporte si fuera necesario la creación de una red de distrito.

No hay estudios que combinen energía solar de tipo PTC con geotermia para plantas desalinizadoras o estudios que sugieran reconvertir las plantas desalinizadoras no renovables existentes en España de la forma aquí presentada. Por tanto, sería deseable que este estudio pudiera servir de referencia a otras áreas con condiciones climáticas y geotérmicas similares.

También sería interesante realizar estudios en diferentes áreas geográficas costeras (insulares o peninsulares) donde sea necesario desalinizar debido a la escasez de agua potable o de riego con otros perfiles de radiación solar y otros recursos geotérmicos Desde otros tipos de colectores solares diferentes a los parabólicos, así como otros tipos de plantas de desalinización con otras posibles configuraciones diferentes a las presentadas en esta tesis.

En cualquier caso, se ha demostrado por medio de este trabajo que el potencial es enorme en este campo.

4.3. Publicación 3: "Economic and environmental benefits of geothermal energy in industrial processes".

- **Autores**: Palomo-Torrejón E, Colmenar-Santos A, Rosales-Asensio E y Mur-Pérez F.
- **Título:** Economic and environmental benefits of geothermal energy in industrial processes.
- **Revista**: Renewable Energy.
- **Factor de impacto** (año 2020): 8,001
- **Factor de impacto últimos 5 años**: 7,435
- **Cuartil en la categoría Energy&Fuels:** Q1 (ranking 16 de 114).
- **Estado**: Aceptado en Abril 2021 y publicado en Agosto 2021.

4.3.1 Resumen de la publicación

Resumen en español

Dado que el sector industrial es uno de los mayores emisores de gases de efecto invernadero del mundo, es necesario encontrar una solución, y la energía geotérmica puede contribuir significativamente a este reto.

Este estudio demuestra que casi el 85% de los procesos industriales pueden llevarse a cabo con recursos geotérmicos de muy baja, baja y media temperatura en España. En este contexto, se evitarían más de 80 millones de toneladas de CO_2 al año a la atmósfera y 15 años sería el periodo de amortización de esta inversión para procesos industriales de hasta 45 °C en España.

Como visión práctica, se realiza un estudio técnico-económico mediante la reconversión de la energía solar ya existente de las plantas pertenecientes al SHIP plant español en energía geotérmica para los procesos industriales obteniendo un ahorro del 18% de la inversión respecto a la energía solar.

Resumen en inglés

As the industrial sector is one of the world's largest greenhouse gas dispatcher, a solution must be found, and geothermal energy can make a significant contribution to this challenge.
This study shows that almost 85 % of the industrial processes can be carried out with very low, low and medium geothermal temperature resources in Spain. In this context, the CO_2 emissions avoidance to the atmosphere would mean more than 80 million tons per year and 15 years would be the amortization period for this investment for industrial processes of up to 45 °C in Spain.

As a practical vision, a technical-economic study is performed by means of the reconversion of the already existing solar energy into geothermal energy of the plants belonging to the Spanish Solar heat for industrial processes obtaining savings of 18 % of the investment with respect to the solar energy.

4.3.2. Conclusiones de la publicación

Poder alimentar con energía limpia como la geotérmica el consumo industrial de un país es un reto. Pensar en la energía geotérmica más allá del uso doméstico es una necesidad, y este estudio ha demostrado que es una realidad al evaluar el consumo energético industrial de todo un país como España con este recurso.

Los procesos industriales de hasta 45 °C son los más adecuados para utilizar la energía geotérmica dada la orografía de España y el potencial de desarrollo y económico de determinadas zonas geográficas. Seis regiones de las 17 que hay en España son las más lógicas para afrontar este reto. En este rango se encuentran los procesos relacionados con el lavado y precalentamiento en la industria en general, pero también en la industria alimentaria, de bebidas y textil, así como los procesos de galvanizado en la industria del metal y la automoción y los procesos de secado en la industria de la madera y el papel. Actuar sobre estas industrias desde los gobiernos regionales para promover la energía geotérmica es un deber.

Los procesos industriales que requieren temperaturas más elevadas tienen periodos de amortización más largos gracias al uso de la energía geotérmica. Por un lado, España no dispone de mucho territorio geotérmico de alta entalpía, pero, por otro lado, los costes asociados a las perforaciones más profundas siguen siendo bastante elevados a nivel mundial y también en España. Una mayor competitividad en el mercado por parte de un mayor número de empresas dedicadas a la explotación de este recurso reduciría previsiblemente sus costes. La demanda de las grandes potencias consumidoras o de los conglomerados de industrias con mayores necesidades energéticas justificaría entonces esa inversión en perforaciones más profundas. Un cambio de paradigma en el modelo energético empresarial con costes energéticos compartidos se presenta como alternativa al modelo actual.

Utilizar los estudios previos realizados en cada zona y/o invertir en una prueba de respuesta térmica, TRT [108], para conocer mejor el terreno y así poder evaluar los costes reales de la perforación es también un requisito previo.

Una buena comunicación en la fase de exploración entre las empresas geotérmicas y las comunidades locales es también esencial para el éxito del proyecto [109].

Para comprobar los resultados del estudio se eligieron quince industrias en España las cuales, si se alimentaran con energía geotérmica en algunos rangos de temperatura, se obtendría un ahorro del 18% respecto al uso de la energía solar. Los resultados son realmente relevantes porque se obtiene un ahorro al compararla con la energía solar. Justifica además la implantación en toda la industria española condicionada por fuentes de energía no renovables en su mayoría [110].

Una extensión del estudio local es perfectamente posible a nivel global ya que serían aplicables los tres criterios definidos y la conexión entre los recursos geotérmicos locales disponibles con sus rangos de temperatura y los de los procesos industriales. Del mismo modo, la extrapolación a todas las industrias de la planta SHIP global es posible y deseable.

5.CONCLUSIONES/CONCLUSIONS

5.a Conclusiones

El objetivo de esta tesis ha sido presentar a la energía geotérmica como una alternativa real por sí sola o bien en hibridación con otras fuentes de energía renovables como solución para el ámbito del mercado español y europeo. Hasta el momento el principal protagonismo lo había tenido la geotermia de baja entalpia asociada a bombas de calor a escala residencial y doméstico, pero por medio de esta tesis se demuestra su potencialidad para usos directos asociados a escala industrial y a la industria de la desalinización en particular.

Como punto de partida se ha evaluado en qué situación se encontraba la energía geotérmica y para ello se ha realizado un análisis profundo en cuatro grandes bloques a saber, el nivel de implementación ,las barreras ,las medidas y las ventajas a adoptar para esta fuente de energía en escenarios diferentes (escala de isla, Canarias país, España o continente, Europa) e incluso teniendo en cuenta sectores de actividad a priori poco desarrollados como el agrícola o discriminando por tipo de energía, de baja o alta entalpia geotérmica para ver si diferían entre sí los resultados. El análisis de numerosa bibliografía y la consulta a expertos llevaron a las siguientes conclusiones:

- El nivel de implementación en general es bajo (valor 2 en una escala de 1 a 5) siendo peor la situación para la geotermia de alta entalpia y para el sector agrícola. En cuanto a escala de isla (Islas Canarias] es peor que a escala de país (España) excepto para el mix y a su vez en España es peor que a escala de continente (Europa) excepto para la geotermia de baja entalpia.

- Referente a las barreras surgen las económicas como las más relevantes sobre todo para la geotermia de alta entalpia tanto en España como en Europa.

- En una escala global las principales barreras para la geotermia de alta entalpia son las económicas y financieras mientras que para la geotermia de baja entalpia son las culturales y sociales.

- Referente a las medidas a adoptar, para la UE serían la inversión privada para la geotermia de usos eléctricos y la promoción para la geotermia de usos térmicos mientras que para España sería la inversión pública para la geotermia de usos eléctricos y es coincidente la promoción para la de usos térmicos.

Gracias a tan exhaustivo estudio, conocer cuál ha sido el punto de partida de la geotermia ha permitido llegar a las conclusiones presentadas en el primer artículo que dieron origen a los sucesivos.

Sin duda, la industria de la desalinización es un enorme consumidor energético que afecta a la sostenibilidad global sobre todo cuando debido al cambio climático la temperatura del planeta es cada vez mayor y más regiones son y serán áridas y con escasez de agua en los tiempos venideros. La búsqueda de recursos energéticos renovables locales son una necesidad para reducir dicho consumo al máximo y por tanto se ha convertido en objetivo del segundo artículo. En este caso se ha elegido una planta desalinizadora multiefecto, - MED-, de 9000 m^3/d que opera a 70 °C y se han hecho varias propuestas de alimentación con energía solar y/o con energía geotérmica llegando a las siguientes conclusiones:

- Alimentar dicha planta desalinizadora con solo energía solar procedente de colectores cilíndrico parabólicos en la región objeto de estudio es una pérdida de tiempo porque solo se podría conseguir durante el 9% de los días anuales.

- La situación mejora si se añade una bomba de calor de absorción de doble efecto, -DEHP-,la cual bajaría la temperatura de salida para alimentar la planta desalinizadora tipo MED consiguiendo alimentar con dicha energía durante un 29% del tiempo anual.

- La situación es incluso mejor si se añade un pozo de geotermia donde pudiera ir la energía sobrante de los colectores cilíndrico parabólicos en cuyo caso la planta desalinizadora tipo MED podría trabajar durante un 76% del tiempo anual en las condiciones geológicas de la tierra en la localización de los campos de Níjar que es t = 41,8 °C a 490 m de profundidad.

- Por otro lado, el hecho de tener una temperatura de 70 °C a 790 m en estos campos de Níjar, abre la posibilidad de alimentar una planta desalinizadora multiefecto, -MED-, con solo energía geotérmica de una forma continua lo cual sería más que deseable y uno de los temas más críticos de las energías renovables en general porque se aseguraría su no intermitencia.

Como una extensión del estudio teórico que nos acaece, se ha realizado también una extrapolación de los resultados a las plantas desalinizadoras ya existentes no renovables del proyecto A.G.U.A localizadas en el sureste de España. El propósito es evaluar el impacto económico y ecológico de las mismas por el uso de energías renovables en general y del mix solar-geotermia en particular. Los resultados teóricos de dicha extrapolación arrojaron unas cifras nada despreciables de 6 años aproximadamente de amortización y 510 387 920 kg/CO_2 anual evitado a la atmósfera para todas las plantas

Hay que tener en cuenta también que una buena parte del territorio español (no solo el sureste o sur) está afectado por un gran número de horas de sol anual, pero con unos recursos geotérmicos de baja temperatura (30-100) °C. Este hecho no es un inconveniente para la desalinización, especialmente para la desalinización térmica como se ha visto. De hecho, se han resaltado dos factores: Por un lado, es posible reducir el exceso de temperatura de los colectores cilindro parabólicos por medio de una bomba de calor de absorción de doble efecto y energía geotérmica por un lado y por otro lado, esta clase de recursos de baja entalpía son apropiados para plantas desalinizadoras tipo destilación multiefecto, -MED. Como comentario, el área de los campos de Níjar es uno de los 22 en la región de Andalucía y solo representa el 2,5% del potencial geotérmico disponible en esta zona [59].

Como es lógico, la localización de las plantas de desalinización cercanas a la costa, la localización del campo de colectores solares y la realización de las prospecciones para los pozos geotérmicos son factores a tener en cuenta para una mayor proximidad a los puntos de consumo energético y la posible evaluación de las pérdidas de transporte si fuera necesario la creación de una red de distrito.

No hay estudios que combinen energía solar de tipo PTC con geotermia para plantas desalinizadoras o estudios que sugieran reconvertir las plantas desalinizadoras no renovables existentes en España de la forma aquí presentada. Por tanto, sería deseable que este estudio pudiera servir de referencia a otras áreas con condiciones climáticas y geotérmicas similares.

También sería interesante realizar estudios en diferentes áreas geográficas costeras (insulares o peninsulares) donde sea necesario desalinizar debido a la escasez de agua potable o de riego con otros perfiles de radiación solar y otros recursos geotérmicos, desde otros tipos de colectores solares diferentes a los parabólicos, así como otros tipos de plantas de desalinización con otras posibles configuraciones diferentes a las presentadas en esta tesis.

En cualquier caso, se ha demostrado por medio de este segundo artículo que el potencial es enorme en este campo.

Dados los resultados del segundo artículo vinculado a la industria de la desalinización con geotermia se propuso hacer otro artículo para ver la potencialidad de la industria española en general alimentada con geotermia y sus beneficios económico-medioambientales.

Como dato de partida para este tercer artículo, en España, el consumo industrial solo representaba el 1,13% del potencial geotérmico del país. En este caso se analizaron los rangos de temperatura de los procesos industriales y qué regiones en España serían las más adecuadas según criterios previamente definidos: geotérmico, térmico y empresarial, aprovechando los recursos locales en función de las industrias existentes, el potencial del terreno donde se ubican y la concentración industrial para un mejor aprovechamiento energético entre las industrias adyacentes y, por supuesto, con costes geotérmicos asumibles.

Las principales conclusiones a las que se llega en este tercer articulo fueron:

- Casi el 85% de los procesos industriales en España pueden llevarse a cabo con recursos de muy baja, baja y media temperatura geotérmica. En este contexto, las emisiones de CO_2 evitadas a la atmósfera serían de más de 80 millones al año y 15 años sería el periodo de amortización para la inversión de procesos industriales de hasta 45 °C.

- Procesos industriales de hasta 45 °C son los más apropiados para el suministro de energía geotérmica dada la geografía española y el potencial económico y de desarrollo de ciertas áreas geográficas. Seis regiones de 17 en España son las más lógicas para acometer el reto. En este rango se encuentran los procesos relativos a lavado y precalentamiento en la industria en general, pero también en la comida, alimentación e industria textil, así como procesos de galvanizado en la industria del metal y del automóvil y procesos de secado en la industria de la madera y del papel.

- Procesos industriales que requieran altas temperaturas tienen periodos de retorno mayores debido al uso de energía geotérmica. Por un lado, España no tiene mucho territorio de geotermia de alta entalpía, pero por otro lado, los costes asociados a pozos profundos son elevados en todo el mundo y en España también.

- Quince industrias en España se eligieron para verificar los resultados del estudio. Si estas industrias fueran alimentadas con energía geotérmica en algunos rangos de temperatura, se obtendría un ahorro de un 18% respecto al uso de energía solar. Este hecho justifica su implementación en toda la industria española condicionada en su mayoría por recursos energéticos no renovables.

- Una extensión del estudio local es perfectamente posible a nivel global al ser aplicables los tres criterios definidos y la conexión entre recursos geotérmicos locales disponibles con el rango de temperatura y los procesos industriales. De forma similar, una extrapolación a todas las industrias del SHIP-plant global es posible y deseable.

Actuar en las industrias desde gobiernos regionales para promocionar la energía geotérmica es un deber.

Una mayor competitividad en el mercado por un gran número de compañías dedicadas a la explotación de este recurso sería deseable para reducir su coste. La demanda de un gran número de consumidores o conglomerados de industrias con grandes necesidades energéticas justificarían entonces la inversión en pozos profundos. Un cambio de paradigma en el modelo energético actual con costes energéticos reducidos se presenta como alternativa al modelo energético actual.

La metodología empleada para la realización de esta tesis ha sido amplia, diversa y multidisciplinar al emplear desde métodos no probabilísticos y validación por medio de juicio de expertos pasando por consulta de numerosa bibliografía como se pone de manifiesto en el primer artículo para a continuación hacer un modelado termodinámico y experimental en el segundo artículo y emplear por último el uso de herramientas financieras como el VAN y el TIR para valoración de proyectos de inversión en el tercer artículo.

Por medio de la investigación llevada a cabo por medio de esta tesis se aporta un nuevo enfoque al estado del arte de la energía geotérmica al ser presentada como una alternativa real por sí sola o bien en hibridación con otras fuentes de energía renovables como solución para el ámbito del mercado español y europeo como ya se ha comentado.

La energía geotérmica encaja perfectamente en el paradigma industrial español y debe ser tenida como una fuente de energía renovable prioritaria en cualquier desarrollo empresarial que se vaya a acometer para lo cual una mayor promoción de la misma ligada a unas condiciones económicas y financieras más favorables la elevarían al lugar que le corresponden de entre el conjunto de RES.

5.b Conclusions

The aim of this doctoral thesis has been to present geothermal energy as a real alternative on its own or in hybridisation with other renewable energy sources as a solution for the Spanish and European market. Until now, the main role has been played by low enthalpy geothermal energy associated with heat pumps on a residential and domestic scale, but this doctoral thesis demonstrates its potential for direct uses associated with industrial scale and the desalination industry in particular.

As a starting point, the situation of geothermal energy has been evaluated and for this purpose an in-depth analysis has been carried out in four large blocks, namely the level of implementation, barriers, measures and advantages to be adopted for this energy source in different scenarios (island scale, Canary Islands country, Spain or continent, Europe) and even taking into account sectors of activity a priori little developed such as agriculture or discriminating by type of energy, low or high enthalpy geothermal energy to see if the results differed from each other. The analysis of extensive literature and the consultation of experts led to the following conclusions:

-The level of implementation in general is low (value 2 on a scale of 1 to 5) with the situation being worse for high enthalpy geothermal and for the agricultural sector. In terms of island scale (Canary Islands) it is worse than at country scale (Spain) except for the mix and in Spain it is worse than at continent scale (Europe) except for low enthalpy geothermal.

- With regard to the barriers, economic barriers emerge as the most relevant, especially for high enthalpy geothermal energy both in Spain and in Europe.

- On a global scale, the main barriers for high enthalpy geothermal energy are economic and financial, while for low enthalpy geothermal energy they are cultural and social.

- Regarding the measures to be adopted, for the EU they would be private investment for geothermal electricity and promotion for geothermal thermal uses, while for Spain it would be public investment for geothermal electricity and promotion for thermal uses.

Thanks to such an exhaustive study, knowing what the starting point of geothermal energy has been has allowed us to reach the conclusions presented in the first article that gave rise to the successive articles.

Undoubtedly, the desalination industry is a huge energy consumer that affects global sustainability, especially when, due to climate change, the temperature of the planet is increasing and more regions are and will be arid and water-scarce in the coming times. The search for local renewable energy resources is a necessity to reduce such consumption as much as possible and has therefore become the objective of the second article. In this case, a 9000 m^3/d multi-effect desalination plant (MED) operating at 70 °C has been chosen and several proposals for solar and/or geothermal energy supply have been made, reaching the following conclusions:

- Powering such a desalination plant with only solar energy from parabolic trough collectors in the region under study is a waste of time because it could only be achieved for 9 % of the annual days.

The situation improves if a double-acting absorption heat pump -DEHP- is added, which would lower the outlet temperature to feed the MED-type desalination plant and would be able to feed the plant with this energy for 29 % of the annual time.

- The situation is even better if a geothermal well is added where the surplus energy from the parabolic trough collectors could go, in which case the MED type desalination plant could work for 76 % of the annual time in the geological conditions of the land at the location of the Nijar fields, which is t = 41.8 °C at a depth of 490m.

On the other hand, the fact of having a temperature of 70 °C at 790 m in these Nijar fields, opens the possibility of feeding a multi-effect desalination plant, -MED-, with only geothermal energy in a continuous way which would be more than desirable and one of the most critical issues of renewable energies in general because it would ensure its non-intermittency.

As an extension of the theoretical study at hand, an extrapolation of the results to the existing non-renewable desalination plants of the A.G.U.A. project located in the southeast of Spain has also been carried out. The purpose is to evaluate the economic and ecological impact of the use of renewable energies in general and of the solar-geothermal mix in particular. The theoretical results of this extrapolation yielded not inconsiderable figures of approximately 6 years of amortisation and 510 387 920 kg/CO_2 avoided annually in the atmosphere for all the plants.

It should also be taken into account that a large part of the Spanish territory (not only the southeast or south) is affected by a large number of hours of sunshine per year but with low temperature geothermal resources (30 °C-100 °C). This fact is not a disadvantage for desalination, especially for thermal desalination as we have seen. In fact, two factors have been highlighted: On the one hand, it is possible to reduce the excess temperature of the parabolic trough collectors by means of a double effect absorption heat pump and geothermal energy on the one hand and on the other hand, this kind of low enthalpy resources are suitable for desalination plants of the multi-effect distillation type, -MED. As a remark, the area of the Nijar fields is one of 22 in the region of Andalusia and represents only 2.5 % of the available geothermal potential in this area [59].

Logically, the location of the desalination plants close to the coast, the location of the solar collector field, and the survey for the geothermal wells are factors to be taken into account for a closer proximity to the energy consumption points and the possible assessment of the transport losses if a district network is necessary.

There are no studies that combine PTC-type solar energy with geothermal energy for desalination plants or studies that suggest retrofitting existing non-renewable desalination plants in Spain in the manner presented here. Therefore, it would be desirable that this study could serve as a reference for other areas with similar climatic and geothermal conditions.

It would also be interesting to carry out studies in different coastal geographical areas (insular or peninsular) where desalination is necessary due to the scarcity of drinking or irrigation water with other solar radiation profiles and other geothermal resources, from other types of solar collectors different from the parabolic ones, as well as other types of desalination plants with other possible configurations different from those presented in this doctoral thesis.

In any case, it has been demonstrated through this second article that the potential in this field is enormous.

Given the results of the second article linked to the geothermal desalination industry, it was proposed to make another article to see the potential of the Spanish industry in general powered by geothermal energy and its economic-environmental benefits.

As a starting point for this third article, in Spain, industrial consumption only represented 1.13 % of the country's geothermal potential. In this case, the temperature ranges of industrial processes were analysed and which regions in Spain would be the most suitable according to previously defined criteria: geothermal, thermal and business, taking advantage of local resources depending on the existing industries, the potential of the land where they are located and the industrial concentration for better energy use among adjacent industries and, of course, with assumable geothermal costs.

The main conclusions reached in this third article were:

- Almost 85 % of the industrial processes in Spain can be carried out with very low, low and medium temperature geothermal resources. In this context, the CO_2 emissions avoided to the atmosphere would be more than 80 million per year and 15 years would be the payback period for the investment of industrial processes up to 45 °C.

- Industrial processes up to 45 °C are the most appropriate for the supply of geothermal energy given the Spanish geography and the economic and development potential of certain geographical areas. Six regions out of 17 in Spain are the most logical to undertake the challenge. In this range are processes related to washing and preheating in industry in general but also in the food, food and textile industry as well as galvanising processes in the metal and automotive industry and drying processes in the wood and paper industry.

- Industrial processes requiring high temperatures have longer payback periods due to the use of geothermal energy. On the one hand, Spain does not have much high enthalpy geothermal territory but on the other hand, the costs associated with deep wells are high all over the world and in Spain as well.

- Fifteen industries in Spain were chosen to verify the results of the study. If these industries were powered by geothermal energy in some temperature ranges, a saving of 18 % would be obtained with respect to the use of solar energy. This fact justifies its implementation in the whole Spanish industry mostly conditioned by non-renewable energy resources.

- An extension of the local study is perfectly possible on a global level as the three defined criteria and the connection between available local geothermal resources with the temperature range and industrial processes are applicable. Similarly, an extrapolation to all industries of the global SHIP-plant is possible and desirable.

Acting in the industries from regional governments to promote geothermal energy is a must.

A greater competitiveness in the market by a large number of companies dedicated to the exploitation of this resource would be desirable to reduce its cost. Demand from a large number of consumers or industry clusters with large energy needs would then justify investment in deep wells. A paradigm shift in the current energy model with reduced energy costs is presented as an alternative to the current energy model.

The methodology used for this doctoral thesis has been broad, diverse and multidisciplinary, using non-probabilistic methods and validation by means of expert judgement, consulting numerous bibliographies as shown in the first article, followed by thermodynamic and experimental modelling in the second article and, finally, the use of financial tools such as NPV and IRR for the valuation of investment projects in the third article.

By means of the research carried out in this doctoral thesis, a new approach to the state of the art of geothermal energy is provided, as it is presented as a real alternative on its own or in hybridisation with other renewable energy sources as a solution for the Spanish and European market, as already mentioned.

Geothermal energy fits perfectly into the Spanish industrial paradigm and should be considered as a priority renewable energy source in any business development that is to be undertaken, for which a greater promotion of the same linked to more favourable economic and financial conditions would raise it to its rightful place among the group of RES.

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7. CURRICULUM VITAE DEL DOCTORANDO

Español

Perfil

Project manager con más de 15 años de experiencia en la industria. Con historial probado de éxito mediante un enfoque centrado en el cliente, garantizando una supervisión eficaz y la adopción de medidas correctoras adecuadas siempre que sea necesario. También con profundo conocimiento y experiencia de los aspectos normativos y reglamentarios en el ámbito industrial y en lo que respecta a las energías renovables en particular.

Comunicadora inspirada, oyente receptiva y gran colaboradora con capacidad analítica y resolutiva sobre los aspectos teóricos y prácticos que requiere un proyecto. Implicada y siempre aprendiendo. Una planificadora y tomadora de decisiones de primer nivel. De mente abierta, entusiasta, enérgica y con una actitud positiva.

Educación

Ingeniera Industrial: Master **1996 - 2002**

Tercer año intensificación en **Tecnología de los materiales**. Proyecto fin de carrera basado en nuevos materiales para las barras de control de una central nuclear **(evaluado con Matrícula de Honor)**.

Universidad Carlos III de Madrid, España.

Carrera profesional

INDUSTRIAS REHAU. Madrid [España] [13 años] **2008 – actual**

Responsable de proyecto

Prescripción del rango de productos relativos a eficiencia energética y sostenibilidad de la empresa REHAU en la división de construcción e industria a nivel nacional.

Búsqueda de clientes potenciales: Grandes cuentas y apoyo a clientes con perspectivas de desarrollo en el medio-largo plazo.

Presentación en Colegios oficiales principalmente de ingeniería y arquitectura.

Presentación en instaladores/distribuidores del sector HVAC y áreas relacionadas.

Presentación de productos de REHAU y sistemas en empresas de ingeniería y arquitectura.

Asistencia y soporte en reuniones con la Administración: IDAE, GEOPLAT, APPA, FENERCOM.

Asistencia técnica al cliente.

Apoyo interno/externo en el desarrollo de otras líneas de negocio de la empresa REHAU.

Asistencia a numerosas formaciones internas de empresa en Alemania y Austria.

Tecnología: Key-user para la implementación del módulo CRM de SAP en España y Portugal, Microsoft Office advance, Autocad.

Idiomas: Inglés B2 advanced, alemán B1.

ALFA CONSULTING Madrid y Barcelona [España] [2 años] **2006 – 2008**

Consultora senior

Análisis del proceso de planificación del Puerto de Barcelona [cliente ACCIONA TRASMEDITERRANEA].

Implementación de una nueva línea de negocio en cada una de las plataformas de Call center a nivel nacional. [cliente ENDESA ENERGÍA].

Análisis de los procesos operacionales y comerciales de medio voltaje en la factoría de Griñón (Madrid) [cliente SCHNEIDER ELECTRIC].

Análisis de la estructura organizacional de la división GMF [cliente COMSA].

Análisis de los procesos logísticos de la división de servicios Desktop [cliente T-SYSTEMS].

Tecnología: Microsoft Office advance.

SOCOTEC IBERIA Madrid [España] [2 años] **2004 – 2006**

Responsable del departamento eléctrico, energía y medio ambiente

Planificación de auditorías de calidad de ENAC [Entidad nacional de acreditación en España].

Coordinación y planificación del trabajo de inspección.

Responsable directa de la contratación de personal.

Prospección de nuevos clientes (grandes cuentas) así como coordinación del trabajo de inspección principalmente en compañías instaladoras e ingenierías.

Merece la pena mencionar los trabajos de inspección en los túneles de Madrid METRO de Madrid con la constructora FERROVIAL, las inspecciones eléctricas de los restaurantes VIPS a nivel nacional así como las inspecciones del alumbrado público de diferentes ayuntamientos de la Comunidad de Madrid y de diversos hospitales.

Planificación y coordinación de los controles de calidad a nivel nacional (Andalucía, Cataluña, Baleares y Canarias) de los centros de generación de ENDESA ENERGIA SAU.

Planificación y coordinación de inspecciones de las subestaciones eléctricas de alto voltaje en toda España (cliente INECO-TIFSA).

Tecnología: Microsoft Office Advance

GENERAL ELECTRIC Consumer& Industrial **2003 – 2004**

Ingeniera de ventas

Apoyo técnico a distribuidores e instaladores de las líneas de producto de la empresa.

Elaboración y presentación de ofertas a clientes.

Atracción de nuevos clientes y promoción (especialmente instaladores eléctricos y compañías de ingeniería del sector).

Promoción de productos de automatización y bajo-medio voltaje de la empresa.

UNILEVER **2002– 2003**

Beca

Implementación, supervisión y auditoria de la metodología TPM [Total Production Management].

Mejoras enfocadas al análisis TPM usando las herramientas características: 5's, MapDO, why-why, 5W1H, PM analysis, 4M's...

Mejora de la eficiencia de las líneas de producción y de los costes de no calidad.

Gestión de almacén y adaptación de las bases de datos locales.

Cursos

Cumplimiento de la legislación antimonopolio, anticorrupción y código de conducta **2017-2019**

REHAU

Curso de diseño de Instalaciones solares de baja temperatura **2006**

COIIM [Colegio official de ingenieros industriales de Madrid]

Curso de Prevención de riesgos laborales **2003**

IRSS [Instituto regional de seguridad y salud]

Data mining, inteligencia artificial, redes neuronales aplicadas al análisis estadístico **2003**

Technología: Statgraphics, Splus, R, SPSS.

Departmento de Estadística. Universidad Carlos III de Madrid

Formación en TPM [Total Production Management y **2002**

Regulaciones básicas [OHSAS 18001, ISO 9002, ISO 14000]

UNILEVER SPAIN

I, II, III, IV and V **Conferencia de Materiales**

Instituto de Química y Materiales Álvaro Alonso Barba **2002**

Inglés

Profile

Project manager with over 15 years of experience in the Industry. Proven record of successful delivery through customer centric approach, ensuring effective supervision and appropriate remediation measures are in place whenever required. Also a deep knowledge and experience of the normative and regulatory aspects in the industrial field and in what concerns the renewable energies in particular.

An inspiring communicator, responsive listener and great collaborator with analytical and solving capacity on the theoretical and practical aspects that a project requires. Driven and always learning. A first-rate planner and decision maker Open-minded. Enthusiastic, energetic and with a positive attitude.

Education

Industrial Engineer: Industrial Engineer Master`s degree **1996- 2002**

Third year intensification in **Materials technology**. Final project based on the control rods of a nuclear power plant evaluated with honors.

Carlos III University of Madrid, Spain

Career history

INDUSTRIAS REHAU. Madrid [Spain] [13 years] **2008-present**

Project Manager

Prescribed REHAU's product range for energy efficiency and sustainability systems in the building and industry divisions nationwide.

Searched for potential clients: Large accounts and support to clients with medium-long term development perspective.

Presented in official schools, mainly for engineers and architects.

Presented to installers/distributors in the HVAC sector and related areas.

Presented of REHAU products and systems in engineering and architecture.

Assisted and supported in meetings with the Administration: IDAE, GEOPLAT, APPA, FENERCOM.

On-site assisted: technical support for customers.

Internal/external supported in the development of other REHAU business lines.

Assisted to various training courses in Germany and Austria on new products of the firm.

Technology: Key-user for the implementation of the CRM module [SAP] in Spain and Portugal, Microsoft Office advance, Autocad.

Language: English B2 advanced, German B1.

ALFA CONSULTING Madrid and Barcelona [Spain] [2 years] **2006 – 2008**

Senior consultant

Analyzed of the Planning process in the Port of Barcelona [client ACCIONA TRASMEDITERRANEA

Implemented of new business line in each of the Call Centre platforms at national level.[client ENDESA ENERGÍA]

Analyzed of the Operations and Commercial process of the Medium Voltage Factory in Griñón [client SCHNEIDER ELECTRIC]

Analyzed of the organizational structure in the GMF division [client COMSA]

Analyzed of the Logistics Process of the Desktop Services Division [client T-SYSTEMS]

Technology: Microsoft Office advance

SOCOTEC IBERIA Madrid [Spain] [2 years] **2004 – 2006**

Manager for the electrical, energy and environmental department

Planned for quality audits of ENAC [National accreditation entity in Spain]

Coordinated and planned of the work of the inspectors [20 people with a technical engineering degree and/or higher].

Directly managed for the recruitment of personnel [engineering profile]

Prospected for new clients [large accounts] as well as coordination of inspection work mainly in engineering and installation companies

It was worth noting electrical inspections in the tunnels of the extension of the Madrid METRO with FERROVIAL AGROMAN, electrical inspections of the VIPS restoration chain at a national level, as well as inspections of the public lighting of several City councils in Madrid Community and in different hospitals

Planned and coordinated of quality controls at a national level [Andalusia, Catalonia, Balearic and Canary Islands] carried out at its clients' centers [capacitor banks and generators including visual inspection as well as infrared thermography] [client ENDESA ENERGIA SAU]

Planned and coordinated of inspections of all high voltage electricity substations throughout Spain [client INECO-TIFSA]

Technology: Microsoft Office Advance

GENERAL ELECTRIC Consumer& Industrial **2003 – 2004**

Sales engineer

Technical supported to distributors/customers and marketing of our products.

Elaborated and presented of technical offers to clients.

Attracted new customers and promoting old ones [especially electrical installers and engineering companies in the same sector].

Promoted of GE Power Control Low voltage and automation products in both Low Voltage and Medium Voltage.

UNILEVER **2002– 2003**

Scholarship

Implemented, supervised and audited of the TPM [Total Production Management] work methodology.

Focused improvements based on TPM analysis using the characteristic tools: 5's, MapDO, why-why, 5W1H, PM analysis, 4M's...

Improved line efficiencies and reduce non-quality line costs

Plant warehouse managed and updated the local improvement database.

Professional training

Compliance anti-trust law, anticorruption, compliance rules and procedures and code of conduct **2017-2019**

REHAU Company

Course of designer in Low temperature solar energy installations **2006**

COIIM [Official College of Industrial Engineers of Madrid]

Senior Technician in Occupational Risk Prevention **2003**

IRSS [Regional Institute for Occupational Safety and Health]

Data mining, artificial intelligence, neuronal networks applied to statistical analysis **2003**

Technology: Statgraphics, Splus, R, SPSS.

Department of Statistics. Carlos III University of Madrid

Training in TPM [Total Production Management and **2002**

Basic regulations [OHSAS 18001, ISO 9002, ISO 14000]

UNILEVER SPAIN

I, II, III, IV and V **Materials Conference**

Institute of Chemistry and Materials Technology Álvaro Alonso Barba **2002**

ANEXO I "Measures to Remove Geothermal Energy Barriers in the European Union". COPIA DE LA PUBLICACIÓN

energies

MDPI

Article

Measures to Remove Geothermal Energy Barriers in the European Union

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Abstract: This article examines the main market barriers that hamper the introduction of geothermal energy at local, national, and European levels as well as the necessary steps that need to be taken to eradicate them, thus contributing to the general use of this renewable source of energy. The novelty of this study lies in the detailed description of four different scenarios: the European Union (EU), Spain, the Canary Islands, and the agricultural sector for the three types of geothermal energies and their uses: Low-enthalpy or thermal uses, high-enthalpy or electrical uses and renewable energy mix. The results are expected to differ in terms of level of introduction, barriers, and measures to be taken. We have selected Spain within the European context due to its meagre 0.1% geothermal market share in primary demand for renewable energy, and the Canary Islands in particular, given its insular nature. We have likewise picked the agricultural sector due to its underdevelopment as far as renewable energies are concerned, including geothermal energy.

Keywords: geothermal energy; barriers; analysis; energy efficiency; European Union

1. Introduction

Various indicators show that there is still a commitment to subsidize fossil fuels at the expense of renewable energy and energy efficiency projects, as shown in the results of the Madrid Summit [1–4]. In the case of micro grids, the lack of specific regulation and the fact that it is still a budding technology renders it a rather costly option as a source of energy, not so much because of technical barriers—even though this aspect could be improved but due to regulatory, legislative, and economic vacuums [5].

Given today's increasing demand for energy, a response that deals with a sustainable energy framework is essential. Many articles raise the question of identifying the actual barriers to the introduction of renewable energies all over the world. These barriers, however, are expected to differ according to different types of renewable energy, environment, and sector of activity. As far as geothermal energy is concerned, despite its all-year-round availability and its independence from external climatological factors, it is scarcely used both on its own and as an energy mix. Hence, there is a need to elaborate more specific studies on the barriers that affect it and the actions that need to be taken to take full advantage of its potential.

One of the main challenges that geothermal energy faces, both for thermal and for electrical uses, is the ignorance of the general public [6]. In the case of geothermal power generation, the absence of a favorable regulatory framework results in the complete lack of power plants in Spain despite isolated entrepreneurial endeavors to establish them [6]. On the other hand, and excluding the barrier of the initial investment and the regulations required of high-enthalpy geothermal projects, we would like to point out that there has been certain improvements regarding knowledge and research of the subsoil in areas considered potentially favorable in Spain, besides, a greater involvement in the development of this sector will lead to an increase in projects of this kind [6]. In the case of low-enthalpy geothermal energy, non-compliance in recent years derives from the fact that it requires a higher initial investment than that of a conventional plant, and the climate of economic downturn over the last decade has not helped. However, in the current, more favorable, context in Spain, there are numerous private initiatives being carried out, especially as far as building renovations are concerned [6].

Considering the substantial technical barriers in the case of micro grids, an implementation of changes in meters, safety, ground and linking with the existing electricity grid as well as management of production and consumption and aggregation of new energy sources are seen as necessary at a local level [5]. As far as geothermal energy in Spain is concerned, working towards not only the introduction of regulatory actions but also on demonstration programs, knowledge management on geothermal potentiality, technology development programs aimed at reducing production costs, and increasing efficiency and developing a training and certification model are viewed as a must [6].

There are numerous references that confirm that the main disadvantage of using renewable energies stems from adverse climatological factors—rain, sun, wind [7,8]. By contrast, the main advantage of geothermal energy, both in its isolated form and in the form of an energy mix lies in its complete year-round availability and the fact that it does not need to oversize the capacity of the system to compensate for lack of energy. Furthermore, solar and wind energy have a negative impact on the landscape and farming land. This is not the case of geothermal systems due to its concealed nature [7,8]. Many articles mention the need to implement renewable energies and improve energy efficiency in remote areas, such as islands not only from an environmental point of view (CO_2 and greenhouse gases emissions reduction) but also because they have proven to be more profitable than conventional polluting energy sources, where part of the cost of the bill is often subsidized [1,2,7,8].

It is worth noting that the contribution of renewable resources to the sustainability of energy is ever more relevant in remote and insular areas [9]. Therefore, the Canary Islands were handpicked for this study. One of the most recurrent topics in a variety of articles is the importance of implementing renewable energies at a local level. Unfortunately, European policies show little support on this matter [10]. There are examples in insular areas, such as the Spanish island of Menorca, of potential energy self-sufficiency through photovoltaic solar energy, where a geothermal study would be desirable [2]. In other European islands like Mykonos in Greece, there have been studies on solar and wind energy production [7]. They are all similar case studies: tourist islands with high electricity and water consumption in which fuel produced electricity is shared with agriculture and industry [2,8]. Some studies propose the desalination of sea water through renewable energies in insular areas, again making use of solar and wind resources [8] but with a need to oversize installations in the absence of such resources. An interesting option would be installing a geothermal line that could guarantee year-round energy resources without needing to oversize the systems. In fact, in some studios, the use of geothermal energy for thermal desalination can be justified only in the presence of cheap geothermal reservoirs or in decentralized applications that focus on small-scale water supplies in coastal regions, provided that society is able and willing to pay for desalting [11].

The proposal of desalination plants using energy mix is an interesting option for coastal, insular, or desert areas where water resources are scarce since it would benefit both drinking water consumption and water destined to irrigation areas, thus helping to develop the agricultural sector in a sustainable way. Besides, the coupling solar-geothermal in regions with a lot of radiation is a very interesting option for cogeneration plant based on an Organic Rankine Cycle (ORC), powered by a medium-enthalpy geothermal resource and a Parabolic Trough Collector solar field [12]. Some studies show the importance of land management (planning, agriculture, conservation) and geographic studies to implement energy strategies [13]. Geothermal energy can be put into a myriad of uses and many have already been studied, though most of them are still in pilot stage—from electricity production to urban heating or agricultural applications, such as greenhouse and stockbreeding facilities heating, besides industrial applications through the use of underground infrastructures, heating for residential and official buildings and swimming pools, just to name a few.

Economic and environmental analysis of different District Heating systems aided by geothermal energy were analyzed in a set of buildings located in the province of León in the north of Spain. Real data comparison of the different scenarios studied revealed the most suitable option from an economic and environmental point of view was the assumption of a district heating system totally supplied by geothermal energy clearly stands out from the rest of options [14].

Most case studies around the word relate to domestic and residential uses that use geothermal heat pumps, although there are endless applications and sectors still to be developed and improved. In the agricultural sector, for example, the use of geothermal energy in Greece for fruit drying or in Iceland for cod drying are of interest [13]. In the case of Spain, studies on central heating and sanitary hot water have been carried out in Madrid, greenhouse heating in Cartagena, Murcia and in the sandy fields of Dallas in Almeria [15]. Residential examples elsewhere, like the one in Okotoks, Canada [16] or Crailsheim in Germany, are also worth noting [17], both cases consisting on the hybridization of solar thermal energy with geothermal energy through a geothermal storage. In a similar way, an innovative space-conditioning system is proposed, and a life-cycle assessment is presented for an industrial building. A ground-source heat pump system and an upstream thermal storage are analyzed to reduce the size of the geothermal installation [18].

Based on the above-mentioned references, it is reasonable to conclude that geothermal energy has an enormous potential both for small-scale projects like home heating and for greenhouse or large district heating projects with subsoil thermal energy accumulation capable of supplying thermal energy to an entire city [19].

Unfortunately, market parameters, such as acceptance from investors, regulatory framework, planning restrictions, and environmental impact, need to be addressed for this kind of technology to achieve effective development [19].

Nevertheless, specific studies exploring barriers to the introduction of geothermal energy and/or geothermal energy mix have not been found, although in some cases they are mentioned as an objective for exploration [2]. Most of the references consulted are on wind and solar energies [2,20]. There are some theoretical references in Turkey, where different types of renewable energy were contrasted with five criteria to be taken into consideration: technical, economic, political, social and environmental. According to this, geothermal energy gets the highest score [21]. Likewise, six production plants in that country are analyzed based on a series of criteria: technology and sustainability, economy, quality of life and socio-economic aspects. Here, geothermal plants rank in the third position.

There exist some investigations that focus on the main barriers and actions needed regarding the introduction of renewable energies in different uses, contexts, regions, and countries [18]. However, the novelty of this study resides in the scrutiny of barriers and steps to be taken to introduce an energy with such a strong potentiality and as little known as geothermal energy.

In other non-detailed studies on renewable energies where northern European countries (from now on N) are compared with southern European countries (from now on S), it seems like financial barriers are more significant in the latter due to, among other reasons, little tradition of financial support for this type of project from legally established cooperatives. It is also due to a lack of local or municipal initiatives aimed at electricity production, or difficulty to access credits and incentives. As far as social and cultural barriers are concerned, it seems that lack of environmental awareness in southern Europe against a history of energy activism in the N has enabled the creation of bioenergy towns in countries like Germany, thus contributing towards lowering barriers to the introduction of renewable energies to a greater extent than their southern counterparts [22]. Other studies show that oil prices and the initial investment needed are significant financial barriers [23].

In a study of a hybrid project comprising solar, geothermal and wind energies for a greenhouse in Turkey [24], initial investment as opposed to established heating systems for agriculture and buildings, appears to be the most relevant barrier".

However, this study concludes that with enough wind this system is preferable to conventional ones.

Similarly, other studies show that, in some cases, institutions contribute significantly to the energy mix and energy policies, proving that institutional quality and income resources are of great importance in the development of renewable energies in any country [25]. As far as cultural and social barriers are concerned, it is worth noting that in all cases a lack of social acceptance may be a great deterrent to the achievement of desired targets in Europe [26].

More generic studies on renewable energies [13] consider promotion as a key measure for development, along with the establishment of national regulations concerning licenses, permits, and procedures. Renewable energy strategies at the local level based on knowledge, training, and monitoring are also necessary. Some studies suggest that once the use of a technology is explained, the intention to use it increases [27]. This is directly linked to the importance of promotion as part of the effort to introduce new technologies. In articles that analyze the situation of Dutch industrial companies in terms of implementation of energy efficiency, public investment is also highlighted as a key element [27]. In Michalena and Hills' studio, security and diversification of electricity supply are mentioned as elements to take into consideration due to, on the one hand, the high dependency of fossil fuels in many regions and, on the other hand, the high cost of oil [13]. Lin and Omoju's article underlines that in the short run, oil price increase affects the development of renewables, but in the long term, financing plays an important role and therefore only adequate planning can help promote the change towards energy transition [28].

After the initial introductory section, the second section explores materials and methods and presents the methodology applied on this article for national (Spain) and European contexts, as well as focusing at a local level (the Canary Islands) and in the specific sector of agriculture. In section three, the results obtained will be examined and discussed. In the final section, we present conclusions reached as a result of the research carried out in the article. All sections are complemented with a series of Appendices A–D containing relevant extra information. Appendix A includes the forms that were sent to various experts in the field; Appendix B contains graphic information and questions asked to experts in the field; Appendix C gives graphic information on the most relevant advantages stemming from implementing this kind of technology; Appendix D contains an additional questionnaire of eight closed-ended questions with graphic representations relevant to the above mentioned questionnaire.

2. Materials and Methods

To carry out our research, we will start by looking at barriers to entry from the point of view of the market and examine the extent to which they coincide with replies obtained in this section. For the development of the research, fifty-four experts were contacted and sent a series of questionnaires (Appendix A). Each questionnaire contained twenty questions, as elaborate and detailed as possible, about ways of finding solutions to barriers to the introduction of geothermal energy in Spain, the EU, the Canary Islands, and in the agricultural sector and taking requisite steps to eradicate them. A total of eleven replies from experts were received with a success rate of twenty percent.

The methodology used corresponds to "non-probabilistic sampling" since it is a small but representative sample well known to the researchers [29]. Validation is supported by "expert judgment" for which relevant experts in the field of geothermal energy and renewable energies in a position to give an answer to the current situation concerning barriers to the introduction of this technology in Spain, the EU and the Canary Islands were contacted for a period of three months (from October 2017 to December 2017). Questionnaire models can be found in Appendix A. The study is structured in four main blocks intended to cover each of the three technologies and the four scenarios shown in Figure 1.

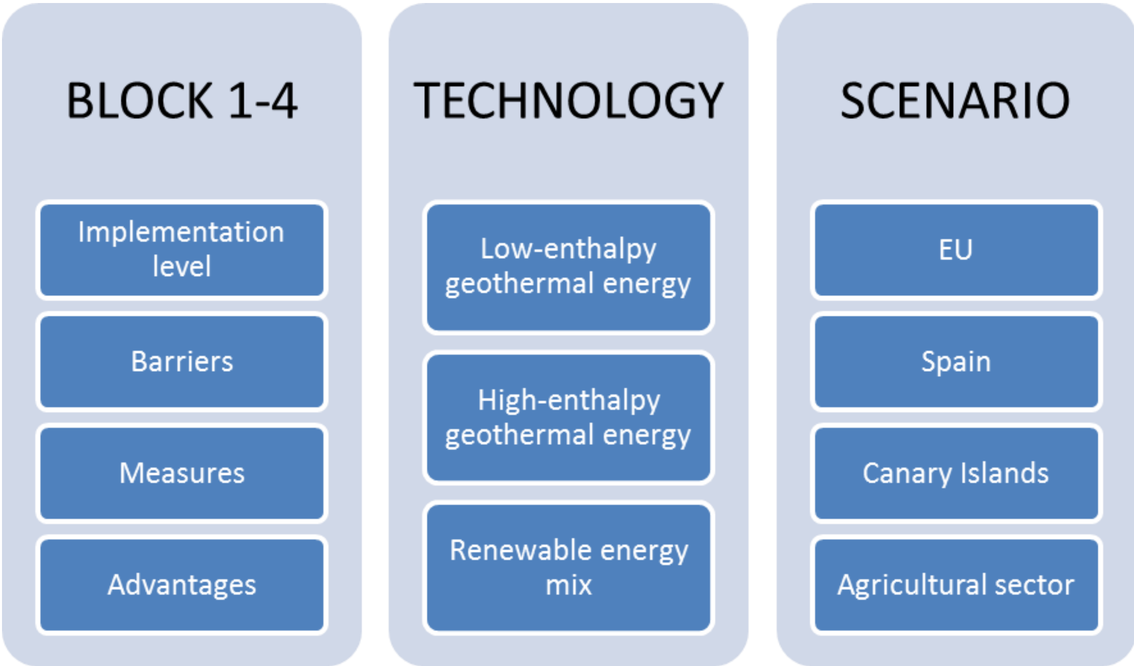

Figure 1. Representation of the blocks, technologies and scenarios studied. Source: Own elaboration.

3. Results and Discussion

As mentioned in the previous section, the results of this study are presented in four main blocks. They are intended to verify whether the questions formulated in the materials and methods section apply to the situation of geothermal energy in all its modalities and to the energy mix in specific locations and sector.

3.1. Block 1: Level of Implementation

Figures 2–4 support BLOCK 1: Level of introduction of geothermal energy in all its modalities: Low-enthalpy, high-enthalpy and even as part of renewable energy mix in Spain, the EU, the Canary Islands, and on the specific currently underdeveloped sector of agriculture. In view of the results reflected in Figure 2 regarding the level of introduction of geothermal energy, the smallest differences of opinion between Spanish and European experts can be seen in the implementation of low-enthalpy geothermal energy or thermal uses and geothermal energy in the agricultural sector.

On the other hand, the greatest differences of opinion between Europe and Spain relate to high-enthalpy geothermal energy, renewable mix, and renewable energy in the agricultural sector. The greatest difference of opinion is on potential electrical uses for geothermal energy.

In all cases for this first graph (Figure 2), the European experts evaluate a higher level of development of geothermal energy in the EU in all its facets as compared to the Spanish experts in Spain. It seems that it is not exclusive to geothermal energy, since some studies compare the situation of renewable energies in general between N and S countries in Europe and the level of involvement and acceptance is also greater in the former [21].

Other studies highlight the fact that the higher the level of development or income of a country, the more relevant the investment in renewables [6,30].

In the case of the Canary Islands as compared to the whole of Spain (Figure 3), all questions are slightly lower on the assessment scale than those on the general situation in Spain, except for the energy mix.

In view of the aforementioned, Figure 4, which includes judgement of all the experts consulted from Spain, the Canary Islands, and the European Union, is drawn up.

In all questions asked the level of development equals 2 on a 1–5 scale, the rating is even lower on geothermal energy for electrical uses as well as geothermal energy on the agricultural sector compared to the others. In any case, from the observation of Figures 2–4 we can infer that for all questions, the level of development is around 2, meaning underdevelopment.

Without a doubt, and quoting Surtesic, "It is of the utmost importance to make great efforts to promote strong renewable technologies such as geothermal energy" [31].

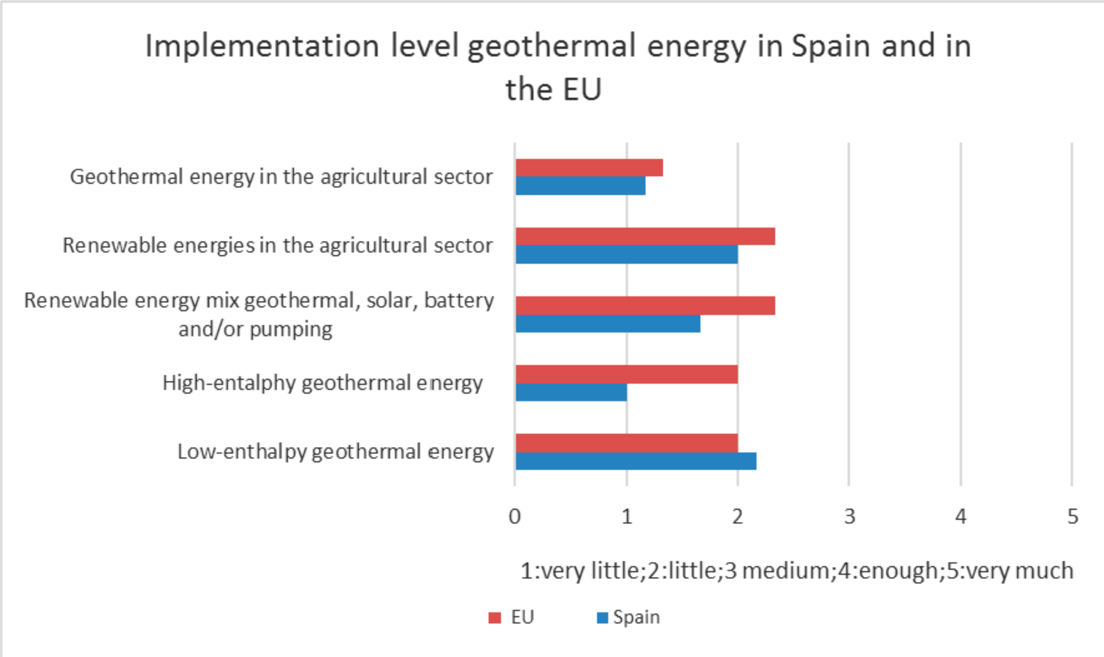

Figure 2. Comparative at the implementation level: Geothermal energy in Spain and in the EU. Source: Own elaboration.

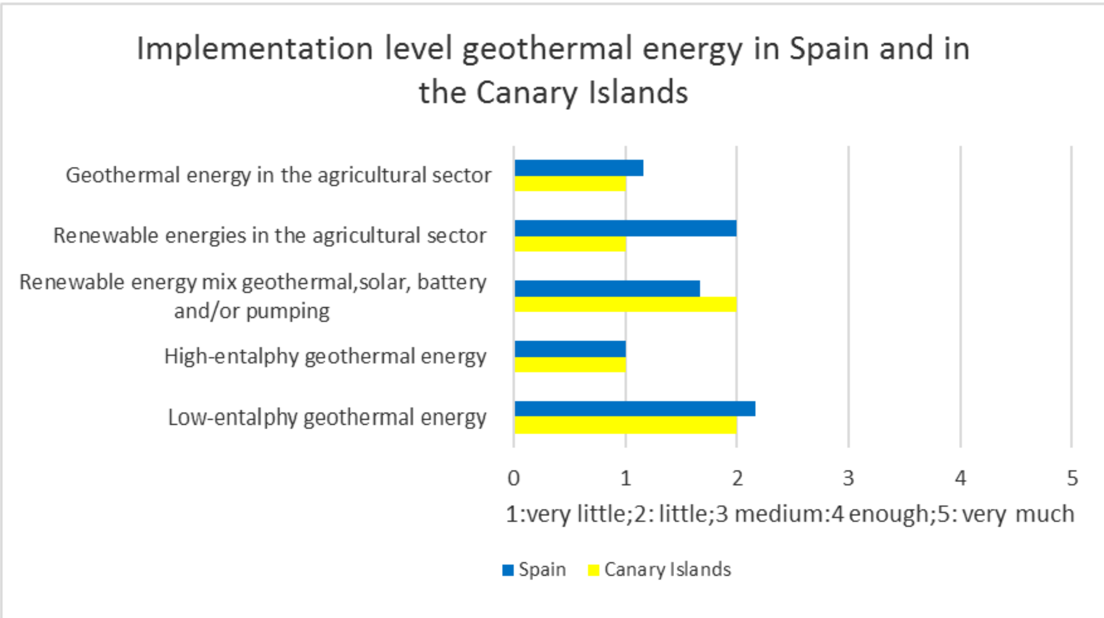

Figure 3. Comparative at the implementation level: Geothermal energy in Spain and in the Canary Islands. Source: Own elaboration.

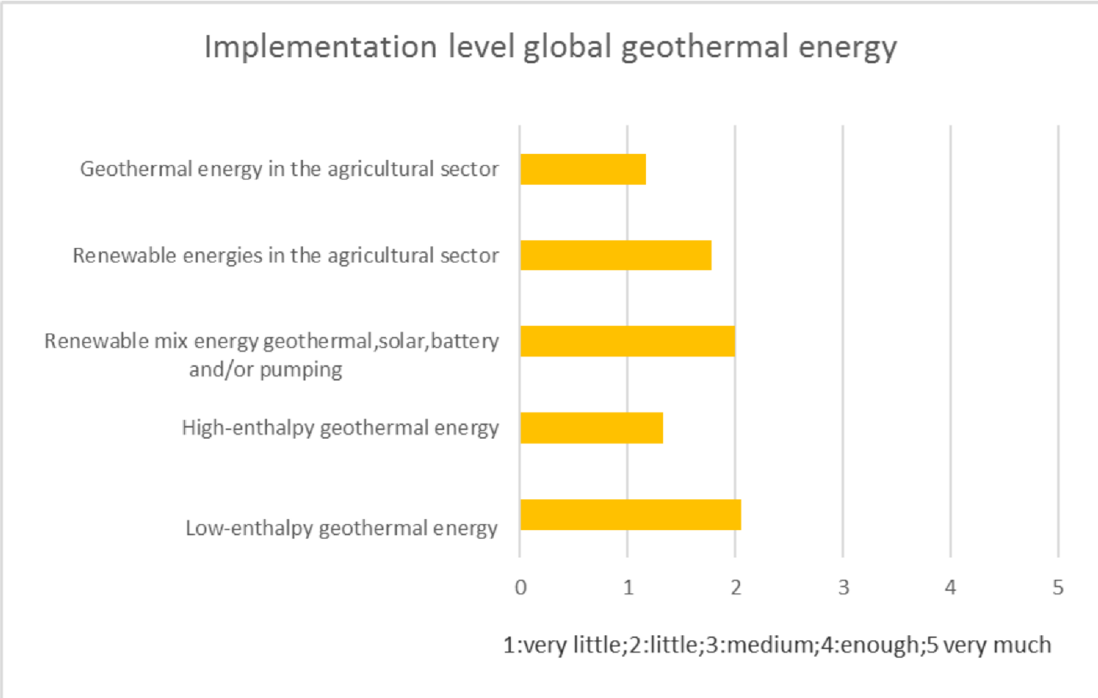

Figure 4. Comparative at the implementation level: Global geothermal energy. Source: Own elaboration.

3.2. Block 2: Barriers

3.2.1. Low-Enthalpy Geothermal Energy

As far as graphs of BLOCK 2 are concerned (Figures 5–8 on low enthalpy geothermal energy), Figure 5 shows how European experts unanimously consider economic or financial barriers for Europe, followed at a lower percentage by regulatory/institutional, technical, and cultural/social. For the Spanish experts, economic or financial barriers are also the most important, the technical type is less representative.

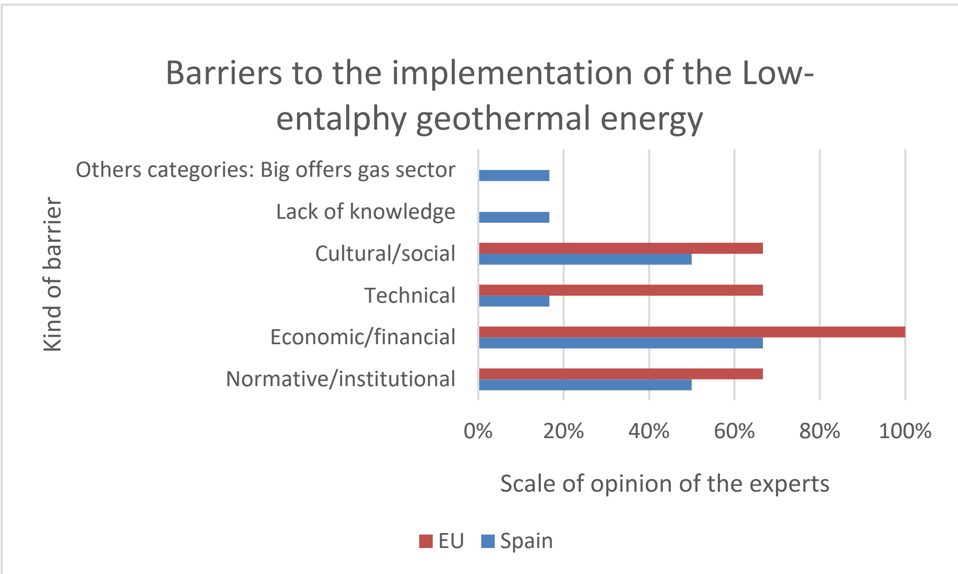

Figure 5. Barriers to the implementation of the low-enthalpy geothermal energy (comparative between Spain and the EU). Source: Own elaboration.

On the agricultural sector (Figure 6), along with economic/financial barriers, cultural/social barriers appear to the same extent, and in the case of the Canary Islands (Figure 7) beside cultural/social stands regulatory/institutional. Considering the opinion of all the experts consulted in Spain, the EU, the Canary Islands and on the agricultural sector and after applying their specific weight on the issues here considered, we obtain Figure 8, which reveals that the main barriers are cultural/social followed by economic/financial and regulatory/institutional. Excluding the opinion of experts in the Canary Islands and in the agricultural sector, which represent the smallest of the samples, the main barriers are economic/ financial, followed by regulatory/institutional and cultural/social on equal terms.

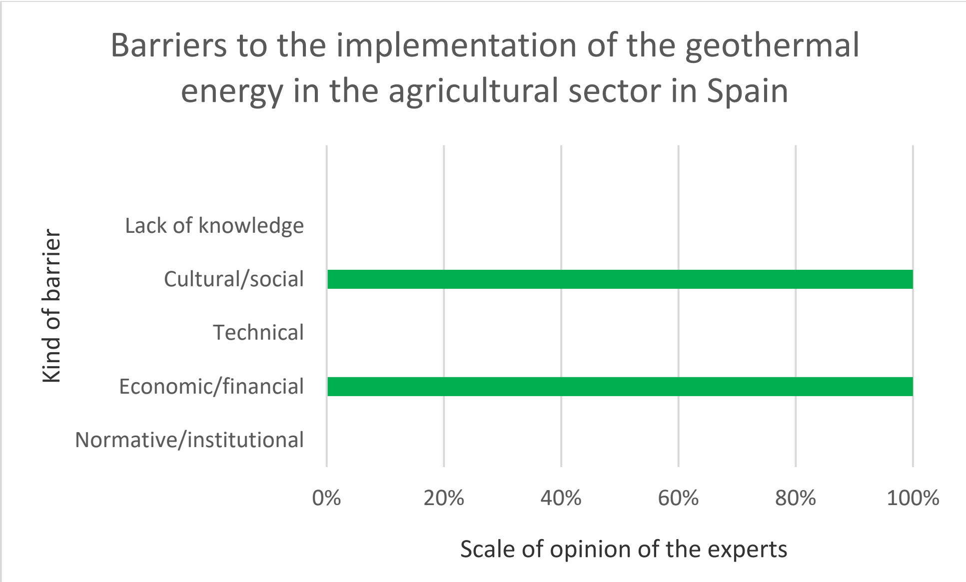

Figure 6. Barriers to the implementation of the geothermal energy in the agricultural sector in Spain Source: Own elaboration.

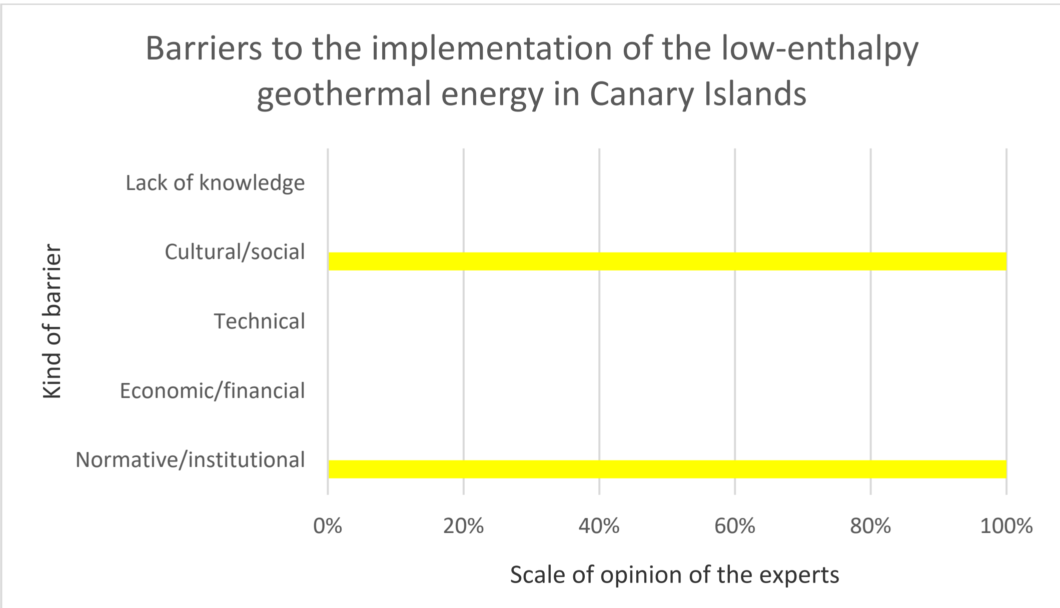

Figure 7. Barriers to the implementation of the low-enthalpy geothermal energy in the Canary Islands. Source: Own elaboration.

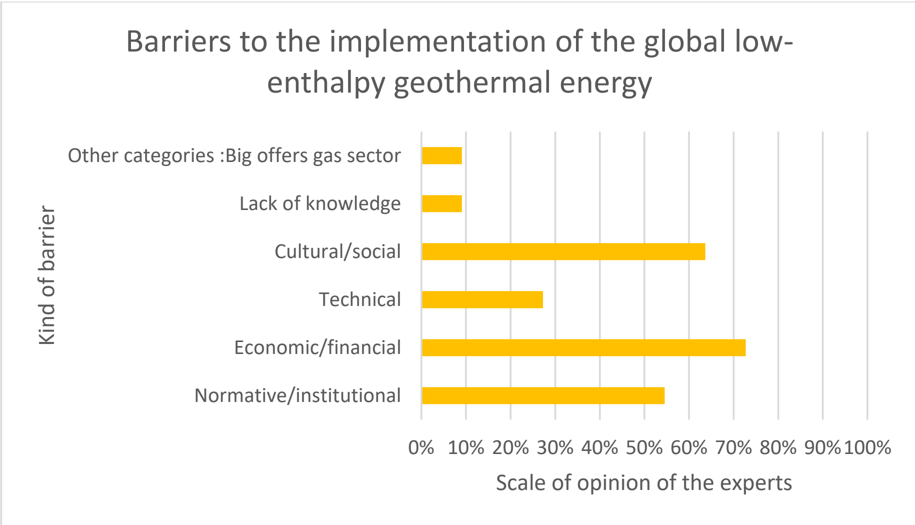

Figure 8. Barriers to the implementation of the global low-enthalpy geothermal energy. Source: Own elaboration.

3.2.2. High-Enthalpy Geothermal Energy

In terms of electrical uses, geothermal energy has been studied in Spain, the EU, and the Canary Islands. As far as the agricultural sector is concerned, it has only been considered as renewable energy in general and geothermal in particular without differentiating its thermal or electrical end uses or even the geothermal mix.

With reference to barriers to the introduction of high-enthalpy geothermal energy reflected on Figure 9 judgement of experts is unanimous for the situation in Spain and the EU, economic/financial being the main barriers. It is the same case of the Canary Islands (Figure 10).

On an analysis of high-enthalpy, similar to the one on low-enthalpy that takes into consideration the opinion of all the experts asked about the situation in Spain, the EU, and the Canary Islands (with their specific weight), we once again find unanimity of criteria with 100% thinking the most important barriers are economic/financial. However, in this case and unlike on low-enthalpy geothermal, the second most important barriers seem to be technical (Figure 11).

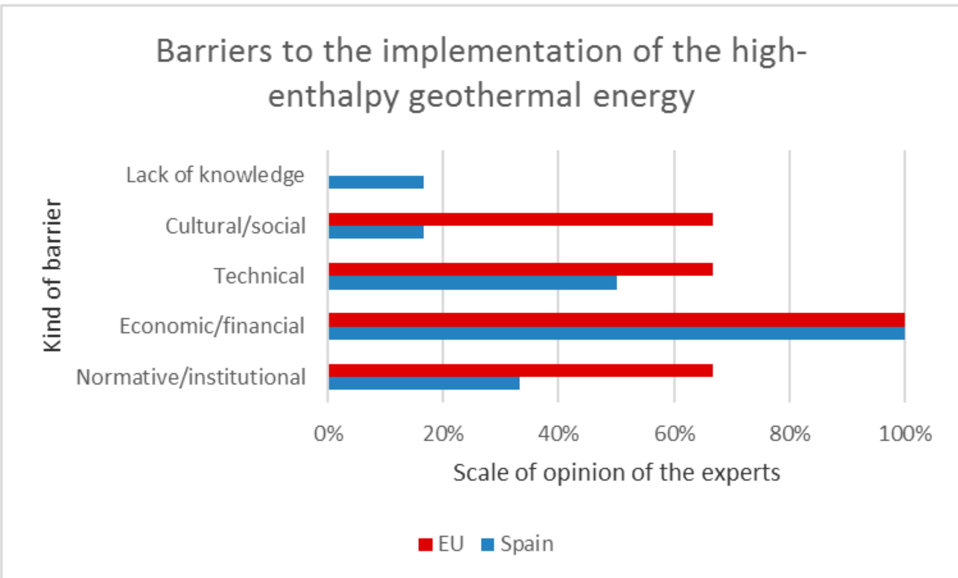

Figure 9. Barriers to the implementation of the high-enthalpy geothermal energy (comparative between Spain and the EU). Source: Own elaboration.

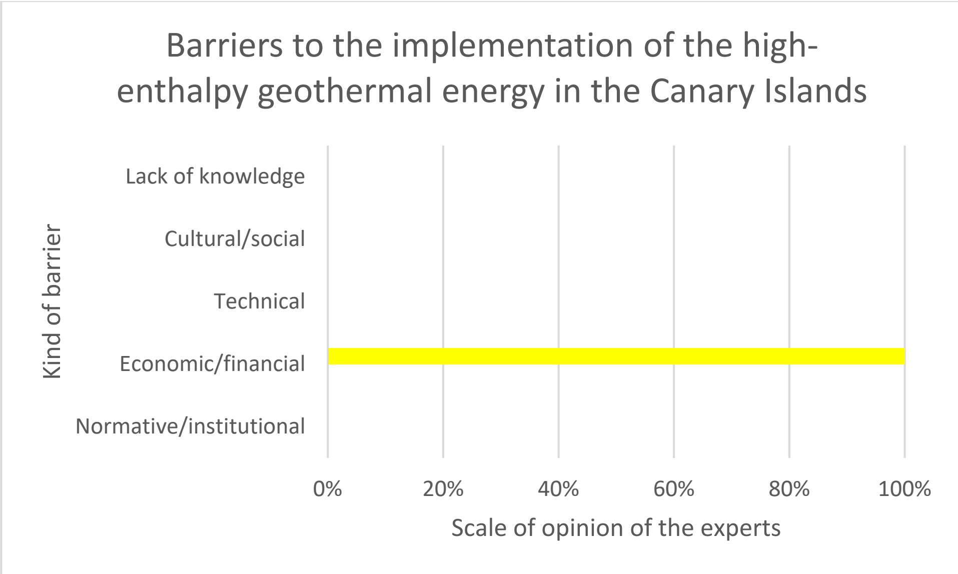

Figure 10. Barriers to the implementation of the high-enthalpy geothermal energy in the Canary Islands. Source: Own elaboration.

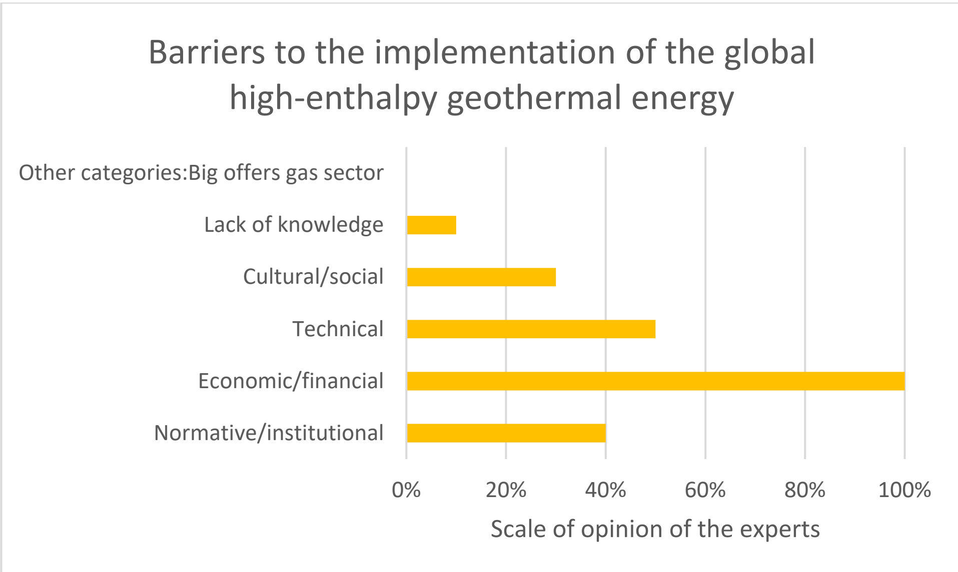

Figure 11. Barriers to the implementation of the global high-enthalpy geothermal energy. Source: Own elaboration.

3.3. Block 3: Measures

3.3.1. Low-Enthalpy Geothermal Energy

Next, in BLOCK 3, measures to eradicate barriers to low and high-enthalpy geothermal energy and energy mix are examined. Figure 12 compares values in Spain and the EU in the field of low-enthalpy, which are coincident with the fact that the main action to be taken both in Spain and the EU would be promotion. In the case of the EU, public investment is also valued as a key action to take. In the case of the agricultural sector (Figure 13), it would be training and promotion, and for the specific case of the Canary Islands (Figure 14), it would encompass three aspects: training, promotion, and public investment.

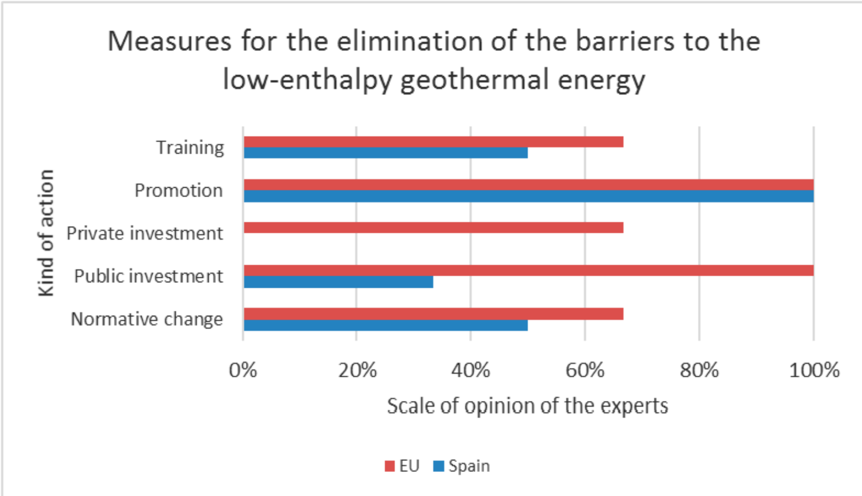

Figure 12. Measures for the elimination of the barriers to the low-enthalpy geothermal energy (comparative between Spain and the EU). Source: Own elaboration.

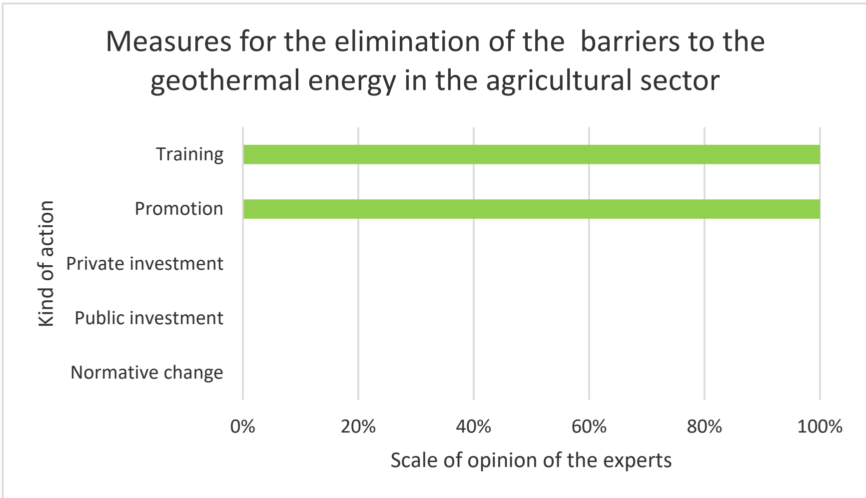

Figure 13. Measures for the elimination of the barriers to the geothermal energy in the agricultural sector. Source: Own elaboration.

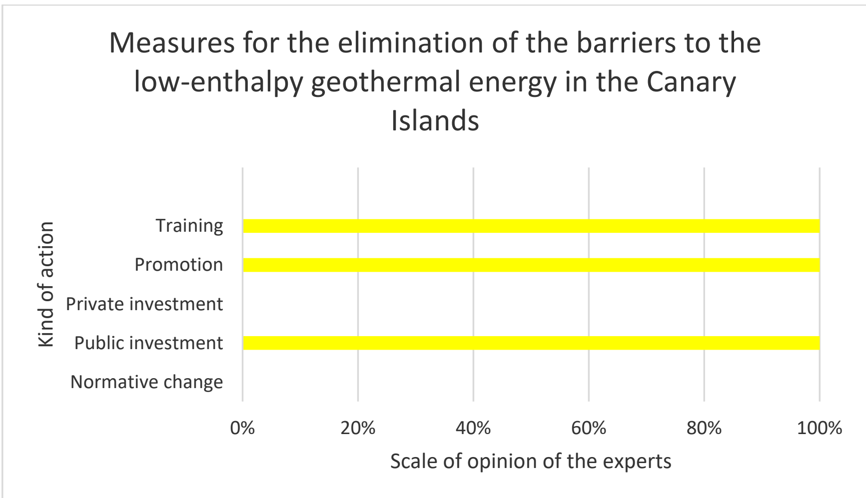

Figure 14. Measures for the elimination of the barriers to the low-enthalpy geothermal energy in the Canary Islands. Source: Own elaboration.

Figure 15 shows a graph reflecting the opinion of all the experts regarding measures to take to eliminate barriers to low-enthalpy geothermal energy in Spain, the EU, the agricultural sector, and the Canary Islands. It shows how promotion would be the most important action to take, followed by training and public investment.

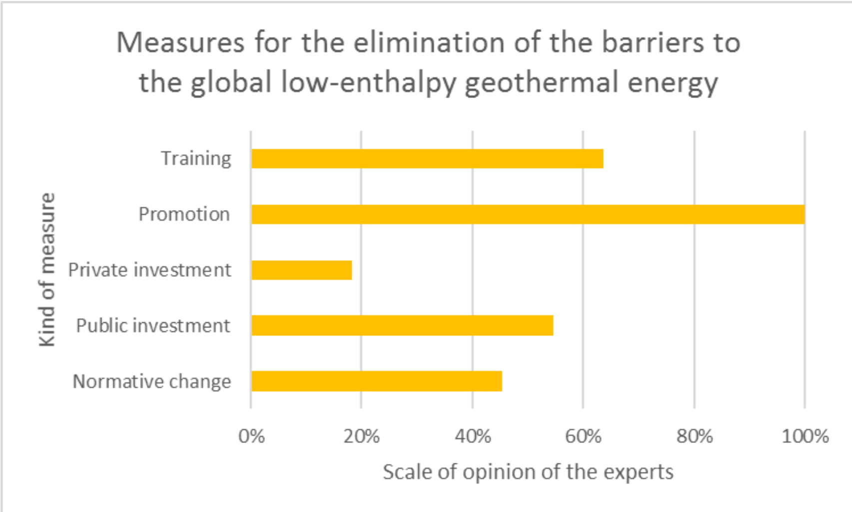

Figure 15. Measures for the elimination of the barriers to the global low-enthalpy geothermal energy. Source: Own elaboration.

3.3.2. High-Enthalpy Geothermal Energy

Regarding the steps to take to eradicate barriers to high-enthalpy geothermal energy, we again assess the situation in Spain compared to the EU and the Canary Islands. In this case, the agricultural sector has not been specifically considered regarding high-enthalpy. Figure 16 shows there is no unanimity of judgement of European and Spanish experts since, for the former, the main actions to take would be private investment and promotion, whilst for the latter it would be public investment. In the case of the Canary Islands (Figure 17), it would be public investment and promotion. Examining the situation as a whole for all experts and locations (Figure 18), it would be public investment followed by promotion and private investment. As far as low-enthalpy is concerned, only promotion would be on top.

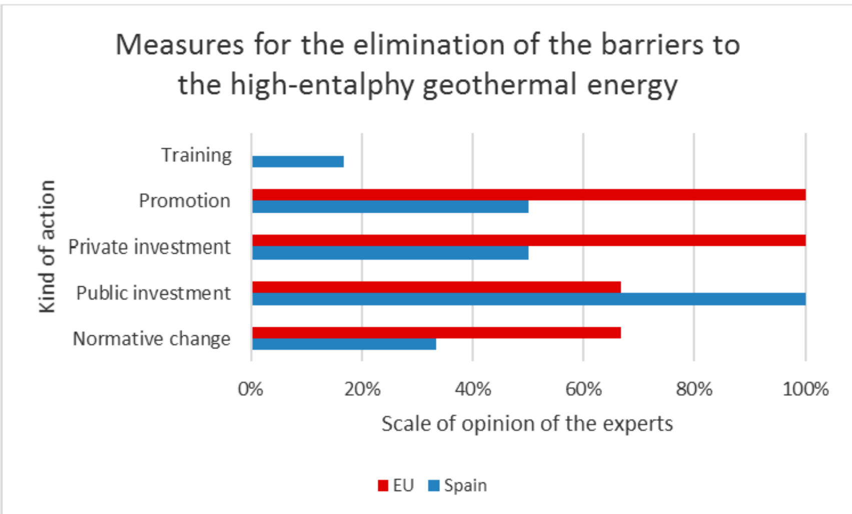

Figure 16. Measures for the elimination of the barriers to the high-enthalpy geothermal energy (comparative between Spain and the EU). Source: Own elaboration.

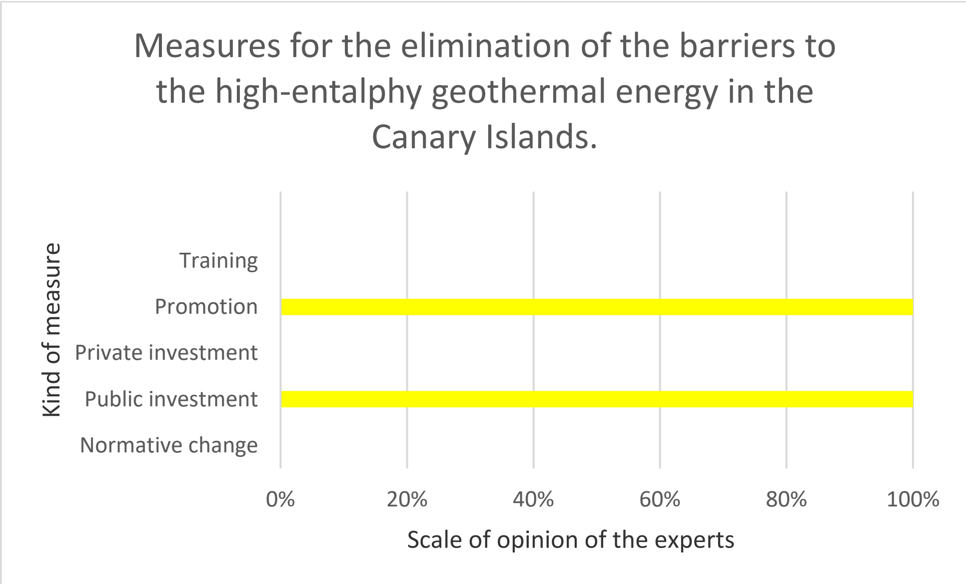

Figure 17. Measures for the elimination of the barriers to the high-enthalpy geothermal energy in the Canary Islands. Source: Own elaboration.

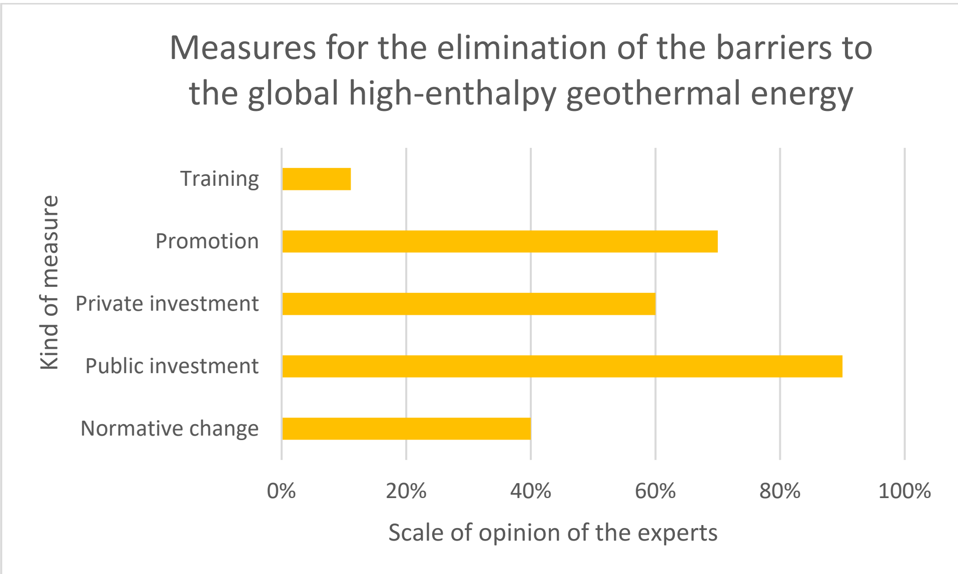

Figure 18. Measures for the elimination of the barriers to the global high-enthalpy geothermal energy. Source: Own elaboration.

3.3.3. Energy Mix

The last measures to be assessed are those related to energy mix. Both in the EU and Spain (Figure 19), regulatory change is seen as the most significant step to take and public investment, private investment and promotion follow. In the case of the Canary Islands (Figure 20), the measures are regulatory change and public investment. From a global assessment (Figure 21), regulatory change remains on top, followed closely by investment.

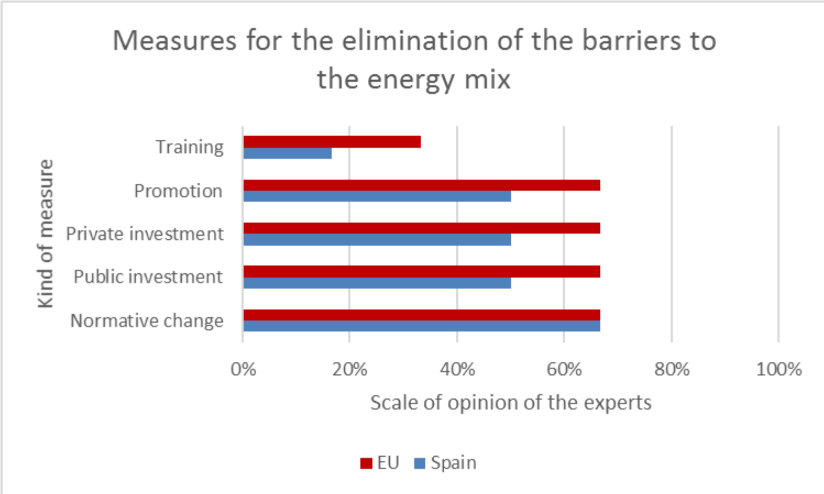

Figure 19. Measures for the elimination of the barriers to the energy mix (comparative between Spain and the EU). Source: Own elaboration.

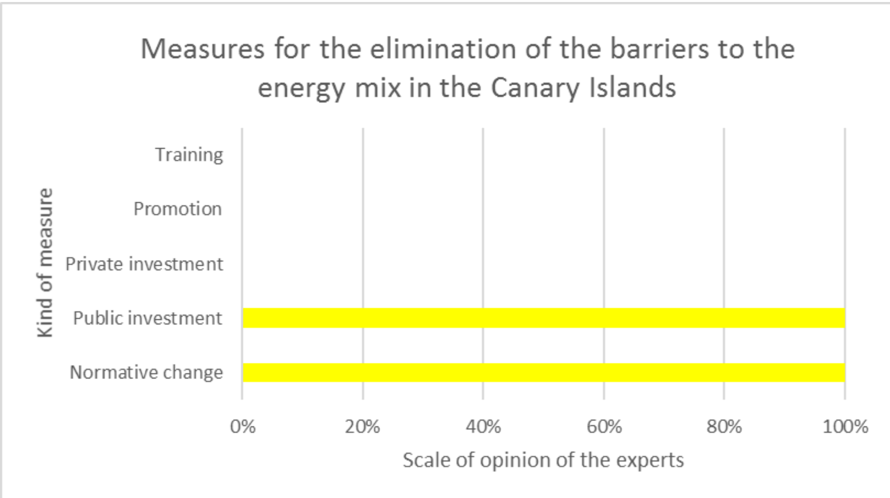

Figure 20. Measures for the elimination of the barriers to the energy mix in the Canary Islands. Source: Own elaboration.

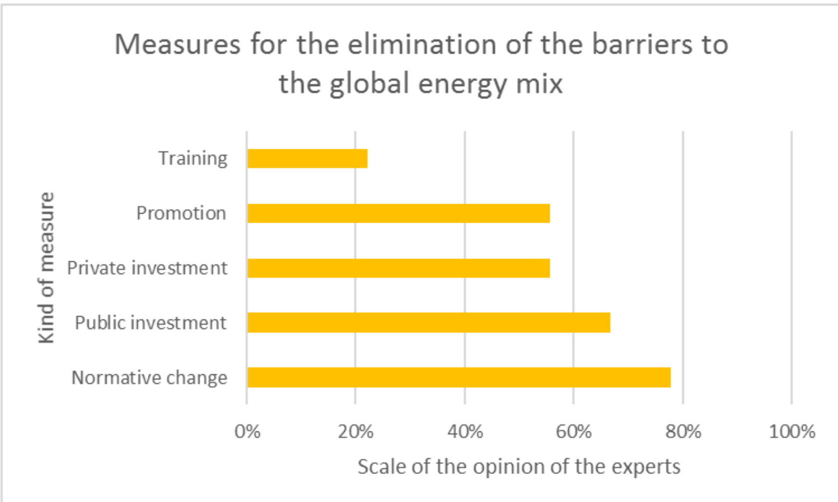

Figure 21. Measures for the elimination of the barriers to the global energy mix. Source: Own elaboration.

3.4. Block 4: Advantages

3.4.1. Low-Enthalpy Geothermal Energy

Once barriers and actions to take are addressed, there is a need to know what the real advantages to the introduction of each technology are: these are low-enthalpy, high-enthalpy geothermal and mix, in each one of the scenarios described above. The results are presented on Figures A9–A11 (Appendix C). On Figure A9, the advantage which scores higher in all examined scenarios, Spain, the EU, the agricultural sector, and the Canary Islands is reduction of external energy dependence. Lowest on the list is energy security.

The greatest number of advantages to the implementation of this technology is given by the EU and Canary Islands experts.

3.4.2. High-Enthalpy Geothermal Energy

As far as the advantages to the introduction of high-enthalpy geothermal energy are concerned (Figure A10), once again the EU and the Canary Islands would benefit the most. Top of the list for value is CO_2 emissions reduction and energy independence. Low on the list are opening to new markets stability of the electrical grid and energy costs reduction.

3.4.3. Energy Mix

Regarding energy mix (Figure A11), the greatest advantages would be for Spain and the EU. In this instance, external energy independence followed by energy costs reduction are on top of the list, while on the bottom are opening new markets and local development.

3.5. Closed Questions Questionnaire

To obtain a more detailed assessment from the experts, a further questionnaire with 8 closed questions is presented (Appendix D, Table A5) and Figures A12–A19 are also shown on the aforementioned Appendix.

The most promising results on whether further development of geothermal technology would reduce its cost are for the EU, the Canary Islands, and the agricultural sector (Figure A12), and it is in some way consistent with one of the main advantages shown in Figure A9, which is energy cost reduction.

Once again, the most encouraging scenarios are for the EU, the Canary Islands, and the agricultural sector regarding final consumer concerns about the origin of the energy consumed (Figure A13). We must bear in mind that European experts believe that the demands of the citizens from the N of Europe are greater than those of the S of Europe.

Also, as previously mentioned, the Michalena and Hills study [13] shows differences between the N and S countries of Europe. For example, training and monitoring are more important for S countries than for N countries where established local social networks already exist. On the other hand, within the European 2020 strategy [30], differences between N and S are not considered, although they obviously exist. Similarly, subsidiary requirements should be tailored at a regional level [13].

Regarding whether the final consumer is aware of environmental, social, and economic advantages related to the implementation of this technology (Figure A14), there is no unanimity of criteria. The most favorable judgement is for the agricultural sector and for the EU. This question and its answers are consistent with one of the main actions needed to eradicate barriers for this technology: promotion.

In some articles, a parallel is drawn between citizens' income and environmental protection [32]. Also, the higher the level of development of a country, the more the investment in renewable energy [33].

Regarding whether the initial investment needs to be larger due to the innovative nature of this technology (Figure A15), the scenarios with the highest score are those of the Canary Islands and the agricultural sector. These answers are consistent with actions needed to eradicate barriers to geothermal energy since investment appeared as one of the main actions to take. Initial investment, together with oil prices, appear to be key financial barriers on previous geothermal studies that consider the agricultural and the livestock sectors. An energy performance contract (EPC) could be the solution to resolve geothermal energy financial barriers. There are examples of energy performance contract in buildings but not in the agricultural or livestock sectors. Primary productive sectors such as agriculture and livestock would benefit from this cost-effective solution using a low-enthalpy geothermal heat pump [24].

In the section of theoretical framework, a study on solar hybridization located in Turkey was cited which, despite the initial investment being larger than that of conventional energies, proved that with sufficient wind load, this combination is preferable to conventional energies [25].

Regarding the question of whether geothermal energy is at a disadvantage due to its costs against other renewable sources (Figure A16), a high percentage of respondents are very clear on the matter and categorical in their judgement for the EU, the Canary Islands, and the agricultural sector.

To the question of whether the government policies can be an obstacle to the introduction of this technology, there is disparity of criteria which ranges from those who, as in the case of the agricultural sector, do not answer to those who agree completely as in the case of the Canary Islands, or half of the respondents in the case of Spain, who believe this to be a hindrance (Figure A17).

Regarding the environmental awareness of companies, there are also some differences of judgement according to the context. It is clear that this is not so in the case of the Canary Islands (Figure A18).

The greatest degree of agreement in this batch of eight questions is reached on question number eight, which refers to whether institutions continue to support fossil fuels and cross-border energy grids to the detriment of renewable energies as a consequence of lobbying. The more a country depends on fossil fuels, the less renewable development it has [32].

Figures A12–A19 reflect the judgement of experts for all possible scenarios and shows score levels. The answer with the highest score is supported from institutions to fossil fuels and cross-border grids. With the lowest score is the question: is the final consumer aware of the environmental, social, and economic advantages and is the current political situation and government policies an obstacle? The first issue could be resolved by regulatory change affecting high-enthalpy geothermal energy rather than low-enthalpy, which seems to keep on progressing in the market. The moratorium on renewable energies should be lifted along with a reform in the electricity sector. Institutions at the national and European level need a strong commitment to implement this kind of technology. Some institutions and individual companies indeed support its development, but there is still a long way to go to achieve large-scale progress [34].

On the matter of the question with the lowest score—Is the consumer aware of environmental, social and economic advantages?—training and promotion are needed.

As stated in the section on the theoretical framework, there are numerous applications for geothermal energy, and many cases have already been studied, although many of them are still in the pilot phase [34]. It seems necessary to develop all these projects to move on from the pilot stage and enter the market. This will only come to fruition with due training and promotion.

4. Conclusions

The fact of being able to discriminate in this study according to the different uses of geothermal energy (thermal or electrical or mix) depending on the region examined (island, country, or continent) or even including a specific activity sector, in this case agricultural, though it could be any other, allows us to focus attention where it is really needed and to identify the actions more fit for each case.

This work contemplates four big blocks, namely the degree of implementation, barriers, measures and advantages for the three technologies and the four scenarios mentioned in it, thus moving from a global approach to a more specific one and analyzing its results.

The main conclusions of this study are as follows. First, regarding level of implementation of this energy, a lower degree in Spain than in the EU has been identified for all the examined scenarios except for low-enthalpy geothermal energy. It is even lower in the Canary Islands than in the main land in all scenarios except for the geothermal energy mix. On a general level, the degree of development turned out to be two for underdevelopment on a 1 to 5 scale (from lowest to highest), the situation being poorer as far as high-enthalpy geothermal energy is concerned as well as geothermal energy on the agricultural sector.

Second, regarding barriers, when discriminating renewable energies by type and thus separating geothermal from the rest and even its thermal or electrical end uses as in the research that concerns us, we find that economic barriers to low-enthalpy geothermal energy in Spain are not as significant as might be expected and that, in fact, this score is lower than its European counterparts. On the other hand, in the case of high-enthalpy geothermal energy production, economic barriers are high both in Spain and in the rest of Europe. On a global scale, the study concludes that the main barriers to the introduction of electrical uses for geothermal energy are economic/financial, while for thermal uses, they are cultural or social. At a regional level, in the EU economic/financial barriers are still the most important, both for low and high-enthalpy geothermal. This is also true in Spain, although in the latter case to a lesser extent. In the case of the Canary Islands, the main barriers are cultural/social along with regulatory/institutional for low-enthalpy geothermal energy and economic/financial for high-enthalpy geothermal energy.

As stated previously, one of the most commonly cited topics in a variety of articles [35,36] is the importance of implementation of renewable energies at a local level, although European policies (and not only in Europe) give minimal support to this issue.

According to the findings of the research carried out here, the institutional or regulatory barriers rank third on the general scale for both high and low enthalpy, being more important in the EU than in Spain especially for electrical uses. As indicated above, the importance of the Canary Islands is also worth mentioning in this case.

In the third place, the measures to be taken, this study concludes that at the regional level, the EU considers that the actions to be taken are private investment in the case of high-enthalpy geothermal energy and promotion for low-enthalpy geothermal energy. In the case of Spain, for the high-enthalpy geothermal energy, it would be public investment and, again, promotion for thermal uses. In the case of the Canary Islands, public investment for low and high-enthalpy, training, and promotion for low-enthalpy. In the agricultural sector, training and promotion would be the most significant measures both for renewable energy in general as well as for geothermal energy in particular. Regarding global actions, depending on whether it is low-enthalpy geothermal, high-enthalpy geothermal or energy mix, public investment, promotion, and regulatory change in this order.

The figures show that when examining barriers to the introduction of renewable energies by focusing on geothermal energy in particular and its energy mix, it is not only promotion and regulatory that change rank on the first positions but also private and public investment, being of more or less importance depending on the region case study and the type of geothermal technology.

Lastly, as far as advantages are concerned, energy security does not seem to be the main concern of experts since this is covered by other sources of energy in the short term (renewable and non-renewable). This is more relevant in the Canary Islands due to its isolated and insular nature. Nonetheless, our study does share with others the crucial importance of energy independence from external sources [37]. The case of the Canary Islands is not different from the rest of the insular areas in Europe and worldwide, where distributed generation and micro-grids become a fundamental issue. For all three technologies that have been studied here—low-enthalpy, high-enthalpy, and energy mix—the EU scenario is the most positive. This circumstance is repeated in all questionnaires.

A study with more subject matter experts in the field would be desirable in the future when this technology will be well known, to evaluate its differences to the current one. In the same way, it is expected that future research in the line proposed here include new technologies such as dry hot rock, stimulated geothermal systems, or supercritical deposits.

Author Contributions: E.P.-T. and E.R.-A. designed and performed the experimental and theoretical basis of the research. E.P.-T. implemented the methodology and calculations and analyzed the results. E.R.-A. provided technical and theoretical support. E.P.-T. wrote the manuscript and all authors read and approved the final version.

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

Abbreviations

DK/DA	Doesn't know/doesn't answer
N/S	North/South
y/n	yes/no
European Union	EU

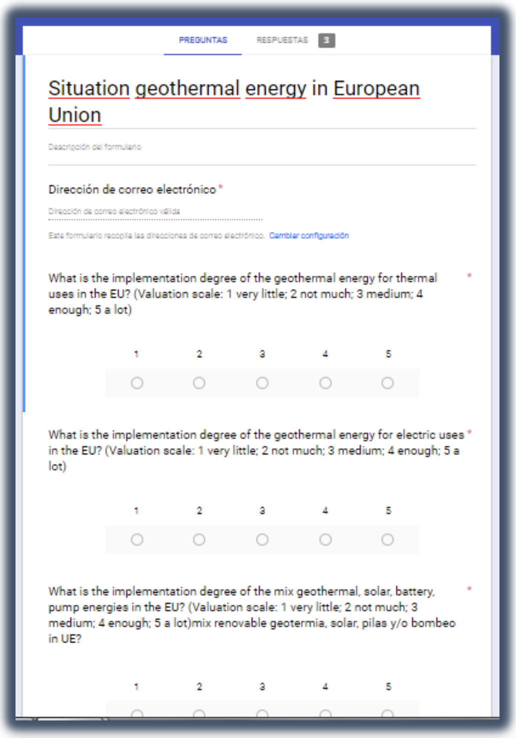
Appendix A

Four questionnaire models were elaborated with Google Docs and experts considered most suitable for each region pertinent to the study were invited to reply via e-mail.

Below is a summary of the links and forms that were sent to experts.

Form 1: European Union

https://docs.google.com/forms/d/1qSAmdOFryKOqJ78Wi5BRftkLtXH3dYCrfJ4mGhVdKN4/edit.


PREGUNTAS RESPUESTAS 3

Situation geothermal energy in European Union

Descripción del formulario

Dirección de correo electrónico *

Dirección de correo electrónico válida

Este formulario recopila las direcciones de correo electrónico. Cambiar configuración

What is the implementation degree of the geothermal energy for thermal uses in the EU? (Valuation scale: 1 very little; 2 not much; 3 medium; 4 enough; 5 a lot) *

1 2 3 4 5

What is the implementation degree of the geothermal energy for electric uses in the EU? (Valuation scale: 1 very little; 2 not much; 3 medium; 4 enough; 5 a lot) *

1 2 3 4 5

What is the implementation degree of the mix geothermal, solar, battery, pump energies in the EU? (Valuation scale: 1 very little; 2 not much; 3 medium; 4 enough; 5 a lot)mix renovable geotermia, solar, pilas y/o bombeo in UE? *

1 2 3 4 5

Figure A1. Form model EU. Source: Own elaboration.

Form 2: Spain
https://docs.google.com/forms/d/1jEkObggXyDD_8pdcfKkulz3vnxaWtfsl2lQyhXUbKlE/edit.

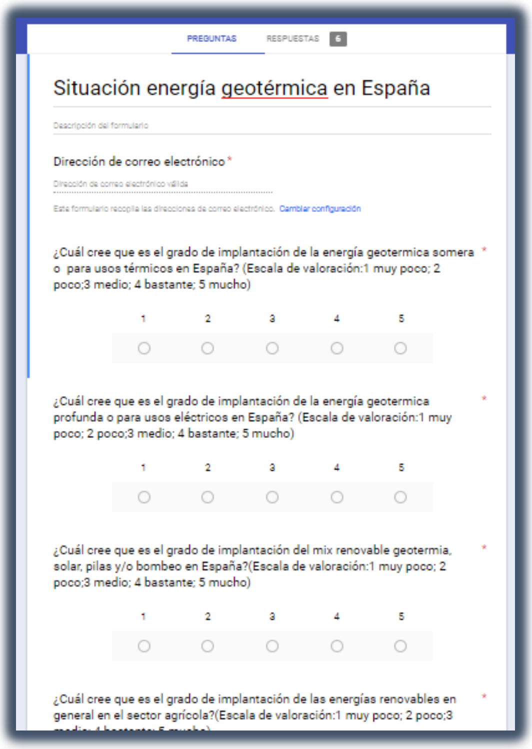


Figure A2. Form model Spain. Source: Own elaboration.

Form 3: Canary Islands
https://docs.google.com/forms/d/1H0sIcClMp1Mk7J9Xt8Z-36BZkJBSvb8c2qok6leIS28/edit.

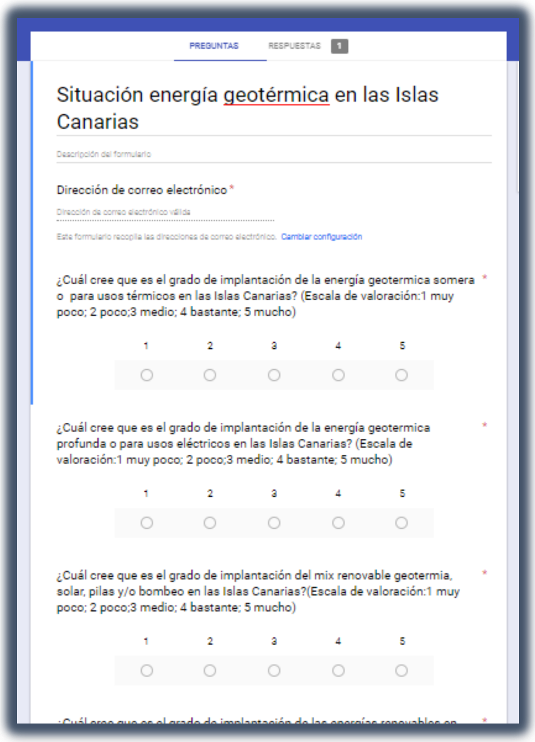
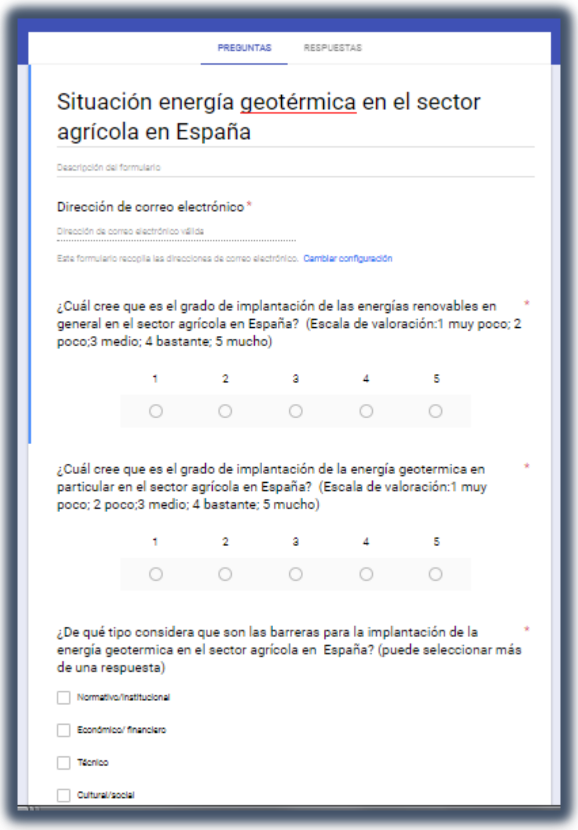


Figure A3. Form model Canary Islands. Source: Own elaboration.

Form 4: Agricultural sector
https://docs.google.com/forms/d/12jxJ_Ek35RCKlWfzcZo53y_XCln5hOvJNkpnz1DvIDg/edit.


PREGUNTAS RESPUESTAS

Situación energía geotérmica en el sector agrícola en España

Descripción del formulario

Dirección de correo electrónico *

Dirección de correo electrónico válida

Este formulario recopila las direcciones de correo electrónico. Cambiar configuración

¿Cuál cree que es el grado de implantación de las energías renovables en general en el sector agrícola en España? (Escala de valoración:1 muy poco; 2 poco;3 medio; 4 bastante; 5 mucho) *

1 2 3 4 5

¿Cuál cree que es el grado de implantación de la energía geotermica en particular en el sector agrícola en España? (Escala de valoración:1 muy poco; 2 poco;3 medio; 4 bastante; 5 mucho) *

1 2 3 4 5

¿De qué tipo considera que son las barreras para la implantación de la energía geotermica en el sector agrícola en España? (puede seleccionar más de una respuesta) *

- Normativo/Institucional
- Económico/ financiero
- Técnico
- Cultural/social

Figure A4. Form model agricultural sector. Source. Own elaboration.

Appendix B

Block 1: Level of implementation

In this first block, the level of implementation of geothermal energy for each of scenario and technologies shown in Figure 1 is examined. We work with a scoring scale of 1: very little to 5: a lot. See Figure A5 and Table A1.

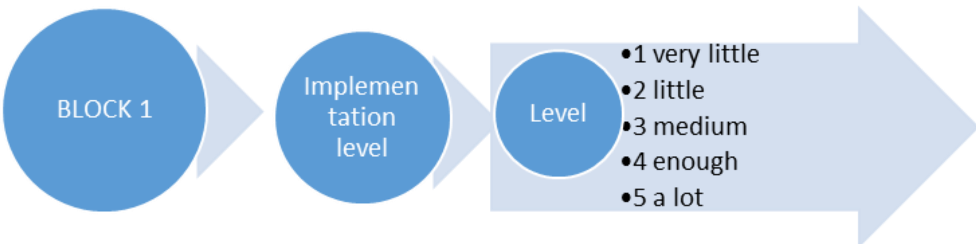


Figure A5. Implementation level for low-enthalpy, high-enthalpy and mix geothermal energy in Spain, EU, Canary Islands, and agricultural sector. Source: Own elaboration.

Table A1. Questions regarding the implementation level of geothermal energy for each of the four scenarios proposed: Spain, EU, Canary Islands, and agricultural sector. Source: Own elaboration.

BLOCK	SCENARIO		1	2	3	4
	QUESTIONS	SCORING SCALE	SPAIN	EU	CANARY ISLANDS	AGRICULTURAL SECTOR
1	What do you think is the implementation level for the low-enthalpy geothermal energy?	1: very little 2: little 3: medium 4: enough 5: a lot			Figures 2–4	
	What do you think is the implementation level for the high-enthalpy geothermal energy?	1: very little 2: little 3: medium 4: enough 5: a lot				
	What do you think is the implementation level for the mix renewable: geothermal, solar, battery and/or pumping?	1: very little 2: little 3: medium 4: enough 5: a lot				
	What do you think is the implementation level for the renewable energy in the agricultural sector?	1: very little 2: little 3: medium 4: enough 5: a lot				
	And the geothermal energy in particular in the agricultural sector?	1: very little 2: little 3: medium 4: enough 5: a lot				

Block 2: Barriers

In this second block, barriers to the introduction of all types of geothermal energy and in the 4 scenarios—Spain, the EU, the Canary Islands, and the agricultural sector—are studied, for which a series of multi-answers are established (Figure A6 and Table A2).

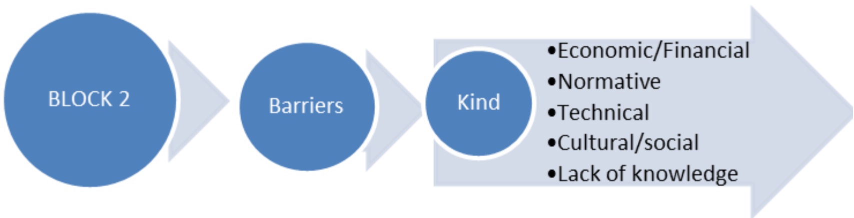


Figure A6. Barriers to the implementation of the low- and high-enthalpy geothermal energy and mix energy in Spain, EU, Canary Islands, and agricultural sector. Source: Own elaboration.

Table A2. Questions regarding the barriers to the implementation of geothermal energy for each of the four scenarios proposed: Spain, EU, Canary Islands, and agricultural sector. Source: Own elaboration.

BLOCK	SCENARIO		1	2	3	4
	QUESTIONS	MULTI ANSWERS	SPAIN	EU	CANARY ISLANDS	AGRICULTURAL SECTOR
2	Which among these do you think are the barriers to the implementation of low-enthalpy geothermal energy?	Economic/Financial Normative Technical Cultural/social Lack of knowledge Others; Big offers gas sector			Figures 5–11	
	Which among these do you think are the barriers to the implementation of high-enthalpy geothermal energy?	Economic/Financial Normative Technical Cultural/social Lack of knowledge Others; Big offers gas sector				

Block 3: Measures

In this third block, the most appropriate actions to take toward the eradication of barriers to the introduction of all types of geothermal energy are studied: thermal, electrical and mix uses for the four proposed scenarios. Also, the methodology in this case consists of a series of multi-answers.

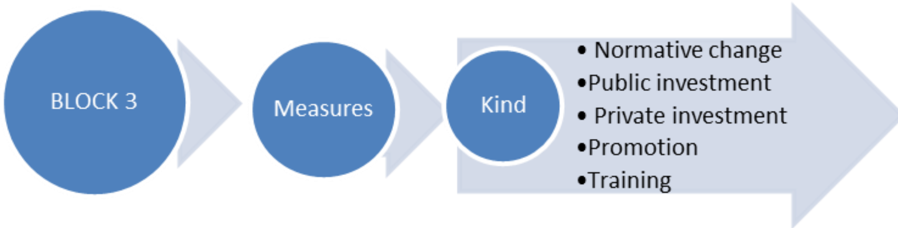


Figure A7. Measures to eliminate barriers to the implementation of low- and high-enthalpy geothermal energy, and mix energy in Spain, EU, Canary Islands, and the agricultural sector. Source: Own elaboration.

Table A3. Questions related to the measures that eliminate barriers to the implementation of geothermal energy for each of the four proposed scenarios. Source: Own elaboration.

BLOCK	SCENARIO		1	2	3	4
	QUESTIONS	MULTI ANSWERS	SPAIN	EU	CANARY ISLANDS	AGRICULTURAL SECTOR
3	What would be the most appropriate measures for the elimination of low-enthalpy geothermal energy barriers?	Normative change Public investment Private investment Promotion Training	Figures 12–21			
	What would be the most appropriate measures for the elimination of high-enthalpy geothermal energy barriers?	Normative change Public investment Private investment Promotion Training				
	What would be the most appropriate measures for the elimination of renewable energy mix barriers?	Normative change Public investment Private investment Promotion Training				

Block 4: Advantages

In this last block, a series of advantages are laid out to see the most appropriate based on the criteria from the experts for each of the scenarios and proposed technologies.

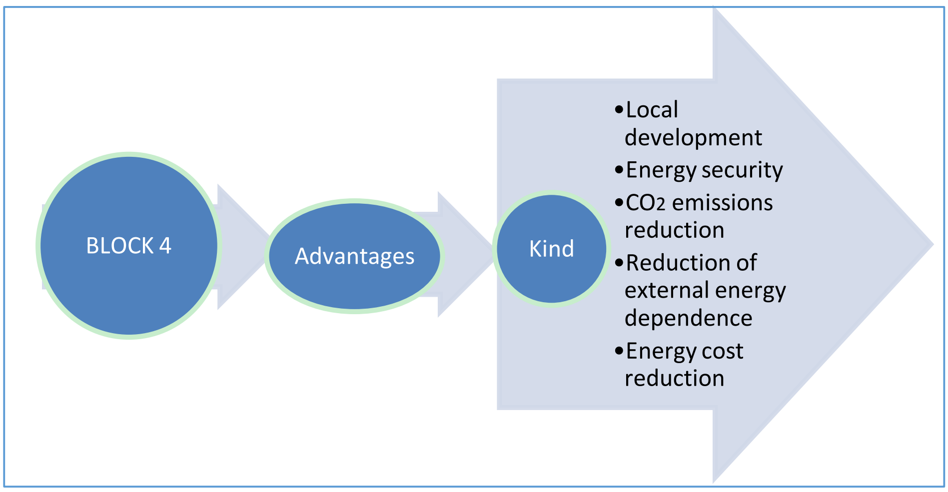


Figure A8. Advantages of the implementation of low, high enthalpy geothermal energy and mix renewable energy in Spain, EU, Canary Islands, and agricultural sector. Source: Own elaboration.

Table A4. Questions related to the advantages of the implementation of geothermal energy for each of the four proposed scenarios: Spain, EU, Canary Islands, and the agricultural sector. Source: Own elaboration.

BLOCK	SCENARIOS		1	2	3	4
	QUESTIONS	MULTI ANSWERS	SPAIN	EU	CANARY ISLANDS	AGRICULTURAL SECTOR
4	What advantages would a greater development of low-enthalpy geothermal energy have?	Local development Energy security CO_2 emissions reduction Reduction of external energy dependence Energy cost reduction				
	What advantages would a greater development of high-enthalpy geothermal energy have?	Local development. Energy security CO_2 emissions reduction Reduction of external energy dependence Energy cost reduction			Figures A9–A11	
	What advantages would a greater development of renewable mix energy have?	Local development Energy security CO_2 emissions reduction Reduction of external energy dependence Energy cost reduction				

Appendix C

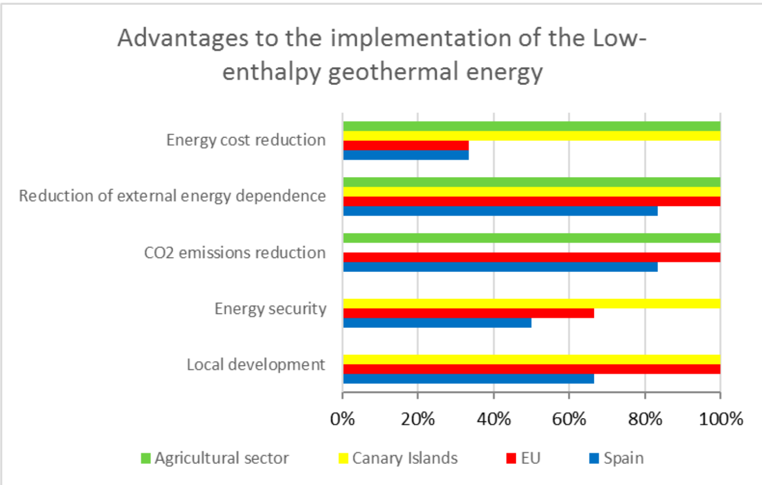


Figure A9. Advantages to the implementation of the low-enthalpy geothermal energy. Source: Own elaboration.

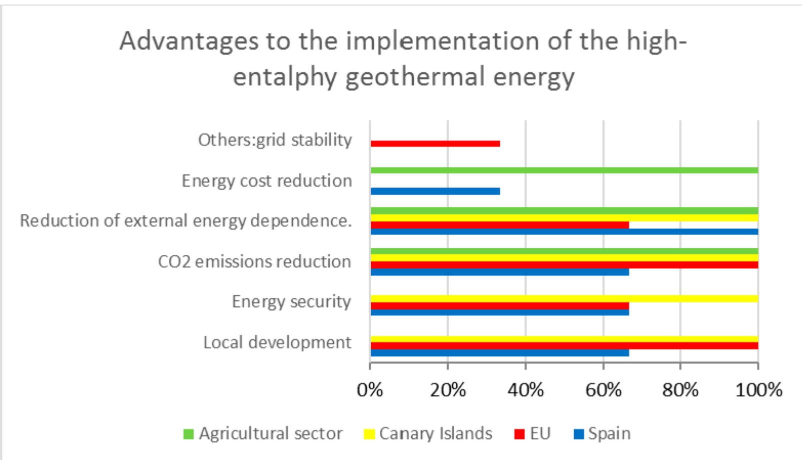


Figure A10. Advantages to the implementation of the high-enthalpy geothermal energy. Source: Own elaboration.

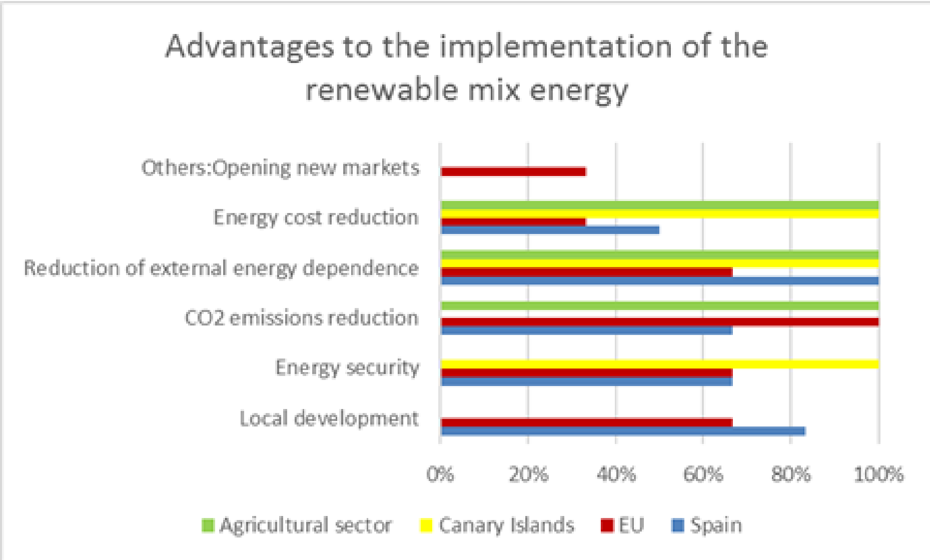


Figure A11. Advantages to the implementation of the mix renewable energy. Source: Own elaboration.

Appendix D

Table A5. Closed questions related to the situation of geothermal energy and other renewable energies in the context and proposed scenarios. Source: Own elaboration.

SCENARIOS		1	2	3	4
QUESTIONS	**ANSWERS**	**SPAIN**	**EU**	**CANARY ISLANDS**	**AGRICULTURAL SECTOR**
Do you think that further development of this technology (low- and/or high-enthalpy geothermal energy and/or energy mix with other sources of energy) would reduce its cost?	Yes No DK/DA	Figures A12–A19			
Do you think that the final consumer is becoming more demanding with the origin of the energy he (she) consumes?	Yes No DK/DA				
Do you believe that the final consumer is aware of the environmental, social and economic benefits of clean energy consumption?	Yes No DK/DA				
Do you think that the initial investment is greater due to the use of a new technology?	Yes No DK/DA				
Do you think that geothermal energy is at a cost disadvantage with other renewable energies of greater implantation?	Yes No DK/DA				
Do you think that the current government situation is an obstacle on the implementation of this technology?	Yes No DK/DA				
Do you think that companies are increasingly aware of environmental issues beyond purely economic ones?	Yes No DK/DA				
Do you think that the institutions continue to support fossil fuels and the creation of cross-border energy networks to the detriment of local renewable energies?	Yes No DK/DA				

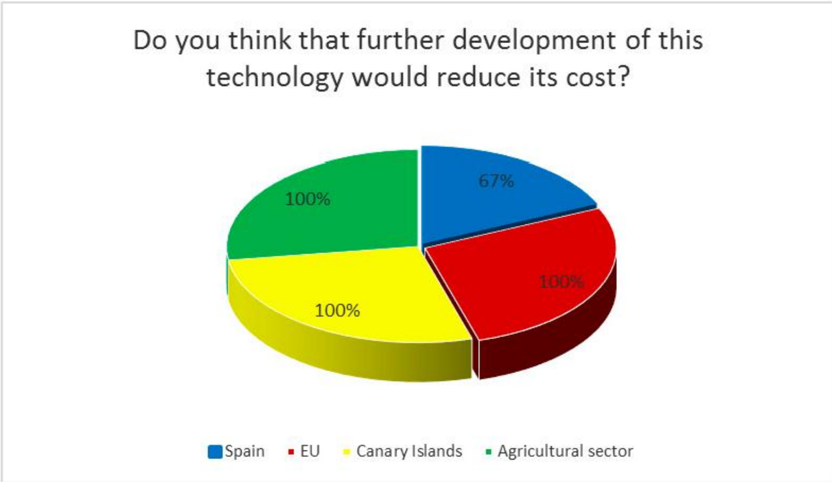


Figure A12. Comparative between development of the technology and cost reduce in the proposed scenarios Percentages in the graph showed for Yes. Source: Own elaboration.

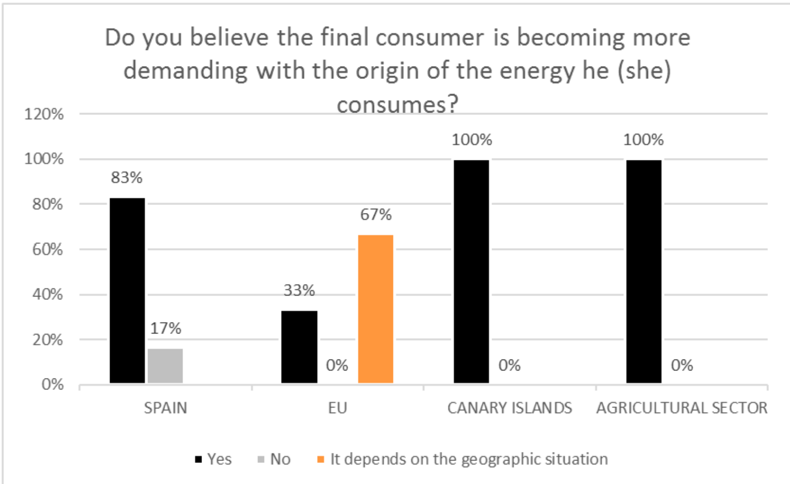


Figure A13. Comparative between demanding of the final consumer and the origin of the energy he (she) consumes in the four proposed scenarios: Spain, EU, Canary Islands, and agricultural sector. Source: Own elaboration.

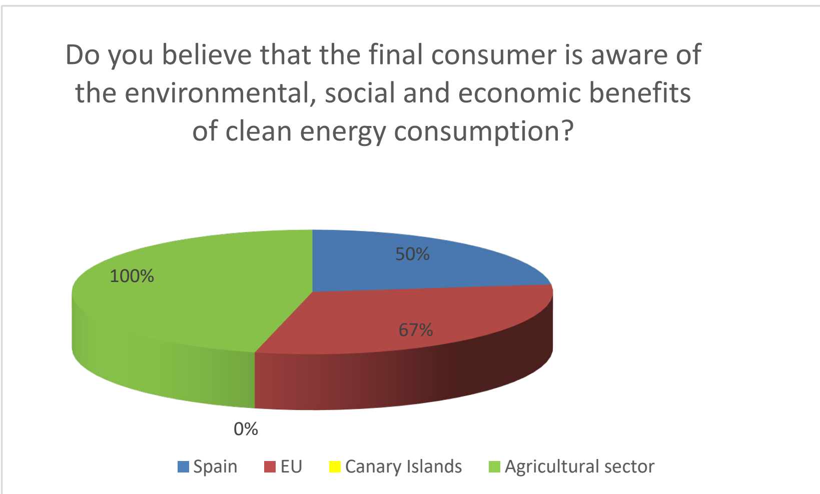


Figure A14. Comparison between the final consumer awareness and the advantages of clean energy consumption in the four proposed scenarios: Spain, EU, Canary Islands, and the agricultural sector. Percentages in the graph showed for Yes. Source: Own elaboration.

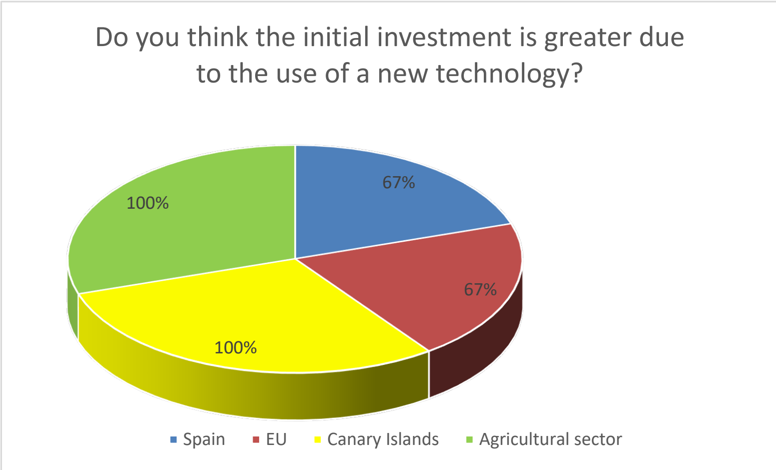


Figure A15. Comparison between initial investment and the use of a new technology in the four scenarios proposed: Spain, EU, Canary Islands, and the agricultural sector. Percentages in the graph showed for Yes. Source: Own elaboration.

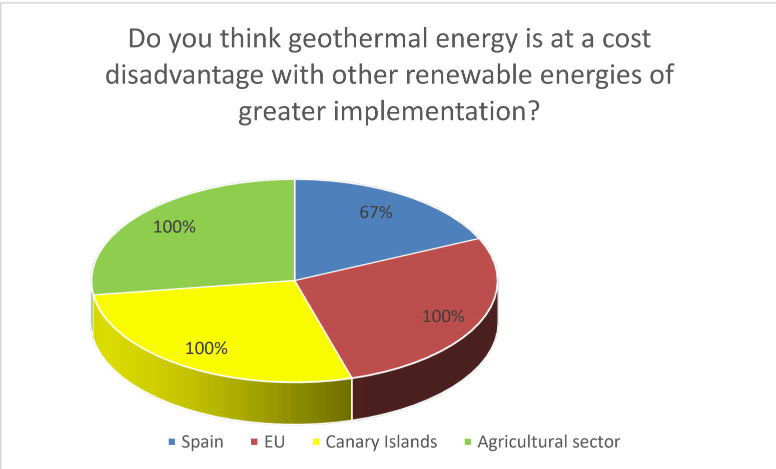


Figure A16. Comparison between disadvantage in cost of the geothermal energy and other renewables energies in the four proposed scenarios: Spain, EU, Canary Islands, and the agricultural sector. Percentages in the graph showed for Yes. Source: Own elaboration.

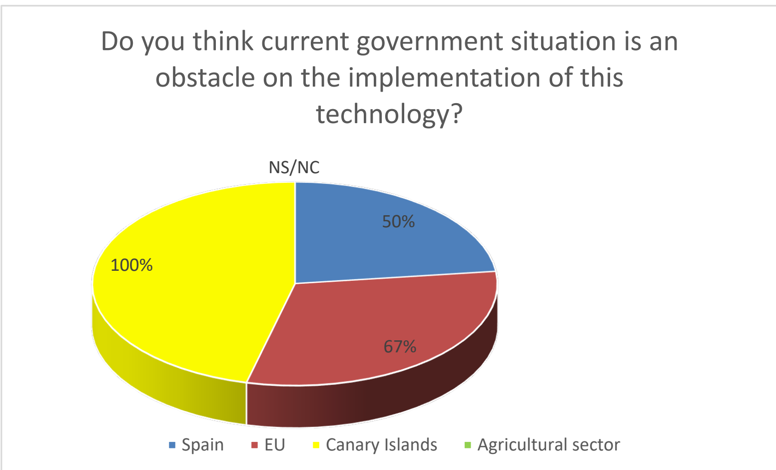


Figure A17. Comparison between current government situation and the impediment to the implementation of the geothermal energy in the four scenarios proposed: Spain, EU, Canary Islands, and the agricultural sector Percentages in the graph showed for Yes. Source: Own elaboration.

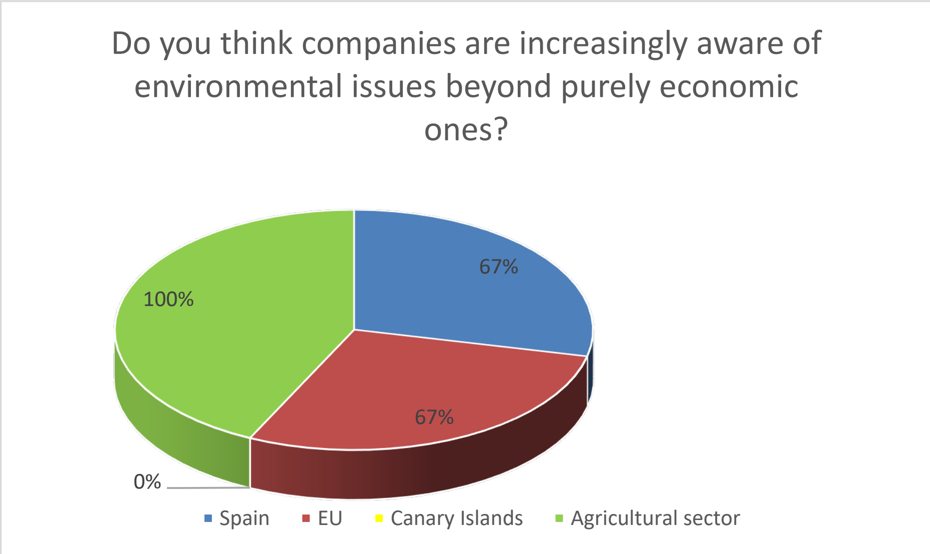


Figure A18. Comparison between awareness of the companies about environmental issues in the four scenarios proposed: Spain, EU, Canary Islands, and the agricultural sector. Percentages in the graph showed for Yes. Source: Own elaboration.

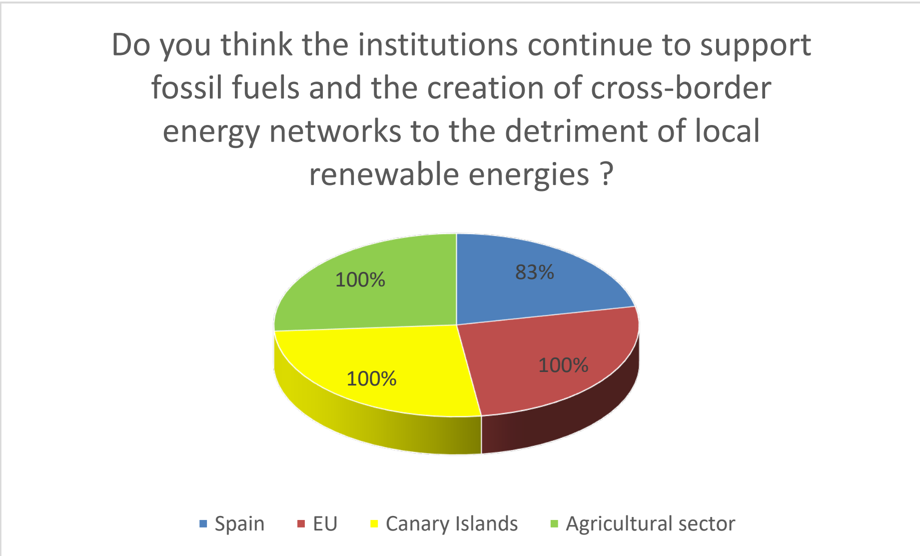


Figure A19. Comparison between support for the institutions to the fossil fuels and cross-border energy networks to the detriment of local energies in the four proposed scenarios: Spain, EU, Canary Islands, and the agricultural sector Percentages in the graph showed for Yes. Source: Own elaboration.

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ANEXO II "Measures to Remove Geothermal Energy Barriers in the European Union". FACTOR DE IMPACTO DE LA PUBLICACIÓN

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ANEXO III "Measures to Remove Geothermal Energy Barriers in the European Union". CERTIFICADO DE LA PUBLICACIÓN


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ANEXO IV "Thermal desalination potential with parabolic trough collectors and geothermal energy in the Spanish southeast". COPIA DE LA PUBLICACIÓN

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Thermal desalination potential with parabolic trough collectors and geothermal energy in the Spanish southeast

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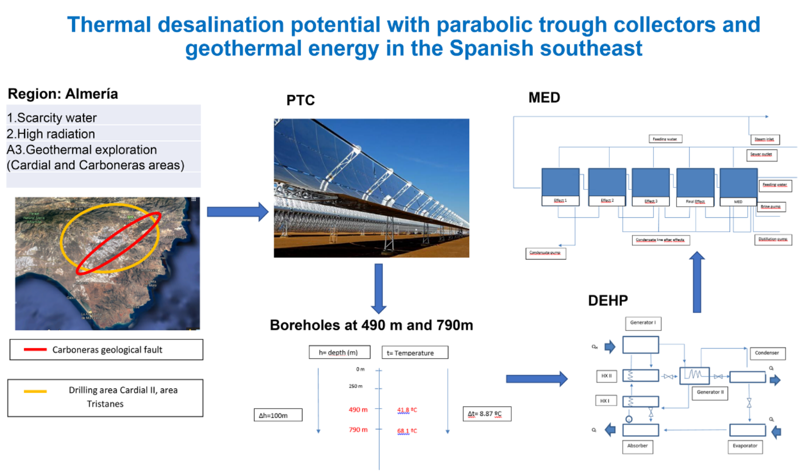
HIGHLIGHTS

- Renewable desalination in coast areas with water scarcity is a must.
- 76% annual time works a Multi-effect distillation plant with geothermal-solar energy.
- 100% annual time works a Multi-effect distillation plant with geothermal energy.
- Double effect absorption heat pump improve the results during 30% annual time.
- 6 years amortization and 510,387,920 kg/year CO_2 avoided for the existing plants.

GRAPHICAL ABSTRACT



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ABSTRACT

Desalination industry has become essential for the survival of the population in places with shortages of fresh water. Because is a costly process, the constant search for the best local renewable energy sources is a necessity.

A theoretical Multi-effect distillation plant of 9000 m^3/d located in the southeast Spanish (Almería) is intended to fed thermally with solar (parabolic trough collectors) and geothermal energy.

Starting from the history of solar irradiation and temperatures of the province of Almería from 1994 to 2016 provided by Solargis database, a discrimination of the profile of temperatures is obtained at the exit of the solar panels. Putting in common the profile exit temperatures and the potentiality of the geothermal resource at the depth in the area under study, a series of possible configurations are obtained.

The theoretical results of the study indicate that during 76% of the annual time is achieved with both resources (solar and geothermal) at that depth of the well in that specific climatological zone (490 m, t = 41.8 °C).

Since the thermal gradient in the area is 8.87 °C per 100 m depth according to the studies carried out, only geothermal energy would be necessary at deep of 790 m to obtain working temperatures of the desalination plant at 70 °C.

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Applying the results to the existing desalination plants of the Spanish project named Actions for the Management and Utilization of Water is obtained 6 years of amortization and 510,387,920 kg/y CO_2 avoided to the atmosphere for all of these plants.

1. Introduction

The World Energy Outlook Sustainable Development Scenario takes its inspiration from the UN Sustainable Development Goals (SDG) most closely related to energy: achieving universal energy access, reducing the impacts of air pollution and tackling climate change. It sets out what would be needed to deliver these goals in the most cost-effective way. The Scenario now also includes a water dimension, focusing both on the water needs of the energy sector and the energy needs of the water sector.

This free excerpt from World Energy Outlook 2018 reveals the benefits of an integrated approach to SDG on energy access and SDG on clean water and sanitation: Decentralised renewables [1] deployed in rural areas for energy access can also provide clean drinking water. Achieving universal access to clean water and sanitation would add less than 1% to global energy demand in 2030 [2].

By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity [3].

In an increasingly globalized world, the impacts of water-related decisions cross borders and affect everyone. Extreme events, environmental degradation, population growth, rapid urbanization, unsustainable and inequitable consumption patterns, conflicts and social unrest, and unprecedented migratory flows are among the interconnected pressures faced by humanity, often hitting those in vulnerable situations the hardest through their impacts on water.

Addressing the inequalities faced by disadvantaged groups requires tailored solutions that take account of the day-to-day realities of people and communities in vulnerable situations. Properly designed and adequately implemented policies, efficient and appropriate use of financial resources, as well as evidence-based knowledge on water resources and water-related issues are also vital to eliminating inequalities in access to safe drinking water and sanitation [4].

Improved water resources management and access to safe water and sanitation for all is essential for eradicating poverty, building peaceful and prosperous societies, and ensuring that 'no one is left behind' on the road towards sustainable development [4].

In the context of the correct management of water resources, the role of solar energy is crucial to obtain those goals. Solar energy is considered to be one of the most important renewable energy sources and there are many applications in the industrial sector beyond desalination, especially through the use of parabolic through collectors, hereinafter PTC because of their high temperatures suitable for certain industrial processes such as solar energy systems: Refrigeration and hot air, drying, cleaning, pasteurization, etc. [5].

However, due to its intermittent nature, it is essential to combine it with other sources of renewable energy, if possible, and study the line of storage of the different types of energy: electrochemical, mechanical, electrical and thermal and, of course, the legislative and economic aspects that affect it [6] to precisely replace the aforementioned intermittent energy.

Some studies propose renewable hybridization systems with use of solar and wind resources to desalinate [7]. Perth desalination plant in Australia is an example [8].Others propose the hybridization of solar energy through PTC with biomass and storage of thermal energy at those times of the year with scarce solar radiation [9]. Special mention in insular areas as the Canary Islands [10] for the desalination systems due to the lack of tap water and in Canary Islands too it is analized that locally available technology potentials are sufficient for a fully renewable supply of the islands' power, heat, and land transport energy demands [11].

Other examples in the literature review by coupling a heat pump to a desalination plant where the "Gained output ratio", hence forth GOR, is analyzed, and it is one of the most important indicators in plants of this type [12]. By coupling a multi-effect desalination plant, MED, to a thermal vapor compression, hereinafter TVC in areas with different solar radiation and different water temperature [13] and even by analysis of the Universal Performance Ratio, hereinafter UPR, for a better comparison of all desalination methods and the importance of integration with renewable energies [14].

Regarding the UPR, it is worth mentioning the article by Kim Choon Ngz and Muhammad Wakil Shahzad where the thermocline energy of the sea is harnessed to feed a MED and achieve a UPR value of 158 (the highest seen so far in the literature) [15].

Also, stochastic optimization techniques are used to analyze the size of renewable energy resources, hereinafter referred to as RES, to feed a reverse osmosis desalination plant in the most profitable way possible [14].

Numerous studies show the increase in the production of distilled water with the increase in temperature and mass flow [16].

The importance of desalination costs is evident in numerous articles and some of them go further by charging more specific but also influential costs such as the cost of land, previous implementation studies and associated taxes [17].

Solar and geothermal hibridization energy is proposed to feed a desalination plant, for the production of electricity, as well as for warming and cooling spaces in small towns such as the island of Pantelleria [18,19]. There are also articles that talk of the hybridization of both energies (solar and geothermal) using PTC to increase the temperature of the geothermal resource and thus improve the production of an existing binary cycle plant [20] or it is demonstrated that by means of the hybridization technology increases the net power but decreases the efficiency of the plant [21].

Hybridizing a geothermal power plant with concentrating solar power and thermal storage to increase power generation and dispatchability is analized in Coso geothermal field [22].

At a domestic level, it is worthy to talk about the research of an integrated, solar-driven membrane distillation system for water purification and energy generation [23].

Putting the focus in Spain, it will be say that it is one of the world leaders, both in the regulatory framework (there are few countries that regulate this matter), and in wastewater regeneration technologies. Spain has an installed reuse capacity of 500 hm^3/y in the more than 320 Refined Water Regeneration Stations, hereinafter, RWRS and a desalination capacity close to three million m^3/d, being the fifth country in capacity installed worldwide [24].

In the specific case of Almería, there are currently three desalination plants: Del Bajo Almanzora, Carboneras and Campo de Dalías, producing between three more than 90 hm^3/y and benefiting more than 640,000 inhabitants, from now on inh and more than 31,000 ha of irrigated land [25]. Knowing the population of inh of the province of Almería (704,297 inh) [25] and that the average consumption per inh and day is 132 l/d, [26], the consumption of drinking water as well as water for irrigation in this region is covered.

These aforementioned plants formed part of a more ambitious plan called A.G.U.A that arose as a result of the repeal of the Ebro river transfer by Royal Decree 2/2004 and the promulgation of Law 11/2005 of modification of the National Hydrological Plan. This plan redirected the water policy in Spain to meet the new needs in the peninsular

Nomenclature

A_c	Area of collectors required (m^2)
AEMET	State Meteorological Agency
A.G.U.A	Actions for the Management and Utilization of Water
COP	Performance coefficient
CPC	Compound parabolic concentrator
$C_{p,c}$	Specific water heat (kJ/(kg·K))
DEHP	Double effect absorption heat pump
Δh	Depth increase
ΔT	Temperature increase
Generator I	High temperature generator
Generator II	Low temperature generator
GOR	Gained output ratio
h	Depth.
hm^3/y	Cubic hectometer per year
HX I	High temperature heat exchanger
HX II	Low temperature heat exchanger
I	Maximum irradiation
inh	Inhabitant.
kW/y	kilowatt/year
kW/d	kilowatt/day
kW/h	kilowatt/hour
l	Liter
l/d	Liter/day
m^3/d	Cubic meter per day
$\dot{m}_w$	Mass flow of partial circulating water by the PTC (kg/s)
$\dot{m}_t$	Mass flow of total circulating water by the PTC (kg/s)
MED	Multi-effect distillation plant
MED-FFH	Distillation multi effect advance with heater
MED-PF	Multi-effect distillation-feeding in parallel
MENA	Middle East and Africa Countries
MES	Multiple effects stacks
MSF	Instantaneous multistage distillation plant
n	Number of columns needed in the PTC
nd	Number of days per year
nh	Number of hours per year
ppm	particle per million
P	Desalting power (kW)
PF	Performance ratio
PTC	Parabolic trough collector
q	MED flow (m^3/h)
q_d	Average desalination consumption (kWh/m^3)
$\dot{Q}_a$	Annual energy required by the desalination plant (kWh/y)
$\dot{Q}_c$	Daily energy provided by the solar collectors
$\dot{Q}_d$	Daily energy required by the desalination plant (kWh/d)
Q_H	Heat from the solar panels feeding to Generator I (kWh)
Q_I	Outgoing heat from the condenser and absorber (kWh)
Q_L	Incoming heat in evaporator (kWh)
ρ	Water density (kg/m^3)
η_c	Collector performance contributed by the manufacturer
RES	Renewable energy systems
RO	Reverse Osmosis
RWRS	Refined Water Regeneration Stations
s	surface of the PTC receiver tube (m^2)
t	Temperature
t_0	Collector outlet temperature (°C)
t_i	Collector inlet temperature (°C)
TDS	Dissolved Salts Content
TK1	water storage tank prior to the entrance to the MED
TK2	water storage tank for the entrance to the PTC
TVC	Thermal compression of steam
UPR	Universal Performance Ratio
v	Water velocity inside the PTC (m/s)
y	year

Mediterranean Arc through desalination. Through this program, the construction of 16 new plants to produce 350 hm^3 was proposed and, on average, each desalination plant cost 68.7 M €. The supply was 54% for urban consumption and 46% for irrigation. The main cost was the energy that represented 36% of the total costs [27].

Despite the extensive experience in Spain with this type of desalination plants, the energy cost has not been taken into account until now and an innovative approach is essential to produce energy (thermal and/or electrical) through renewable energies.

At the state level (Spain) in the last strategic lines for the water sector defined by the Ministry of Agriculture, Food and Environment, there is already talk of the need to improve energy efficiency and the use of renewable energy in that sector [24].

As indicated above, one of the main problems of desalination plants is the high cost of producing drinking water due to the high cost of energy and the high cost of the installation itself.

As we are seeing, the hybridization of solar and geothermal energy is known. Nevertheless the novelty of this study is combining the solar resource through PTC and the geothermal existing resource in the area of Almería -an arid area with water scarcity in the southeast of Spain (see Figs. C1 to C4 in Appendix C)-to feed thermally a theoretical MED type desalination plant. As an addition, verify the profitability of implementing it in the existing water treatment plants of the A.G.U.A project.

Until now, the main challenge associated with renewable energy with desalination plants is to optimize their variability with the continuous demand for drinking water, that is why clean and permanent energies are sought over time, such as geothermal energy. Having a continuous clean energy, close to the point of desalination is what it is intended in this article in addition to an economic framework and a reasonable amortization over time.

The article has been divided into 4 sections and 4 appendices (A, B, C, D): The first section of Introduction represents the importance of desalination in the whole planet but especially in arid and insular regions and its relationship with energy. In this section, a review is made of the current literature regarding PTC, desalination plants and geothermal energy and the focus is on the situation of Spain about this topic. In Section 2 of Materials and Methods proposes the study of a theoretical desalination plant of 9000 m^3/d in a specific area of Almería through hybridization of solar energy and geothermal energy, for which eight possible configurations are proposed. Section 3 presents the Results and Discussion of the study and Section 4 the Conclusions. Appendix A contains information about each of the technologies that will be combined in this paper. Appendix B contains a link with formulas and calculations for the historical profile of PTC outlet temperatures. Appendix C contains information related to geological and hydrographic conditions in Almería and Appendix D related to geothermal resources in Andalusia.

2. Material and methods

Once viewed separately the state of the art of desalination techniques, absorption heat pumps, solar resource and geothermal resource (*Appendix A*) is going to proceed in this section to combine all of them through a series of possible configurations for the next sections proceed to its analysis and conclusion. The majority of studies analyzed show the combination of PTC and/or geothermal energy for electrical use to desalinate. For example, it is increased the temperature of the geothermal resource through PTC. Then it is improved the production of an existing binary cycle plant [20]; or using two double-flash geothermal power plants integrated with absorption heat transformation and water desalination [28] or using gas and oil wells to inject water and obtain energy from them to desalinate in areas of frequent periods of drought such as Texas [29]

In other studies such as that of AQUASOL, PTC and DEHP are combined to desalinate with a thermal use of the desalination plant and with non-renewable auxiliary energy [30].

In the present study, it is going to deeper into this aspect by combining the solar resource through PTC and the geothermal resource to feed a MED type desalination plant, obtaining various configurations that will be detailed in Section 3.

2.1. Starting data:

Starting situation:

- Theoretical desalination plant with capacity for 9000 m^3/d. This size is chosen by previous studies where the cost of desalting is optimal for this flow with a MED of three evaporators [31].
- Geographical location: Almería.

With the two previous premises, on the one hand, the choice of a MED seems feasible compared to other desalination techniques since it is a medium-sized plant in terms of desalination capacity [32]. On the other hand, given the climatic profiles seen in the *Appendix C* on the province of Almeria it seems feasible to make use of the solar resource as a feed to the desalination plant by means of a renewable energy source. The type of collectors chosen will be PTC type (they only capture direct radiation). However, as expected, the solar resource will not be sufficient to provide 100% of the energy required by the desalination plant and therefore a combination with the geothermal resource will be considered.

Starting from the history of solar irradiation and temperatures of the province of Almería from 1994 to 2016 provided by Solargis [33], a discrimination of the profile of temperatures obtained at the exit of the solar panels will be made dimensioning the area of collectors for maximum irradiation.

Starting from an average consumption of the desalination plant, $q_d = 2.9\ kWh/m^3$ [34] and taking the initial data for a MED flow plant, $q = 9000\ m^3/d$, the following values would be obtained:

$$\dot{Q}_d = q_d \times q = 2.9\ \ kWh/m^3 \times 9000\ \ m^3/d = 26100\ \ kWh/d \quad (1)$$

Being $\dot{Q}_d$: Daily energy required by the desalination plant (kWh/d)

$$\dot{Q}_a = \dot{Q}_d \times nd = 26100\ \ kWh/d \times 365\ \ d/y = 9526500\ \ kWh/y \quad (2)$$

(assuming it works 365 days per year).

Being $\dot{Q}_a$: Annual energy required by the desalination plant (kWh/y)

$$P = \dot{Q}_a \times nh = (9526500\ \ kWh/y)/(8760\ \ h/y) = 1087.5\ \ kW \quad (3)$$

(assuming it works 8760 h/y,without discounting the hours of stops or lost in lines or equipment)

Being P: Desalting power (kW)

2.2. Analytical thermodynamic modelling for the solar resource.

To determine the area of solar collectors required, which involves solar radiation and collector efficiency, equation (4) [20], will be used. Determining in consequence, the increase of temperature that is possible to reach.

$$\dot{Q}_c = \frac{A_c \cdot I}{\eta_c} = \dot{m}_t \cdot C_{p,c}(t_0 - t_i) \quad (4)$$

Sizing the collector area taking into account the time of maximum radiation (in summer) and taking the maximum daily irradiation of Almería: 5.8 $kWh/m^2.d$ [35], so that the area of collectors was minimal, following equation applies: (5) [20]

Table 1
Technical characteristics VICOT solar panels. Source: [36].

PTC specifications	
Description	Parameter
Collector length/unit	4.29 m
Parabolic opening width	2.5 m
Collector total height	2.445 m
Column height	1.45 m
Collector reflective area/unit	11.25 m^2
Transmission media	L-QC320 Transmission oil
Recommended speed of oil	1.3–3 m/s
Operation temperatures range	100 °C-280 °C
Weight/Collector aperture area	46.4 kg/m^2
Weight/Installation area	23.2 kg/m^2 Approximately
Focal length	850 mm
Ambient temperatures range	40 °C-60 °C
Max resistance wind speed	102 km/h
Max operational wind speed	50 km/h
Useful life expectancy	20 y
Collector solar thermal efficiency	75%
Receiver absorptivity	0.94
Mirror reflectivity	0.938

$$\dot{Q}_c = \frac{A_c \cdot I}{\eta_c} = \dot{Q}_d \quad (5)$$

With the data provided by the manufacturer of the panels VICOT in terms of performance, η_c [36] and known the daily consumption of the desalination, , the following result is obtained for the surface of collectors required:

$$A_c = \dot{Q}_d \times \eta_c / I = (26100\ \ kWh/d \times 0.75)/5.8\ \ kWh/m^2{\cdot}d = 3375\ \ m^2 \quad (6)$$

Once the required collector area is known, the mass flow circulating through the PTC will be calculated, once again making use of the technical characteristics of the VICOT panels on the one hand, Tables 1 and 2 [36] and on the density of the water on the other, Table 3 [37]. The circulating fluid will be water, since in some studies, [38] it is clear that despite the high pressures associated with the use of water directly in the PTC for high temperatures, the use of water for high temperatures/pressures is has always considered as an attractive option. It allows to increase the global efficiency of the solar system and to reduce

Table 2
VICOT vacuum receiver specifications. Adapted from [36].

Vacuum receiver specifications		
Model		VZK102-42/2860
Length	mm	2860
Glass tuve		
	Diameter (thickness) mm	Ø 102 (2,8) mm
	Transmittance	T ≥ 92%
Stainless steel tube	Diameter (thickness) mm	Ø 42 (2) mm
Weight	kg	12.3
Operating pressure	MPa	≤3
Selective coating	Absorptance	α ≥ 94%
	Emissivity	€ ≤ 10% (at aprox.200 °C)
Vacuum degree		Gas pressure ≤ (1 ~ 3) × 10^{-2} Pa
Max operation temperature	°C	280
Ambient temperature	°C	−40 ~ 60
Impact resistance		Solid steel ball of Ø 30 mm falls freely from a height of 0.5 m on it and there is no damage

Table 3
Density of water as a function of pressure and temperature. Adapted from [80].

Presion	Temperature	Specific volumen m^3/kg Saturated liquid
bar	°C	$(v_f \times 10^3)$
10	179.9	1.1273

the thermal losses in the field of collectors. This has motivated the development of several projects during the last decades to investigate this technology known as Direct Steam Generation (GDV).

To calculate the mass flow, the expression (7) will be used:

$$\dot{m}_w = \rho \cdot v \cdot s \tag{7}$$

Where

ρ = 1/1.1273 kg/m^3 (Table 3: At the pressure of 10 bares and 180 °C a density of 1/1.1273 kg/m^3 is obtained).
v = 2 m/s (see manufacturer data sheet [36]).
s = 1.38 × 10^{-3} m^3
And therefore, $\dot{m}_w$ = 2.44 kg/s (rounded to 2.5 kg/s)

With the following additional considerations extracted from the manufacturer's data sheet [36]:

- 180 m^2 of panels per column
- 18 columns (3240 m^2/180 m^2 per column) [36]

Total mass flow is calculated with (8):

$$\dot{m}_t = n \cdot \dot{m}_w \tag{8}$$

Given as a result, $\dot{m}_t$ = 18 columns × 2.5 kg/s = 45 kg/s

Taking the value of the specific heat of the water, $C_{p,c}$ = 4.184 kJ/(kg K) and with the rest of the values already calculated, it is re-introduced into (9) obtaining the output temperature profile (t_0), being the inlet temperaturet_i de 15.6 °C [39].

$$\dot{Q}_c = \frac{A_c \cdot I}{\eta_c} = \dot{m}_t \cdot C_{p,c}(t_0 - t_i) \tag{9}$$

Being:

$\dot{Q}_c$ = 26.100 kWh/d
η_c = 0.75
I = 5.8 kWh/m^2
A_c = 3240 m^2
$\dot{m}_t$ = 45 kg/s
$C_{p,c}$ = 4.184 kJ/(kg K)
t_0 = Exit temperature of the collectors.
t_i = 15.6 °C

For the calculation of the output temperature profile (t_0,), it is used the Solargis data base [33] with the average daily radiation from 1994 to 2016.With the introduction in equation (9) are as described above, it is obtained the historical profile of the PTC outlet temperatures that is

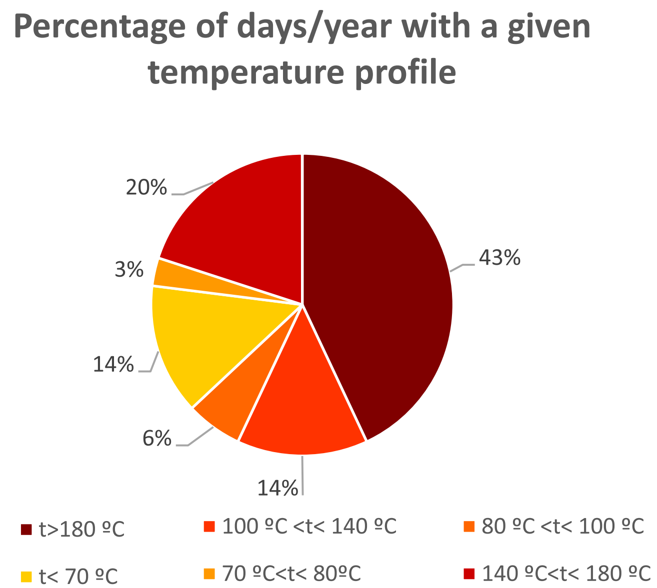

Fig. 1. Percentage of days/year with a given temperature profile in the history of the solar irradiation and temperature from 1994 to 2016 in Almería, Own source.

collected in a link in the Appendix B.

With this historical profile of outlet temperaturest_0 of the last 20 years a group will be made by temperature intervals that in turn will condition the use of the MED, the DEHP and the geothermal resource and will lead to a series of configurations in section 2 and a summary in Table 4. This table shows a discrimination by number of days, n_t, at a certain previously selected temperature interval and the average percentage (%) that is represented in Fig. 1.

In view of Table 4 and given that the MED works with temperatures of 70 °C, the solar resource will not be enough 365 days a year (interval 4, Table 4),-how we suspected-, despite being an area with high insolation from the southeast of Spain. Different situations will be analyzed for the use of the geothermal resource as a complement.

2.3. Experimental modeling of the geothermal resource.

It is noteworthy that in the vicinity of Níjar, a town belonging to the province of Almería, water has recently been found at 41.8 °C and at 490 m depth with a thermal gradient of 8.87 °C in increments per 100 m and a flow of 22.72 l/s [40]. So it would be to take advantage of this resource (see illustrations of Figs. 2 and 3) for the current study. Fig. 2 shows a geological map of the province of Almería and the location of the geothermal well and Fig. 3 shows a profile of the increase in temperature with the depth obtained from the geothermal borehole.

Putting in common the profile of the PTC outlet temperatures and the potentiality of the geothermal resource at the depth in the area under study, a series of possible configurations are obtained.

Table 4
Number of days in the history of the solar irradiation and temperature from 1994 to 2016 in Almería, n_t and average percentage (%) for six previously defined temperature ranges (from 1 to 6). Own source.

	Temperature ranges					
	1 t>180 °C	2 100 °C < t < 140 °C	3 80 °C < t < 100 °C	4 t < 70 °C	5 70 °C < t < 80 °C	6 140 °C < t < 180 °C
n_t	3581	1190	476	1212	227	1715
%	43%	14%	6%	14%	3%	20%

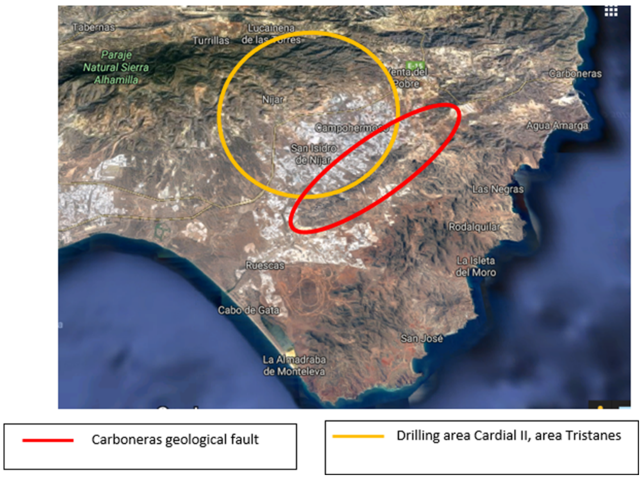

Fig. 2. Geological map of the province of Almería. Source: Adapted since [40].

2.4. Configurations of the solar and geothermal resource to feed the MED

A series of configurations (not being unique) have been chosen in this study according to the PTC output temperatures.

For each of these configurations, a maximum thermal jump of 5 °C is assumed as energy losses between the primary circulation through the panels (water and/or oil at a given pressure and temperature) and the secondary one, which is the fluid that would go to the DEHP, to the geothermal well, or storage tank prior to the MED.

For all the configurations, TK1 is defined as the water storage tank prior to the entrance to the MED and TK2 as the network water storage tank for the entrance to the PTC.

TK1 and TK2 are daily heat storage tanks (not stationary).

In the configurations shown, the diagrams have been simplified and, therefore, no auxiliary equipment or heat exchangers, pumps, expansion vessels or valves have been drawn.

2.4.1. Configuration 1

In this first case, the PTC outlet temperatures exceed 180 °C for 43% of the annual time (according to information extracted from Table 4). It would be injected into the Níjar geothermal well at depth = 490 m and t = 41.8 °C and there would be two situations that are configuration 2 (t range between 100 °C and 140 °C) with reinjection back to the Níjar well at depth = 490 m or, configuration 6 (t range between 140 °C and 180 °C). See Fig. 4.

2.4.2. Configuration 2

In this configuration, 14% of the days obtained temperatures between 100 °C and 140 °C, which would be injected into the Níjar geothermal well at a depth of 490 m with a t = 41.8 °C. In the most unfavorable case (PTC outlet temperature at 140 °C, when mixed with well water at 41.8 °C, then 90 °C would be obtained, which would be mixed again with feeding water at 15.6 °C [39] and the temperature required by the MED. See Fig. 5.

2.4.3. Configuration 3

In this case, where the working temperatures obtained are between 80 °C and 100 °C, it would be mixed with feeding water, obtaining the Fig. 6 or it would be taken to a timeless geothermal store (explained later by means of configuration 8).

2.4.4. Configuration 4

In this configuration 4, which it accounts for 14% of the days of the year, energy cannot be guaranteed to feed the MED as it does not reach the 70 °C required by the desalination plant through the PTC. Wherewith it is proposed to obtain the energy by means of the Níjar geothermal well previously mentioned [41] but at a greater depth (depth = 790 m). The thermal gradient is 8.87 °C per 100 m depth [42] and water would be obtained at 70 °C, which would be necessary to feed the MED at times that are not possible with the PTC. The simplified scheme is the one presented in Fig. 7.

Another possibility for this 14% of the annual time is to feed the MED with conventional energy.

2.4.5. Configuration 5

In this case, only 3% of the annual days would be working temperatures between 70 °C and 80 °C that will go direct to the MED (previous storage tank step TK1) The simplified scheme is the one presented in Fig. 8.

2.4.6. Configuration 6

In this range of temperatures (between 140 °C and 180 °C) is where DEHP works [43] and the situation would be as explained below (Fig. 9):

It is noteworthy that for the configurations 1 to 6 exposed and summarized in Table 5, the heat recovered from the MED and/or from the geothermal well that could feed the DEHP is not taken into account.

Another two configurations (7 and 8) are explained below but they are not included in Table 4.

2.4.7. Configuration 7

In this configuration, the use of the geothermal resource as residual energy complementary to that of the last stage of the MED to feed the DEHP is considered. The simplified scheme is the one presented in Fig. 10.

2.4.8. Configuration 8

In this approach, it is proposed that the ground serves as a timeless

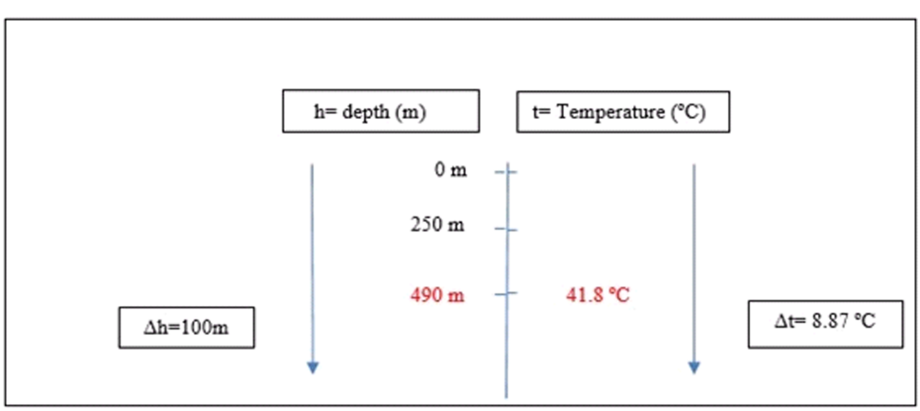

Fig. 3. Temperature profile obtained at the Níjar geothermal reservoir [60] according to depth.

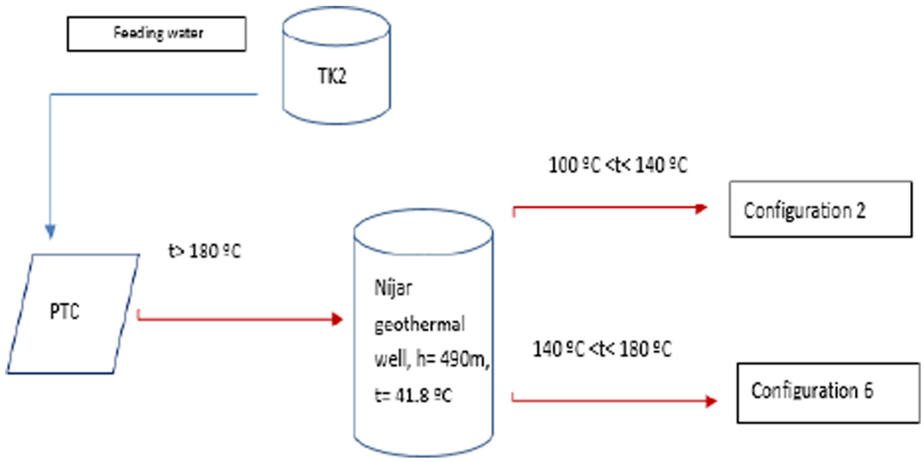

Fig. 4. Simplified diagram of feeding a MED with solar and geothermal energy if t > 180 °C at the output of the PTC and t = 41.8 °C at 490 m depth in the well Own resource.

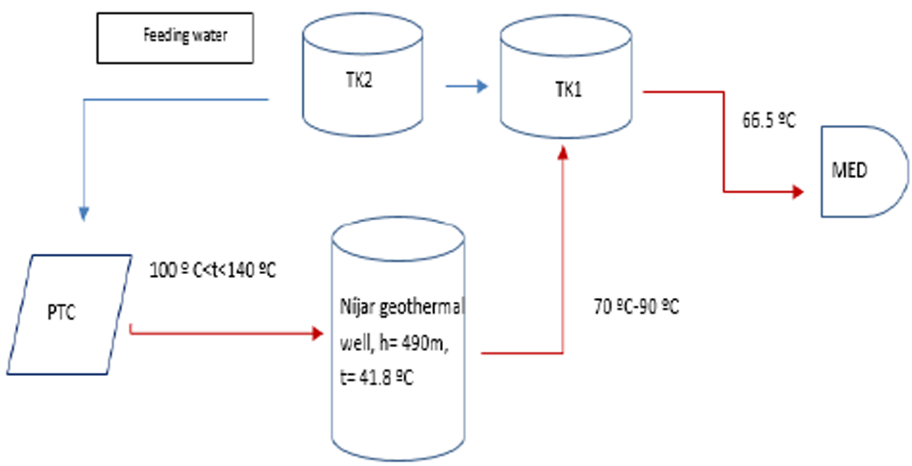

Fig. 5. Simplified diagram of feeding a MED with solar and geothermal energy if 100 °C < t < 140 °C at the output of the PTC and t = 41.8 °C at 490 m depth in the well Own source.

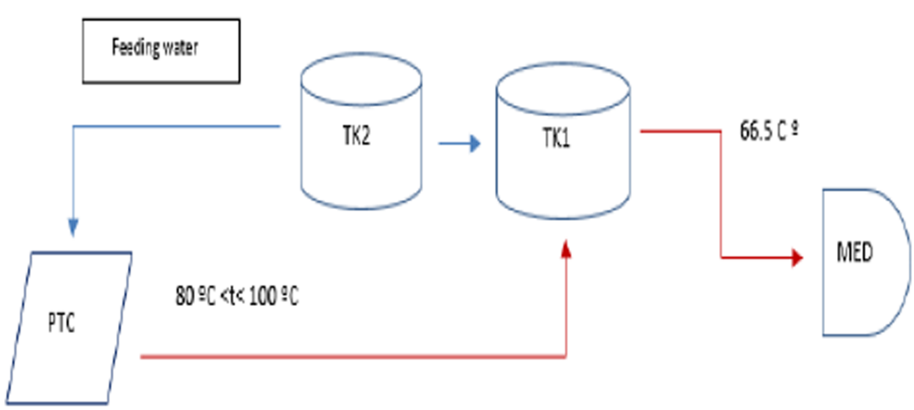

Fig. 6. Simplified diagram of feeding a MED with solar energy if 80 °C < t < 100 °C at the output of the PTC. Own source.

geothermal store for the supply of energy or water at a temperature of 70 °C to the MED at those times of the year when there is not enough solar radiation from the PTC. See Fig. 11.

3. Results and discussion

Once viewed separately each of the possible configurations proposed in this study, a summary of each of them and the actions to be implemented according to the PTC outlet temperature are represented in Fig. 12 and Table 5 (only configurations 1 to 6). On the other hand, Table 6 represents the degree of coverage with renewable energy of the MED according to the possible configurations proposed.

- From the analysis of configuration 1, when the temperature is higher than 180 °C at the output of the PTC and after reinjecting the energy in the well at depth = 490 m, two situations can be given, go to configuration 2 or go to configuration 6. In the event that the PTC outlet temperatures are above 240 °C, when mixed with the 41.8 °C

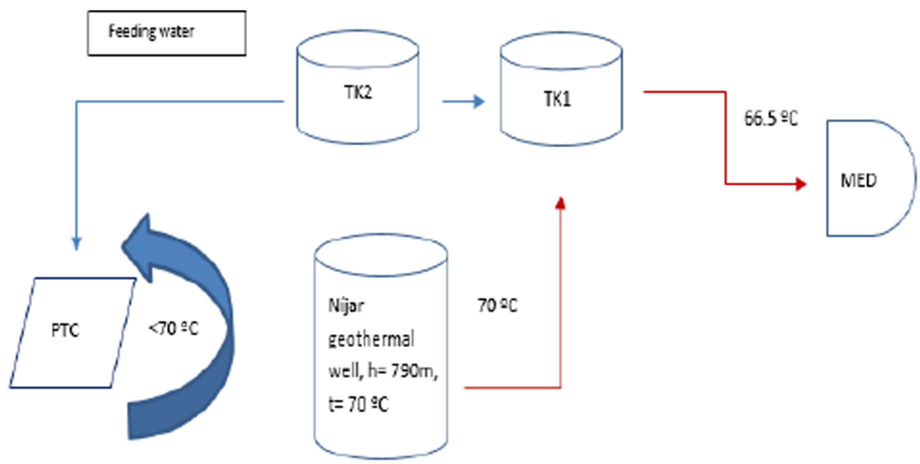

Fig. 7. Simplified diagram of feeding a MED with geothermal energy if t < 70 °C at the output of the PTC. In this case, the feeding heat comes of the well at 790 m. Own source.

of the well at depth = 490 m, temperatures above 140 °C would be obtained (simplifying equal volumes and considering the heat exchanger) and therefore go to the DEHP (or configuration 6). This only happens for 812 days (see *Appendix B*) in the range of the year 1994 to 2016 and therefore about 10% of the time. This 10% of the time linked to 20% of the configuration 6 yields a value of 30% of the annual time of use of the DEHP in this study, which contributes to making greater the use of the PTC due to the high temperatures obtained during a great part of the year.

- In line with what was suggested by Alarcón-Padilla DC [30], a better use of the DEHP would still be seen in configuration 7 where the geothermal resource in this case is used as residual energy complementary to that of the last stage of the MED to feed the DEHP.
- On the other hand, respect to the configuration 3 with 6% of days of PTC outlet temperatures between 80 °C and 100 °C (configuration 3) the more logical thing is mix with feeding water and go to the MED.
- In this case, it would not be justified to create a timeless geothermal store as the scheme represented in the configuration 8 that will store this energy and will be used later in the MED in days with low or no solar radiation. The situation in other climatic zones may be different and justify the mentioned storage if that temperature range occurs. For example, in a study with flat plate solar collectors, results from a theoretical study confirm that thermal energy storage is a useful component of the system for conserving thermal energy to meet the energy demand when direct solar energy resource is not available. A solar collector area of 18 m^2 with a thermal energy storage volume of 3 m^3 is adequate to produce 100 l/d of freshwater round the clock considering fluctuations in the weather conditions [32]. In another investigation, it is provides a critical review on current energy storage options for different desalination processes powered by various renewable energy and waste heat sources with focus on thermal energy storage and battery energy storage systems. While the benefits of energy storage systems can be realized from energy, environmental and economic perspectives, the energy storage option may not be ideal or economical in all cases since its feasibility depends on the location, type and size of the desalination application and the available renewable energy sources. Whether an energy storage option is feasible for a given application has to be determined by careful evaluation of the aforementioned factors [41].
- Only 14% of the time when it does not reach 70 °C as we can see in configuration 4, it would be necessary to think about the use of a conventional energy. But,
- if a drilling at 790 m is feasible as can be deduced from the geothermal surveys carried out [40], the use of the MED is guaranteed 100% of the time
- The ideal temperature range for the MED is only reached in configuration 5 and occurs during 3% of the annual days
- The only solar contribution for the MED (without geothermal energy) guarantees the use of the same for 29% of the annual time resulting from the sum of the configurations 3, 5 and 6 (case 2, Table 6). That is to say, only with this renewable source is it being wasted for the area studied the range of higher temperatures (more than 100 °C, configurations 1 and 2). An additional problem of using only solar resource is the overheating due to high temperatures and the use of dissipation equipment.
- The situation worsens with the use of solar energy (PTC) but without DEHP because only the range of temperatures given by configurations 3 and 5 would be used, which gives a result of only 9% of annual time of use of the MED (case 1, Table 6). At this point is

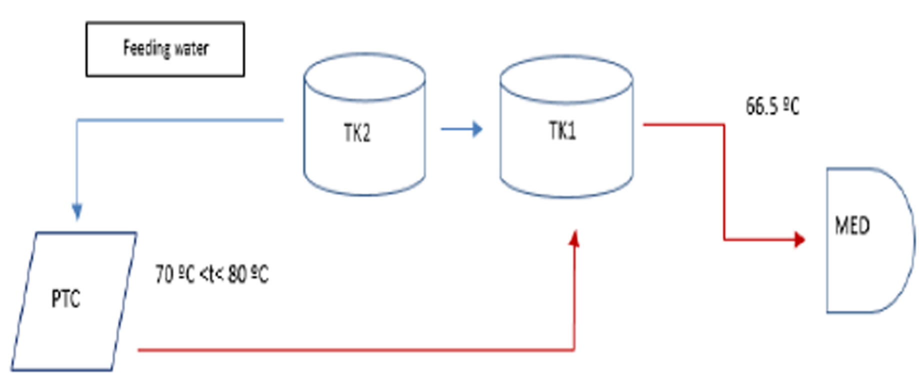

Fig. 8. Simplified diagram of feeding a MED with solar energy if 70 °C < t < 80 °C at the output of the PTC. Own source.

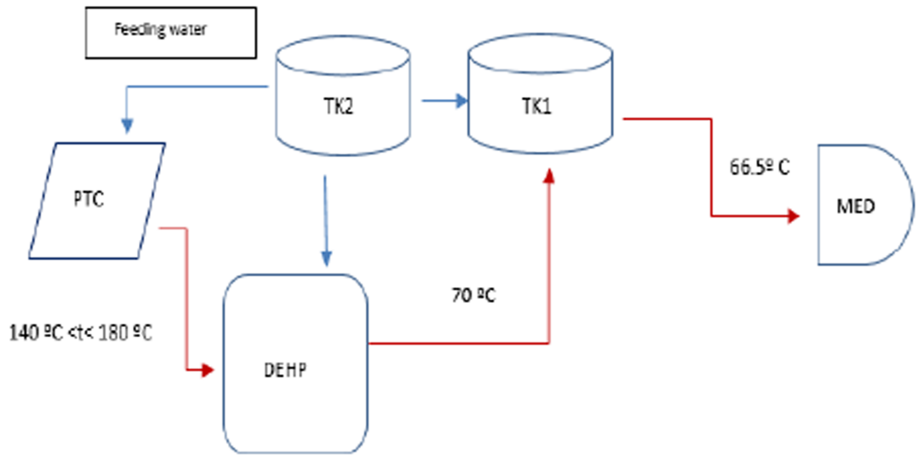

Fig. 9. Simplified diagram for feeding a MED with solar energy if 140 °C < t < 180 °C at the output of the PTC. A DEHP works reduce the temperature until 70 °C. Own source.

precisely the importance of the use of DEHP on the one hand to lower the temperature of the PTC and the hybridization with the geothermal well on the other hand to raise that 9% of energy use up to 76% with the well at depth = 490 m.

- The situation improves in the event that solar energy is combined with the geothermal well at depth = 490 m, the use of the MED is guaranteed for 76% of the time (case 3, Table 6).
- As can be seen in Table 6, case 4 with only geothermal energy at 790 m depth MED coverage is total.

It must be borne in mind that the study carried out here makes an approach to a theoretical MED type desalination. On one hand it is estimated the PTC outlet temperatures and on the other hand takes advantage of the experimental values obtained from the geothermal surveys carried out in the Cardial area. These values obtained from the surveys are adequate both for the hybridization with solar (well at 490 m) and for the use of only geothermal energy (well at 790 m) to feed a MED.

3.1. An approach to the mix solar-geothermal desalination potential of the A.G.U.A project

On the occasion of the A.G.U.A project [27] that there has been explained in chapter 1, 16 plants were built in Spain (Figs. 13 and 14) that currently desalinate q = 344.68 hm^3/y and assumed a total expense of € 313.8 million.

In view of the results of this article about a theoretical desalination plant feed with solar-geothermal energy, we will make an approximate calculation regarding the investment amortization and savings in CO_2 emissions for those existing plants of the A.G.U.A project. It would be desirable for these plants to adapt renewable energy solar-geothermal mix in the line of the study carried out in this article in question and given that the geographical location is close to the area of influence of the study.

In 2006 relative to 16 plants, 215.67 M € were for maintenance and conservation and 50% in turn represented energy costs (approximately 108 M €). This figure amounted to € 186 million in 2012 [27].

On the other hand, with data for 2012, the total energy consumption of the 16 plants was C_e=1 302,010,000 kWh.

Regarding the total investment, I_0,what would have to be done in these desalination plants to adapt them to operation with renewable energy (solar-geothermal mix) would be according to (10).

$$I_0 = I_{Cs} + I_{HP} + I_{AE} + I_G \tag{10}$$

where

I_0 = *Total investment.*
I_{Cs} = *Solar field investment.*
I_{HP} = *Heat pump investment.*
I_{AE} = *Auxiliary equipment investment.*
I_G = *Geothermal investment*

It is known from previous studies that:

- $I_{Cs} + I_{HP} + I_{AE} \sim$ 1800–2000 €/kW [44]
- I_G = 1375$-3500 $/kW [45,46]
(considering 1 $~0,88 € [47])
Resulting, $I_0 \sim$ 4045 €/kW

Table 5
Percentage of days/year with a given output PTC temperature profile and actions to be implemented according to the 6 configurations. Own source.

	Configurations					
	1 t>180 °C	2 100 °C < t < 140 °C	3 80 °C < t < 100 °C	4 t < 70 °C	5 70 °C < t < 80 °C	6 140 °C < t < 180 °C
n_t	3581	1190	476	1212	227	1715
%	43%	14%	6%	14%	3%	20%
Action	Reinject to Níjar geothermal well at depth 490 m(t = 41.8 °C) and then go to the configuration 2 or 6	Reinject to Níjar geothermal well at depth 490 m(t = 41.8 °C) and mix with feeding water and then go to the MED (*)	Mix with feeding water previous to the MED (*)	Without radiation, use alternative energy or geothermal energy well at depth 790 m and t = 70 °C and then go to the MED (*)	Go straight to the MED (*)	Go to the DEHP and then to the MED

* Previously go to TK1 (t max 90 °C).

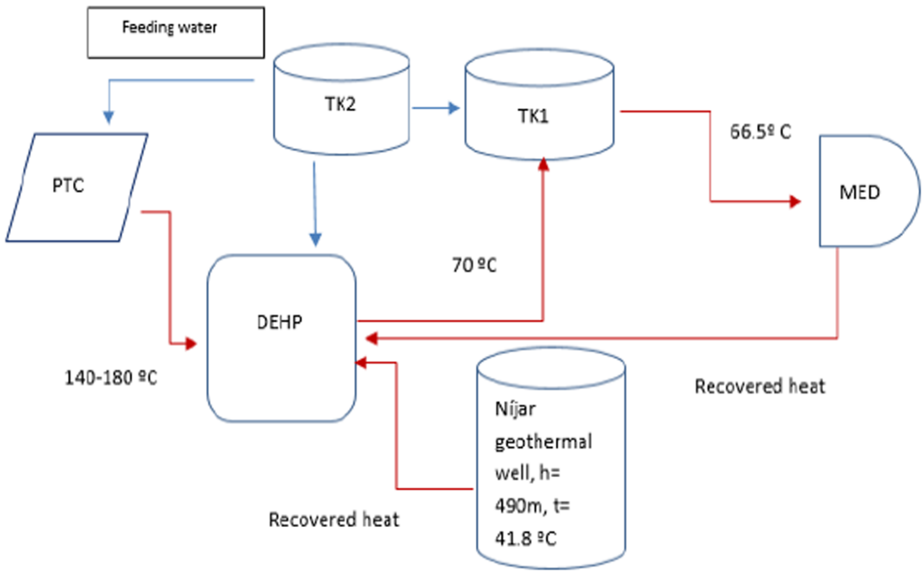

Fig. 10. Simplification of a hybrid solar-geothermal model to feed a MED using as supplementary energy the heat recovered from the MED [75] and the heat from a geothermal well at 490 m depth [33]. Own source.

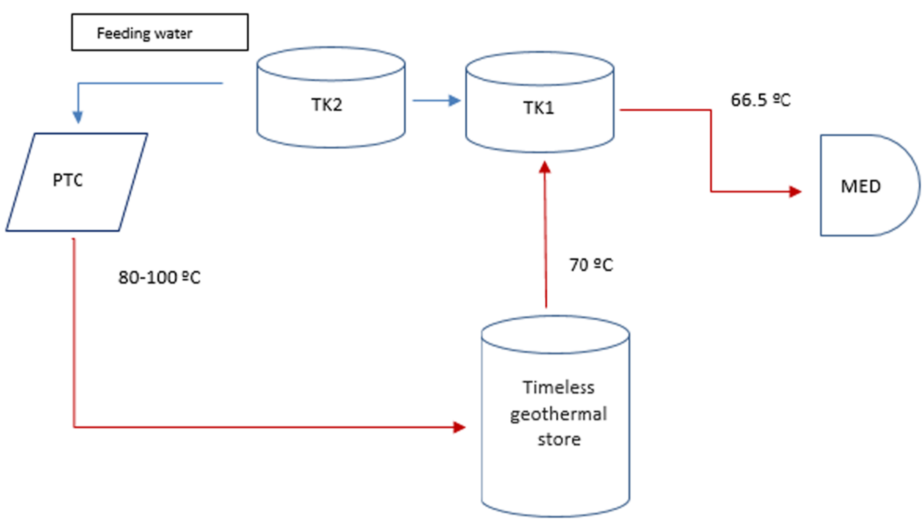

Fig. 11. Simplification of a hybrid solar-geothermal model to feed a MED through a timeless geothermal store. Own source.

Assuming that the operation of the 16 desalination plants in the A.G.U.A project was only partial (50%), as is the case in the Dalías field whose operating hours are 4560 h, resulting from dividing 114,000,000 kWh between 25 MW [42], a power would be obtained. according to the equation (11):

$$P = C_e/n \quad (11)$$

$P = 285{,}528.50$ kW
Being
C_e=1,302,010,000 kWh
$n = 4560$ h

And therefore a total investment, I_t=1,154,962,782, 5€ according to the equation (12):

$$I_t = P \times I_0 \quad (12)$$

With an energy cost of $c_{2012} = 186$ M€, figure as we saw in 2012 and without taking into account the increased effect of the electricity price in the following years, it would be amortized in 6,2 years according to the equation (13).

$$n = I_t/c_{2012} \quad (13)$$

n=6.2 years.

This duration is the concession of the above-mentioned plant [42] although the useful life is estimated at 30 years for civil works and 10 years for machinery and installations [27].

Beyond the amortization, in terms of CO_2 emissions, knowing that the mix of the peninsular electricity grid of 2017 is estimated at m_e= 392 g CO_2/kWh [48], it would be obtained according to the equation (14) [49–53]:

$$m_t = m_e \times C_e \quad (14)$$

m_t= 510,387,920 kg/CO_2 annual avoided to the atmosphere.

4. Conclusions

The potential for improvement of the desalination industry from the point of view of energy sustainability is enormous due to the large amount of energy required for its operation. The search for local optimal renewable energy sources is a necessity to reduce such consumption to the maximum and therefore is the objective of this paper.

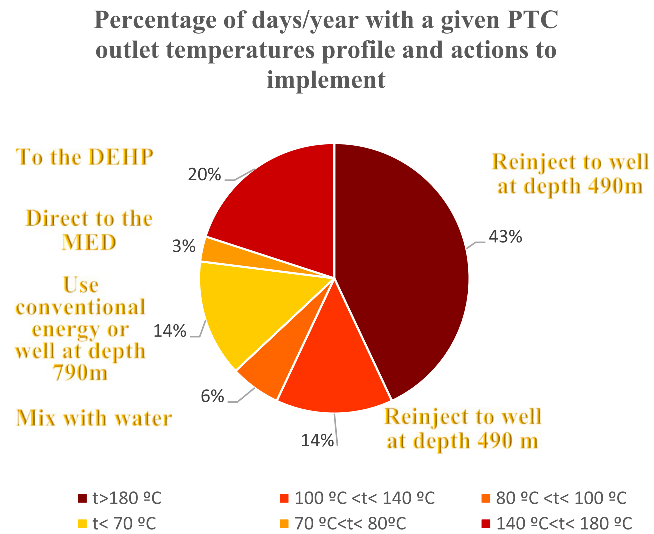

Fig. 12. Percentage of days/year with a given PTC output temperature profile according to the 6 configurations. Own source.

Fig. 13. Desalination plants of the Mediterranean coast in Spain. Source: ACUAMED [76]

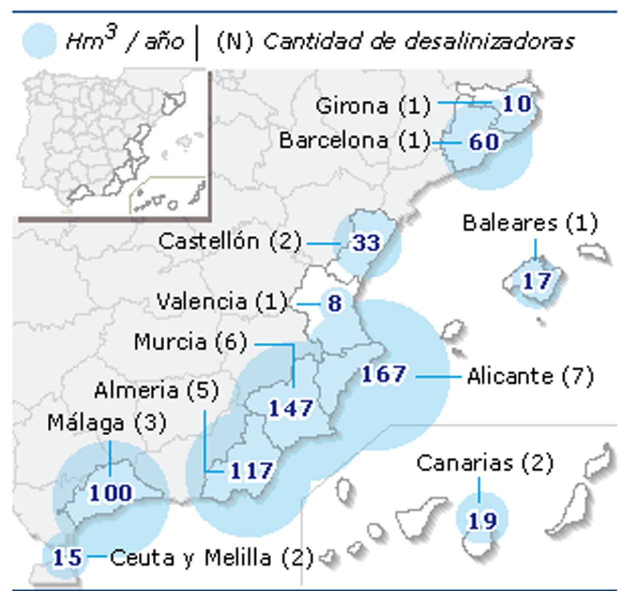

Fig. 14. Desalination plants of the A.G.U.A. project. Source: Ministry of Agriculture, Fisheries and Food of Spain [77].

The novel results of this study indicate that:

- Feeding a 9000 m^3/d type Multi-effect distillation plant that operates at 70 °C from only the solar energy proceed of the Parabolic trough collectors in the studied region is a waste by only taking advantage of 9% of the days of the year.
- The situation improves if a Double-effect absorption heat pump is added that manages to lower the outlet temperature to feed the Multi-effect distillation plant giving an advantage of 29% of the annual time.
- The situation is even better when we add a geothermal well where the remaining energy of the Parabolic trough collectors can go because in that case the desalination plant could work for 76% per year in the geological conditions of the land in the location of the Nijar fields, that is, t = 41.8 °C at 490 m deep.
- As seen too, the fact of having a temperature of 70 °C at 790 m in these Níjar fields, it opens the possibility of feeding the Multi-effect distillation plant only with geothermal energy in a continuous way that is desirable and one of the more critical things for renewable energies in general in the sense of ensuring its non-intermittency.
- As an extension of the theoretical study that becomes us, it has also been proposed an extrapolation of the results to be applied in the existing non-renewable desalination plants of the A.G.U.A project located in the southeast of Spain. The purpose is to evaluate the economic and ecological impact of them by the use of renewable energies and in particular of the geothermal-solar mix. The theoretical results, approximately 6 years amortization and 510,387,920 kg/CO_2 annual avoided to the atmosphere for the all plants deserve attention.

It must be taken into account that a good part of the Spanish territory (not only the Southeast or the South) is affected by a large number of hours of sunshine but a low temperature geothermal resources (30–100 °C) [54]. This is not an inconvenience for desalination, especially for thermal desalination, as we are seeing. In fact, we will highlight two factors. On one hand, it is possible to reduce the Parabolic trough collectors temperature excess by a Double-effect absorption heat pump and geothermal energy, and on the other hand this kind of low geothermal resources are appropriate for desalination plants type Multi-effect distillation plant. As a comment, the area of the Níjar fields is one of the 22 in Andalusia region and only represents 2.5% of the available geothermal potential in this zone [54].

As it is logical, the location of the desalination plant next to the coast, the location of the solar collector field and the realization of the prospections for the geothermal wells are factors to be taken into account for the greater proximity to the point of energy consumption and

Table 6
Energy coverage rate of the MED with each proposed technology (alone or mix). Own source.

Cases	Technology	Coverage of the MED	Sum of configurations
1	Solar (PTC)	9%	3 + 5
2	Solar (PTC) + DEHP	29%	3 + 5 + 6
3	Solar (PTC) + DEHP + Geothermal energy (well at 490 m)	76%	1 + 2 + 3 + 5 + 6
4	Geothermal energy (well at 790 m)	100%	4

the possible evaluation of transport losses if the creation of a district network is necessary.

There are no known studies that combine solar energy by means of PTC with geothermal energy for desalination plants or studies that suggest reconverting the non-renewable desalination plants existing in Spain in the way presented in this paper. Therefore, we wish this study could serve as a reference in other areas with similar climatic and geothermal conditions.

Future studies in different coastal geographical areas (insular or peninsular) where it is necessary to desalinate due to the shortage of drinking water and/or irrigation and with other profiles of solar radiation and geothermal resources could be proposed. From other types of solar collectors as the compound parabolic collectors or flat solar collectors as well as other types of desalination plants with other possible configurations different from these exposed here according to site requirements.

In any case it has been demonstrated through this paper that the potential is enormous in this field.

CRediT authorship contribution statement

Antonio Colmenar-Santos: Conceptualization, Methodology. **Elisabet Palomo-Torrejón:** Data curation, Writing - original draft. **Francisco Mur-Pérez:** Supervision. **Enrique Rosales-Asensio:** Conceptualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

In this section, the choice of one or another desalination technology and its feeding by solar thermal energy with or without an absorption heat pump and with or without a geothermal resource will be explained and justified since they are all “actors” involved in this article.

1. Desalination techniques:

Historically there are different ways to classify desalination techniques: According to the principle and according to the energy.

According to the principle in three large groups namely: Phase change, selective membranes and chemical bonding. Within the phase change in turn in evaporation and freezing. As for the selective membranes, we find the reverse osmosis (RO) and electrodialysis (ED). In terms of chemical bond ion exchange (CI) and solvent extraction.

On the other hand, depending on the energy used, the desalination techniques can be thermal (to this group also belongs MED), electrical, mechanical and chemical, the first being the most economical.

Below is a table with the desalination processes according to the energy used [31].

MED, MFS and RO plants continue to be the main actors in the large-scale desalination and the choice between one technology or another depends on many factors. Location of desalination plants, type, source and amount of energy used, production scale, water characteristics, desired quality of drinking water, chemical materials, spare quantity, type of exploitation contract, subsidies, life of facilities or indirect costs [55]. In recent articles, desalination technologies are compared on the basis of primary energy consumption [56] too.

Approximately, half of all pure water obtained by desalination is produced by thermal processes through the distillation of seawater. To reduce costs, this process is carried out in a distillation plant controlling the boiling point, reducing the water pressure, since the temperature necessary to reach the boiling point decreases as the pressure is reduced. The reduction of the boiling point is fundamental in the processes of desalination to achieve a multiple boiling and to control the incrustations [30].

Multi-effect distillation consists of a series of containers whose temperature drops in the direction of water flow, which allows the boiling point of seawater to be reduced without the need to heat it after the first effect.

In general, an effect consists of a container, a heat exchanger and devices to transport the fluids between these containers. In the process there are a series of effects of condensation and evaporation, with the lowest pressure in each successive effect. Fig. 8 shows what was explained previously

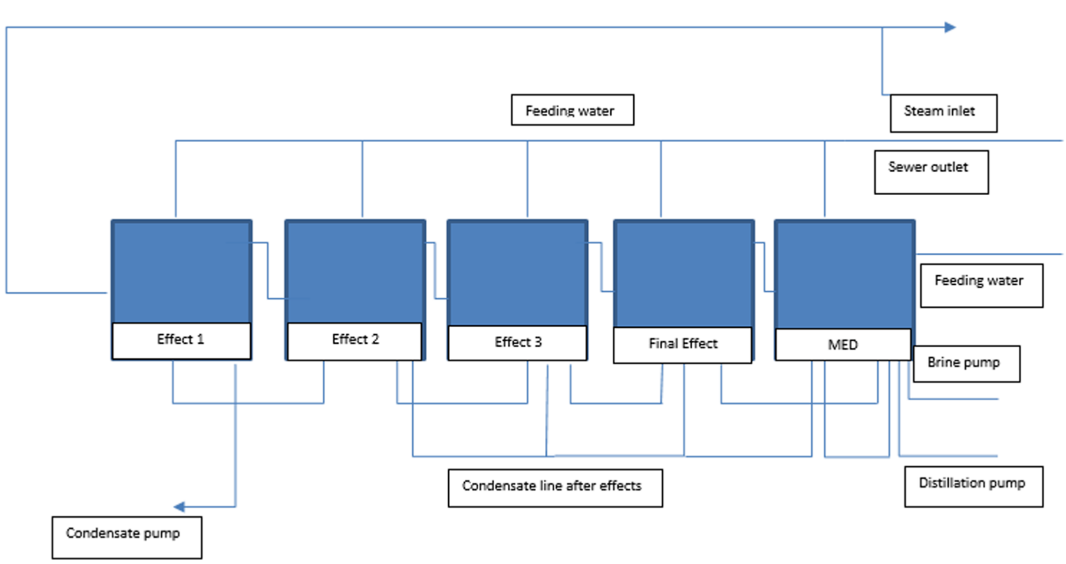

Fig. A1. Multi-effect distillation scheme. Own source.

(see Fig. A1 and Tables A1 and A2).

Among the various types of evaporators used in MED, the "multiple effect stack" (MES) Fig. A2, is the most appropriate for solar energy applications because in the case of sudden changes, it is stable between 0% and 100% and is able to track variations in undisturbed steam supply [57].It is a one-step system that minimizes the risk of scale formation and, therefore, has low costs in chemical pretreatment (the product obtained is of high quality with a Dissolved Salts Content, hereafter, TDS of less than 5 ppm)

Among the different techniques of the market, in this article we will focus on the MED for its medium-high production capacity, lower energy consumption than the MSF [58], smaller area of land next to the high quality of the water produced (see Table A.2) and lower operating temperature [55]. Having overcome the corrosion problems of the first MED [30], the reduction of energy consumption will come partly due to the recovery systems [59] as the latent heat lost is lower and therefore the specific energy consumed will be lower. The use of renewable energies that operate operationally 100% of the time will be a requirement.

2. PTC

Among the different ways of contributing energy to a desalination plant, solar thermal may seem to be the most appropriate due to the fact that many areas with water shortages such as coastal and arid areas have a high solar radiation. In fact, there are several studies that suggest that the most suitable renewable energy for MED and MSF plants is solar thermal energy [60] and that MED plants are suitable in places with high solar radiation [61]. Not surprisingly, MED is a mature technology that can be coupled with solar thermal systems for large scale production since its temperature and operating pressure are less critical than for example an MSF as already mentioned above.

Other clean energies to consider are the wind, the tidal and of course, the geothermal energy that will be considered in this study.

Apart from the environmental factors, there are other factors such as the demand for drinking water and the availability of these energies increase considerably at the same time. For example, in many coastal towns when in summer the demand for drinking water increases due to the tourism that the area experiences, it is precisely when you have more hours of sunshine [31].

In the case of agriculture, the potential is also very high because of its location in temperate climates (for example, in Mediterranean areas) where rainfall is scarce but the need for irrigation water is very high.

Some studies raise the possibility of using a thermosolar plant to produce electrical energy, and to produce the necessary heat that is needed to carry out the desalination [31].

One of the systems of capture of solar energy is the linear concentration that consists in concentrating all the solar radiation in a linear receiver that is located above the mirror, this system reaches lower temperatures by having a lower degree of freedom of solar tracking. An example of linear concentration, is the system by concentration parabolic-cylinder mirrors, above them is placed the pipe with the carrier heat fluid. The function of these mirrors is to concentrate the maximum possible energy in the tubes as far as the fluid passes. Fig. A3 shows the main components of the parabolic trough collectors, and a diagram of how the sun reflects on the tube.

This system will be the one used in the article in question for the high solar radiation in the studied area and the possibility of obtaining higher temperatures than with a flat solar collector which can be used for various uses.

Taking into account the state of the art of large scale desalination and renewable energies, the MED and solar energy are processes that present one of the best perspectives for the future to be simple processes that can be combined with solar collectors in a way viable. Among the different possible configurations, MED-FFH: Distillation multi-effect advance with heater and MED-PF: Multi-effect distillation-feeding in parallel proved to be the most efficient for solar energy applications [62].

The coupling between desalination plants and renewable energy technologies is a current challenge.

3. Double Effect Absorption Heat Pump

A double effect absorption machine arises from the addition of equipment to the single effect cycle. In order to improve its performance, it consists of two steam generators (the high and the low temperature), two heat recovery units from the solution, two condensers, two expansion valves, the evaporator and the absorber. This is possible in machines with the BrLi-H_2O pair since they work with very low pressure levels, while it is not possible in the case of working with the NH_3-H_2O mixture. Since introducing a new stage would increase the temperature of work and the increase in pressure that this would originate a very robust structure which would make it unviable [31].

In the double effect absorption units, the latent heat of condensation of the refrigerant obtained in the single effect generator, is used in a second generator, double stage, to improve the efficiency of the cycle [63].

Fig. A4 shows a schematic of a double-effect machine with all the components of the system. In the high temperature generator (Generator I), the

Table A1
Classification of desalination processes by the different forms of energy.
Source [20]

Energy	Process	Method	Simbology
Thermal	Evaporation	Sudden Distillation (Flash)	MSF
		Multi-effect Distillation	MED
		Steam thermal compression	TVC
		Solar Distillation	DS
	Crystallization	Freezing	CO
		Hydrate formation	FH
	Filtration and evaporation	Distillation with membranes	DC
Mechanics	Evaporation	Mechanical vapor compression	CV
	Filtration and evaporation	Inverse osmosis	RO

Table A2
Comparison of the different desalination technologies.
Source: [20]

Characteristics	MSF	MED	CV	OI
Type of energy	Thermal	Thermal	Electric	Electric
Cost of facilities	High	High/Medium	High	Medium
Production capacity (m^3/d)	High (> 50 000)	Medium (< 25 000)	Low (< 5000)	High (greater than50 000)
Posibility of expansion	Difficult	Difficult	Difficult	Easy
Operational reability	High	Medium	Low	High
Desalinated water quality (ppm)	High (< 50)	High (< 50)	High (< 50)	Medium (300–500)
Land area required for installation	A lot	Medium	Small	Small

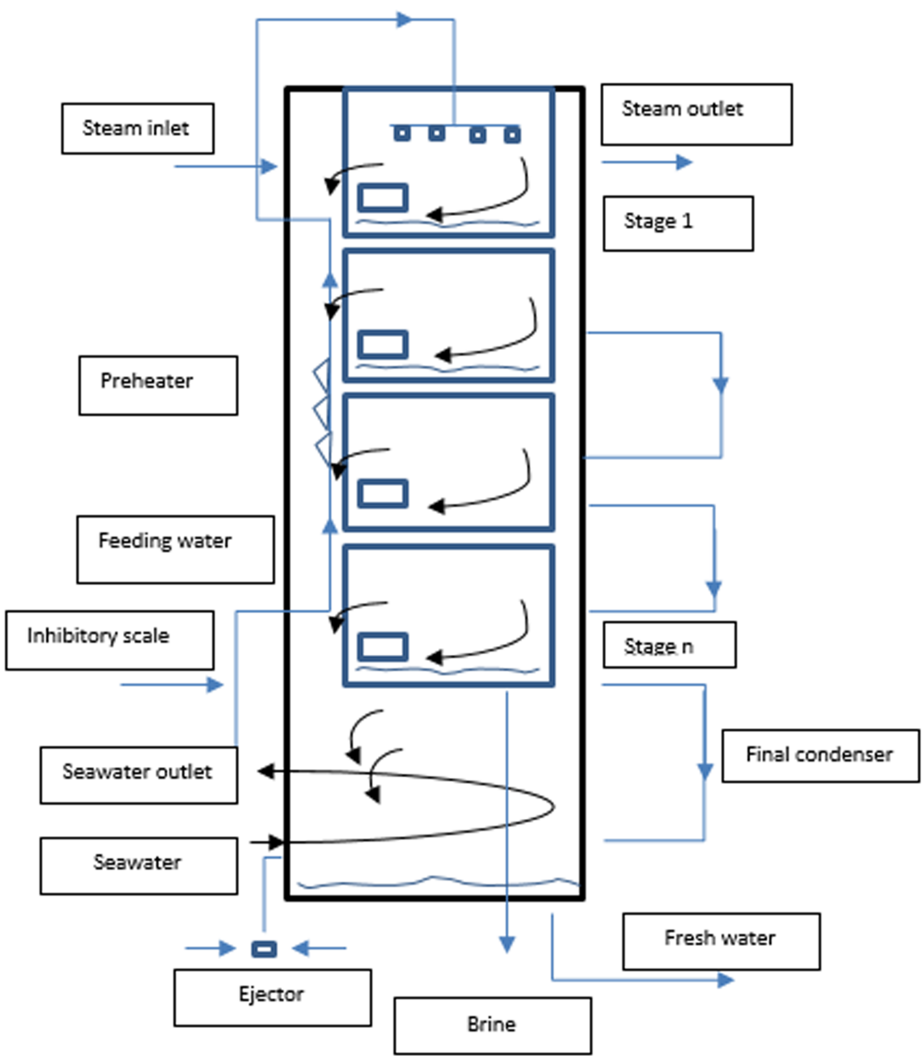

Fig. A2. "Multiple Effect Stack" (MES). Own source.

aqueous solution will be heated by the thermal energy source. In the case of solar cooling will come from the collector field, QH in which part of the solution water evaporates from the rest obtaining an intermediate solution to which we will call a semi-concentrated solution, the water vapor goes directly to the low generator (Generator II). HX I and HX II represent heat recovery units.

To achieve greater efficiencies, a cycle that takes advantage of the availability (energy) associated with a higher temperature of a thermal source is necessary. The technology of refrigeration systems by absorption of lithium bromide-water double effect is a technology that produces higher efficiencies and allows to compete with conventional systems of vapor compression by producing coefficients of COP yields in the range of 1.1–1.33.

Fig. A5 shows the relationship between the COP and the working temperature of the generator of several multi-effect chillers with the same size and under identical operating conditions (cooling water temperature at 30 °C and set temperature of the water to be cooled at 7 °C).

Fig. A3. Concentration scheme through a parabolic cylinder mirror. Source: [78].

It should be noted that, for each absorption cycle, there is a minimum value of the temperature to be supplied to the generator, below which it does not work. Therefore, adequate control systems must be implemented where the condition to start up the absorption machine and its respective pumps is that the temperature available in the upper part of the heat accumulation tank is 85 °C (single effect) or 180 °C (double effect). To stop the equipment, be 75 °C (single effect) or 170 °C (double effect); for the case of obtaining thermal energy by a solar capture system [31].

The main advantage of a double effect cycle compared to a simple effect cycle is that the cooling effect per unit of heat can double. As shown in Fig. A5, these systems require temperatures above 140 °C, but their COP reaches values of 1.0–1.33. Although these systems are not the most suitable for use with common solar collectors, it can be an interesting option by combining them with parabolic trough collectors, evacuated tube type, solar concentrators of the parabolic composite type, hereinafter CPC.

Although a double-effect system is more expensive than a system with an effect of the same capacity, however, having an efficiency of the order of 1.3 instead of 0.7, requires a smaller amount of energy (although more quality), that a system of an effect.

Their joint application offers an opportunity to overcome the barrier of efficiency of existing refrigeration systems, based on single-effect machines with flat or vacuum collectors. However, it is necessary to emphasize the need to keep the working temperature high, in order to avoid a sudden decrease of the COP. This consideration will influence the design of the solar system in relation to work pressures, expansion vessel, etc. This application is especially suitable for climates with high direct radiation [33].

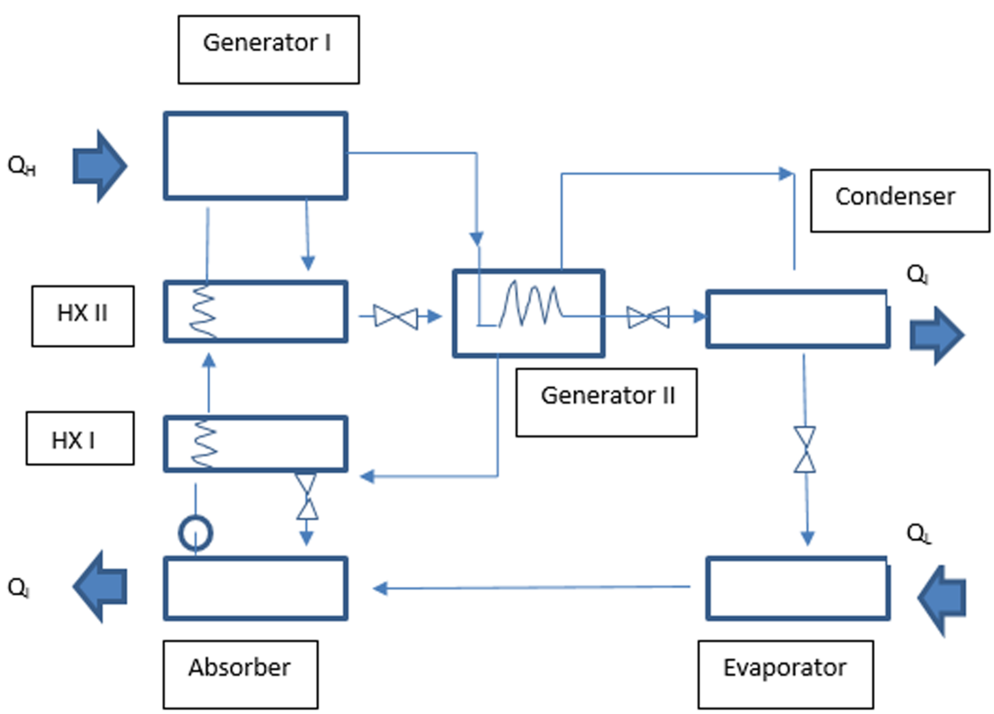

Fig. A4. Description of a double-effect absorption machine. Own source.

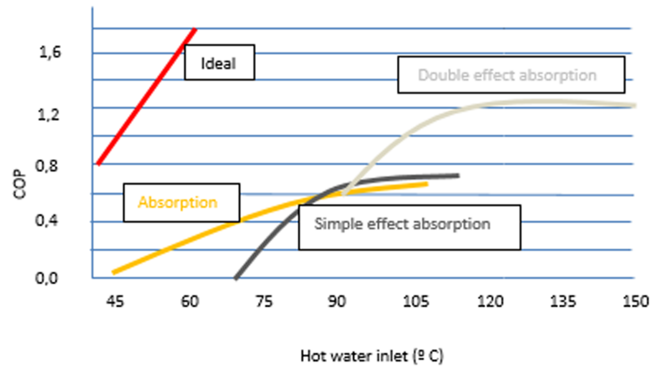

Fig. A5. Comparison of the absorption machines according to their COP and their activation temperature. Own source.

Another advantage in absorption heat pumps is that they can operate at partial load, an important aspect due to the variability of renewable energies.

The coupling of a MED and a heat pump has been proposed as one of the best systems for desalination, being the same competitive in comparison with RO (as an energy recovery, the absorption heat pump allows to yield much more than those with the plant alone) [30].

The operation of the DEHP with a gas boiler together with the MED plant and the compound parabolic collector, CPC in the Plataforma Solar de Almería, hereinafter PSA (which constitutes the SOL-14 plant) demonstrated its viability and the highest performance has reached [64]. The consumption of solar thermal energy and the requirement of the solar field was about 50% less than that required for the conventional operation of the MED [64]. The system together with the DEHP of LiBr-H2O, consumed 108 kJ of thermal energy at 180 °C and 10 bar per kg of distilled water, which represents 32 kJ/kg of exergy consumption. This is less than half the thermal energy required at 70 °C [64]. In addition, the DEHP reduces the flow of water to cool the distillate, which reduces the investment required in water and pumps, both in size and in energy consumption. With the distillation system without the heat pump, the performance ratio, hereinafter, PF, was 10, while with the absorption heat pump it was 21.3, recovering the distilled water at a temperature of 35 °C, a power of around 100 kW [64].

In some articles [65], the use of absorption and PTC heat pumps is shown, taking into account that the current absorber tubes withstand pressures of around 100 bar and on the other hand it is proposed to work directly with water instead of oil (in this way, the solar thermal system could be thermally and economically improved). In [65], it is pointed out that the competitiveness of steam generation in MED plants located in the south of Spain depends mainly on the cost of both fossil fuels and of solar collectors.

In [66], it is shown that it is not advantageous to use desalination plants connected only to a renewable energy system based exclusively on solar energy due to the high percentage of time that would be inactive.

Water storage is the most economical of all energy storage systems and is suitable for temperatures in the range of 50 °C to 95 °C [67]. In addition, according to [68] the water production of an MSF plant can be increased by using hot water as a transfer fluid in solar collectors and by increasing the number of storage tanks together with their volume.

According to the previously exposed, the state of the art of the MED plants driven by renewable energy goes through an installation of parabolic cylindrical collectors with absorption heat pump and also in this article goes through geothermal energy as a complement to the variability of the rest of renewable energies.

4. Geothermal energy

Geothermal energy is the heat that is extracted from the surface of the earth. Water and/or steam are responsible for bringing this energy to the surface. Depending on its characteristics, geothermal energy can be used for heating and cooling purposes or it can be used to generate clean electricity. However, for electricity, high or medium temperature generation resources are needed, which are generally located near tectonically active regions.

The main advantages of geothermal energy are that it does not depend on external climatic conditions and has very high capacity factors. For these reasons, geothermal power plants are capable of supplying basic load electricity, as well as providing ancillary services for short and long term flexibility in some cases.

There are different geothermal technologies with different levels of maturity. Technologies for direct uses such as district heating, geothermal heat pumps, greenhouses and for other applications are widely used and can be considered mature. The technology for the generation of electricity from hydrothermal reserves with a naturally high permeability is also mature and reliable, and has been operating since 1913.

Many of the power plants in operation today are either dry steam or flash plants (individual, double and triple) that use temperatures of more than 180 °C. However, medium temperature fields are increasingly used to generate electricity or to combine heat and electricity thanks to the development of binary cycle technology, in which the geothermal fluid is used through heat exchangers to heat a process fluid in a closed circuit. In addition, new technologies are being developed such as Geothermal Enhanced Systems (EGS), which are in the demonstration stage [69].It is worth highlighting the study of Ahinoam Pollack and Tapan Mukerji that compares two methods for optimizing eight common EGS engineering decisions, including well configuration and fracture spacing. The decisions were optimized to maximize the Net Present Value (NPV) of an EGS [70].

Other papers present methods of harnessing energy through various geothermal technologies, as well as their potential integration with other technologies. Current advancement in technology, as well as an economic analysis, environmental impact, and summary of benefits and drawbacks

[71].

There are already studies that exhaustively analyze the barriers to the implementation of geothermal energy in Spain and in the European Union, discriminating according to whether it is geothermal energy for thermal, electrical or renewable uses [72].

The potential of geothermal generation in Spain amounts to 610 GWt, thus being an interesting country for the use of this technology directly and in the same way in binary production plants [73].

On the other hand, there are also studies that link desalination processes with this technology, some such as the use of gas and oil wells to inject water and obtain energy from them to desalinate in areas of frequent periods of drought such as Texas [29] as we explain in chapter 1.

Other studies provide a solid scientific basis for the efficient and sustainable use of large bodies of subterranean water in flooded mines for geothermal energy recovery as this of Ting Bao, Zhen (Leo) Liu [74].

In view of the above considerations, the potential for desalination in Spain with geothermal energy is presented as an option to be considered either in isolation or in its mix with other renewable technologies and it is therefore studied in the present article.

Appendix B

This appendix contains a link with calculations for outlet temperatures of the solar collectors in the historical from 1996 to 2016 in the province of Almería to desalinate a type plant of 9000 m^3/d according to the premises of the manufacturer of the panels [36] and the area of collectors required.

https://drive.google.com/file/d/1K-iSrQabNy6_1_ryOe2cxHRjPBO6Gg6q/view

Appendix C. . Geological and hydrographical conditions in Almeria

See Figs. C1–C4.

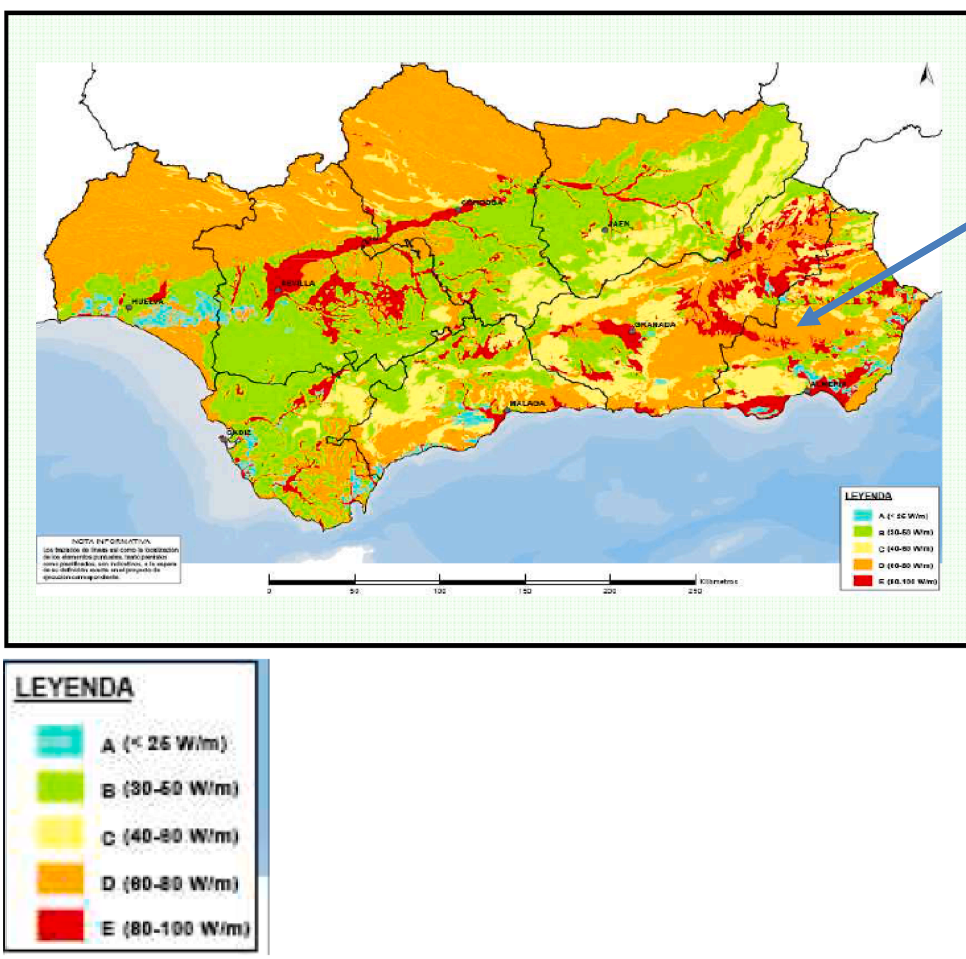

Fig. C1. Geothermal resource in Andalusia. Source: Andalusian Energy Agency [54].

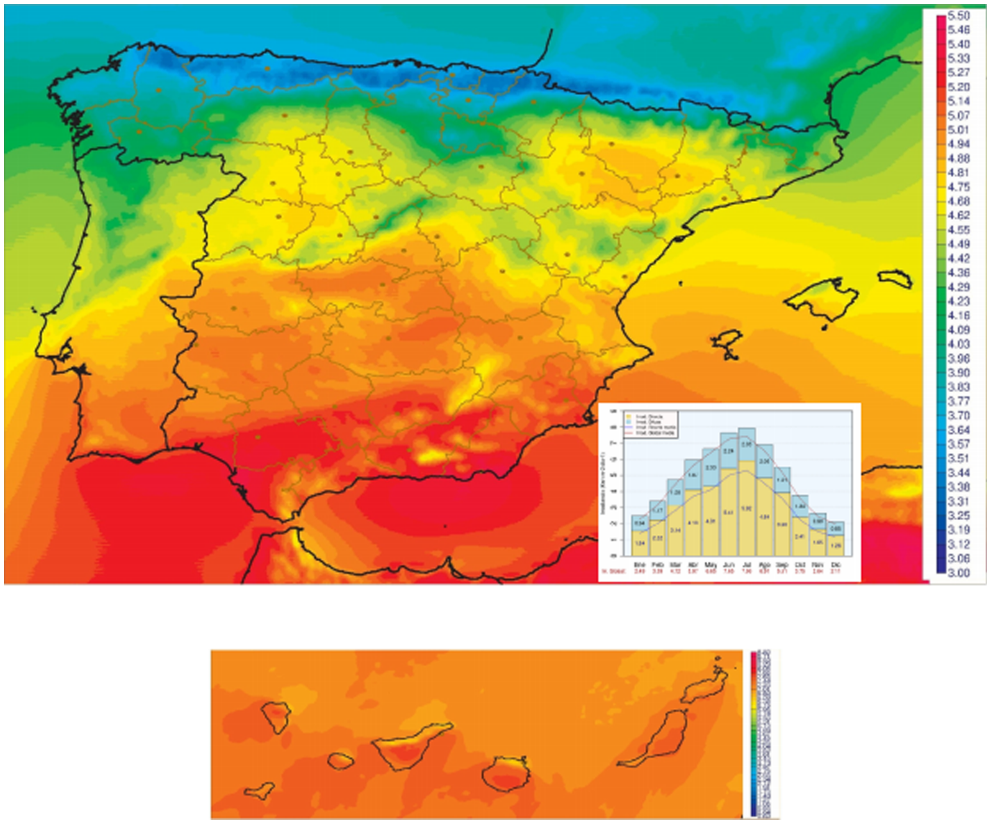

Fig. C2. Atlas of solar radiation in Spain. Source: Andalusian Energy Agency [54].

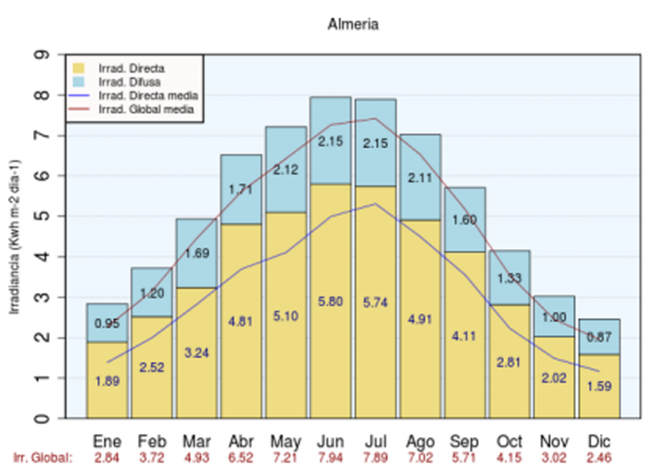

Fig. C3. Global, direct and diffuse solar irradiation in Almería. Period 1983–2005. Source: Atlas of solar radiation in Spain. AEMET [35].

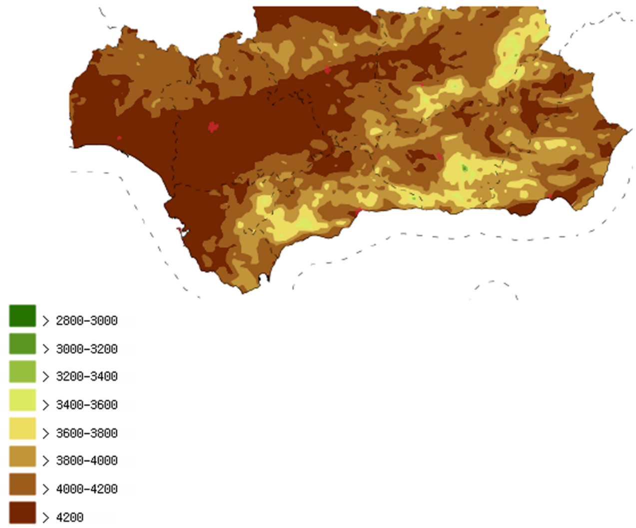

Fig. C4. Number of hours of sunshine per year. Source: Department of Andalusia and spatial planning. Junta de Andalusia [79].

Appendix D

See Tables D1 and D2.

Table D1
Description of geothermal resources in Andalusia.
Source: [54]

N° Order	Nomenclature geothermal zone	Estimated area (km^2)	Province1	Province area 1(km^2)	Province 2(km^2)	Province area 2 (km^2)	Estimated storage formation	T max (°C)	Max depth (m)	Min depth (m)
1	Huelva	1160	Huelva	1160	–	0	Tertiary Basal and Jurassic	80	1000	500
2	Seville Guadalquivir	1320	Seville	1210	Córdoba	110	Tertiary Basal	90	1500	1000
3	Córdoba Guadalquivir	750	Córdoba	750	–	0	Tertiary Basal	90	1500	1000
4	Jaén Guadalquivir	1230	Jaén	1230	–	0	Tertiary Basal and Jurassic	80	2000	1500
5	Algeciras	170	Cádiz	160	Málaga	10	Subbetic	70	1500	1000
6	Manilva	70	Málaga	70	–	0	Subbetic	90	2500	2000
7	Cádiz subbetic	260	Cádiz	200	Málaga	60	Subbetic	90	2500	2000
8	Álora-Cártama	50	Málaga	50	–	0	Maláguide	60	1500	1000
9	Sevilla subbetic	500	Sevilla	390	Málaga	110	Subbeti	90	2500	2000
10	Córdoba subbetic	140	Córdoba	140	–	0	Subbetic	90	1500	1000
11	Jaén subbetic	240	Jaén	240	–	0	Subbetic	90	1500	1000
12	Granada	370	Granada	370	–	0	Tertiary Basal, Subbetic and Alpujárride	100	1500	1000
13	Lanjarón	60	Granada	60	–	0	Snowy-Filábride	120	1500	1000
14	Guadix-Baza	1000	Granada	770	Almería	230	Tertiary Basal and Alpujárride	90	1500	1000
15	Huéscar Orce	380	Granada	380	–	0	Subbetic	60	1500	1000
16	Albuñol	60	Granada	40	Almería	20	Alpujárride	70	1000	500
17	Dalías field	110	Almería	110	–	0	Alpujárride	60	1000	500
18	Catchment area of Andarax	100	Almería	100	–	0	Alpujárride	70	1000	500
19	Alhamilla	15	Almería	15	–	0	Snowy-Filábride	110	1500	1000
20	Sorbas	110	Almería	110	–	0	Tertiary Basal	50	1000	500
21	Níjar	190	Almería	190	–	0	Tertiary Basal	60	1000	500
22	Low Almanzora	120	Almería	120	–	0	Alpujárride	80	1000	500

Table D2
Low Accessible resources at 3.5 and 7 km in the selected low temperature areas.
Source: [54]

Zone N°	Name	Area (km^2)		RBA_3 (J × 10^{20})	RBA_5 (J × 10^{20})	RBA_7 (J × 10^{20})
		Total	Effective			
1	Huelva	1160	435	1,37	3,82	7,48
2	Seville Guadalquivir	1320	665	2,10	5,84	11,44
3	Córdoba Guadalquivir	750	412	1,30	3,62	7,09
4	Jaén Guadalquivir	1230	343	1,08	3,01	5,90
5	Algeciras	170	93	0,29	0,82	1,60
6	Manilva	70	70	0,22	0,61	1,20
7	Cádiz subbetic	260	260	0,82	2,28	4,47
8	Alora-Cártama	50	50	0,16	0,44	0,86
9	Seville subbetic	500	300	0,95	2,63	5,16
10	Córdoba subbetic	140	91	0,29	0,80	1,57
11	Jaén subbetic	240	108	0,34	0,95	1,86
12	Granada	370	370	1,17	3,25	6,36
13	Lanjarón	60	60	0,19	0,53	1,03
14	Guadix Baza	1000	650	2,05	5,70	11,18
15	Huéscar Orce	380	247	0,78	2,17	4,25
16	Albuñol	60	60	0,19	0,53	1,03
17	Dalías field	110	110	0,35	0,97	1,89
18	Almería flaw	100	100	0,32	0,88	1,72
19	Alhamilla	15	15	0,05	0,13	0,26
20	Sorbas	110	110	0,35	0,97	1,89
21	Níjar	190	190	0,60	1,67	3,27
22	Aguilas	120	120	0,38	1,05	2,06
TOTAL				**15,35**	**42,64**	**83,57**

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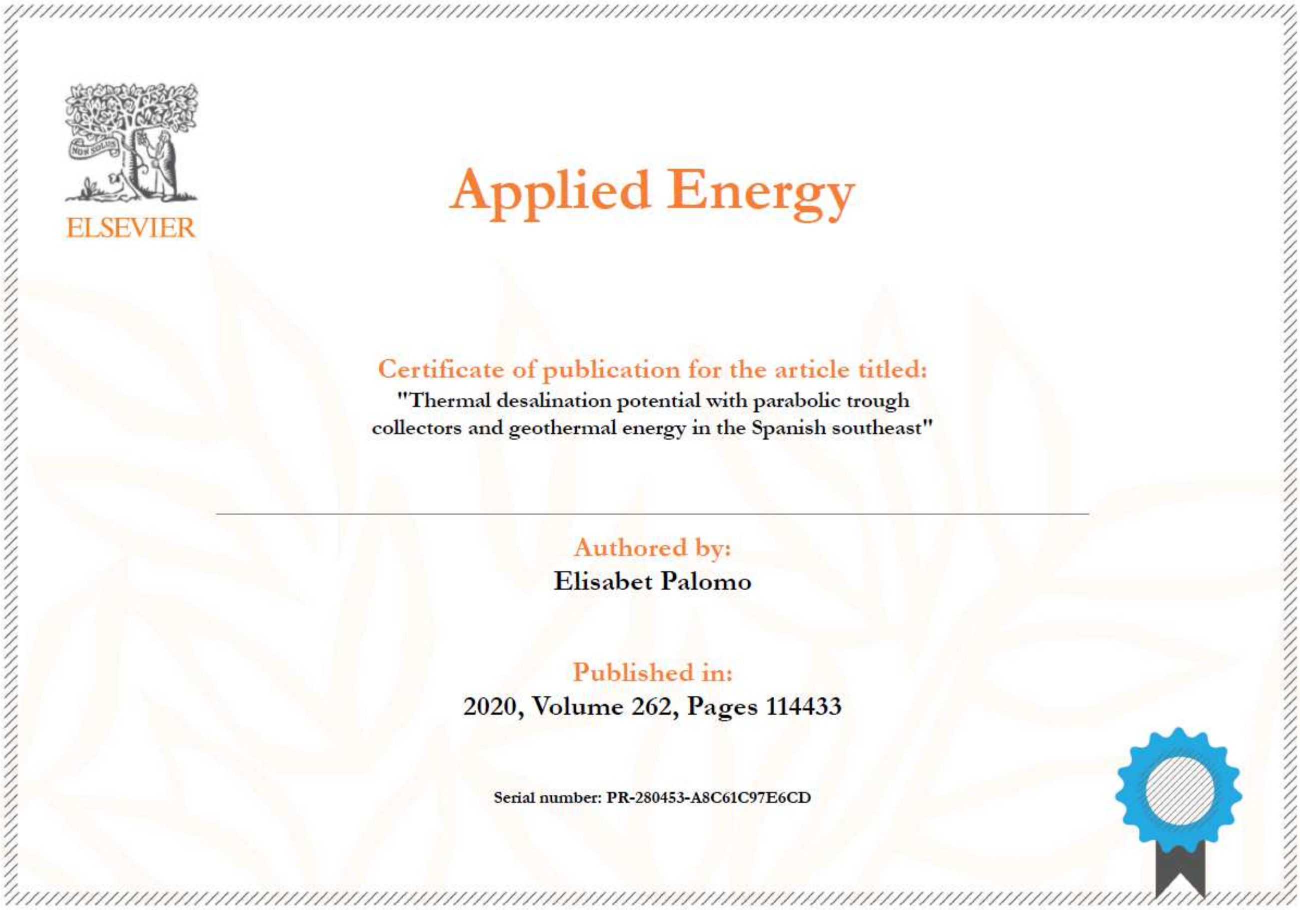
ANEXO V ”Thermal desalination potential with parabolic trough collectors and geothermal energy in the Spanish southeast”. FACTOR DE IMPACTO DE LA PUBLICACIÓN

- Factor impacto año 2020: 9,746
- Factor impacto últimos 5 años: 9,953
- Categoría de JCR: Energy&Fuels
- Clasificación en la categoría: 9 de 114
- Cuartil en la categoría: Q1
- Estado: Aceptado en Diciembre 2019 y publicado en Marzo 2020

ANEXO VI ”Thermal desalination potential with parabolic trough collectors and geothermal energy in the Spanish southeast”. CERTIFICADO DE LA PUBLICACIÓN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ANEXO VII “Economic and environmental benefits of geothermal energy in industrial processes ”. COPIA DE LA PUBLICACIÓN

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Economic and environmental benefits of geothermal energy in industrial processes

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ABSTRACT

As the industrial sector is one of the world's largest greenhouse gas dispatcher, a solution must be found, and geothermal energy can make a significant contribution to this challenge.

This study shows that almost 85% of the industrial processes can be carried out with very low, low and medium geothermal temperature resources in Spain. In this context, the CO_2 emissions avoidance to the atmosphere would mean more than 80 million tons per year and 15 years would be the amortization period for this investment for industrial processes of up to 45 °C in Spain.

As a practical vision, a technical-economic study is performed by means of the reconversion of the already existing solar energy into geothermal energy of the plants belonging to the Spanish Solar heat for industrial processes obtaining savings of 18% of the investment with respect to the solar energy.

1. Introduction

Despite the efforts that have been made over the years, according to the International Energy Agency, hereinafter IEA, at a global level, energy demand in industry continues to be predominantly fossil fuel (EIA, 2020).

This is also true in Spain, where industrial energy consumption is distributed as follows: gas with 40%, followed by electricity with 32%, oil products (14%), renewable energies (7%) and 6% coal [1].

Among renewable energies, geothermal energy is a minority and the IGA (International Geothermal Association) database discriminates by direct use or for electricity for this resource.

World-wide, for direct-use geothermal energy, industrial uses account for only 2.7% [2]. Most direct use of geothermal energy is for geothermal heat pumps, swimming and bathing, and space heating as shown in Fig. 1.

In the literature, there are numerous cases for space heating like this of Majorowic [3] where it is showed that geothermal energy is the best option for municipalities in Alberta (Canada). And this other of Zhang [4] where a ground source absorption heat pump driven by an urban heating system is used for heating a municipal space being more energy and economical efficient.

In the case of Spain, the percentage with respect to the industrial uses is even lower than the world average because they are not considered industrial processes. Only Spas and swimming pools heating, geothermal heat pumps, greenhouses and space heating are considered direct uses (Table 1).

In Spain and according to Table 2, the installed power for direct use geothermal energy only represents 0.09% of the world's power and 0.06% of the world's energy (see Figs. 2 and 3). The situation is even worse with respect to the installed power, in geothermal energy for electrical uses in Spain, as it does not exist as shown in Table 3.

As can be seen, no industrial processes powered by geothermal energy are contemplated in Spain and they are therefore the object of research in this field.

For geothermal energy, these industrial operations tends to be large and have high energy consumption [6]. Besides, it has the highest capacity factor (annual operating hours at full load of an installation) among direct uses (0.70, or 70%).

These are industrial processes that operate during a large part of the year [2].This is a good reason to implement the industrial use of

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Nomenclature and units

A_{colec}	Collector's area
AACC	Autonomous Communities
C_e	Energy costs for the six AACCs: Catalonia, Community of Madrid, Community of Valencia, Basque Country, Andalusia and Galicia
$C_g, b1$	Very low and low temperature geothermal cost (up to 45 °C)
$C_g, b2, m$	Low temperature geothermal cost (between 45 °C and 100 °C) and medium temperature geothermal cost (between 100 °C and 150 °C)
$C_P, b1$	Partial energy cost for very low temperature and low temperature geothermal (up to 45 °C)
$C_P, b2$	Partial energy cost for low temperature (between 45 °C and 100 °C)
C_P, m	Partial energy cost for medium temperature (between 100 °C and 150 °C)
Dk/Na	Doesn't know/doesn't answer
EU	European Union
Fn	Cash flow
GHP	Geothermal heat pump
GWh	Gigawatts · hour
i	Discount rate
Ib	Investment in very low and low temperature geothermal energy up to 45 °C
IEA	International energy agency
IGA	International geothermal association
Im	Investment in very low temperature geothermal energy between 45 °C and 100 °C and medium temperature up to 150 °C
INE	National statistics institute
I_0	Initial investment
ISIC	International uniform industrial classification
I_{solar}	Solar energy investment
IRR	Internal rate of return
K	Thermal conductivity of soil
ktoe	Kiloton of oil equivalent
L	Length of geothermal drilling
LPG	liquefied petroleum gas
m_e	mass of CO_2 avoided to the atmosphere
m_t	mass of CO_2/kWh
MW	Megawatts
MWt	Thermal megawatts
n	Number of periods
NACE	National classification of economic activities
NPV	Net present value
N/a	Not applicable
O&M	Operation and Maintenance
P_{evap}	Evaporator power
PJ/y	Petajoules/year
P_t	Thermal power
PTC	Parabolic trough collector
Q_e	Energy consumption of Spanish companies
$Qg, b1$	Very low temperature and low geothermal energy consumption (up to 45 °C)
$Qg, b2, m$	Low temperature and medium geothermal energy consumption (between 45 °C and 100 °C)
Q_p	Consumption of industrial processes in Spain susceptible to geothermal energy
$Q_p, b1$	Partial energy consumption of the six AACCs in very low and low temperature (up to 45 °C)
$Q_p, b2, m$	Partial energy consumption of the six AACCs in low and medium temperature (between 45 °C and 100 °C)
t	Temperature
TJ/y	Terajoules/year
TRT	Thermal response test
T_{solar}	Solar temperature
SHIP	Solar heat for industrial processes
y	year

geothermal energy if it is compared with the capacity factor of heat pumps (0.27) or even with the world average (0.15).

Strangely, despite the lack of use, the geothermal potential of low and medium enthalpy in Spain would amply cover the needs of its industry as shown in Table 4.

In view of Table 4, the energy consumption of Spanish industry, hereinafter *Qe*, would only represent 1.13% of the potential for use and exploitation of the geothermal resource in Spain. Therefore, the potential is enormous in this regard therefore.

It is true that there are some industries in Spain (especially the most powerful) that have carried out in recent years initiatives to reduce energy consumption and implement measures for apply renewable energy [7–9]. Nevertheless, the margin for improvement is huge considering the figures of Spanish energy consumption by type of energy source of the National Institute of Statistics, hereinafter INE [10]. (Appendix E).

Unlike geothermal energy, other renewable energy sources have been more fortunate than this, as is the case of solar energy, especially in Spain.

Solar energy is considered as one of the cleanest and therefore one of the most important in the world for domestic applications and for the industrial sector [11–14]. Solar heat as a renewable energy source for industrial processes is well known in many studies and reports [15–17] but not so much geothermal heat,-which is the subject of this article.

There are numerous studies of solar applications in the industrial sector, such as that of Solar Concentra [18], which links industrial processes with solar energy. The study by Lilliestam [19] which shows the importance of solar thermal energy for generating electricity even in winter, and which can supply base load at low cost in some cases.The study by Sharma et al. [20], which also links industrial processes with solar thermal heat as one of the cleanest sources on the planet. Other studies [21]; Chu et al., 2019 [22]; show that the conversion of solar energy into thermal energy is much more efficient (up to 70%) than the conversion into electricity.

Procter et al. [23] conducted a study in a food processing industry in Australia where they concluded that half of the energy required for processes between 40 °C and 60 °C could be supplied by solar collectors.

As barriers, to solar thermal energy for heat in industrial processes, the lack of support for solar thermal for electricity generation and photovoltaics is mentioned, as it is shown in numerous literature [24–28].

Another solar thermal barrier is that the Spanish business network is mostly composed of small and medium sized industries, which have more difficulty making an initial investment in this type of system. The latter would be reproducible to geothermal energy where most installations in Spain (and in the EU) are with geothermal heat pumps led by small companies [2].

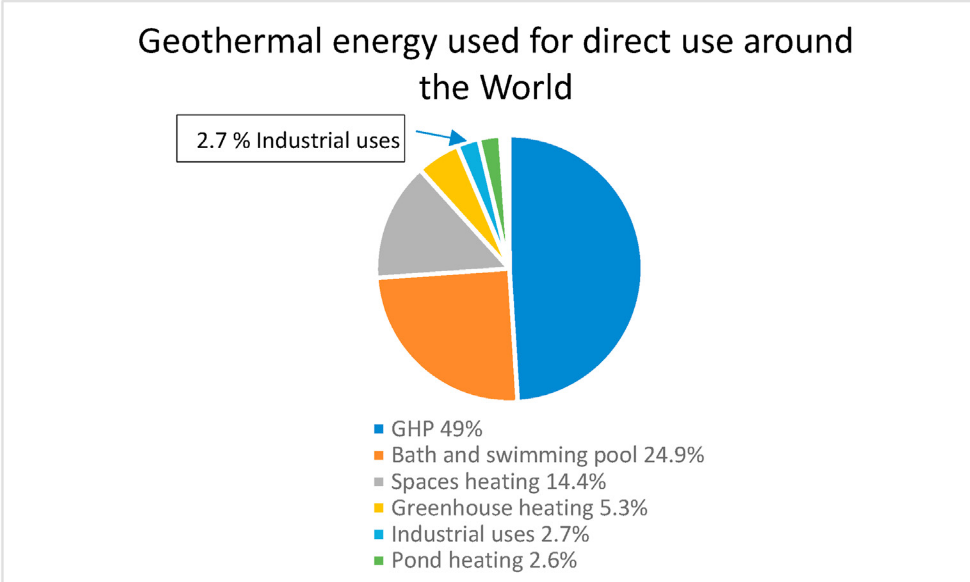

Fig. 1. Geothermal energy used for direct used around the World: Adapted from [2].

Table 1
Installed capacity and annual use of geothermal energy in Spain. Data year 2015. Source: Adapted from Ref. [5]].

	Installed capacity (MW)	Annual use (GWh)
Bathing and swimming-pool	2.59	52.5
Geothermal heat pump	43 087	121.67
Greenhouses	14.93	94.42
Space heating	3.52	76.26
Total	43 108.04	344.85

Table 2
Power and geothermal energy for direct use: World and Spanish comparisons. Source: Adapted from Ref. [5]].

	Year 2015	
Location	Power (MWt)	Energy (TJ/y)
World-wide	70 329	587 786.40
Spain	64.1	344.9

Vargas Payera [29] highlights with respect to the geothermal energy, social barriers in Chile such as lack of trust, spiritual relationship to volcanoes, and uncertainty about environmental impact as factors that affect risk and public perception.

Also in the studio of Cagno et al. [30] are mentioned the barriers and drivers but in this case for the energy efficiency in some industries in the Netherlands.

In the studio of Ilic and Trygg [31]] it becomes clear the economic and environmental benefits of converting industrial processes to District Heating.

The use of geothermal energy as an integral part of the energy model is essential in order to solve the problem of solar collector space and the intermittent nature of solar energy on days with insufficient radiation. Other studies, such as Mahmoud et al. [32] consider mechanical energy storage systems as a solution.

It is essential to be able to evaluate the best sustainable energy resource for each area in question. This means taking into account geothermal energy alone or in hybridization, as shown in some articles [33–39] since it is sometimes the most appropriate.

In the same way, as quoted in some articles, once the economic barriers of geothermal energy have been overcome [40], the value of hybridization of systems has been emphasized [33], the recovery of flooded mines has been considered where possible as geothermal wells [41]] and a better knowledge of simulation techniques has been obtained to reduce techno-economic uncertainties [42] then, the geothermal energy will take its rightful place as a source of clean and renewable energy.

The way in which geothermal energy is approached as a renewable source for industrial processes is novel in this article. It is associated with each industrial process that works in a given temperature range the most suitable type of geothermal energy according to the geographical location of the industry in question in the sense of performance of the soil and the concentration of the companies.

The research presented is divided into four sections: A first section of introduction where the situation of the industry is analyzed and therefore of the industrial processes fed with renewable energies and in particular with solar energy and geothermal energy. A second section of materials and methods where the working temperatures of the industrial processes are related to the temperatures of the geothermal resources according to the geographical and geological location of the industries in question and according to the business criterion of the different regions in Spain.

The CO_2 emissions avoided to the atmosphere and the years of amortization for implementing the geothermal energy model in Spanish industries are also calculated in this second section.

A third section of results and discussion where the results obtained are presented. In addition, the geothermal potential of the companies of the Spanish SHIP-plants is analyzed. Finally, one last section, the fourth, of conclusions. The article is completed with six appendices Appendix A shows a classification of the industrial processes. Appendix B shows the geothermic situation of Spain according to each temperature range. Appendix C establishes a ranking of municipalities in Spain according to a defined business criterion. Appendix D indicates a classification of the economic activities. Appendix E denotes the energy consumption according to activity sector. Appendix F contains a link with the calculations

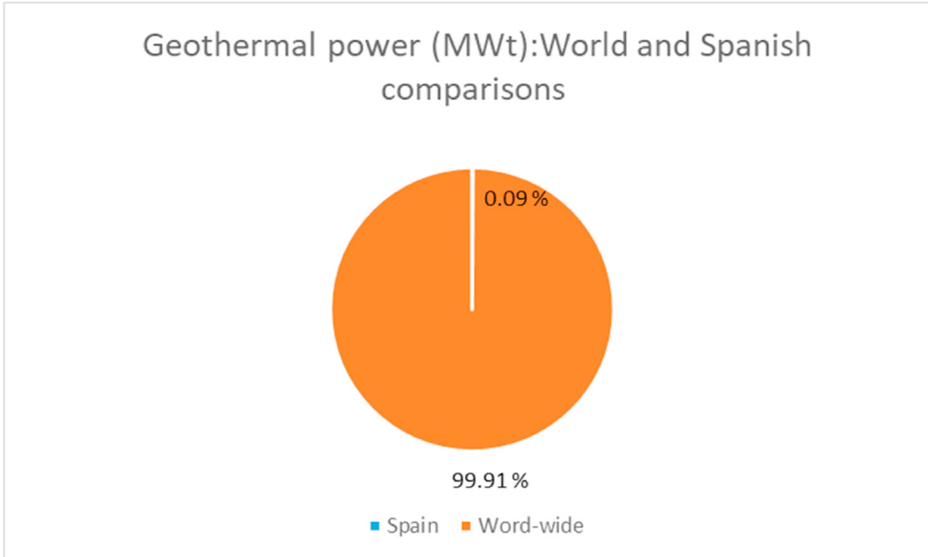

Fig. 2. Geothermal power for direct use: World and Spanish comparisons. Source: Adapted from Ref. [5].

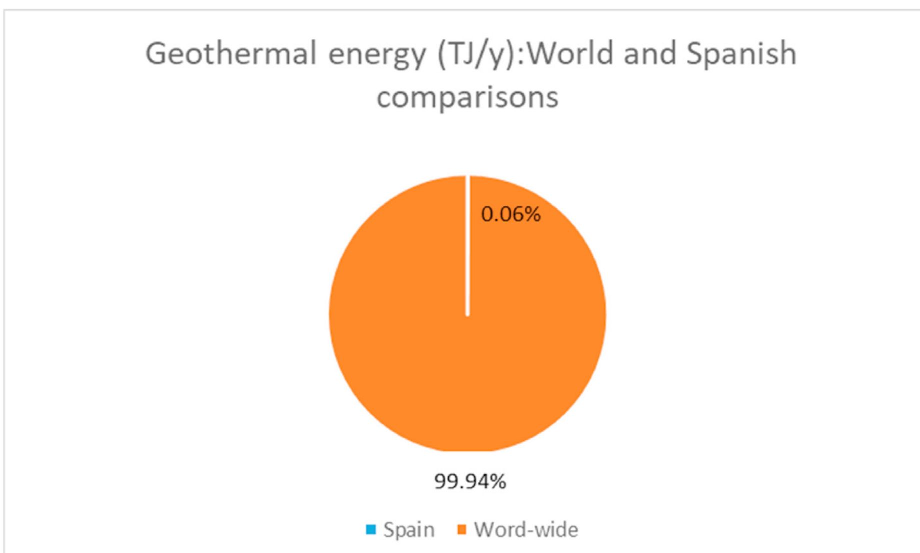

Fig. 3. Geothermal energy for direct use: World and Spanish comparisons. Source: Adapted from Ref. [5].

Table 3
Geothermal electricity generation by country. Fuente: Adapted from Ref. [5]].

	Year 2015
Location	Power (MWe)
World-wide	12 636.10
Spain	0

for the NPV and IRR, the energy consumption by AACCs and an analysis of the 15 companies of the Spanish SHIP-plants if they were supplied with geothermal energy.

2. Materials and methods

Each type of industry is associated with a series of industrial processes that require several temperature levels. The aim of the research presented here is to be able to supply the energy required by these processes from natural and sustainable sources. To this end, we will focus on a resource such as geothermal energy. In particular, it will be evaluated the geothermal potential for the Spanish industrial energy consumption and a study will be carried out to link the thermal criterion of industrial processes in the industry in Spain with the geothermal criterion and with the business criterion. (See Fig. 4).

The novelty of this article consists precisely in discriminating, with a more in-depth analysis and a practical vision, which temperature range of industrial processes and regions would be the most suitable according to the previously defined criteria (geothermal, thermal and business). For this purpose, taking advantage of local resources in terms of existing industries, the potential of the land where they are located and industrial concentration for a better energy use between adjacent industries and, of course, assumable geothermal costs.

Table 4
Comparison of the potential use of low and medium enthalpy geothermal resources in Spain and energy consumption by Spanish industries. Year 2018. Source: Adapted from Ref. [2]] and [1]].

	Potential use and exploitation of geothermal resources (GWh)	Energy costs of Spanish industries (€)	Type of fuel	Energy consumption of Spanish industries (GWh)
Low	15 990 000	78 653	Electricity	
Medium	5 423 000	96 726	Gas	
		34 622	Diesel oil,fuel oil,others oil products	
		15 398	Coal and coke	
		17 119	Renewable energies	
Total	21 413 000			242 508

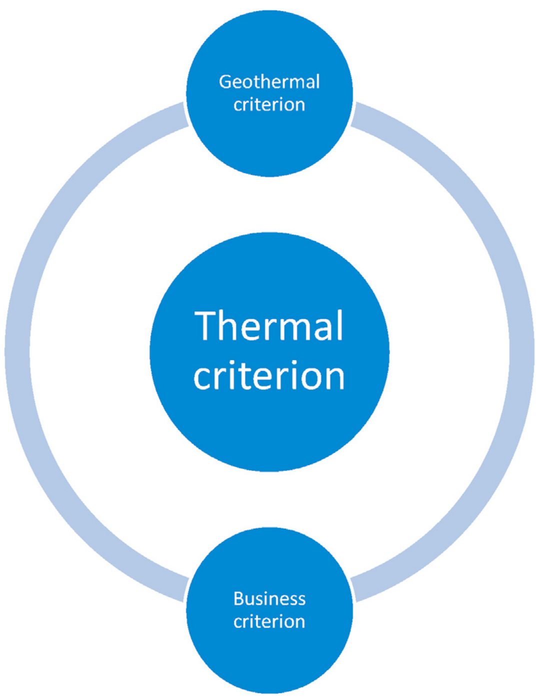

Fig. 4. Scheme of the three chosen criteria. Own resource.

As thermal criterion that will be defined by the temperature range of the industrial processes, we will establish five classes, namely, processes of less than 30 °C; between 30 °C and 45 °C; between 45 °C and 100 °C; between 100 °C and 150 °C and more than 150 °C.

As geothermal criterion, there are also five geothermal zones with profiles of very low (up to 30 °C); low (between 30 °C and 45 °C); low (between 45 °C and 100 °C); medium (between 100 °C and 150 °C) and high geothermal temperature (over 150 °C).

Finally, three subcriteria are defined as business criterion, namely the highest degree of business concentration, the highest turnover and finally the highest investment in tangible assets, giving rise to a ranking of regions in Spain that meet theses business criteria.

In addition, we will calculate the expected savings both in CO_2 emissions into the atmosphere and years of amortization if we were able to supply the majority of the industrial processes required for industry in Spain with this energy source alone.

2.1. Thermal criterion

The working temperatures of the industrial processes of the industries in question will be related to the type of soil with geothermal potential where they are located. Five temperature ranges of the industrial processes that take place in the industry are established as shown in Table 5 and Fig. 5.

Appendix A details the type of industry and the type of industrial process and its working temperature range.

2.2. Geothermal criterion

Next, five temperature ranges will be established for the geothermal potential of very low, low, medium and high temperature [2]. This low t range has in turn been divided into two temperature levels.

- Range 1: t < 30 °C. This could be achieved with a very low t geothermal resource, at shallow boreholes (up to 200 m). It occurs practically throughout the Spanish geographical panorama [2]. It would make direct use of heat and may or may not require a geothermal heat pump, hereinafter GHP, to reach 30 °C.
- Range 2: 30 °C < t < 45 °C. In this case, the temperature profile is within the low t geothermal range. For this second range of t, direct use of heat would be made, and a GHP may also be needed to achieve 45 °C [2] and shallow drilling (in Spain).
- Range 3: 45 °C < t < 100 °C. It is also within the low t range of geothermal and would be direct heat use. It occurs at greater depths between 1500 m and 2000 m or below 1000 m in areas with thermal anomalies (in Spain).
- Range 4: Approximately between 100 °C and 150 °C. This would be a geothermal resource area of medium t, which would be used for electricity in binary cycle plants. It occurs at depths between 1500 m and 3000 m (in Spain).
- Range 5: t > 150 °C. In this case, t > 150 °C is required, so it would be a high temperature geothermal resource zone at depths of between 1500 m and 3000 m (in Spain), which would be used for electricity production in conventional flash plants [2].

Appendix B shows the geothermic situation of Spain according to each temperature range.

2.3. Business criterion

The aim is to establish a correlation between the location of industrial companies in Spain and the potential of the geothermal soil that is capable of supplying clean energy to some of these industrial processes required by these industries.

For the business criterion, the number of companies per municipality, the turnover per autonomous community, hereinafter AACC, and the investment in material assets will be taken into account as it can be seen in Fig. 6.

This is a restrictive criterion because the three features must be fulfilled for the region to be considered for the application of

Table 5
Average number and percentage of industrial processes according to t range. Source: Adapted from Ref. [43]].

Table Bibliography [43]	N° industrial processes t < 30 °C	N° industrial processes 30 °C < t < 45 °C	N° industrial processes 45 °C < t < 100 °C	N° industrial processes 100 °C < t < 150 °C	N° industrial processes t > 150 °C
Industrial processes according to temperature range	2	7	16	13	7
Percentage	4%	15.5%	36%	29%	15.5%

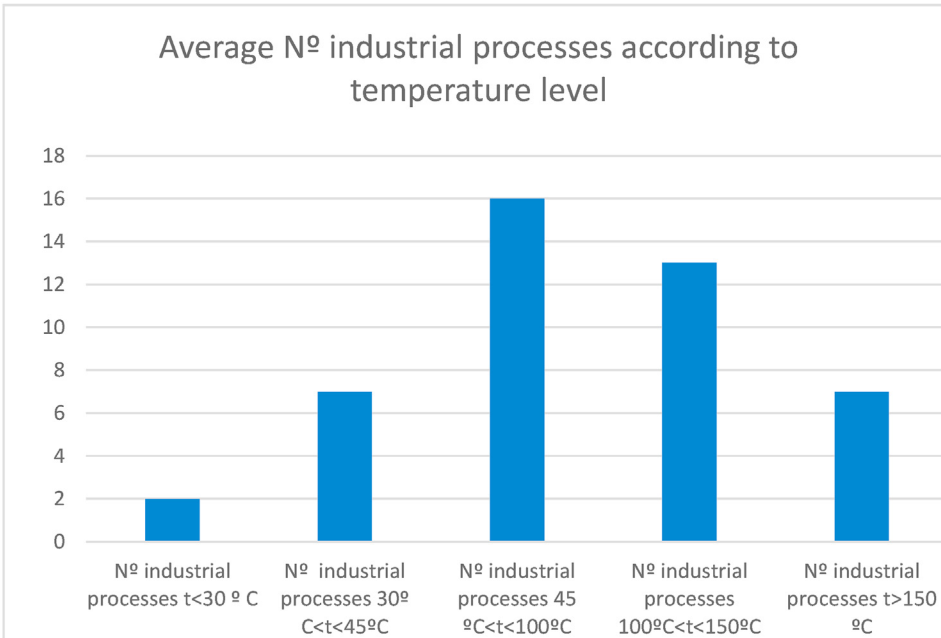

Fig. 5. Average N° industrial processes according to temperature range. Source: Adapted from Ref. [43].

geothermal energy to its industries. The reason for this criterion is linked to a greater concentration of companies for a possible geothermal district heating and the region's own wealth for public or private financing.

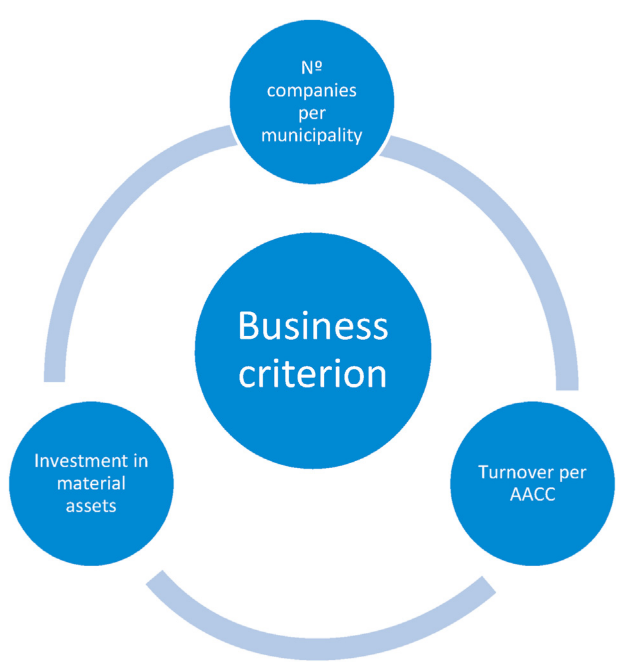

Fig. 6. Scheme of the three restrictive features defined for the business criterion Own source.

Appendix C compiles this information, obtaining a ranking of the municipalities in Spain that meet this criterion. In Appendix F (Analysis of the 15 companies of the Spanish SHIP-plants, Figure M.3), a political map of Spain is indicated for a better understanding of the location of the regions.

Next, Fig. 7: represent a compound of the three criteria mentioned.

2.4. Calculation of CO_2 emissions avoidance to the atmosphere

As shown in the introduction, the energy consumption of Spanish industries, *Qe* amounts to 242 508.76 GWh (assuming that this consumption comes from industrial processes).

On the other hand, the industrial processes susceptible to apply geothermal energy in Spain represent 84.5% of the total as can be seen in Table 5.

The consumption of the industrial processes in Spain, from now on, *Qp* would suppose according to equation (1)

$$Qp = Qe \; x \; 0.845 \quad (1)$$

Resulting in: $Qp = 204\,919.90$ GWh

In terms of CO_2 emissions, knowing that the mix for the electricity grid is estimated at $m_e = 392$ g CO_2/kWh [44], it would give a value according to equation (2).

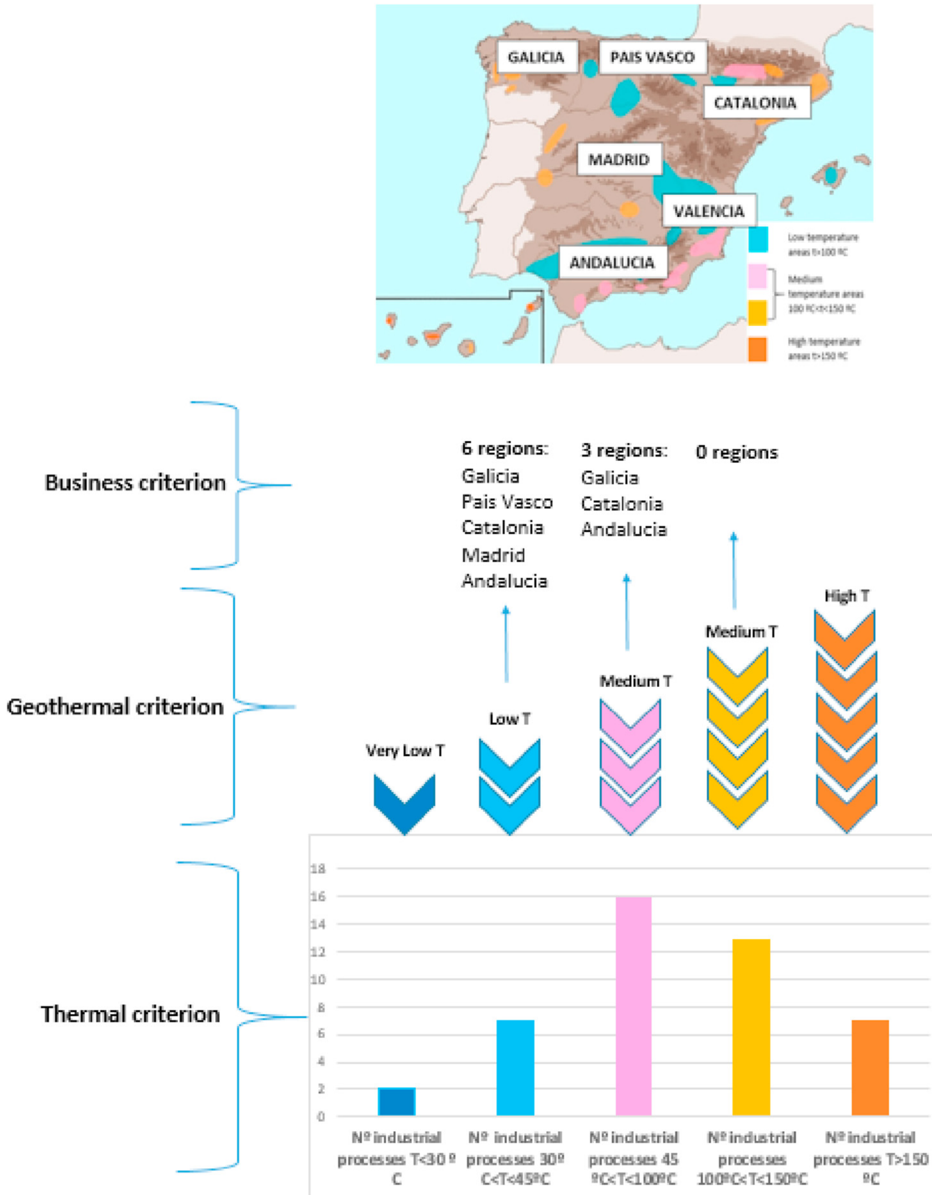

Fig. 7. Scheme of the three defined criteria: Thermal, geothermal and business and a representation of the Spain geological map. Spain. Own resource.

$$m_t = m_e \times Qp \quad (2)$$

m_t = 80 328 600.8 tons CO_2 annual avoid to the atmosphere.

2.5. Calculation of the return on investment. Calculation of the next present value, internal rate of return and payback period

2.5.1. Calculation for very low and low temperature resources up to 45 °C

It has been seen that 19.5% of the processes could be carried out with very low and low t resources up to 45 °C in the Communities of Catalonia, Andalusia, Madrid, Valencia, the Basque Country and Galicia. On the other hand, according to the INE [45], the energy cost in economic figures for these communities, C_e, amounts to 6 407 212 000 € (See Appendix F, calculations of Energy consumption).

19.5% of said value will be calculated, $C_P, b1$ which represents the energy cost of industrial processes of less than 45 °C.

$$C_P, b1 = C_e \times 0.195 \quad (3)$$

Resulting in $C_P, b1$ = 1 249 406 340 €.

Knowing that Q_e = 242 508.76 GWh, 19.5% of this energy supposed:

$$Qp, b1 = Q_e \text{ x } 0.195 \quad (4)$$

$Qp, b1$ = 47 289.20 GWh.

Geothermal energy has a capacity factor of around 0.7, which means a total of 6132 h of annual operation.

The required geothermal power would be calculated with (5):

$$Qg, b1 = Qp, b1/6132 \quad (5)$$

Resulting in $Qg, b1$ = 7.71 GW.

On the other hand, it is known that for shallow drilling up to about 200m the geothermal costs, $Cg, b1$ amount to approximately

1500 €/kW [46,47].

The investment in very low and low t geothermal Ib, would be calculated with (6)

$$Ib = Qg, b1 \text{ x } Cg, b1 \quad (6)$$

Resulting in $Ib = 1.15 \times 10^{10}$ €

The amortization period would be calculated with (7) and (8) [48,49]

$$NPV = \sum_{n=0}^{N} \frac{Fn}{(1+i)^n} - I_0 \quad (7)$$

$$IRR = \sum_{n=0}^{N} \frac{Fn}{(1+i)^n} = 0 \quad (8)$$

Knowing that [48,49].

$I_0 =$ Initial investment
F_n = Cash flow
i = discount rate
n = number of periods

It is known:

$I_0 = Ib = 1.15 \times 10^{10}$ € (Assuming that the cost of financing the project is not taken into account).

It is calculated F_t as:

$F_t = Cp, b1\text{-}Cm, o$ (Supposed constant cash flow).

Where $Cp, b1$ is the energy cost of industrial processes of less than 45 °C and Cm, o is the estimated geothermal energy cost for O&M.

$Cp,b1$ = 1 249 406 340 € (industrial processes energy cost of less than 45 °C).

Cm, o = 2.5% x $Cp, b1$ (O&M cost is estimated as 2.5% total cost) [50].

i = 6% (typical for renewable projects) [51].

As a result:

- NPV = 810 710 382.94 €
- IRR = 7%
- Payback period = 15 years

(Calculations details for the NPV and IRR in Appendix F).

Then, the payback period would be 15 years for industrial processes that require temperatures of up to 45 °C and are powered by geothermal energy.

2.5.2. Calculation for low t (between 45 °C and 100 °C) and medium t (up to 150 °C) resources

Similar reasoning will be made for the low temperature resource from 45 °C to 100 °C and for the medium temperature resource (up to 150 °C).

Again, low temperature resource occurs in the six communities defined above and feeds 36% of the industrial processes between 45 °C and 100 °C (Table 5).

$$C_P, b2 = C_e \times 0.36 \quad (9)$$

Knowing that, C_e, amounts to 6 407 212 000 €.

Resulting in $C_P, b2$ = 2 306 596 320 € which represents the industrial cost of industrial processes between 45 °C and 100 °C for the six defined AACCs.

On the other hand, 29% of the industrial processes with temperatures between 100 °C and 150 °C (Table 5) would mean:

$$C_P, m = C_e \times 0.29 \quad (10)$$

Knowing that, C_e, amounts to 6 407 212 000 €.

Resulting in $C_{P,m}$ = 1 858 091 480 € which represents the industrial cost of industrial processes between 100 °C and 150 °C for the six defined AACCs.

The geothermal power required in this case would be the result of applying (11) knowing that resources between 45 °C and 150 °C represent 36% + 29% of industrial processes.

$$Q_p, b2, m = Qe \text{ x } (0.36 + 0, 29) \quad (11)$$

Knowing that Q_e = 242 508.76 GWh.

Resulting: $Q_p, b2, m$ = 157 630.694 GWh

Geothermal energy has a capacity factor of around 0.7, which means a total of 6132 h of annual operation. The required geothermal power would be calculated with (12):

$$Qg, b2, m = Qp, b2, m/6132 \quad (12)$$

Resulting: $Qg, b2, m$ = 25.70 GW.

For the low temperature resource between 45 °C and 100 °C and medium temperature (>100 °C), deeper drilling is required and the ratio is estimated at 4045 €/kW [52].

The investment in low t geothermal energy in the interval of 45 °C to 100 °C and of medium t (>100 °C) Im, it would be calculated with (13)

$$Im = Qg, b2, m \text{ x } Cg, b2, m \quad (13)$$

Knowing that $Cg, b2, m = C_P, b2 + C_P, m$ = 4 164 687 800€

Resulting in $Im = 10.39 \times 10^{10}$ €

The amortization period would be calculated with (7) and (8)

It is known:

$I_0 = Im = 10.39 \times 10^{10}$ € (Assuming the cost of financing the project is not taken into account).

It is calculated F_t as:

$F_t = Cg, b2, m\text{-} Cm, o$ (supposed constant cash flow).

Where $Cg, b2, m$ is the energy cost of industrial processes between 45 °C and 150 °C, and Cm, o is the estimated geothermal energy cost for O&M.

$Cg, b2, m = C_P, b2 + C_P, m$ = 4 164 687 800€

Cm, o = 2.5% x $Cg, b2, m$ (O&M cost is estimated as 2.5% total cost) [50].

i = 6% (typical for renewable projects) [51].

As a result:

- NPV = 1.550.799.161,23 €
- IRR = 2%
- Payback period = 36 years

(Calculations details for NPV and IRR in Appendix F).

Meaning, the amortization period would be 36 years for industrial processes that require temperatures between 45 °C and 150 °C.

3. Results and discussion

The energy consumption of Spanish industry only represents the minimum figure of 1.13% of the potential for the use and exploitation of the geothermal resource as we could see in Table 4. In view of this figure, there are sufficient geothermal resources to supply all the country's industrial consumption. However, from a practical point of view, three criteria have been identified as essential in this study for implementing the widespread use of geothermal energy in Spanish industry. These criteria are based on

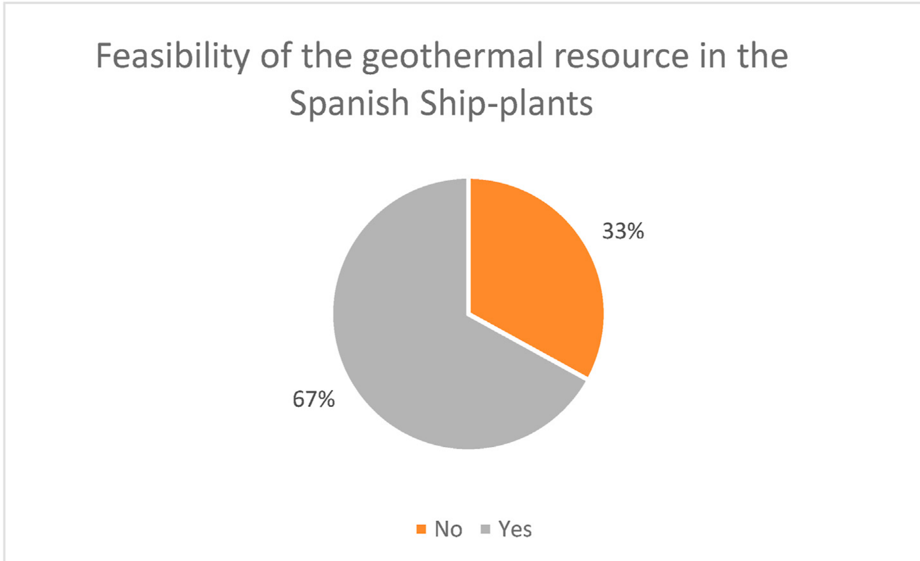

Fig. 8. Feasibility of applying geothermal energy as a source of energy in the SHIP-plants in Spain Source: Adapted from Ref. [53].

thermal, business and geothermal reasons and have led to the following results:

- 19.5% of all industrial processes are below 45 °C and could occur with very low and low temperature geothermal resources with or without GHP with shallow drilling (up to 200m) throughout the country. In addition and accordance with the business criterion, the regions of Catalonia, the Community of Madrid, the Community of Valencia, Andalusia, the Basque Country and Galicia would benefit most from having surface extraction powers of over 60 W/m.
- 36% of all industrial processes are between 45 °C and 100 °C and would be reached with low temperature resources for thermal use in the areas of Catalonia, Andalusia and Galicia with perforations of less than 1000 m thanks to the thermal anomalies of these areas. On the other hand, in the regions of Community of Madrid, Community of Valencia and Basque Country would be reached with deeper perforations of between 1500 m and 2000 m.
- 29% of all industrial processes would be covered with medium temperature resources in the regions of Catalonia, Galicia and Andalusia at depths of 1500 m–3000 m.
- 15.5% of the industrial processes require temperatures of more than 150 °C and could not be covered in the areas defined by the business criterion in Spain.
- 84.5% of the industrial processes in industry in Spain could be carried out with very low, low and medium temperature geothermal resources.
- The not inconsiderable figure of 80 328 600.8 tons CO_2 would be the amount avoided in the atmosphere by the use of geothermal energy as an energy source applied to industrial processes in industry in Spain.

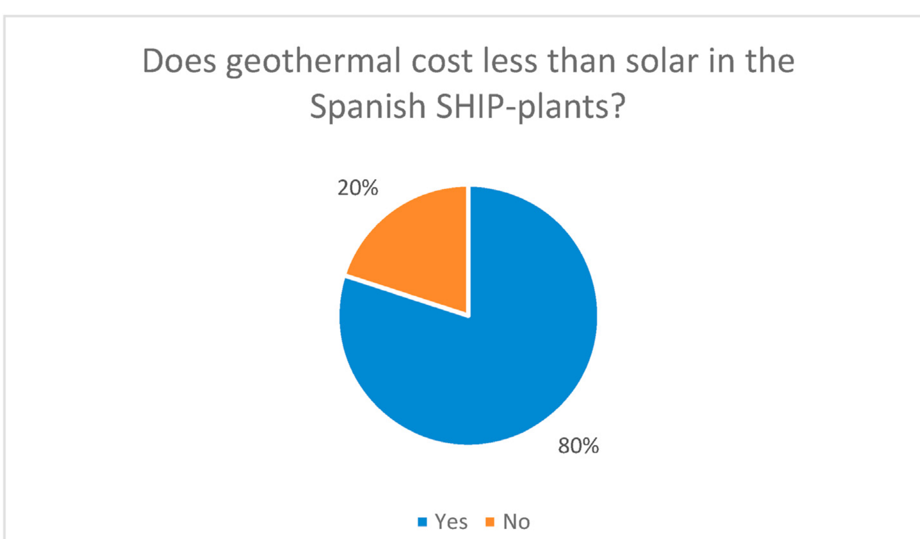

Fig. 9. Economic viability of SHIP-plants in Spain capable of using geothermal energy. Source: Adapted from Ref. [53].

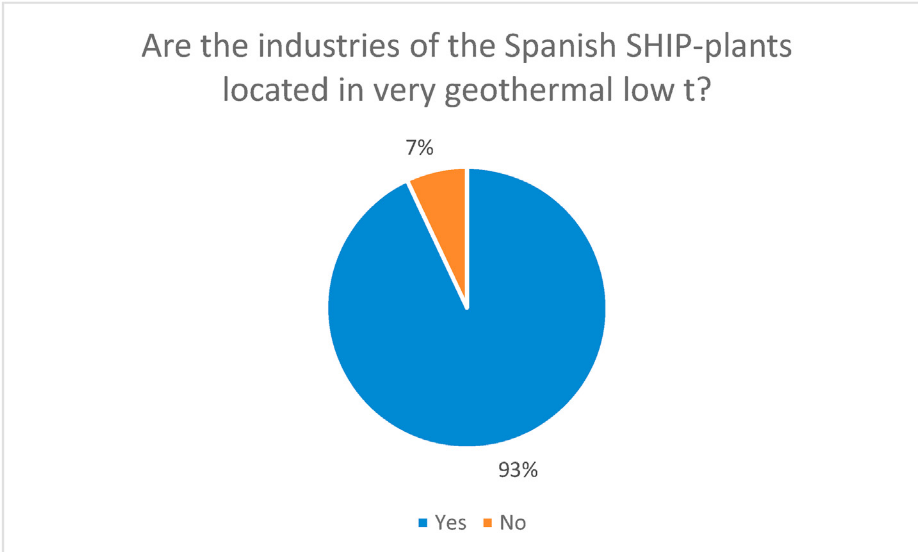

Fig. 10. Percentage of SHIP-plants industries in Spain located in very geothermal low t zone. Source: Adapted from Ref. [53].

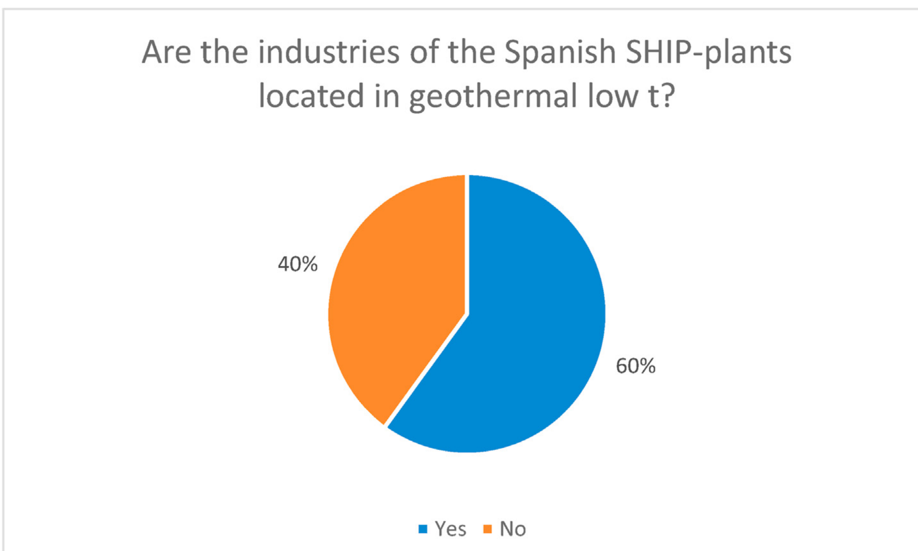

Fig. 11. Percentage of SHIP plants industries in Spain located in geothermal low t. zone. Source: Adapted from Ref. [53].

- Amortization periods of 15 years would be the result of investment in geothermal energy for industrial processes of up to 45 °C. Processes that require higher temperature are discarded because of the high return on investment

3.1. Analysis of the geothermal potential of the SHIP-plants companies in Spain

The Solar Heat for Industrial Processes, hereafter SHIP-plants reflects world-wide a database for integration of solar heat in industrial processes [53].

As a complement to the article presented at national level, it will be analyzed from a practical point of view if the mentioned Spanish plants belonging to the world-wide SHIP-plants and that were once fed with solar energy for their industrial processes, are located in areas of geothermal interest as well.

The SHIP-plants database was created within the framework of IEA Task 49/IV [54]. This online database provides a world-wide overview of solar thermal plants that supply thermal energy to production processes for different industrial sectors. Each plant contains a range of information on the field of collector size, collector technology or point of integration into the production process [53].

In the case of Spain, 17 companies are known to belong to this database (of which only 15 will be analyzed) as of March 15, 2020 (it is a dynamic database that continuously incorporates companies).

Appendix F (Analysis of the 15 companies of the Spanish SHIP-plants) reflects information on these plants and the corresponding geothermal calculations.

The results obtained from the industrial processes that take

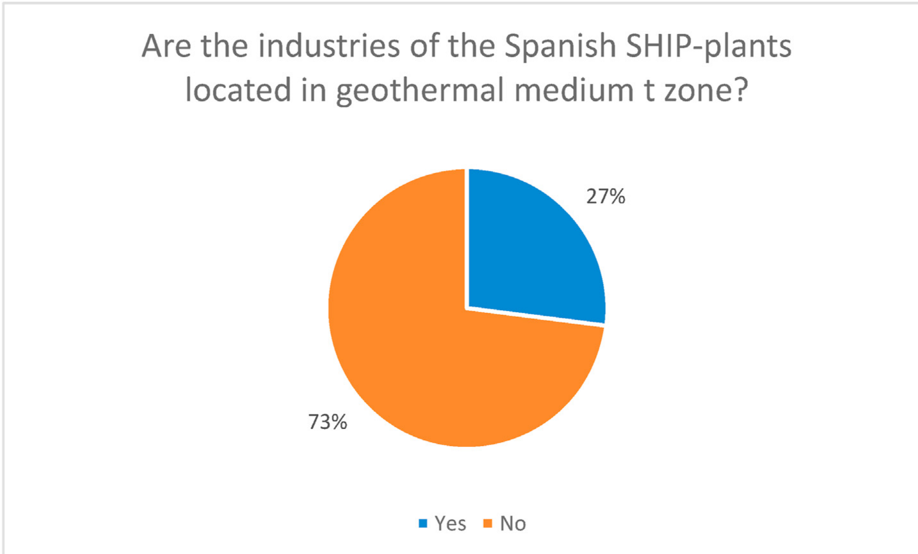

Fig. 12. Percentage of SHIP-plants industries in Spain located in a geothermal medium t zone. Source: Adapted from Ref. [53].

place in the 15 cases studied of the SHIP-plants industries are the following:

- In 10 out of 15, representing 67% of the cases, the geothermal resource can be used and it seems even more convenient than the current solar resource as shown in Table M.2 (Appendix F, analysis of the 15 companies of the Spanish SHIP-plants)) and Fig. 8.
- Of the ten cases in which it would apply to use very low t geothermal in some range of its industrial process, eight out ten have a lower geothermal cost than solar, Fig. 9. (Table M.2, Appendix F, analysis of the 15 companies of the Spanish SHIP-plants). Furthermore, considering that in most cases the solar fraction does not exceed 50% [53] compared with the availability of 100% of the geothermal resource then, the geothermal cost is always lower.
- With respect to the location of the 15 industries, only one has geothermal extraction power below 60 W/m [2], i.e. 14 of the 15 industries, which means that 93% are in areas of interest for the application of very low temperature geothermal energy. The temperatures range obtained between 20 °C and 30 °C by direct heat use or up to 45 °C-50 °C by use of a GHP (See Fig. 10). Making the analogy with the general article, it can be seen in the business criterion that 90% of the concentration of companies per municipality were in areas with extraction powers above 60 W/m.
- With respect to those located in low temperatures zones, nine, that is, 60% of the industries (see Fig. 11) there are in areas where t could be obtained at a certain depth, which normally varies between 500 m and 3000 m, of up to 100 °C. In the general study, the six AACCs with the best business criterion all have low temperature resources.
- With respect to those located in the area of medium temperature, it can be seen that there are four, i.e. 27%. In these areas, at the appropriate depth, up to 150 °C it could be obtained (see Fig. 12). In the general study, half of the most industrialized regions (three AACCs) have medium temperature resources.
- With regard to those located in high t zone, we find that there is none. Neither in the general study are they located in a high geothermal temperature zone.
- Analyzing the ten cases in which it would apply very low t geothermal resources in some range of its industrial process, it could obtain saving of 445 751€ for all 10 plants (calculations in table M.2, column 20, Appendix F, analysis of the 15 companies of the Spanish SHIP-plants). Therefore, the geothermal investment would have been 18% cheaper than the solar already made in these plants.

4. Conclusions

Being able to feed clean energy like geothermal energy into a country's industrial consumption is a challenge. Thinking about geothermal energy beyond domestic use is a necessity, and this study has shown that it is a reality when evaluating the industrial energy consumption of an entire country like Spain with this resource.

Industrial processes of up to 45 °C are the most suitable for utilizing geothermal energy given the terrain in Spain and the development and economic potential of certain geographical areas. Six regions out of 17 in Spain are the most logical to meet this challenge. In this range are the processes related to washing and preheating in the industry in general but also in the food, beverage and textile industry, as well as galvanizing processes in the metal and automotive industry and drying processes in the wood and paper industry. Acting on these industries from regional governments to promote geothermal energy is a duty.

Industrial processes that require higher temperatures have longer payback periods due to the use of geothermal energy. On one hand, Spain does not have much high enthalpy geothermal territory but on the other hand, the costs associated with deeper drilling remain quite high world-wide and in Spain too. A greater competitiveness in the market by a greater number of companies dedicated to the exploitation of this resource would foreseeably reduce its costs. The demand from larger consuming powers or conglomerates of industries with higher energy needs would then justify such investment in deeper drilling. A change of paradigm in the business energy model with shared energy costs is presented as an alternative to the current model.

Using previous studies carried out in each area and/or investing in a thermal response test, TRT [55], to better understand the terrain and thus be able to evaluate the real costs of drilling is also a prerequisite.

A good communication in the exploration phase between geothermal companies and local communities is also essential for the success of the project [56].

Fifteen industries in Spain were chosen to verify the results of the study.If these industries were fed with geothermal energy in some temperature ranges, a saving of 18% would be obtained with respect to the use of solar energy. The results are really relevant because savings are obtained by comparing it with solar energy. It further justifies the implementation in all Spanish industry conditioned by non-renewable energy sources in their majority [1].

An extension of the local study is perfectly possible at a global level since the three criteria defined and the connection between the local geothermal resources available with their temperature ranges and those of the industrial processes would be applicable. Similarly, extrapolation to all industries in the global SHIP-plant is possible and desirable.

CRediT authorship contribution statement

Elisabet Palomo-Torrejón: Data curation, Writing – original draft, Simulation. **Antonio Colmenar-Santos:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Enrique Rosales-Asensio:** Conceptualization, Writing – review & editing. **Francisco Mur-Pérez:** Conceptualization, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.renene.2021.04.074.

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ANEXO VIII "Economic and environmental benefits of geothermal energy in industrial processes". FACTOR DE IMPACTO DE LA PUBLICACIÓN

- Factor impacto año 2020: 8,001
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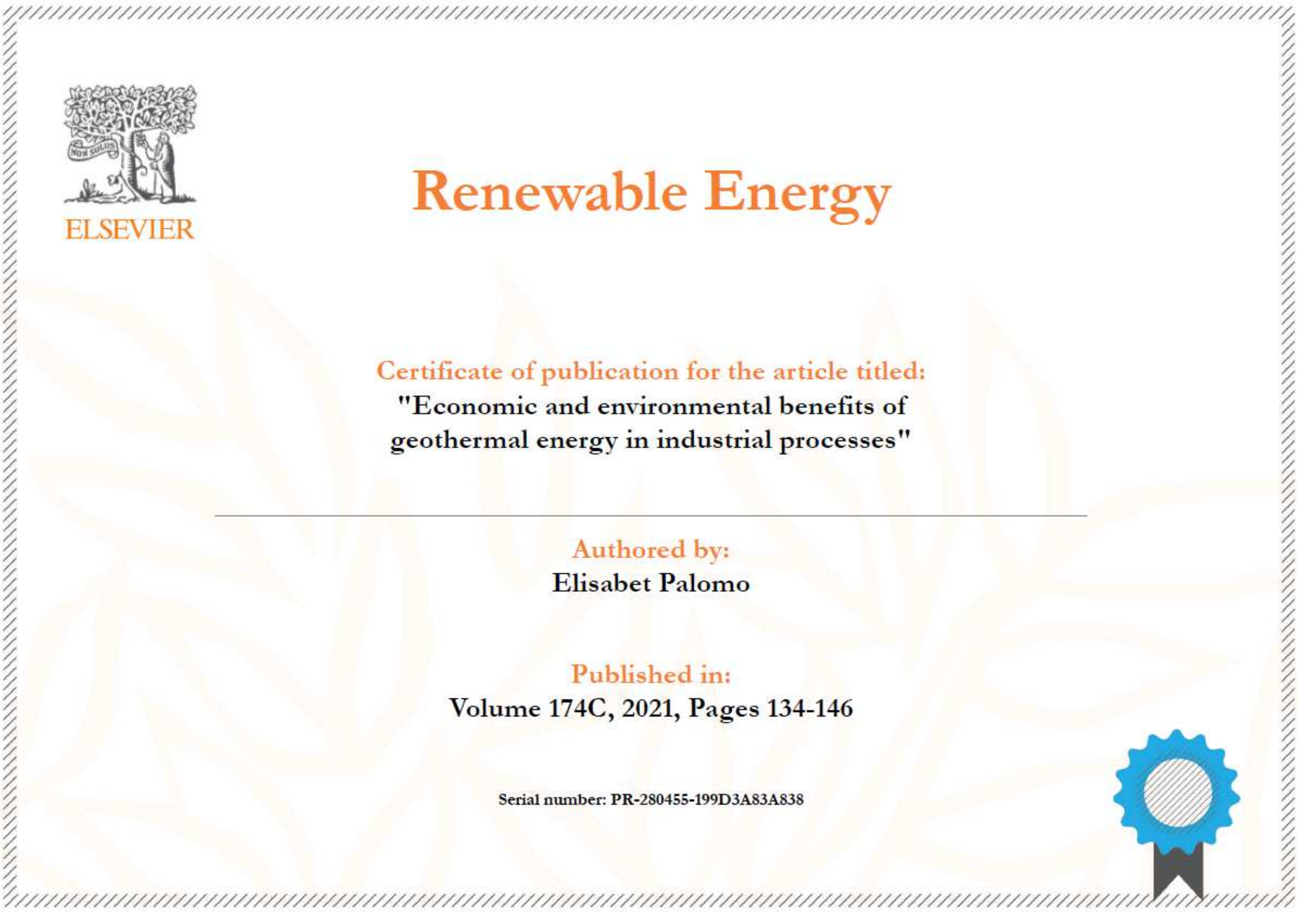
ANEXO IX "Economic and environmental benefits of geothermal energy in industrial processes". CERTIFICADO DE LA PUBLICACIÓN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