Tesis Doctoral

Programa de Doctorado en Ingeniería de Producción y Computación, Universidad de León

Evaluación de la viabilidad y desarrollo de la innovación de sistemas energéticos híbridos para la desalinización: Una aplicación a las pequeñas y medianas empresas

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A mi familia

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Francisco José García Moya

León, 2022

Resumen

El sector energético ha sido, es y será esencial para el desarrollo de las sociedades. Actualmente las tecnologías de generación de energía renovable se convierten en elemento clave para un diseño sostenible de estas, y no solo por el hecho de que permitan generar energía con menor impacto medioambiental que las tecnologías tradicionales basadas en fuentes de energía primaria fósil.

La presente Tesis Doctoral se centra en analizar la factibilidad de sistemas innovadores híbridos en plantas desaladoras, desde un punto de vista técnico, económico. A partir del análisis de los sistemas se estudian las sinergias entre los sectores del abastecimiento de agua, de comida, y generación de energía en sistemas que necesitan de plantas desaladoras para el abastecimiento de agua. Dada la gran dimensión de estos sectores, un incremento en el conocimiento de su gestión sostenible permitirá diseñar una gestión integrada de recursos que reduzca el impacto medioambiental. Aquellos incluyen la definición de las sinergias, la evaluación de las principales herramientas que se emplean para la ordenación y la contabilidad de estas sinergias.

Así pues, el principal objetivo del trabajo de investigación de esta Tesis es contribuir al conocimiento sobre el desarrollo integrado y sostenible de estos sectores a través del análisis de un sistema con escasez de agua. Con este objetivo, las líneas de investigación incluyen tanto trabajo de campo y pruebas de laboratorio, procesamiento experimental y de simulación y diferentes tareas informáticas que permitan aclarar la factibilidad de la innovación propuesta en esta Tesis.

Desde la identificación inicial de las variables que definen sinergias, los esfuerzos se han centrado en la realización de una extensa revisión del estado de arte y trabajo de campo. Posteriormente, los trabajos experimentales han sido reforzados mediante el empleo de herramientas informáticas y software específico que han permitido completar los estudios prácticos y teóricos. Se espera que las conclusiones fruto de la investigación presentada en esta Tesis puedan contribuir al desarrollo de la investigación sobre sostenibilidad de sectores los futuro más óptimo. En conclusión, la Tesis Doctoral presentada alberga información valiosa, que ha sido compilada a través de diferentes trabajos científicos, que incluyen todo el saber hacer y la experiencia adquirida durante la etapa de investigación.

Abstract

The energy sector has been, is and will be essential for the development of societies. In particular, renewable energy generation technologies become a key element for the sustainable design of these, and not only because they allow energy to be generated with less environmental impact than traditional technologies based on fossil primary energy sources.

This Doctoral Thesis focuses on analyzing the feasibility of innovative hybrid systems in desalination plants, from a technical and economic point of view. Based on an analysis of the systems, the synergies between the sectors of water supply, food, and energy generation in systems that need desalination plants for water supply are studied. Given the large dimension of these sectors, an increase in the knowledge of their sustainable management will allow the design of systems with integrated resource management with less environmental impact. These include the definition of synergies, the evaluation of the main tools used for management and the accounting of these synergies.

Thus, the main objective of the research work of this Thesis is to contribute to the knowledge on the integrated and sustainable development of these sectors through the analysis of a system with water scarcity. With this objective, the lines of research include both field work and laboratory tests, experimental and simulation processing and different computational tasks that allow to clarify the feasibility of the innovation proposed in this Thesis.

From the initial identification of the variables that define synergies, efforts have been focused on an extensive review of the state of the art and field work. Subsequently, the experimental work has been reinforced by the use of computer tools and specific software that have allowed the completion of practical and theoretical studies. It is hoped that the conclusions drawn from the research presented in this thesis can contribute to the development of research on sustainability of sectors in the most optimal future. In conclusion, the Doctoral Thesis presented contains valuable information, which has been compiled through different scientific works, including all the know-how and experience acquired during the research stage.

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Nomenclatura

An	Consumo de los equipos
BBDD	Base de datos
CCC_T	Central de ciclo combinado
CO_{2-eq}	Dióxido de Carbono equivalente
COW	Coste de agua
CRF	Factor de Recuperación de Costes
DAFO	Debilidades Amenazas Fortalezas Oportunidades
DEM	Modelo de elevación digital
DRES	Fuente de energía renovable distribuida
E	Energía
EB	Balance energético
$Egen_n$	Energía Generada por el sistema de generación renovable n
ET_n	Potencia Generada por la Turbina Hidráulica n
FDW	Flujo de agua desalada
FTCE	Flujo para un sistema para controlar la energía
FTSE	Flujo para almacenar energía
FTWn	Flujo de agua n para un sistema externo
GEI	Gases de efecto invernadero
GWh	Giga Wattios Hora
H_n	Altura n
I_{eff}	Tasa de Inversión Efectiva
J	Julios
KPI	Indicador clave de rendimiento
$L \rightarrow E$	Tierra para energía
LCOE	Coste nivelado de la energía
Ln	Nivel de los Depósitos
m^3	Metros cúbicos
MEF	Destilación multiefecto
MTD	Mejores Técnicas Disponibles
MW	Megawatios
N	Necesidades de Agua

ODS	Objetivos de Desarrollo Sostenible
OI	Osmosis inversa
PC_E	Precio de Compra de Energía Eléctrica
P_{gen}	Potencia generada por el sistema de generación de electricidad
PHS	Almacenamiento de energía por bombeo hidráulico
P_n	Potencia Nominal
P_T	Potencia
PV_E	Precio de Venta de Energía Eléctrica
PVH	Precio de Venta del Recurso Hídrico
ROI	Retorno de la inversión
SIG	Sistema de información geográfica
tCO_2	Toneladas de CO_2
UBR	Almacenamiento inferior de agua
URS	Almacenamiento superior de agua
VC	Compresión de Vapor
$W \rightarrow E$	Agua para energía
$W \rightarrow F$	Agua para alimentos
WEF	Agua-Enegía-Alimentos

1 INTRODUCCIÓN

"Satisfacer las necesidades actuales sin comprometer la capacidad de las futuras generaciones para satifacer las suyas."

Brundtland Commission

Este primer capítulo introduce el marco teórico general en el que se circunscribe la investigación llevada a cabo en esta Tesis Doctoral. A continuación, se presenta la motivación que ha impulsado la realización de este trabajo, así como los objetivos generales que se marcan. Así mismo, se presenta la modalidad de presentación de este trabajo, así como las publicaciones que comprende la misma. Este capítulo introductorio termina presentando la estructura de la Tesis Doctoral, realizando una descripción de los temas tratados en cada capítulo y que conforman las diferentes líneas de investigación que se han seguido, resultando en la publicación de los artículos que han conformado este trabajo doctoral.

1.1 Marco teórico en esta Tesis Doctoral

Entre los logros que ha propiciado el desarrollo tecnológico debe destacarse la contribución al incremento del nivel de calidad de vida, especialmente durante los dos últimos siglos. Gracias a este desarrollo, las sociedades modernas se han beneficiado de más bienes, productos y servicios. Entre estos destaca facilitar el acceso a alimentos y agua para la población mundial. Esta situación de marcado y constante desarrollo, unido al incremento de la población en un mundo cada vez más globalizado ha generado una presión creciente sobre los recursos, siendo las fuentes de energía primaria de carácter no renovable un claro ejemplo. Entre las fuentes de energía de origen fósil destacan el carbón, el petróleo o el gas. El uso de las tecnologías para su aprovechamiento como vector energético provocan efectos medioambientales negativos asociados principalmente a las emisiones de gases de efecto invernadero, lo que a su vez induce efectos negativos a escala local, regional y global.

Es especialmente importante en las sociedades actuales afrontar la preocupación por satisfacer las necesidades de alimentación puesto que se ha llegado a un punto en el que la capacidad del planeta para satisfacer la necesidad de recursos se ve comprometida. Este hecho es especialmente acuciante en ciertas regiones debido a la escasez de recurso hídrico, lo que complica en gran medida el desarrollo de las sociedades en los mismos. Esto ha provocado tanto un reto tecnológico, como una creciente preocupación sobre cómo paliar los efectos negativos que las necesidades crecientes en las sociedades provocan. Para conseguir unos estándares aceptables de acceso a alimentos y agua en un contexto de creciente preocupación medioambiental comprender cómo se relacionan los subsistemas que proveen agua-energía-comida es necesario para minimizar los efectos negativos.

El estudio de las sinergias entre los sectores implicados en proveer agua, energía, o comida a las sociedades permitirá identificar los elementos sobre los que se puede incidir para optimizar el uso de estos, y más dada la fuerte interelación entre dichos sectores. Una planificación interconectada y sostenible es indispensable para rebajar la presión sobre los recursos de los que depende la humanidad. En las Islas Canarias, con sistemas energéticos tradicionales altamente dependientes de los sistemas de combustión basados en combustibles fósiles, se están incorporando sistemas energéticos inteligentes a través de sistemas eléctricos híbridos. La isla de Gran Canaria presenta unas características climáticas, físicas, sociales y económicas particulares. Debido a este hecho, el sistema energético de generación de electricidad, y en particular, el sistema de almacenamiento de energía que soporta el sistema de generación de electricidad basado en energías renovables, debe ser diseñado de acuerdo a sus características específicas. Sin embargo, esta Tesis Doctoral propone los sistemas de almacenamiento de energía de bombeo, permite la transferencia de conceptos y experiencias entre los pequeños sistemas de energía.

El desarrollo que se realiza en los siguientes capítulos realiza un análisis enfocado en la investigación de las sinergias que aparecen dentro del sistema de recursos agua-energía-comida. Para analizar estas sinergias, y cómo estos se influyen de forma bidireccional será necesario acometer investigación relacionada tanto con las estrategias energéticas y actividades de alto consumo de energía. Mediante la innovación propuesta en esta Tesis doctoral se trata de mejorar la integración de las energías renovables de generación de electricidad en plantas desaladoras de tamaño pequeño y medio sin olvidar realizar un análisis de su competitividad económica en el mercado liberalizado.

1.2 Objetivos de la Tesis Doctoral

El principal reto de esta tesis doctoral consiste en desarrollar la investigación existente en el área de optimización de recursos en las sociedades para permitir un desarrollo sostenible. Esta tesis doctoral investiga las sinergias que existen entre los sistemas de recursos agua-energía-comida, y pone el foco en un área amenazada por escasez de agua. Por ello es de vital importancia proponer indicadores de sostenibilidad en los sistemas que permitan comparar las diferentes estrategias pueden adoptarse. Especialmente se pone el acento en el diseño de indicadores para modelizar como afectan las diferentes estrategias energéticas sobre el recurso agua y las emisiones de gases de efecto invernadero. Se analizan las consecuencias que tendría sobre un sistema cerrado, una isla en este trabajo, la amplia implantación de tecnologías de generación de electricidad a partir de fuentes de energía renovable con indicadores de sostenibilidad y de interconexiones entre sistemas.

La presente tesis doctoral pretende ahondar en la investigación de la factibilidad de sistemas híbridos de energía que incorporen un sistema de almacenamiento energético que mitigue el problema de intermitencia que las energías renovables tienen en lo que respecta a su aplicación a plantas desaladoras de tamaño pequeño y mediano. Esto se lleva a cabo tanto desde un punto de vista tecnológico, con objeto de evaluar realización técnica, como económico para investigar su posible viabilidad económica.

Esta tesis doctoral presenta una visión innovadora para gestionar el doble recurso agua-energía renovable implementando un esquema de gestión inteligente del recurso agua-energía que maximice el beneficio de la gestión combinada de ambos. Entre los retos tecnológicos que la presente Tesis Doctoral enfrenta destaca el encontrar una forma de gestión combinada de los recursos que maximice el beneficio del esquema propuesto como modelo de negocio. Por ello, otro de los objetivos principales de los trabajos realizados en la presente tesis será proveer un marco de decisión que evalúe la factibilidad de la introducción de un sistema híbrido que mejore la gestionabilidad del doble recurso agua-energía en una región donde la gestión inteligente de estos recursos es especialmente necesaria; así como proponer un sistema de decisión para gestionar el doble recurso agua-energía.

Los indicadores de éxito que se proponen en los siguientes capítulos se clasifican en tecnológicos, medioambientales, prácticos, económicos y de mercados que pretenden dar respuesta a cuestiones sobre cómo afectaría la implantación de un sistema de energía híbrido que alimente a plantas desaladoras de tamaño pequeño y medio. Entre los retos enfrentados a la hora de la implantación de un modelo de negocio en un mercado, otro objetivo será analizar bajo qué supuestos un modelo de negocio sería económicamente rentable. Para aprovechar al máximo los beneficios de un esquema debe revisarse la viabilidad económico-financiera por un lado y la maximización del beneficio en la región objeto de estudio.

1.3 Modalidad de Presentación de esta Tesis Doctoral

Esta Tesis Doctoral se presenta como un compendio de artículos científicos publicados en revistas internacionales de alto factor de impacto. Tal y como especifica la normativa de la escuela de doctorado de la Universidad de León, estos artículos deben albergar una relación temática según una, o varias líneas de investigación.

1.4 Publicaciones que se abordan en esta Tesis Doctoral

Los artículos científicos que conforman esta tesis doctoral han sido publicados en revistas internacionales de alto factor de impacto tal y cómo se detalla en el capítulo 7. El título de las mismas es:

- Water Energy Food Nexus Analysis and Management Tools: A Review[1].
- Decision-making tools for sustainable planning and conceptual framework for the energy-water-food nexus [2].
- Comprehensive assessment of gran canaria water-energy-food nexus with gis based tool [3].
- Stress Mitigation of Conventional Water Resources in Water-Scarce Areas through the use of Renewable Energy Powered Desalination Plants: An Application to the Canary Island [4].
- Feasibility Analysis of Wind and Solar Powered Desalination Plants: An Application to islands [5].

1.4.1 Relación entre las publicaciones

Las dos primeras publicaciones que componen el Capítulo 2 abordan el análisis del estado del arte de la investigación acerca del nexo entre los sectores agua-energía-comida, su definición y ordenamiento, y propone índices de medición basados en indicadores.

Por su parte, en el Capítulo 3, compuesto por los dos siguientes artículos, se realiza un análisis que facilite la implementación de energías renovables para reducir la escasez de agua mediante desalación por osmósis inversa en regiones amenazadas de sequía a la vez que se comprueba mediante indicadores si se aumenta la sostenibilidad de los sistemas gracias a una mejor ordenación de los recursos. Para ello hace uso de sistemas de información geográfica para la localización de los mejores emplazamientos, y de herramientas de optimización para el dimensionamiento de plantas de tamaño pequeño-mediano.

Se continúa en el Capítulo 4 investigando la factibilidad tecno-económica de soluciones híbridas con diferentes tecnologías de desalación, así como el desempeño de las mismas en el mercado.

Para finalizar, el Capítulo 5 propone un esquema patentable para el control optimizado del agua desalada y del sistema de energía energía híbrido en un entorno de múltiples entradas y salidas de ambos recursos.

1.5 Estructura de la Tesis Doctoral

La presente tesis doctoral incluye 5 artículos científicos publicados en revistas internacionales de alto factor de impacto, un esquema patentable para el aprovechamiento del agua y la energía, así como anexos correspondientes, así como un capítulo de validación para presentar las actividades realizadas durante los trabajos de la misma.

En el Capítulo 2 se realiza una revisión de las herramientas que se dedican al análisis de la relación entre los sectores del agua y de la comida, en su conexión con el sistema de generación de energía. Se revisan desde un punto de vista de su integración conjunta. A continuación, el Capítulo 3 particulariza sobre la isla de Gran Canaria el análisis de la conexión de los mencionados sectores con diferentes estrategias de desarrollo del sistema de generación de energía electricidad. Esta región presenta los problemas asociados a la escasez tanto de recurso hídrico como de porcentaje de tecnologías renovables en el parque de generación de electricidad por lo que se particulariza para varios sistemas energéticos que introducen, además de la implantación renovable, los necesarios sistemas para la gestionabilidad del recurso. Se continúa realizando el diseño optimizado de un sistema híbrido solar-eólico combinado con una planta desaladora en la región específica de Arinaga, en la isla de Gran Canaria, que arroja unos resultados prometedores de reducción de costes de la energía y del agua cuando se instala en esta región de características particulares.

Por su parte, el Capítulo 4 se centra en realizar un análisis de la supervivencia económico-financiera comparando plantas desaladoras de dos tipos de tecnologías, osmosis inversa, y una tecnología de destilación novedosa, y que usan energías renovables en su actividad, bajo diferentes supuestos de actividad subvencionable, y de rendimiento de sus actividades comerciales. El Capítulo 5 presenta un esquema patentable para la gestión del doble recurso agua-energía en plantas desaladoras que abastecen tanto a población como a riego.

En el Capítulo 6 se exponen las conclusiones de los resultados de la investigación acometida durante los trabajos de esta tesis y se proponen sugerencias y futuros desarrollos relativos a la misma; y se recoge la bibliografía consultada durante los trabajos conducentes a la elaboración de esta tesis doctoral. A continuación, en el Capítulo 7 se muestran los elementos validadores para la modalidad esocogida en esta Tesis Doctoral por compilación de artículos científicos. Por último, se proporcionan anexos con información que complementa los resultados obtenidos durante los trabajos de la misma.

1.5.1 Organización de la Tesis Doctoral

Esta Tesis Doctoral se organiza en 7 capítulos (ver Figura 1.1) entre los que se incluyen 5 artículos científicos publicados en revistas internacionales de alto factor de impacto, y un capítulo de validación para presentar las actividades realizadas durante los trabajos de la misma.

Figura 1-1 Evaluación de herramientas acciones sobre el Nexo

Capítulo 1: Introducción al contexto general del tema que se aborda en esta Tesis doctoral, y objetivos perseguidos en su redacción. Además, se presenta la metodología seguida tanto para su redacción, como la empleada en el proceso de investigación.

Capítulo 2: En este segundo capítulo de título: "Revisión de herramientas para análisis de sostenibilidad de sistemas combinados Agua-Energía-Alimentos" se aborda el estudio de las diferentes herramientas y puntos de vista que existen para el estudio y modelización de las sinergias y de la relación costo-beneficio existente desde el punto de vista económico y medioambiental. Se incluyen en este capítulo dos publicaciones científicas. La primera, el artículo: *"Water Energy Food Nexus Analysis and Management Tools: A Review"* hace una revisión de las principales herramientas empleadas para realizar el ordenamiento de sistemas de agua-energía-comida desde una perspectiva de sostenibilidad de sistemas.

La segunda publicación que forma parte de este segundo capítulo es: *"Revision of Decision/Making Tools for Sustainable Planning and Proposal of a Novel Conceptual Framework for the Energy-Water-Food Nexus"* en la que se trata de realizar un análisis de los elementos básicos que deben tenerse en cuenta a la hora de formar indicadores que permita contabilizar la sostenibilidad de los sistemas. Esto se lleva a cabo a base de definir las relaciones entre estos subsistemas vinculados para investigar sus sinergias. La gestión inteligente de los recursos en las islas es una cuestión importante debido a su carácter aislado.

Capítulo 3: "Energía Renovable como catalizador de sinergias en sistemas con alto riesgo de escasez de agua" tiene en cuenta indicadores de sostenibilidad para investigar la isla de Gran Canaria, territorio con alto riesgo de escasez de recurso hídrico. Este capítulo se compone de las siguientes publicaciones: La primera: *"Comprehensive assessment of Gran Canaria water-energy-food nexus with GIS based tool"* es una publicación en la que la que un sistema con alto riesgo de escasez de agua se analiza para localizar, según unos indicadores previamente fijados, los emplazamientos más prometedores para implementar una estrategia de almacenamiento energético y de agua que permita mitigar la pobreza energética y de agua bajo la perspectiva de la sostenibilidad de los sistemas.

El siguiente artículo que forma parte del Capítulo 3: *"Stress mitigation of conventional water Resources in Water-Scarce areas through the use of Renewable Energy Powered Desalination Plants:*

An application to the Canary Island” estudia el dimensionamiento de plantas híbridas desaladoras poniendo el foco en investigar si estas plantas híbridas podrían proporcionar una forma sostenible de afrontar y paliar el estrés hídrico que se espera en una región del sistema analizado en el previo artículo.

Capítulo 4: “Análisis de la factibilidad de sistemas energéticos híbridos para plantas desaladoras”. Este capítulo investiga el desempeño de las plantas híbridas cuando funcionan en un mercado concreto de electricidad y agua con objeto de comprender la posible supervivencia económico-financiera de las plantas híbridas desaladoras.

Capítulo 5: Sistema para el control de agua y energía. En este capítulo se pretende dar respuesta al objetivo tecnológico que esta tesis se marca, proponiendo un sistema que permita maximizar tanto la energía renovable generada en el sistema híbrido como el recurso hídrico.

Capítulo 6: Este capítulo se ha resevado para presentar las conclusiones, sugerencias y el desarrollo futuro que se desprende de las líneas que se han seguido durante los trabajos que han conducido a esta Tesis.

La presente tesis doctoral termina presentando en el Capítulo 7 los elementos validadores, siguiendo la normativa de la Universidad de León, e incluye artículos, presentación de trabajos en conferencias internacionales, libros, o capítulos.

2. Revisión de herramientas para el análisis de sostenibilidad de sistemas combinados Agua-Energía-Alimentos

Según vamos adquiriendo conocimiento, las cosas no se hacen más comprensibles, sino más misteriosas.

Albert Schweitzer

Si definimos como un sistema al conjunto de las necesidades básicas de inputs, y outputs de los subsistemas que abastecen a los subsistemas agua, energía, y comida, el conocimiento acerca de cómo se encuentran conectados los mismos así como sus sinergias e interrelaciones es indispensable para permitir el diseño de sistemas más eficientes y sostenibles.

No en vano, tanto dentro de los objetivos del desarrollo del milenio [6], como en 3 de los 17 objetivos marcados por Naciones Unidas para un desarrollo sostenible [7], se pone el acento en el desarrollo sostenible de los sectores de la energía, el agua, y la comida. Dada la cantidad, y complejidad de las sinergias que se establecen entre estos sectores a diferentes niveles y en mayor o menor grado, en función de muchos factores, el conocimiento del del sector de la investigación dedicado modelización de las interacciones, sinergias e intercambios entre los sistemas de agua-energía y comida es indispensable para facilitar el diseño de sistemas para un suministro estable y sostenible de agua y alimentos.

Este capítulo incluye dos artículos que se encuadran dentro de la línea de investigación dedicada al conocimiento de la modelización de las interacciones entre los subsistemas que forman parte del nexo objeto de la presente tesis doctoral. El primer artículo analiza tanto los aspectos cuantitativos como cualitativos que los distintos enfoques y herramientas proponen. Por su parte, el segundo artículo se fija en los aspectos cuantificables de los intercambios y sinergias con objeto de modelizar las interacciones que los diferentes planes de energía provocan en los sistemas del nexo. La investigación para la mejora de la caracterización de la modelización de las interacciones entre los subsistemas que forman parte del nexo se ha llevado a cabo mediante la aplicación de técnicas metodológicas de análisis. Éstas consisten en analizar cómo las herramientas definen y modelan estas relaciones y a partir de ellas proponer estrategias que resuelvan el problema de la ordenación de los recursos. El uso de estas técnicas de investigación permite poner en valor las diferentes estrategias tomadas para resolver las cuestiones del nexo.

A continuación, se expone una breve descripción de las técnicas utilizadas en cada artículo:

2.1. Resúmen del artículo *“Water Energy Food Nexus Analysis and Management Tools: A Review”*

En el artículo 1: *“Water Energy Food Nexus Analysis and Management Tools: A Review”* se identifica el problema relacionado con el nexo; analizando el incremento de producción necesario para satisfacer las crecientes necesidades de alimentación, así como la competencia por recurso de los biocombustibles, todo ello dentro de un escenario de amenaza de escasez de los mismos. Para realizar el análisis de estos subsistemas se identifica tanto los actores involucrados como los distintos elementos que definen la modelización del problema.

Este artículo analiza cómo los diferentes modelos sobre el nexo abordan el problema de asignación de recursos. Para ello realiza una amplia revisión de los métodos y herramientas más importantes, ya sea a nivel cuantitativo y cualitativo del análisis de sostenibilidad de los sistemas agua-energía y comida. Este análisis se hace necesario para evaluar la factibilidad tecnológica, económica, práctica, o de sostenibilidad de las plantas desaladoras híbridas. Se realiza una evaluación tanto de las herramientas como de las acciones propuestas para analizar la viabilidad tecnológica, económica, de sostenibilidad y práctica de las mismas dentro del nexo, así cómo la identificación de errores de definición, lagunas, éxitos de acciones tomadas, o futuro desarrollo.

La gestión combinada de los sistemas agua-energía-comida involucra a los responsables de la toma de decisiones: empresas, gobiernos, habitantes en escenarios a corto, medio y largo plazo para que el aprovechamiento sea rentable y sostenible en el tiempo. En la Tabla 2.1 en la siguiente página se lleva a cabo una revisión del alcance de las principales herramientas existentes que acometen el análisis del nexo entre los sistemas agua-energía-comida. Así mimo, también las Tablas A.01 y A.02 (Apéndice A) profundizan en el análisis de las herramientas usadas. La Tabla A.01 se ha esbozado para ofrecer una explicación de los problemas asociados a cada una de las herramientas analizadas.

Dada la gran cantidad de sinergias existentes entre estos sectores aparece lógicamente una amplitud de análisis y herramientas que utilizan diferentes puntos de vista, y enfoques para analizar el problema. Por ello, si un criterio no ha sido evaluado para una herramienta concreta, la casilla correspondiente dentro del cuadro en la Tabla A.01 se deja en blanco, y si un criterio ha sido evaluado, la información se incluye dentro de la casilla.

Tabla 2-1 Alcance de herramientas de análisis del Nexo. [8][9][10][11] [2][12][13][14]

Objetivo	Herramienta de Cálculo	Capacidad del modelo
Proyección y análisis de escenarios	WEF Nexus Tool 2.0	Cuantitativo
Previsión y análisis de escenarios, cálculo de índices	CLEWs	Cuantitativo/ Cualitativo
Previsión y análisis de escenarios, cálculo de índices considerando 5 diferentes parámetros	Nexus Rapid appraisal Tool	Cuantitativo
Modelo de análisis y previsión de escenarios	MuSIASEM	Cuantitativo
Predicción de los intercambios de agua, energía y tierra	Foreseer Tool	Cuantitativo
Previsión y análisis de escenarios	WEAP/LEAP	Cuantitativo/ Cualitativo
Previsión y análisis de escenarios	iSDG Planning Model	Cuantitativo/ Cualitativo
Modelos de energía y mitigación del clima	Sustainability Tool	Cuantitativo
Análisis multiindicador	WEF Nexus indicator	Cuantitativo
Análisis de las políticas y las narrativas sobre la gobernanza	QST	Cuantitativo/ Cualitativo

A través de la discusión sobre cuáles son los retos a los que se enfrenta la gestión sostenible de los subsistemas que forman parte del nexo se investiga la viabilidad de las soluciones para aumentar las sinergias entre estos para reducir los impactos sobre el medio ambiente. Dada la diferencia en el reparto de recursos, la escasez de agua, y la cantidad de población que habita en una determinada región, algunas destacan al ser regiones con elevado riesgo de desabastecimiento, especialmente de agua, ante eventos climáticos adversos. La Figura 2-1 presenta la evaluación que este artículo acomete para analizar tanto las herramientas empleadas, como las acciones propuestas desde que comenzó la sensibilidad por impulsar la gestión sostenible en sistemas aislados. Para ello, el artículo pretende analizar diferentes puntos de vista de afectación al nexo: económico, tecnológico, medio-ambiental; y desde el punto de vista de ciudadanos, empresas, y gobiernos.

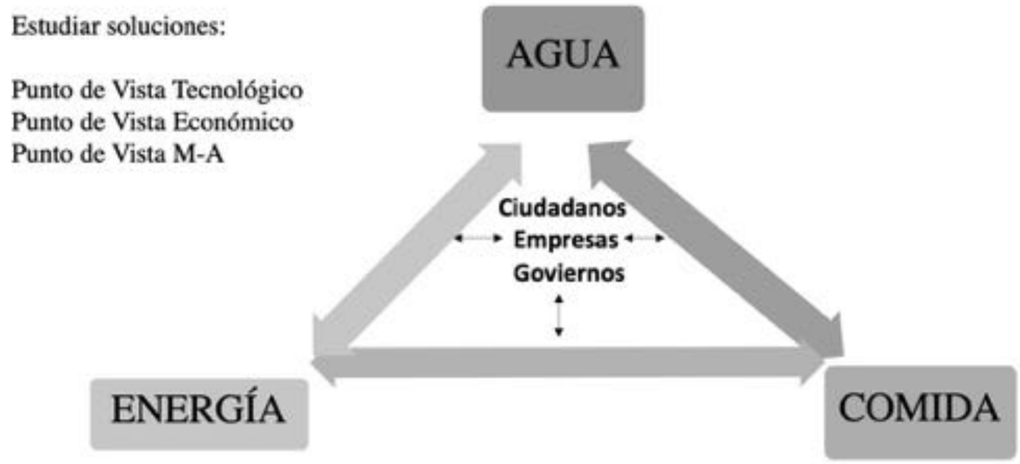


Figura 2-1 Evaluación de herramientas acciones sobre el Nexo

Dado que las herramientas cuantitativas ofrecen la posibilidad de realizar un análisis cuantitativo de información sobre intercambios entre sistemas, se simplifican las acciones de modelizar. Por ello se facilita la evaluación de las políticas y la orientación de las partes interesadas. El aumento de la cantidad de energía procedente de fuentes renovables aportada al sistema energético mundial abre un escenario para la evaluación las consecuencias sobre la sostenibilidad en el nexo de tecnologías energéticas. Las diferentes acciones que potencien las sinergias sostenibles a medio y largo plazo deben ser analizadas con estas herramientas que modelan las interacciones. Estas al menos deben evaluar su desempeño tecnológico, económico o medioambiental a corto, medio y largo plazo. Tras el análisis realizado se identifica como especialmente importante avanzar en las herramientas que permitan desarrollar aspectos cualitativos en cuantitativos con lo que será posible aumentar el grado de definición de sinergias entre sistemas y potenciar los elementos capaces de aumentar las sinergias positivas entre subsistemas. La Figura 2-2 muestra un ejemplo del esquema global para el análisis de propuestas entre los subsistemas agua-energía, o de cómo las acciones tomadas han afectado y cómo se pueden complementar.

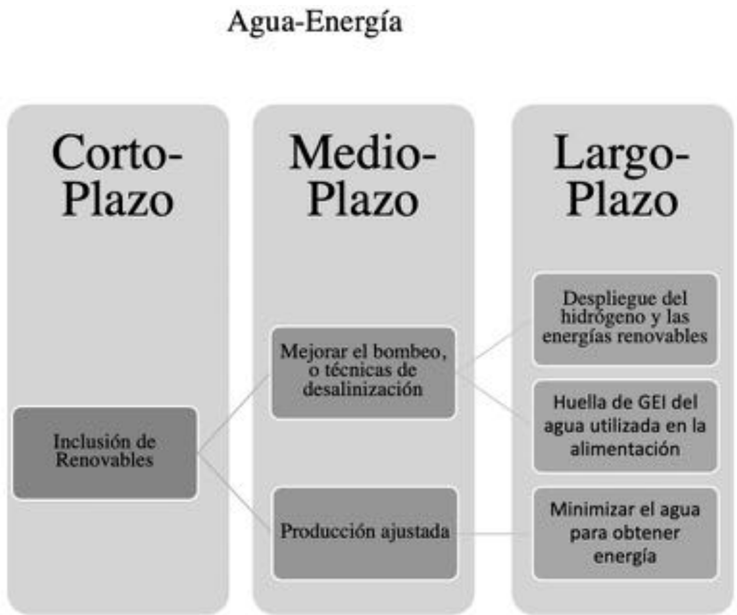


Figura 2-2 Esquema global para el análisis de propuestas-ejemplos.

2.1.1. Abstract en Castellano

"Water Energy Food Nexus Analysis and Management Tools: A Review"

Con el fin de erradicar la escasez de agua-energía-alimentación en las sociedades de hoy día, los Objetivos de Desarrollo Sostenible (ODS) han propuesto hitos para enfrentar el problema de la alimentación. El desarrollo de herramientas y enfoques para el estudio y análisis de la gestión de los nexos agua-energía-alimentación (WEF) ha aumentado durante los últimos años.

El objetivo principal de este artículo es realizar una revisión de los métodos, las herramientas y los ejemplos de gestión sobre análisis del nexo (WEF) para identificar lagunas, objetivos o desarrollo futuro que surgen al modelar los problemas de gestión de los bienes para diseñar un marco de desarrollo sostenible. En concreto se presenta el problema de la competencia entre alimentos y biocombustibles por los recursos, centrándose en los sistemas amenazados por escasez de recurso agua.

Además de la cuestión de la cuantificación de la competencia por los recursos, se propone un análisis para la gestión de los sistemas WEF desde el punto de vista económico, medioambiental y práctico con el fin de identificar los resultados, los retos, las lagunas o los supuestos de los nexos. Los sistemas de energía renovable distribuida destacan como factor capaz de impulsar una gestión combinada y sostenible de estos sistemas.

2.2. Resúmen del artículo *"Revision of decision-making tools for Sustainable planning and proposal of a novel conceptual framework for the energy-water-food nexus"*

Analizando el rendimiento económico, tecnológico, práctico y medioambiental de estas y otras oportunidades se podría evaluar la sostenibilidad de las acciones emprendidas o por emprender. Identificado el potencial de la energía renovable como impulsor para el desarrollo sostenible de subsistemas en el nexo, el artículo 2: *"Revision of decision-making tools for Sustainable planning and proposal of a novel conceptual framework for the energy-water-food nexus"* se centra en analizar el diseño de herramientas cuantitativas para la evaluación del impacto que las diferentes estrategias energéticas basadas en energías renovables pueden tener sobre uno o varios elementos del nexo.

Dado que la mayoría de las decisiones políticas con posibles consecuencias para el nexo entre agua, energía y alimentos se toman a través de diferentes instituciones, este artículo propone un marco de referencia que permita proporcionar a estas instituciones varios elementos de decisión rápida para introducir políticas que afectan colateralmente a estos subsistemas. El marco conceptual propuesto se basa en análisis a partir de balances energéticos de sistema dado son conocidos, ya sea por representar un escenario energético actual o prospectivo basado en las previsiones.

La Figura 2-3 en la siguiente página propone una forma de realizar una estimación de costos de agua, tierra, o emisiones que implicaría adoptar diferentes políticas energéticas evaluadas; concretamente sobre el incremento del consumo en estos recursos.

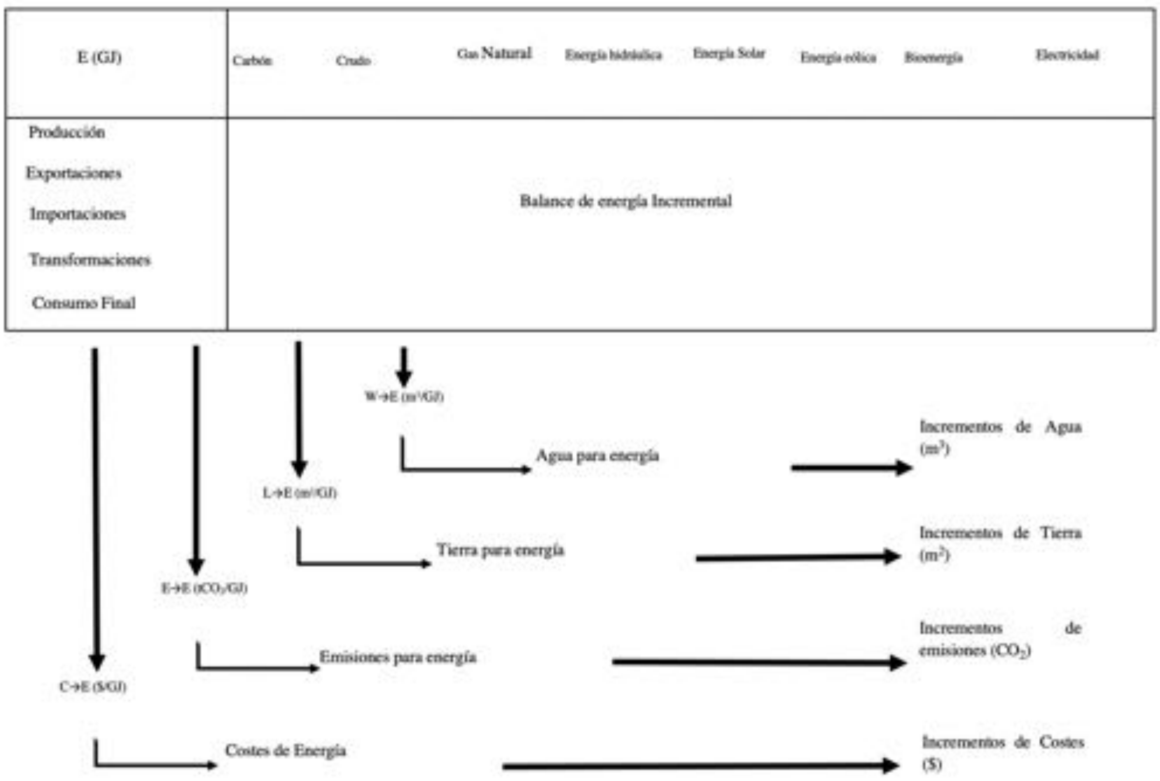


Figura 2-3 Estimación de las implicaciones en costos de agua, tierra, o emisiones para políticas energéticas evaluadas.

La evaluación cuantitativa de distintos planes energéticos permite formarse una idea de las implicaciones que estos planes tienen sobre los recursos agua, tierra, de costes y emisiones de gases de efecto invernadero. Ello permite la elaboración de índices para estiar cada una de estas variables. La agregación de estos índices independientes permite formar un índice de sostenibilidad global del sistema. Este hecho es mostrado en la Figura 2-4, la cual muestra un sistema de información propuesto para legisladores. En función de las características del sistema, o de la importancia relativa dada por estos dentro del sistema, provee a los sistemas políticos una herramienta de evaluación rápida que permite contar con un elemento de decisión adicional para sobreponerse a la dificultad que supone la desconexión en las acciones de planeación.

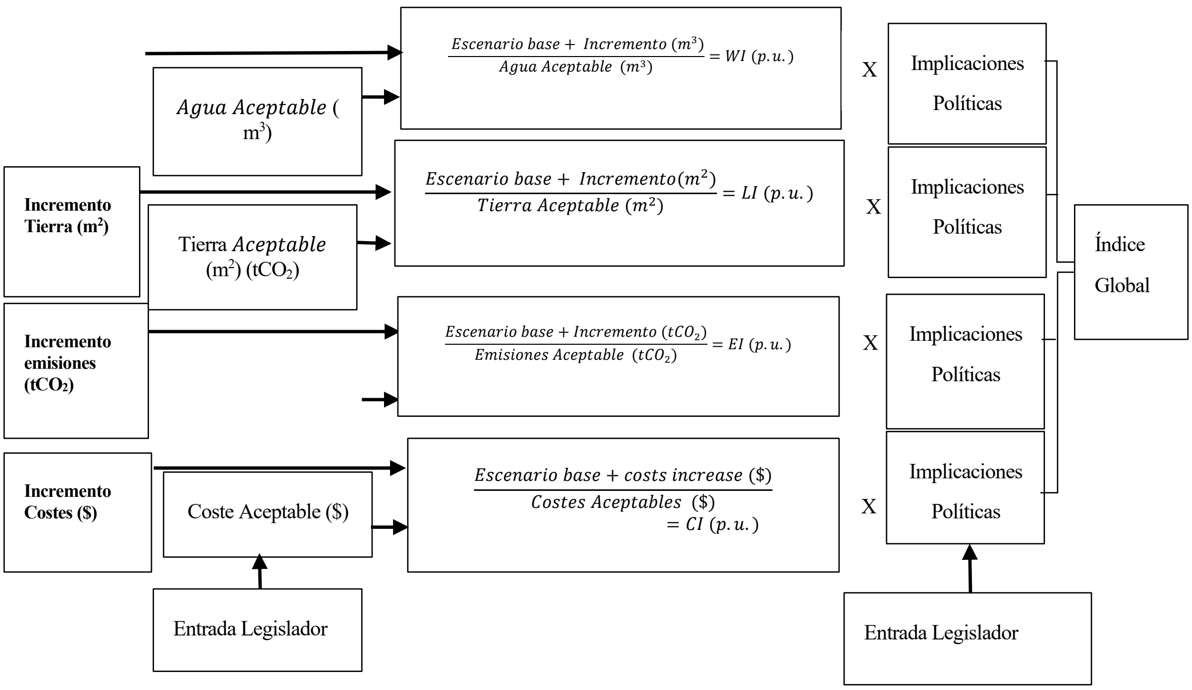


Figura 2-4 Índice de evaluación agregado para sistemas políticos.

Abstract en Castellano

"Revision of decision-making tools for Sustainable planning and proposal of a novel conceptual framework for the energy-water-food nexus"

La evaluación del impacto de las estrategias energéticas, y más concretamente la evaluación de aquellas que promueven un enfoque para la gestión integrada de los recursos en otros sectores tales como son el de abastecimiento de agua y de la alimentación requiere el conocimiento relacionado con la evaluación de la calidad, así como de los conocimientos que pueden ser estimados por medios cuantitativos.

El presente trabajo profundiza en esas necesidades de conocimiento, además de revisar los medios utilizados para obtenerlo, incluyendo los inputs requeridos y los resultados que proporcionan. En respuesta a los problemas de conocimiento reconocidos, este trabajo introduce una estructura básica de referencia que subyace a un sistema para evaluar la forma en que el desarrollo paulatino de las energías inagotables en una región geográfica concreta puede afectar a la demanda de agua y alimentos. En este artículo, el marco conceptual propuesto constituye un enfoque novedoso para los responsables de las políticas energéticas que sólo tienen en cuenta los impactos parciales de la gestión de la energía desde una perspectiva cuantitativa.

Al considerar el nexo entre la energía, el agua y los alimentos, se pueden redefinir las políticas de gestión energética y se deben investigar las diferencias con las políticas actuales.

3. ENERGÍA RENOVABLE COMO CATALIZADOR DE SINERGIAS EN SISTEMAS CON ALTO RIESGO DE ESCASEZ DE AGUA

La energía renovable actúa como catalizador de las sinergias sostenibles entre los sistemas cuando estos hacen uso de esta para proporcionar sus outputs. Este efecto catalizador encuentra gran importancia en los sectores del nexo tales cómo el de abastecimiento de agua, y el de comida potenciándose en, esen sistemas que sufren deescasez de recurso hídrico, y aún más en sistemas aislados. En los trabajos desarrollados en la línea de investigación descrita en este capítulo, se presentan dos artículos. En el primer artículo de este capítulo se presenta y estudia cómo afectan los planes energéticos basados en energías renovables a los índices de sostenibilidad en la región de estudio. Por su parte el segundo artículo se profundiza en la investigación acerca de cómo la energía renovable reduce el stress hídrico en una región concreta, dimensionando y analizando la consecuencia de su implantación sobre los precios de los recursos que las plantas desaladoras híbridas proveen.

A continuación, se expone una breve descripción de las técnicas utilizadas, y los resultados obtenidos en cada artículo:

3.1. Resúmen del artículo: "*Comprehensive assessment of gran canaria water-energy-food nexus with GIS based tool*"

En el primer artículo 1 que forma parte de este capítulo *"Comprehensive assessment of gran canaria water-energy-food nexus with GIS based tool"* se aborda uno de los problemas más importantes desde el punto de vista medioambiental, económico y social: el dimensionamiento del suministro de agua, energía y alimentos, sistemas altamente conectados entre sí. Igualmente se aborda el análisis de la mitigación de los problemas derivados de su operación gracias a una gestión combinada de los recursos en un sistema. Dada la situación de partida de la región de estudio, con altos precios de la energía y con problemas derivados de la escasez de recurso hídrico, se estudian sistemas de almacenamiento de hidrobombeo de agua combinados con plantas de desalinización en la isla de Gran Canaria, del mismo modo necesaria para el abastecimiento de agua tanto a la población como a los cultivos de la región. Para acometer el análisis fue necesario conocer la capacidad de desalación del sistema, la isla de Gran Canaria. La Tabla B-01 (Anexo B) evalúa la capacidad de desalación instalada, así como las características de las tecnologías asociadas, y en la Tabla B-02 (Anexo B) se localiza la capacidad en la isla.

La investigación para la implantación del esquema propuesto se ha llevado a cabo mediante la aplicación de técnicas que incluyen a los sistemas de información geográfica para una mejor caracterización de los recursos geográficos. Éstas consisten en localizar el mejor lugar para la implantación de una planta de desalación que cubra unas necesidades concretas de agua desalada. modelo de elevación del terreno digital, a la vez que se propone una estrategia de análisis apara analizar los elementos de análisis. El método presentado en este artículo ofrece una metodología para la localización de los mejores emplazamientos según las restricciones que se imponen en el mismo.

Tal y como muestra la Figura 3-1 la estrategia seguida consitió en localizar los cuerpos de agua más significativos del sistema analizado e incluirlos en un modelo elaborado con un sistema de información geográfica. El análisis de los mismos se realiza mediante un algoritmo cuya finalidad consiste en diseñar un plan de almacenamiento energético a base de hidrobombeo usando agua desalada procedente de las plantas desaladoras híbridas. Los emplazamientos candidatos son evaluados de acuerdo a unas restricciones que evaluén la factibilidad a corto plazo que dará soporte a diferentes planes energéticos basados en despliegue renovable en el sistema estudiado. Por su parte, la Figura 3-2 muestra la localización de los mejores emplazamientos de la estrategia a corto plazo propuesta.

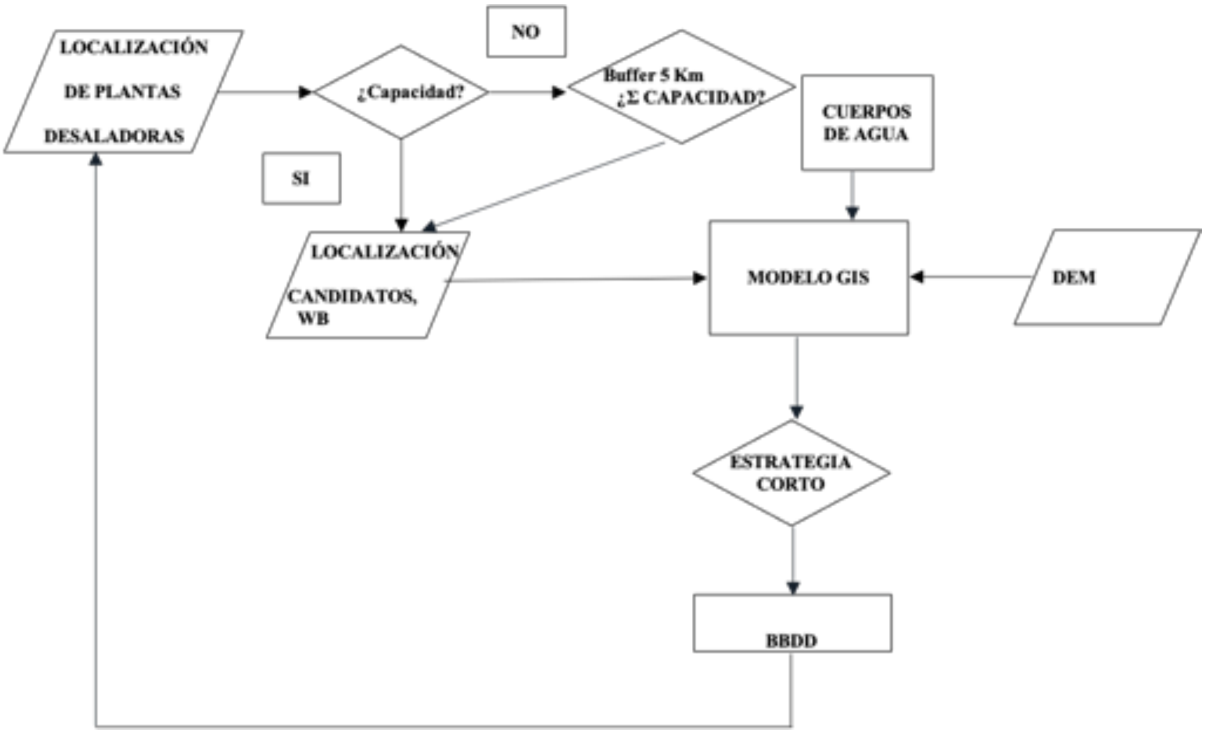


Figura 3-1 Estrategia de análisis de emplazamientos.

El análisis identificó la máxima energía potencial que del total de los cuerpos de agua del sistema podría lograrse para implementar este plan energético. Además, puede consultarse en la Tabla C-02 (ver Anexo C) un listado completo de los resultados de este análisis geomorfológico. Para el análisis de la estrategia a corto plazo se impuso la restricción de realizar el análisis de los emplazamientos con capacidad para proporcionar suficiente flujo en un buffer de 5 km sobre la planta desaladora. Estas se integraron en el modelo SIG, y se comprobaron las restricciones impuestas en el diagrama de la Tabla C-01 (ver Anexo C). Este análisis arrojó como resultado ciertos emplazamientos prometedores para dar soporte a corto plazo a los planes energéticos del sistema estudiado. Gracias a la estrategia propuesta se podría almacenar desde 11,44 GWh/ Hm^3 hasta 30,76 GWh/ Hm^3 en la isla de Gran Canaria. En las Figuras E.01-E.08 del Anexo E se muestran datos registrales de varios de los emplazamientos más prometedores a corto plazo del estudio.

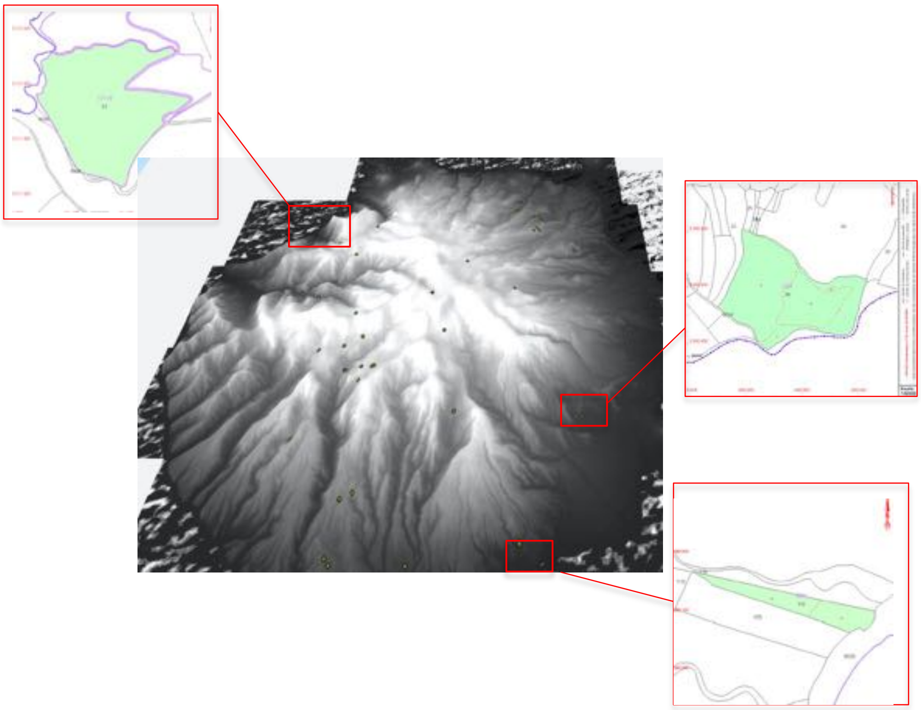


Figura 3-2 Localización de los mejores emplazamientos de la estrategia a corto plazo.

La sostenibilidad de la estrategia fue analizada a continuación. A partir de las condiciones iniciales del sistema energético de generación de electricidad y de sus emisiones de gases de efecto invernadero relacionadas (ver Tabla D-01), así como del relacionado con el subsistema alimentación se analizó un índice de sostenibilidad ad-hoc para apoyar el proceso de toma de decisiones de planeación para los planes energéticos presentados en este capítulo Con objeto de plantear un aprovechamiento rentable y a la vez sostenible en el tiempo es indispensable. Adicionalmente, apartir del análisis DAFO del subsector alimentación (ver Tablas D-02 y D-03 en Anexo D) se encontró que los pisos bioclimáticos destacan como oportunidades en el sistema estudiado, apareciendo sinergias con la estrategia de almacenamiento energético por bombeo hidráulico aquí considerada. Gracias a la estrategia de plan energético renovable combinado con el almacenamiento energético a partir del recurso procedente de plantas desaladoras se halló que podría reducirse la tensión en el subsistema de agua pasando de 8 Hm^3 a 20 Hm^3 impulsando a un sector agrícola que en la isla supone alrededor del 2% (ver Tabla E-03 en el Anexo E).

3.1.1. Abstract en Castellano

"*Comprehensive assessment of gran canaria water-energy-food nexus with GIS based tool*"

La creciente demanda de recursos por parte de la sociedad crea una necesidad urgente de estrategias de asignación de recursos. Este trabajo analizó cómo afectan los planes alternativos de energías renovables a un índice de sostenibilidad relacionado con el nexo Agua-Energía-Alimentación en una región altamente dependiente del agua procedente de plantas desaladoras. Se analizaron 50 cuerpos de agua de la isla de Gran Canaria para evaluar una estrategia de almacenamiento de energía por bombeo hidráulico para apoyar un plan de energía renovable. El almacenamiento utiliza el agua de las plantas desaladoras, lo que permitió aumentar el agua y la energía en el sistema. Con las restricciones impuestas, la isla española de Gran Canaria podría almacenar desde 11,44 GWh/ Hm^3 hasta 30,76 GWh/ Hm^3. Los resultados mostraron que, dependiendo del plan específico de energía renovable y del factor de operación en la planta desalinizadora, el stress hídrico en el subsistema de agua se reduciría de 8 Hm^3 a 20 Hm^3. Se propuso una estrategia de análisis del sistema para controlar el índice de agua, con el fin de apoyar las estrategias de toma de decisiones.

3.2. Resumen del artículo "*Stress Mitigation of Conventional Water Resources in Water-Scarce Areas through the use of Renewable Energy Powered Desalination Plants: An Application to the Canary Islands*"

Por su parte, el artículo 2 que forma parte de este primer capítulo: *"Stress Mitigation of Conventional Water Resources in Water-Scarce Areas through the use of Renewable Energy Powered Desalination Plants: An Application to the Canary Islands*" cuantifica los problemas de escasez de agua en la región, y se centra en un área concreta de la isla de Gran Canaria en la que estos problemas son más acuciantes.

Este artículo analiza el dimensionamiento necesario para incorporar una cierta cantidad de agua desalada al sistema de abastecimiento de agua que mitigue los efectos de la escasez de lluvia. Tras este análisis se discute cómo afecta el uso de la energía renovable en las plantas desaladoras a través del análisis de los indicadores en una región concreta dada la necesidad de agua en función de la población. Las técnicas de investigación empleadas incluyen el dimensionamiento de las necesidades de agua desalada de la región, así como también se hace necesario estimar la energía renovable necesaria para que la planta desaladora funcione y todo ello en un mercado concreto, bajo unas condiciones particulares. Este parte de la necesidad de un análisis para la elección del emplazamiento basado en la existencia de recurso renovable adecuado (Figuras 3.1 y 3.2), partiendo del dimensionamiento necesario para satisfacer unas necesidades de agua desalada del sistema en riesgo.

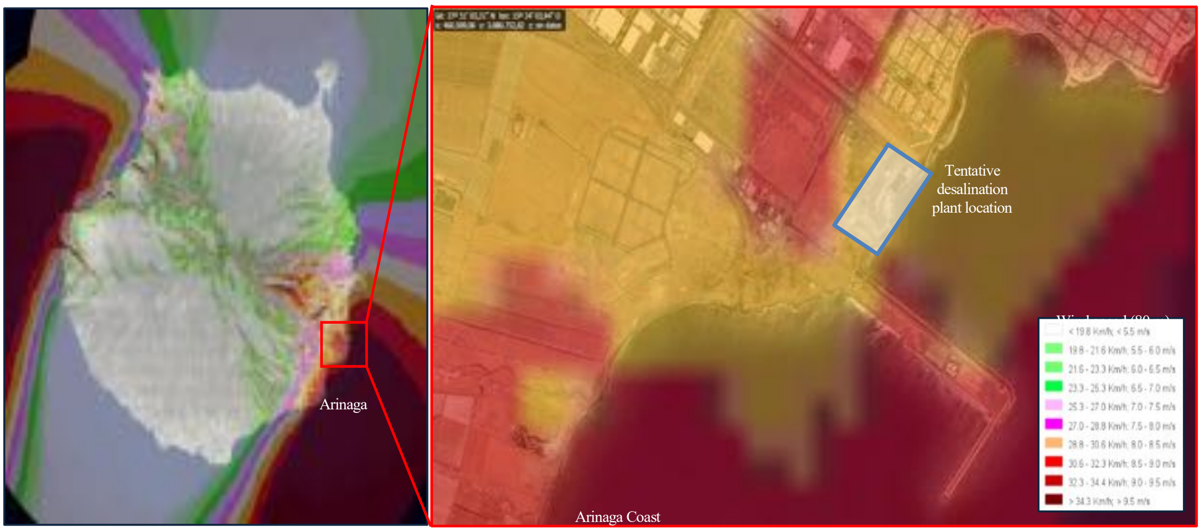


Figura 3-3 Recurso eólico en Gran Canaria (izquierda) y sitio seleccionado, Arinaga (derecha) para 80 m de altura. [15]

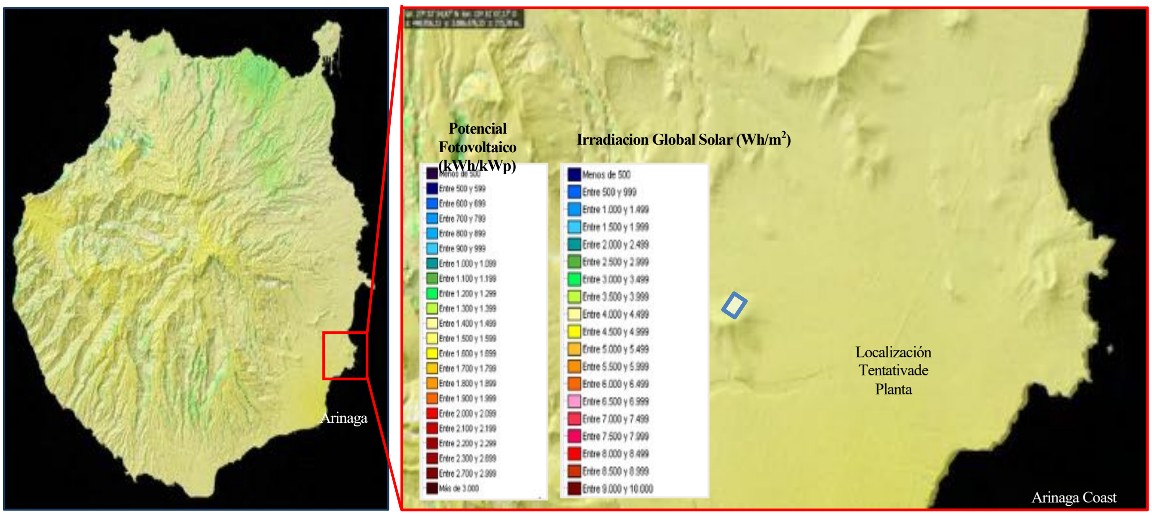


Figura 3-4 Recurso solar para Gran Canaria (izquierda) y en el sitio seleccionado, Arinaga (derecha). [16]

Para el dimensionamiento del mix energético de la planta híbrida y la simulación de su funcionamiento dentro de un mercado con las condiciones económicas particulares de la región se utiliza un software específicamente desarrollado para dimensionar estas instalaciones. Este, únicamente a través de la optimización de tres variables (energía eólica, energía solar y almacenamiento de energía) es capaz de proporcionar un coste operativo mínimo para una planta de ósmosis inversa híbrida, y para una capacidad de desalinización dada [17].

Los resultados del proceso de optimización en la Tabla 3-1, y en la Figura 3-5 muestran el resultado óptimo que el sistema ofrece para el esquema propuesto y según los parámetros introducidos que maximiza el beneficio en el mismo. Atendiendo a estos, destaca el valor de la ratio costes-ingresos, utilizado como parámetro de optimización, que en este resultado significa que cada euro de ingresos tiene un coste de 0,795 euros. El programa además arroja el flujo de caja completo optimizado (ver Tabla F-01 en Anexo F) del proceso.

Tabla 3-1 Resultados del proceso de optimización.

Parámetro	Resultado Optimo	Parámetro	Resultado Optimo
Tamaño Solar PV (kW)	866	Coste Almacenamiento (€)	871,70
Tamaño Wind farm (kW)	4.100	Coste Inversión (€)	5.991.109
Tamaño Almacenamiento(kWh)	1	Coste Total (€)	12.783.098
Coste planta Desaladora (€)	981.600	IngresoTotal (€)	19.366.879
Coste instalación Solar PV (€)	909.300	beneficio anual medio (€/año)	253.222
Coste instalación Wind farm (€)	4.099.337	*Ratio costes-beneficios* (-)	0,795

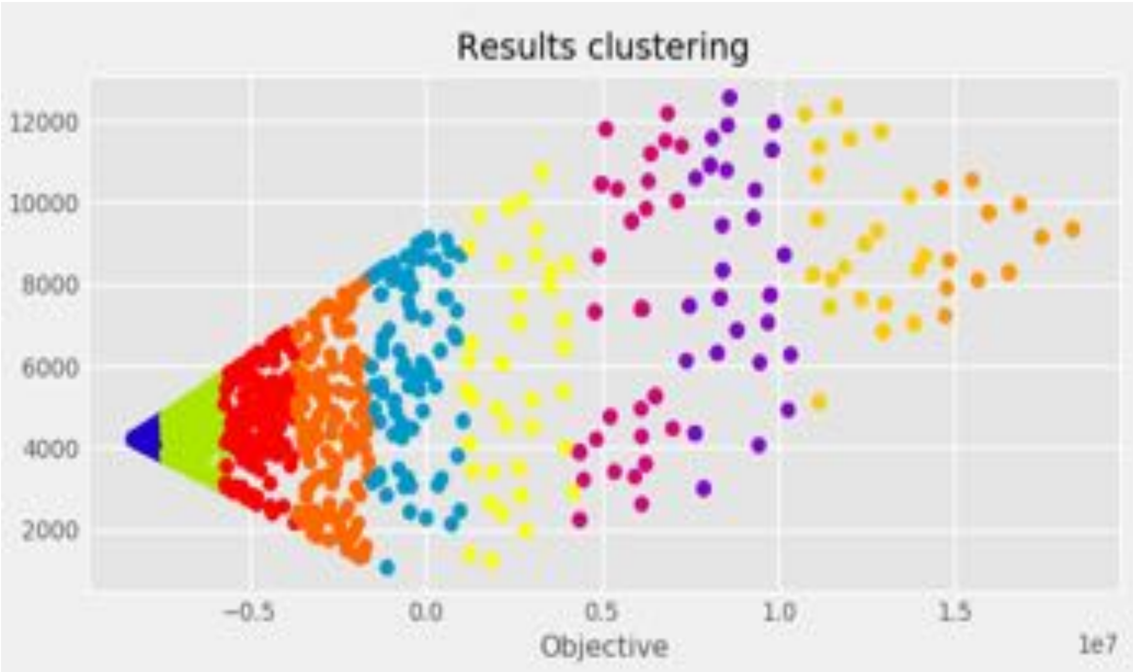


Figura 3-5 Resultados del proceso de optimización.

El valor utilizado como parámetro de optimización no puede compararse con el valor de Coste Nivelado de la Electricidad (LCOE) de generación para una tecnología en particular. El LCOE típico, calculado considerando sólo la instalación de generación de energía, alcanzó un valor de 7,04 €/MWh, lo que representa un 82,23% mejor valor respecto al coste de la energía de la red. Por otro lado, se comprobó que el coste normalizado del agua en las plantas desaladoras con las condiciones de precio de energía alcanza los 12,87€/m^3 en términos clásicos, esto es, sin tener en cuenta los ingresos extra por la venta de electricidad.

3.2.1. Abstract en Castellano

"*Stress Mitigation of Conventional Water Resources in Water-Scarce Areas through the use of Renewable Energy Powered Desalination Plants: An Application to the Canary Islands*"

Las condiciones del cambio climático en las últimas décadas han derivado en una importante reducción de los niveles del caudal en los ríos, irregularidad de las lluvias y, por tanto, dificultades en el acceso al agua potable. Esta situación es especialmente dramática en entornos insulares, como las Islas Canarias en España, donde estas restricciones a los recursos hídricos han llevado a una sobreexplotación de acuíferos y pozos, con el deterioro del medio ambiente que este hecho conlleva. Por este motivo, las plantas desalinizadoras se han hecho imprescindibles, y hay que tratar de reducir su impacto y sus costes, ya que los procesos implicados para la desalinización del agua son altamente intensivos en energía. En este trabajo de investigación se propone una central híbrida eólica y solar fotovoltaica de tamaño optimizado para alimentar una planta desaladora bajo el planteamiento de no sólo proveer de energía al proceso de desalación, sino también suministrar energía limpia a la red eléctrica, aprovechando el excedente de producción eléctrica. De esta manera, no sólo se mitiga el estrés de los recursos hídricos (a través de la producción de agua desalada), sino que la red se beneficia de la integración de una fuente de energía renovable distribuida (DRES). Además, se mejora el modelo de negocio, ya que se reduce el coste de la producción de agua potable y el propietario de la central recibe ingresos extra por la venta de agua. Los resultados de la optimización para un caso de estudio en la isla de Gran Canaria muestran que, considerando el despacho de energía en la isla, los límites de remuneración por la entrega de energía y la remuneración por el agua suministrada, la DRES óptima asociada a una planta desalinizadora que proporciona 5.600 m^3/día de agua desalada y una inyección máxima de electricidad anual a la red eléctrica de 5,88 GWh/año, una instalación híbrida de generación solar fotovoltaica y eólica con almacenamiento electroquímico es una solución factible que hace que el Coste Nivelado de la Electricidad (LCOE) alcance un valor reducido a pesar de considerar los costes adicionales de la planta desaladora, aunque hay que aportar ayuda financiera para reducir el tiempo de retorno de la inversión (ROI).

4. ANÁLISIS DE LA FACTIBILIDAD DE SISTEMAS ENERGÉTICOS HÍBRIDOS PARA PLANTAS DESALADORAS

Con objeto de favorecer el despliegue de sistemas de generación de energía eléctrica basados en fuentes de energía renovable se adoptan medidas de impulso al autoconsumo en industrias y viviendas de forma complementaria a las centrales de fuentes de energía renovables. Este capítulo profundiza en la gestión sostenible de los sistemas agua-energía. En concreto se centra en investigar la supervivencia financiera de los sistemas energéticos híbridos para plantas desaladoras desde un punto de vista de la gestión sostenible entre agua-energía. Dado que se observa una falta de estudios relativos a la comparación de escenarios reales de inversión en un modelo que incluya a sistemas energéticos híbridos combinados con plantas desaladoras. Para desarrollar el análisis de decisión de inversión se realiza la comparación del desempeño económico virtual de dos sistemas de desalación: por un lado, una planta de osmosis inversa cuyo funcionamiento ha sido simulado en el previo capítulo, y por otro una planta de desalación basada en tecnología de destilación la cual ha sido receptora de las acciones de apoyo que se proponen en este estudio.

4.1. Resumen del artículo: "*Feasibility Analysis of Wind and Solar Powered Desalination Plants: An Application to islands*"

Este artículo realiza la evaluación tecno-económica de ambos proyectos para decidir si la inversión o no en estos modelos de negocio sería aconsejable. Para la evaluación de viabilidad de proyectos es habitual el uso de estudios de mercado y técnicos, la evaluación económica, o el análisis y administración del riesgo. El objetivo de este capítulo es averiguar cuál es la influencia de parámetros tales como subvenciones, tasas de inversión, ventas de agua y saneamiento sobre los indicadores de rendimiento clave (KPI) para la decisión de inversión en este tipo de proyectos novedosos asociados a la desalinización del agua. Los indicadores de rendimiento clave para este trabajo se muestran en la Tabla 4-1.

Tabla 4-1 Indicadores clave de rendimiento

OBJETIVO	**MÉTRICAS DE ÉXITO**
Establecimiento de un mix energético óptimo para que una microrred sea rentable en una granja abandonada	Validación de software con experiencias asimilables
Analisis Económico	Diseñar un esquema de microrredes de unos 2 MW que dé lugar a un flujo de caja neto positivo anual de 200.000 euros
Análisis social	Creación de empleo (directo o indirecto)
Impacto desde el punto de vista medioambiental	Reducción de la emisión de 5.000 toneladas de CO_2 a la atmósfera gracias al plan
Reducción de los costes de producción de agua en las plantas desalinizadoras actuales	Proponer una configuración que reduzca los costes de producción de agua en 4 coeur/ m3 en comparación con las experiencias anteriores asimilables utilizando las MTD

Este capítulo analizó si las tecnologías propuestas cumplían con las características deseadas para optar a las subvenciones propuestas (ver Tabla G-01 en Anexo G), el dimensionamiento de las instalaciones (ver Tabla G-02 en en Anexo G), y cuál es su influencia en la decisión de inversión. Para ello se realiza un análisis de sensibilidad que investiga si el modelo de negocio sería lo suficientemente rentable para inversores privados.

El análisis de comercialización sigue el diagrama de flujo de la Figura 4-1. Se varió la cantidad de subvención concedida, la tasa de inversión efectiva (I_{eff}) del resto de la cantidad invertida y se calcularon los parámetros tenidos en cuenta para analizar su desempeño económico. El importe de la subvención concedida para construir la instalación varió entre el 0% y el 100%, y la tasa de inversión efectiva (I_{eff}) del factor de recuperación de costes (CRF) entre el 3,5% y el 24%. El proyecto se analizó para 20 años de retorno de la inversión, variando la cantidad de electricidad vendida, así como las ventas de agua del 70 % al 200 % con el fin de investigar la capacidad de ambas instalaciones para lograr el objetivo (KPI) económico marcado.

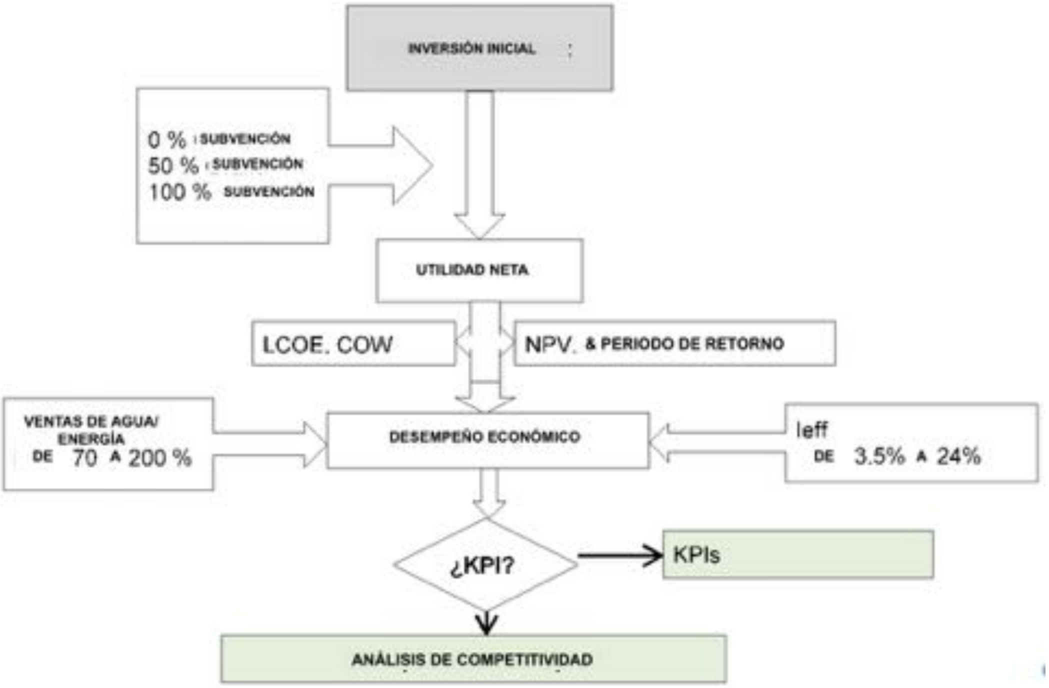


Figura 4-1 Diagrama de Flujo seguido en el análisis.

Tras el análisis realizado se hace notar que el sistema es rentable. La solución es económicamente rentable únicamente bajo ciertas condiciones de subvenciones concedidas y bajo ciertas condiciones de los préstamos concedidos. Además, las ventas de agua y energía se destacan como un factor limitante para conseguir la rentabilidad en ambas plantas virtuales. El LCOE podría ser similar al de la generación española, aunque dependiendo del interés de los préstamos obtenidos en la ejecución de cada uno de los proyectos acometidos.

4.1.1. Abstract en Castellano

"Feasibility Analysis of Wind and Solar Powered Desalination Plants: An Application to islands"

La evaluación económica de proyectos es necesaria para garantizar la mayoría de proyectos de inversión, y en particular los proyectoshídricos impulsados por fuentes de energía no convencionales es un reto. La realización de estas iniciativas en economías basadas en mercados liberalizados enfrenta a los gobiernos con la necesidad de garantizar los profictos. Dado que la disponibilidad de agua se ha convertido en un problema global relevante, y la desalinización en una solución de demanda intensiva de energía, es habitual combinar ambos tipos de tecnologías, los sistemas de energía renovable y las plantas de desalinización. Esta investigación estudia la influencia de las subvenciones, las tasas de inversión y las ventas de energía y agua en la comercialización de dos tecnologías de desalinización. Se ha realizado un análisis de rendimiento teniendo en cuenta diferentes escenarios. Siguiendo este enfoque, se ha comparado una planta de desalinización por ósmosis inversa simulada con respecto a una planta piloto novedosa ya concedida. Los resultados muestran un mejor cumplimiento de los objetivos no económicos, y económicamente profiable no sólo bajo ciertas condiciones de subvenciones concedidas, y los beneficios esperados del inversor, sino también de las ventas de agua-energía, que destacó como un factor limitante. El coste nivelado de la energía podría ser similar al de los medios de generación españoles, dependiendo de la tasa de crecimiento de los costes de los préstamos y de las subvenciones concedidas. Se encontró una reducción de 11 céntimos de euro por debajo del precio medio que se podría conseguir, para el escenario estándar.

5. SISTEMA PARA EL CONTROL DE AGUA Y ENERGÍA EN PLANTAS DESALADORAS

Las tasas actuales de crecimiento de la población, unidas a las crecientes necesidades de recursos de estas, amenazan la capacidad de la tierra para proporcionarlos. Las actividades relacionadas con el desarrollo económico son especialmente difíciles en las islas, y más aún en las islas que carecen de agua. En el transcurso del trabajo realizado para la realización de la Tesis Doctoral se planteó la necesidad de un sistema de control de la generación y consumo de energía en las instalaciones industriales o de generación de energía que tengan instalado el almacenamiento de energía combinado con sistemas de generación de energía a partir de fuentes renovables. La presente invención se engloba dentro del campo de los sistemas de gestión y control de la generación y consumo de energía de las plantas desaladoras que tienen instaladas un sistema de almacenamiento energético en forma de bombeo hidráulico combinado con un sistema de generación de electricidad a partir de fuentes renovables.

5.1. Descripción

5.1.1. Campo de la invención

La presente invención se engloba dentro del campo de los sistemas de gestión y control de la generación y consumo de energía de las plantas desaladoras que tienen instaladas un sistema de almacenamiento energético en forma de bombeo hidráulico combinado con un sistema de generación de electricidad a partir de fuentes renovables.

La patente presentada utilizó como palabras clave para realizar una búsqueda de documentos en el estado del arte: Control de Bombeo de Almacenamiento de Energía y Desalación Eólica. En general, está diseñada para plantas desaladoras, aunque podría ser utilizada por todas aquellas que incorporen en sus procesos productivos fluidos que puedan ser turbinados y una marcada diferencia en el nivel de altura para desarrollar el sistema. No se detectó ningún sistema de control que incorpore la gestión combinada del recurso energético y del recurso hídrico procedente de la planta desaladora.

5.1.2. Antecedentes de la invención

Los sistemas de almacenamiento de energía, entre los cuales se encuentra el almacenamiento de energía por bombeo hidráulico (PHS), son necesarios para la correcta integración de las tecnologías de generación eléctrica a partir de fuentes de energía renovables.

Entre los antecedentes que se deben mencionar es que existen plantas de bombeo hidráulico, y se sabe que los sistemas de almacenamiento de energía son necesarios para la correcta integración de las tecnologías de generación eléctrica a partir de fuentes de energía renovables.

En diferentes documentos de patente se divulga el uso de sistemas de almacenamiento de energía por bombeo hidráulico y el método de control de los mismos, para lo cual se puede emplear energía suministrada por fuentes de energía renovables. Estos sistemas se pueden aplicar en plantas desaladoras.

Sin embargo, en las plantas desaladoras que disponen de un sistema de almacenamiento de energía por bombeo hidráulico combinado con un sistema de generación de electricidad a partir de fuentes renovables los sistemas de control actuales únicamente se centran en el control energético de la instalación, monitorizando la energía consumida y generada para decidir en base a ella (e.g. bombear, turbinar).

La presente invención proporciona una solución a este problema, considerando el recurso hídrico procedente de desaladoras como una variable adicional a considerar en el control integral del sistema, y considerando la utilización de dicho recurso hídrico, el cual puede ser utilizado por ejemplo para regar a diferentes niveles, producir energía en turbina, etc.

5.1.3. Descripción de la invención

La invención se refiere a un sistema para el control del recurso hídrico y energético en plantas desaladoras. De manera ventajosa, la presente invención incorpora la gestión combinada del recurso hídrico y del recurso energético procedente de desaladoras, introduciendo en el proceso decisorio la salida de recurso hidráulico en distintos niveles de altura para diferentes aplicaciones (por ejemplo, para el suministro a huertas, recurso hidráulico, lucha contra incendios, etc.).

El sistema permite controlar la generación y consumo tanto de energía como del recurso hídrico de plantas desaladoras que tengan instaladas sistemas de almacenamiento energético por bombeo hidráulico combinados con sistemas de generación de electricidad a partir de fuentes renovables.

Para ello el sistema realiza un proceso decisorio con objeto de optimizar el recurso hídrico y el energético, en función de unos parámetros dados, como el precio del recurso agua, de la electricidad, necesidades de agua de los cultivos, etc.

El objetivo del sistema consiste en almacenar energía y gestionar el recurso hídrico de forma eficiente y económica para maximizar el uso de estas instalaciones.

Como elementos de una posible realización del sistema 1 de control del recurso hídrico y energético en plantas desaladoras, el sistema utiliza una unidad de control, depósitos de almacenamiento de agua desalada dimensionados específicamente para la aplicación concreta, instrumentación de medida y regulación asociada, bombas y válvulas necesarias para la gestión del flujo hídrico, y al menos una turbina hidráulica (ver Figura 5.1).

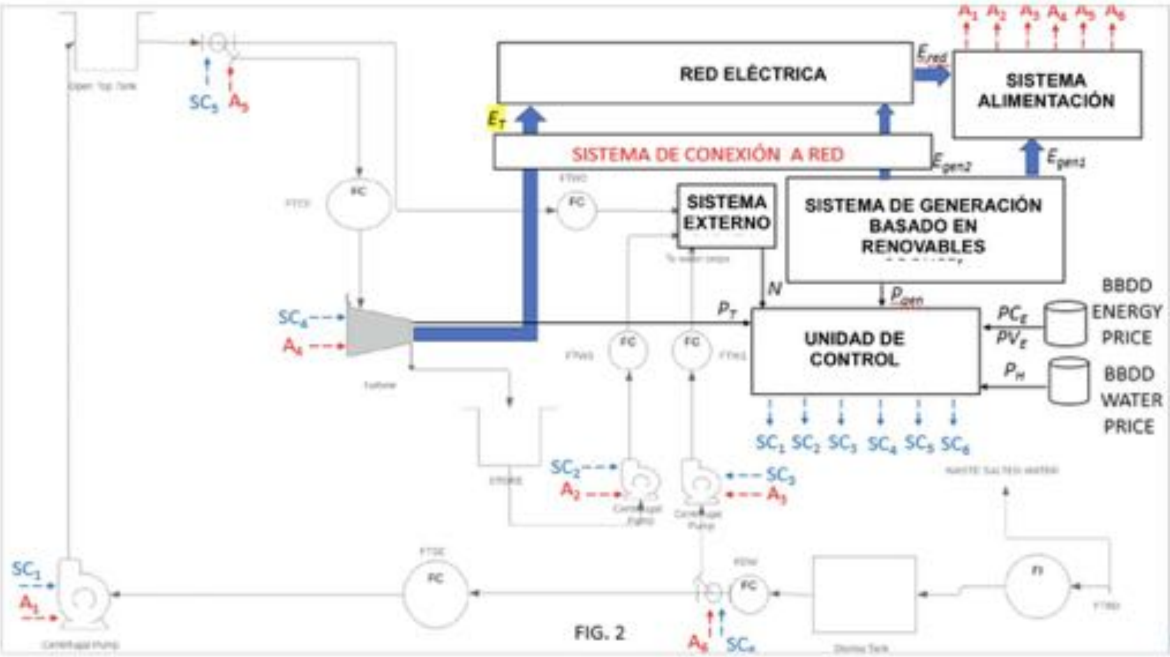


Figura 5-1 Elementos del sistema de control de los recursos hídricos y energéticos.

El sistema realiza el análisis de los flujos reales de información, tanto de la propia planta como del mercado, así como la gestión de la maquinaria (bombas, válvulas, turbina(s), etc.) que permite la operación de la planta. La unidad de control ejecuta un esquema decisorio para el control eficiente del recurso hídrico y energético en plantas desaladoras. Así pues, de forma automatizada el control en la planta desaladora se realiza de acuerdo a un proceso decisorio que tiene en cuenta múltiples factores que pretenden tener una doble concepción del recurso: como recurso energético y como recurso hídrico (ver Figura 5.2).

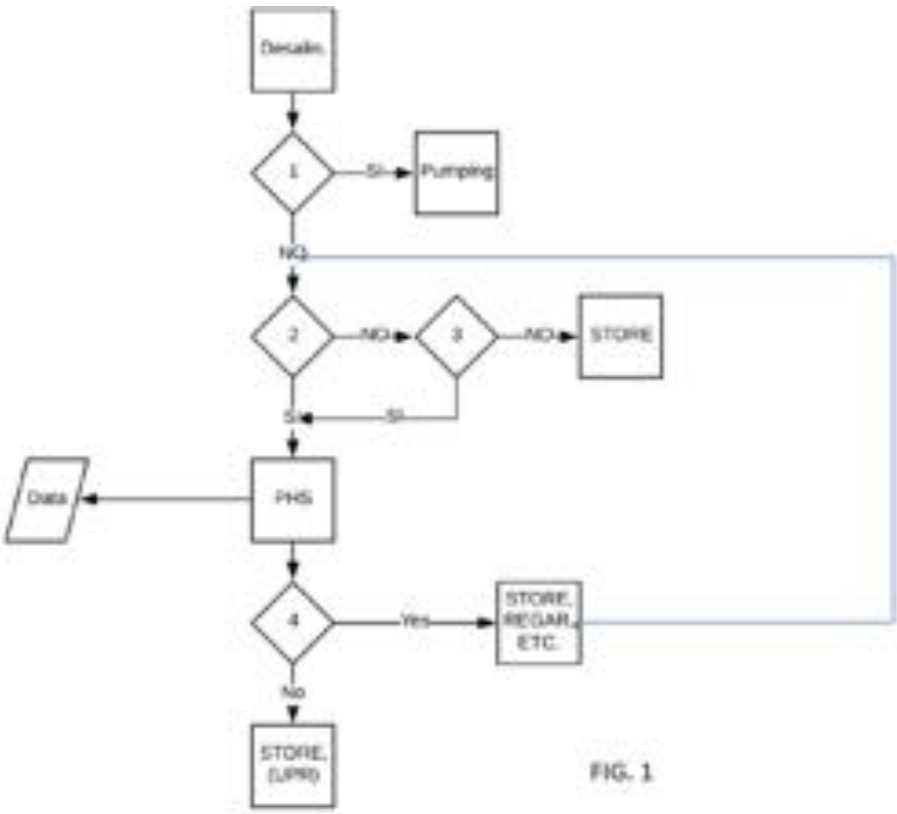


Figura 5-2 Esquema de decisión ejecutado por el sistema para el control eficiente del agua

A nivel energético, el sistema puede decidir si es más rentable producir energía eléctrica y venderla en tiempo real, utilizarla para elaborar los productos energéticos (por ejemplo, agua desalada cuando no haya recurso renovable y no interese comprar de la red), o almacenarla para su posterior despacho. El sistema también optimiza los flujos de agua con el objetivo de suministrar el agua necesaria a un sistema externo, empleada por ejemplo para los riegos en las microrredes rurales.

La energía generada por la turbina puede ser utilizada para venderla en el mercado de energía (ET_2) o para suministrar energía a los equipos del sistema (ET_1), ya sean bombas de elevación, equipos de la planta desaladora, bombas de riego, equipos auxiliares, etc.

La unidad de control puede estar configurada para medir la potencia (P_{gen}) generada por el sistema de generación de electricidad y, en función de la medida:

- Cuando la potencia generada (P_{gen}) es superior a la potencia nominal de la primera bomba, bombear agua desalada hacia el primer depósito mediante la activación de la primera bomba.

- Cuando la potencia generada (P_{gen}) es inferior a la potencia nominal de la primera bomba 6, obtener los precios de compra (PC_E) y de venta (PV_E) de la energía eléctrica y, en función de la diferencia entre dichos precios, cerrar la primera válvula para almacenar en el tanque de almacenamiento el agua desalada obtenida en la planta desaladora, o bombear agua desalada hacia el primer depósito 7 mediante la activación de la primera bomba.

El sistema está diseñado para emplazarse en la escarpada ladera de una montaña, monte, rambla, etc. aprovechando su fuerte pendiente. El sistema puede incluir un mecanismo intercalado para inserción de manguera de extinción de incendio, tales como unas conexiones de manguera rápida intercaladas en sus tuberías para, aprovechando el recurso hídrico, conectar los equipos antiincendios con objeto de hacer frente a posibles incendios que puedan producirse en las laderas colindantes, convirtiéndose en un aporte de agua para la extinción de los incendios. Las mangueras de subida de agua se colocan preferentemente a la vista y de color negro, con objeto de que el fluido se caliente, y con reducción de sección controlada para facilitar el trasiego de elevación de agua.

6. CONCLUSIONES, SUGERENCIAS Y DESARROLLO FUTURO

El arte de sacar conclusiones a partir de experimentos y observaciones consiste en evaluar las probabilidades y en estimar si son lo suficientemente grandes o numerosas como para constituir pruebas.

- Antoine Lavoiser-

Las sinergias entre el mercado de electricidad y del agua se analizan desde la perspectiva de la teoría de sistemas con el objeto de abrir el camino para el diseño de pseudomercados avanzados de agua que afronten el creciente problema de escasez de recurso agua en las regiones especialmente afectadas por problemas de sequías.

6.1. Conclusiones

A modo de resumen conciso de las aportaciones originales de la tesis que han servido para sustentar el argumentario de la misma se incluyen, bajo la forma de enunciaciones simples de los resultados obtenidos, las siguientes conclusiones.

i. Como resultado de la evaluación realizada en esta tesis, se concluyó que los procesos de generación de energía, la desalinización de agua y la producción de alimentos deben coordinarse para convertirse en una actividad más sostenible a través de una planificación y gestión conjunta.

ii. En la actualidad, la mayoría de las decisiones políticas con posibles consecuencias para el nexo entre el agua, la energía y los alimentos se toman a través de diferentes instituciones (como distintos departamentos gubernamentales o distintos puestos en la jerarquía pública del gobierno de turno) sin el grado de coordinación necesario.

iii. Los retos a los que se enfrenta el nexo entre agua, energía y alimentos son, en parte, consecuencia de esta política "fragmentada" aplicada a recursos interrelacionados. Con estas circunstancias, sería deseable un tratamiento completamente coordinado de la situación para perfilar los activos.

Aunque este enfoque totalmente integrado representa un reto, una posición práctica inicial sería examinar de qué manera las conclusiones tienen un efecto sobre aquellos elementos restantes que constituyen el nexo. En particular, y adoptando una perspectiva centrada en el poder derivado de la utilización de los recursos, sugeriría una percepción de las consecuencias del agua y los alimentos para las decisiones energéticas. En este sentido, los marcos analíticos podrían, en un alto grado, ser utilizados de diversas maneras. En este sentido, esta Tesis Doctoral evaluó una serie de herramientas disponibles. La información más significativa descubierta como resultado de la investigación ha sido la siguiente:

i. El acceso a los datos es un reto fundamental. Para llevar a cabo una evaluación adecuada del nexo entre el agua, la energía y los alimentos, es necesario tener acceso tanto a los datos de cada uno de estos sectores como abstracciones capaces de expresar la cantidad de sus conexiones mutuas. La recopilación de datos estandarizados podría servir para resolver los problemas existentes en la actualidad relacionados con la coherencia, la comparabilidad y la escala, además de la ausencia de información estadística que se recoja, observe o registre en intervalos de tiempo regulares.

ii. La mayoría de las herramientas que pueden utilizarse u obtenerse para los responsables o implicados en la formulación de políticas hoy en día son exhaustivas y complejas y requieren una cantidad importante de datos, recursos humanos, tiempo y suficiencia económica.

iii. Está claro que es una opción factible desarrollar un enfoque integrado de este tipo desde el punto de vista de todos los componentes, pero las sinergias deben definirse plenamente para aprovechar al máximo la potencialidad del modelo.

Asimismo, durante los trabajos de esta Tesis Doctoral se ha identificado la necesidad de contar con herramientas capaces de mostrar estimaciones básicas que puedan servir de base para desarrollos posteriores (más complejos). El marco de referencia planteado en este trabajo pretende proponer una herramienta exploratoria que tenga a la energía como punto de entrada, que a su vez proporcione un punto de partida que pueda apoyar en última instancia la integración de la energía dentro del llamado nexo del agua, la energía y los alimentos. Es de utilidad presentar "instantáneas" del impacto del desarrollo de las energías renovables (además de los enfoques alternativos) en los recursos relacionados, como el agua y la ocupación del suelo.

Para el enfoque propuesto, cada resultado constituye un grupo de diferentes decisiones de política energética en las que el balance de energía se acepta como información clave. En este caso, la herramienta propuesta podría calcular o juzgar de forma aproximada el valor del agua, la tierra, las emisiones y las implicaciones de costes de cada resultado con el fin de "combinarlos" en un indicador global que considere específicamente el principio de las acciones propuestas por las elecciones de los gobiernos para cada circunstancia particular.

El "producto" presentado por la herramienta propuesta en esta investigación podría constituir un primer paso en la dirección de un examen más exhaustivo del impacto del desarrollo de las energías renovables en el nexo entre el agua, la energía y los alimentos bajo ciertos supuestos. Así pues, el marco conceptual propuesto constituye un enfoque novedoso para los responsables de las políticas energéticas que sólo tienen en cuenta los impactos parciales de la gestión de la energía. Al considerar el nexo entre la energía, el agua y los alimentos, se pueden redefinir las políticas de gestión de la energía y se deben investigar las diferencias con las políticas actuales.

En esta Tesis se han analizado diferentes escenarios de despliegue energético dentro de un plan energético de origen renovable vinculado al esquema de PHS que apoyan la operación de las plantas desaladoras. La estrategia propuesta para localizar los emplazamientos más adecuados para ubicar las instalaciones de PHS permite desarrollar el plan energético de base renovable definido, tanto a corto como a largo plazo. Con las restricciones aplicadas y en las instalaciones; plantas desalinizadoras en particular, se propusieron varios lugares de la isla para implementar dicho esquema, encontrando un potencial de energía, a corto plazo de: 1,144 GWh / 0,1 Hm^3, y 2,87 GWh / 0,1 Hm^3, que unido al despliegue renovable resultaba insuficiente para generar la misma energía que la procedente de las centrales térmicas.

Por ello, se propuso un método para evaluar, cuantificar y controlar los consumos de agua, evaluando sus consecuencias en el nexo agua-energía-alimentos, siendo relevante por permitir la reducción del estrés hídrico en Gran Canaria, que además presentaba una infraestructura de generación muy dependiente de los combustibles fósiles, que podría ser sustituida por planes de energía de base renovable. La herramienta estableció las condiciones particulares de la región de estudio (Islas con riesgo de escasez con capacidad de desalinización). El análisis del nexo entre agua-energía-alimentos aquí realizado aclaró gracias al cálculo de un índice de sostenibilidad el problema de la toma de decisiones para elegir entre estrategias energéticas. Adicionalmente, estas permitirán el despliegue de estrategias de microrredes rurales con invernaderos, o cultivos, con una cantidad precisa de agua desalada.

Gracias a este análisis del índice agua-energía en dos fases, se podría concluir que a partir del plan energético -incluyendo la estrategia energética de almacenamiento-, podría ser necesario menos de 1

GW de potencia instalada procedente de fuentes renovables, aunque habría que tener en cuenta la gestión de dichas estrategias, el desarrollo de la red. En primer lugar, permitiría controlar el funcionamiento de las plantas desalinizadoras, vinculadas a la estrategia energética, desarrollando un control integrado. En segundo lugar, los servicios de información serían deseables porque la gestión de datos de estos índices proporcionaría mejoras en el sistema de gestión del agua y la energía. En este proceso, los sistemas de información, así como los sistemas de inteligencia artificial, desempeñarán un papel importante a través del análisis de los datos para un mayor desarrollo y programación (asignación de recursos).

Con especial énfasis en Gran Canaria, una isla con importantes carencias de agua y energía que ponen en peligro el desarrollo de la economía local, el marco introducido proporciona una solución eficiente que integra el suministro de agua con el de energía limpia. Para ello, se identifican y discuten las características deseadas de la isla y los factores críticos necesarios para la implementación exitosa de las soluciones sugeridas, mientras se demuestra el marco propuesto. Más detalladamente, se desarrolló un modelo de programación estocástica y se aplicó en la isla de Gran Canaria, con resultados que mostraron que el suministro de energía y agua fiable y basado en las energías renovables es alcanzable a un coste factible bajo ciertas condiciones de precio de venta, así como de cantidad de energía vendida, contribuyendo al mismo tiempo a la considerable reducción de Gases de Efecto Invernadero (GEI). El marco teórico de modelización introducido tiene por objeto explicar el camino de la investigación del suministro integrado de agua y energía para las islas desde una perspectiva de toma de decisiones de alto nivel; por lo tanto, no se califican las soluciones en el nivel detallado de aplicación (es decir, no se tienen en cuenta las cuestiones de ubicación y las características de la infraestructura local).

Se analizó el potencial de integración de pequeños sistemas energéticos inteligentes en la isla de Gran Canaria que funcionarían como microrredes rurales. Se determinaron los parámetros clave que describen los aspectos individuales de los sistemas de energía inteligente para la generación de electricidad energética vinculada a las plantas de desalinización, y se encontró que una mezcla de energía renovable y sistemas de baterías es la columna vertebral favorable para el sistema de generación de electricidad energética.

Los resultados son coherentes con la validación de las características individuales de las islas sin red elegidas. Los resultados del análisis clúster ayudan a los responsables políticos y a los inversores privados a decidir qué proyectos de sistemas energéticos inteligentes son adecuados para cada isla en particular.

Los recursos hídricos de Canarias han sufrido un grave deterioro durante varias décadas, tratando de abastecer el consumo de agua de la población y del turismo, ambos en un crecimiento sin precedentes. Así, la tecnología de desalación de agua de mar ha adquirido un cierto protagonismo en el desarrollo económico de la región, hasta el punto de ser responsable de una gran parte del consumo energético total del archipiélago canario, generalmente procedente de combustibles fósiles, que tienen un impacto negativo en el medio ambiente. Por ello, la combinación de la desalación por ósmosis inversa con las energías renovables, en este caso, la eólica y la solar fotovoltaica, es un paso hacia la sostenibilidad y la reducción de la dependencia de los combustibles fósiles. La capacidad de la planta propuesta, 5.600 m^3/día, pretende abastecer a la totalidad de la población de Arinaga hasta el año dos mil veintinueve, que corresponde a los 10 años previstos de vida de las membranas de la desaladora. Durante este tiempo, se mitigará el estrés de los recursos hídricos convencionales actualmente explotados, obteniendo en este caso agua potable para el consumo humano sin suponer una demanda extra para la red eléctrica, ya que su funcionamiento se basa en el autoabastecimiento.

En los próximos años, a medida que aumente la escasez de agua, el suministro de agua se convertirá en una cuestión crítica, por lo que investigaciones como la presentada en esta tesis doctoral son de gran importancia para investigar cómo una forma sostenible de proporcionar energía del agua podría llegar a ser económicamente atractiva para los inversores no sólo en las regiones amenazadas por la sequía, como lo es la región del Mediterráneo y del norte de África, pero también en otras. Esta Tesis Doctoral proporcionó una mejor comprensión de la problemática que supone la comercialización de estas tecnologías disruptivas, y demostró que a pesar de que ambos esquemas cumplían con las características demandadas de las subvenciones, aparecían diferentes escenarios económicos, aunque condicionados a las condiciones del mercado, y aún a los beneficios económicos de las instituciones públicas.

En conclusión, además del escenario rentable que abre el camino a una inversión económicamente eficiente, esta Tesis Doctoral contribuye proponiendo el uso de un mix energético renovable óptimo para llevar a cabo la desalinización necesaria para proveer de agua dulce a los huertos situados en zonas áridas. Además, se sugiere la posibilidad de vender la energía sobrante a la red eléctrica para conseguir rentabilidad.

Además, se ha demostrado que la rentabilidad de este esquema se puede programar si se aumentan o reducen las ventas de este esquema, la cual hace uso de una novedosa estrategia de gestión del agua que permita aprovechar al máximo el potencial que se puede alcanzar del uso del recurso. Hecho en el que se debe profundizar: maximizar su uso antes de ser gastado.

También se ha demostrado que algunos escenarios alcanzan los objetivos económicos, especialmente en condiciones de mayor venta de energía. Además, el LCOE resultó ser inferior a la media de los costes de generación eléctrica en Gran Canaria. Entre los impactos esperados de este esquema se encuentran algunos efectos sociales notables:

En primer lugar, se puede posibilitar una importante y mejorada disponibilidad, aceptación y uso por parte de las comunidades locales de modelos innovadores de gestión del agua en condiciones climáticas difíciles y zonas áridas.

En segundo lugar, es previsible que se reduzca la presión sobre el medio ambiente, se mejoren los servicios de los ecosistemas, el rendimiento del agua y la producción sostenible de alimentos.

En tercer lugar, se puede conseguir una innovación mejorada en el nexo agua-energía, en particular apoyando el uso sostenible del agua con un coste energético menor y asequible. Esta iniciativa puede aumentar la capacidad de gestión del agua de las comunidades locales en zonas rurales, remotas y áridas. Además, se alcanza el desarrollo de modelos eficaces de transferencia de conocimientos en la gestión sostenible del agua. Y, por último, se podría lograr un aumento del crecimiento socioeconómico y de la estabilidad de las zonas seleccionadas.

En términos generales, se demostró que también se pueden reducir los costes del agua. Paralelamente, los beneficios sobre el medio ambiente impulsan la economía verde que implicará también beneficios sociales. La supervisión económico-financiera de estos proyectos permite que la penetración de las energías renovables en la red eléctrica de Canarias alcance cuotas que oscilan entre el 40% y el 60%, dependiendo de la cantidad de electricidad vendida, al tiempo que se logró una reducción de las emisiones de GEI. En concreto, en esta investigación se constató una reducción de las emisiones de GEI del 0,22% de las emisiones anuales equivalentes de la Central Térmica de Tirajana donde se ubicó. En el problema de la toma de decisiones de inversión en proyectos de tecnologías disruptivas, las subvenciones resultaron indispensables para desarrollar esos modelos de negocio combinados.

Por su parte, se concluyó que sería necesario desarrollar modelos estadísticos de probabilidad que permitan maximizar el beneficio del esquema definiendo condiciones más seguras de funcionamiento.

6.2. Sugerencias y Desarrollo Futuro

A partir de los resultados e investigaciones realizadas en esta Tesis Doctoral, el autor quiere destacar algunas sugerencias y áreas de desarrollo para los resultados alcanzados durante este proceso. A pesar de que existen varios enfoques para el análisis de la problemática Agua-Energía-Nexo, es evidente que todos y cada uno de ellos necesitan procesos cohesionados de toma de decisiones, así como datos reales, precisos y actualizados que permitan, por un lado, diseñar y desarrollar estos sistemas y, por otro, prever y programar el despacho de electricidad y agua. Esto debe preverse tanto a corto, como a medio y largo plazo, por lo que el desarrollo futuro debe conducir a una definición que se ajuste a ellos.

En este sentido, dentro de los problemas relacionados con el nexo agua-energía-alimentación, un proceso de toma de decisiones cohesionado y coherente es vital para sustentar las decisiones tomadas dentro de la planificación y asignación de recursos. Además, se deben investigar en profundidad los mercados en los que se comercializarían los posibles nuevos productos. La huella hídrica y de CO_2 de los productos creados en comparación con los productos que podrían importarse al sistema podría llevarnos a una mejor comprensión de la situación real del sistema.

La disponibilidad de recursos hídricos en islas pequeñas, escasamente pobladas se convierte en uno de los mayores retos. En consecuencia, el marco de optimización propuesto debe mejorarse para lograr no solamente un suministro energético sostenible y estable sino también ampliar el conocimiento del concepto de sostenibilidad de sistemas incluso ampliando a sistemas conexos al agua-energía-comida.

La energía generada a partir de fuentes renovables no puede compartirse fácilmente entre las islas, por lo que el almacenamiento se convierte en un problema importante para las centrales de generación eléctrica dependiente de fuentes de energía renovables, dada su intermitencia. Entre las características de las redes eléctricas locales: escasos márgenes de reserva de energía o la variación de los costes de producción de los motores térmicos disponibles, provocan gastos adicionales.

En el contexto dado, de necesidad de agua desalada al sistema, los problemas de la cadena de suministro estarán intrínsecamente vinculados a la calidad y disponibilidad de la energía renovable de una zona, lo que da lugar a las denominadas consideraciones del nexo agua-energía. En este sentido, el enfoque sobre la gestión combinada del agua y la energía es de vital importancia para la solución de los problemas relacionados con la escasez.

Con especial énfasis en Gran Canaria, una isla con importantes problemas de escasez de agua y energía el peligro del desarrollo de la economía local es elevado. En este sentido, se proporciona una solución eficiente que integre el suministro de agua con el de energía limpia. Además, se identifican y discuten las características de la isla y los factores críticos necesarios para la implementación exitosa de soluciones. Mediante el desarrollo de un modelo de la región, se realizó en una región concreta de la isla un análisis mediante programación estocástica que arrojaron resultados que mostraron que el suministro de energía basado en las energías renovables y agua se puede conseguir a un coste razonable bajo ciertas condiciones de precio de venta, así como de cantidad de energía vendida, contribuyendo al mismo tiempo a la considerable reducción de Gases de Efecto Invernadero (GEI). A pesar de que todos estos aspectos han sido estudiados, deben ser estudiados en profundidad para averiguar cómo avanzar hacia un modelo de gestión sostenible más cuantificable.

El marco teórico de modelización introducido tiene por objeto explicar el camino de la investigación del suministro integrado de agua y energía para las islas desde una perspectiva de toma de decisiones de alto nivel; por lo tanto, no se califican las soluciones en el nivel detallado de aplicación (es decir, no se tienen en cuenta las cuestiones de ubicación y las características de la infraestructura local).

Se analizó el potencial de integración de pequeños sistemas energéticos inteligentes en la isla de Gran Canaria que funcionarían como microrredes rurales. Se determinaron los parámetros clave para describir los aspectos individuales de los sistemas de energía inteligente para la generación de electricidad energética vinculada a las plantas de desalinización, y se encontró que un mix de energía renovable y sistemas de almacenamiento energético será la columna vertebral favorable para el sistema de generación de electricidad energética.

A partir de ahora, se podría realizar una clasificación de las islas según sus similitudes en cuanto a características socioeconómicas y físicas, y potencial de recursos energéticos autóctonos, para evaluar la implantación de un sistema fiable. Qué sistemas serían la columna vertebral más favorable del futuro sistema energético basado en las energías renovables es una cuestión clave de desarrollo que debería investigarse más a fondo. Del mismo modo, se han identificado las oportunidades de vincular los sistemas de electricidad con el suministro de agua y las cargas de energía térmica, así como con el sector del transporte, y deberían seguir discutiéndose para mostrar las sinergias que mejor encajan entre ellos

Además, los estudios de caso realizados durante esta Tesis Doctoral pueden ser de aplicación en otras islas más dependientes de los recursos hídricos lo que refuerza el atractivo de las acciones propuestas en esta tesis desde el punto de vista económico, energético y medioambiental. Además, la estrategia de gestión hidroenergética puede ser útil en otras regiones pese a que no tengan acceso a recurso desalado.

A partir de los resultados aportadoss se demuestra la viabilidad de las soluciones de energía limpia y suministro de agua en la región aislada, aunque no se han analizado factores tales como la generación distribuida afetará a la estabilidad de la red, y el desarrollo de esta. La energía es también un punto central para el suministro de agua, ya que en muchos lugares es uno de los principales factores que limitan la adopción de métodos alternativos de suministro de agua. Los métodos de desalinización con tecnologías maduras que tengan costes de producción de agua competitivos aún no se han introducido de forma generalizada.

Esto se debe a características de las redes eléctricas locales con escasos márgenes de reserva de energía o gran variación de los costes de producción de los motores térmicos disponibles, que requieren gastos adicionales para mejorar la infraestructura energética. En este contexto, resulta evidente que los problemas de la cadena de suministro de agua están intrínsecamente vinculados a la calidad disponibilidad y precio de la energía de una zona, lo que da lugar a las denominadas consideraciones del nexo agua-energía.

Además, también podrían revisarse los sistemas de desarrollo de almacenamiento por bombeo existentes. Deberían investigarse más a fondo las sinergias con otros sistemas del nexo, como el agua y los alimentos, para debatir cómo favorecerían estos sistemas interconectados.

En concreto, el almacenamiento hidroeléctrico por bombeo, como alternativa eficaz para los problemas relacionados con el agua, la energía y la tierra, es esencial que se siga investigando para aprovechar al máximo las ventajas de este sistema interconectado. Además, se propone un mayor desarrollo de las estrategias vinculadas que combinan las estrategias energéticas e hídricas a corto y largo plazo que satisfacen las necesidades energéticas e hídricas a largo plazo de las regiones donde se despliega. Se propone una mejora tecnológica que permita mejorar la disposición para combinar la energía hidroeléctrica y el almacenamiento hidroeléctrico por bombeo.

Dado que el sector energético está experimentando una transición sustancial con el amplio despliegue de tecnologías renovables de generación de energía, la integración de estas fuentes de energía renovables variables e intermitentes, como la energía eólica y la solar entre otras, nos lleva a impulsar la investigación y la innovación para aumentar los efectos positivos que presentan estas centrales eléctricas. Es un hecho conocido que estas fuentes presentan variaciones horarias, diarias, estacionales y anuales; lo que plantea la necesidad de contar con tecnologías de almacenamiento de energía a corto y largo plazo que garanticen el suministro fluido y seguro de electricidad que siga los patrones de consumo de energía.

Se ha revisado críticamente la viabilidad de las pequeñas plantas de almacenamiento hidroeléctrico por bombeo combinadas con una planta desalinizadora, proponiendo algunas disposiciones innovadoras para la ubicación de este sistema de almacenamiento hidroeléctrico por bombeo acoplado, con el fin de aumentar la posibilidad de encontrar ubicaciones adecuadas para el despliegue de emplazamientos que encajen mejor en la estrategia de energía y agua a corto, así como a largo plazo. La estrategia combinada a corto y largo plazo propuesta para el sistema de almacenamiento hidroeléctrico por bombeo podría ser una solución viable para el almacenamiento de energía y para reducir los costes de producción de agua desalada. El sistema propuesto resuelve el problema de la intermitencia de las energías renovables y de los recursos hídricos, a la vez que se ocupa de la gestión del agua desalada, aunque no se ocupa de la curva diaria de consumo de energía eléctrica.

El modelo propuesto ha demostrado las ventajas del sistema y de los subsistemas. Estos deberían seguir desarrollándose para una mejor implementación que constantemente reduzca el impacto de la intermitencia de las energías renovables. La seguridad del suministro de agua se garantiza mediante el control del sistema propuesto, y los beneficios demostrados que se obtienen del sistema hidroeléctrico existente podrían incrementarse mediante un mejor desarrollo del sistema.

Para hacer frente al cambio climático global, varios países han anunciado objetivos ambiciosos para el despliegue de energías renovables, pero la naturaleza intermitente de las fuentes de energía renovable podría tener graves impactos en la red eléctrica existente. No sólo el sistema energético, sino también los recursos hídricos se verán afectados por el cambio climático global. Como solución a los problemas mencionados relacionados con las fuentes de energía renovable y los recursos hídricos de forma simultánea, se propone un sistema integrado y su modelo de funcionamiento para las fuentes de energía renovable y los recursos hídricos, según el cual se consideran la energía hidroeléctrica, la energía hidroeléctrica de bombeo, la energía solar, la energía eólica, las plantas de desalinización y el uso conjunto del agua entre dos embalses.

Se establece un modelo matemático para describir el funcionamiento del sistema en función de los datos de entrada. En cuanto a las plantas desalinizadoras del sistema propuesto, el coste de producción de agua sigue siendo superior al del embalse previsto en el caso de referencia debido a su mayor coste de explotación. Al considerar el beneficio total del sector del agua y de la energía, los gastos adicionales permiten reducir los costes de ambos recursos sólo si se pueden vender más productos de la instalación: agua y electricidad enérgica para la oportunidad de negocio analizada.

En este sentido se propone que:

- Estrategias para el desarrollo de estrategias vinculadas de desarrollo combinado de los recursos.
- Análisis de la huella de agua y carbono de los productos importados frente a los de producción local.
- Analizar la gestión del sistema que permita impulsar la adecuación y la estabilidad transitoria, y más en escenarios que aumenten la capacidad en el escenario renovable en comparación con el escenario de referencia. En concreto, habría que seguir investigando cuál es la combinación óptima de energía renovable variable acoplada al esquema propuesto para una red fiable.
- Deberían proponerse modelos de este y otros sistemas de almacenamiento de energía para desarrollar microrredes en un sistema de red superior.
- Cómo se mantiene la estabilidad de la red con una cuota creciente de energías renovables utilizando opciones adicionales de respaldo y flexibilidad.
- Habría que seguir investigando la relación entre capacidad de la región para la generación de energía a partir de fuentes renovables - necesidades de agua desalada - costes (económicos y energéticos) de la gestión de los recursos.
- Análisis del desarrollo de la red frente a posibles planes energéticos futuros, y su relación con el sistema de gestión de la energía.
- Mejora del análisis geomorfológico para un mejor análisis de las regiones estudiadas con el fin de lograr un mejor análisis sentado para un sistema integrado.
- Otra línea de investigación futura sería el desarrollo de un modelo trifásico combinado de alimentos, agua y energía que aproveche las sinergias entre los subsistemas.
- Cuál es la capacidad técnica posible de las energías renovables intermitentes en la capacidad instalada sin perjudicar la fiabilidad del sistema.
- In order to increase the benefits, a better definition of the forecast models that the system must deal with would be desirable in order to increase the benefits of the scheme.
- Sería muy importante seguir desarrollando sistemas de información para los países desarrollados, así como para los países en vías de desarrollo, que aclaren los costes (en recursos) de las actividades esenciales en las sociedades actuales, que incluyen la industria, la

energía, el turismo, etc. Es esencial que los ciudadanos sepan cuáles son los costes (en recursos) de las actividades. Si toda la información está disponible, será más fácil para ellos tener una opinión más aproximada sobre sus actividades que afectan al nexo.

Por lo tanto, sería necesaria una importante planificación previa, por ejemplo, analizando opciones como la respuesta a la demanda, la reserva de respaldo, las tecnologías de almacenamiento y las interconexiones o las plantas sustitutivas o adicionales que probablemente deberían considerarse para satisfacer la restricción de fiabilidad que cualquier sistema eléctrico debe cumplir en todo momento proporcionando extra inercia al sistema. Este ejercicio de modelización podría analizar la importancia de los intercambios de energía con las zonas circundantes para compartir la cuota de renovables, a pesar de que es más difícil de conseguir en las islas. El amplio despliegue de las FER en la producción de energía debería implicar una mayor cuota de energía para una mejor gestión del sistema.

Básicamente, el autor cree que la estrategia operativa y la optimización del tamaño de un sistema integrado de suministro de energía y agua deberían investigarse más a fondo para aumentar los beneficios que aporta el despliegue de modelos de negocio que necesitan ayuda financiera económica pública. Estos beneficios deben ser contabilizados tanto a corto como a largo plazo.

Entre los objetivos a cumplir en un proceso de optimización destacan minimizar los costes totales de producción anualizados, maximizar el porcentaje de fuentes de energía renovable en la producción total de energía y minimizar la energía eólica recortada. Habría que seguir investigando si los resultados de la optimización se corresponden con los datos reales de una instalación para depurar la lógica del software de la herramienta. El aumento de la producción de FER como parte de la producción total de electricidad es una opción factible desde el punto de vista de la disponibilidad, y no es difícil medir las reducciones de emisiones de CO_2 que se pueden conseguir gracias al aumento de la cuota de renovables. Por otro lado, hay que analizar más a fondo los costes y los ingresos que podría conseguir una instalación de este tipo para entender las condiciones que en ellas podrían ser económicamente eficientes.

La penetración de las fuentes de energía renovable intermitentes, por ejemplo la energía eólica, en el sistema eléctrico de las islas islámicas es limitada, incluso cuando existe un gran potencial. La energía eólica que no puede inyectarse directamente en la red eléctrica suele estar restringida. En este sentido, aplicaciones como la producción de hidrógeno o el bombeo de agua para el almacenamiento de energía se vuelven esenciales y su gestión vinculada, básica. Teniendo en cuenta que algunas islas necesitan desalinizar el agua de mar para producir agua dulce, debe analizarse más a fondo la creciente presión detectada sobre el sistema eléctrico, ya que la desalinización necesita electricidad. En concreto, las consecuencias del despliegue de los palnes energéticos renovables para mantener un flujo sostenible de agua desalada de forma económica podrían implicar que la gestión acoplada agua-renovables será esencial para un correcto rendimiento del sistema con costes específicos. A pesar de que los costes en las islas analizadas son más elevados que los sistemas superiores, como los peninsulares, los costes deben ser totalmente controlados para conocer las ventajas de los sistemas para el sistema energía-agua propuesto. En consecuencia, el problema de escasez de agua de una isla puede ser parte de la solución de su problema de integración de fuentes de energía renovable intermitente, pero debido a las sinergias entre sistemas el desarrollo de sistemas de información que apoyen el proceso de toma de decisiones.

El sistema que se ha propuesto utiliza el exceso de energía eólica en plantas desalinizadoras, y en un almacenamiento hidroeléctrico por bombeo, dando lugar a un sistema integrado de suministro de energía y agua que minimizaría el recorte de energía eólica. Es necesario aumentar el proceso de optimización que dimensione las instalaciones, así como la estrategia de emplazamiento de nuevas plantas que permitan aumentar la potencia de reserva de este esquema. y estrategia operativa de este sistema de desalación eólica y almacenamiento hidroeléctrico por bombeo.

Es importante destacar que además de los aspectos tecnológicos, se presta especial atención a aquellos aspectos que pueden ser críticos para la viabilidad comercial del modelo de negocio estudiado para la producción de agua y electricidad. Se explora la rentabilidad de diferentes configuraciones del esquema para diferentes cantidades de agua y electricidad vendidas, si bien las sinergias económicas que este esquema tiene con el subsistema alimentario deben ser investigadas más a fondo para sacar el máximo provecho del esquema. En este sentido, el modo sostenible propuesto debería definirse mejor y mejorarse para hacer frente a situaciones de incendio, o a sequías severas. Se destacan los factores que resultaron cruciales para el desarrollo de modelos de negocio exitosos, identificando nichos de aplicación potenciales, como los cultivos acuáticos. Además, debe investigarse la oportunidad de los planes de políticas públicas para la integración del sec-tor agrícola vinculado a los sistemas de transporte de energía. En la medida en que la solución más rentable sea la de vender más energía y agua, no cabe duda de que podría tener repercusiones en los mercados locales y en los puestos de trabajo de las zonas circundantes.

Una importante lección aprendida en el transcurso de los trabajos que condujeron a los estudios de doctorado es que la investigación es esencialmente un proceso iterativo. Por cada problema que se vuelve a resolver, surgen nuevas preguntas, lo que entra dentro de la propia naturaleza de la investigación para reconsiderar continuamente los enfoques, resultados e ideas anteriores.

Por último, y desde la perspectiva de la teoría de sistemas, debe continuar la investigación de las tecnologías energético-ambientales, estudiando cómo interconectar, integrar y gestionar estos ámbitos de forma combinada.

7. VALIDACIÓN

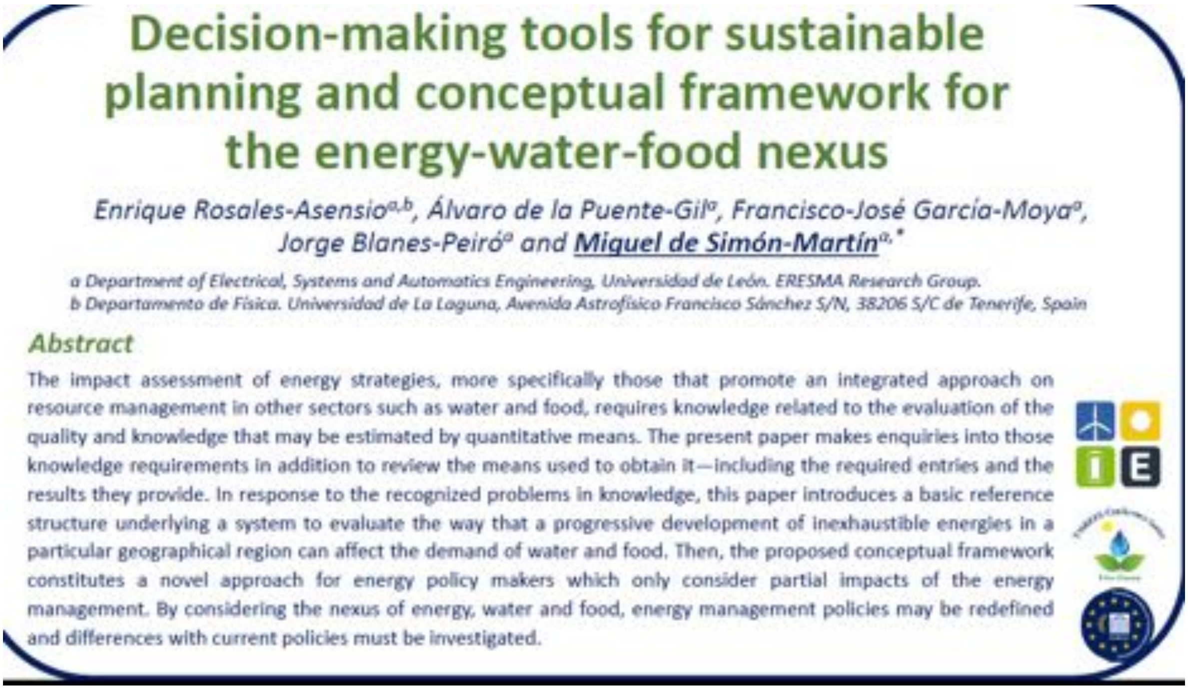
Los trabajos llevados a cabo y las investigaciones realizadas son presentadas en canales científicos reconocidos, tales como congresos, intercambios y publicaciones científicas. Parte de los elementos validadores del trabajo aquí desarrollado consisten en la presentación de los resultados en congresos y conferencias internacionales. Concretamente, los resultados por capítulos fueron los siguientes:

7.1. Congresos

7.1.1. Resultados de presentar el Capítulo 2 en conferencias internacionales

La publicación encuadrada en el capítulo segundo de la presente tesis doctoral cuyo título es el siguiente: Revisión de herramientas para el análisis de sostenibilidad de sistemas combinados Agua-Energía-Comida fue presentada en el congreso: Tmrees20-Greece International Conference. TMREES Conference Series Technologies and Materials for Renewable Energy, Environment and Sustainability. El lugar de celebración del mismo fue: 25-27 June 2020, Athens – Greece. Tmrees, EURACA, 13 to 16 April 2020, Atenas, Grecia.

- Autores: Enrique Rosales-Asensio, Álvaro de la Puente-Gil, Francisco José García-Moya, Jorge Blanes-Peiró and Miguel de Simón-Martín.
- Título: "Decision-making tools for sustainable planning and conceptual framework for the energy-water-food nexus.
- Tipo de participación: comunicación escrita en vía remota.
- Congreso: Tmrees19-Greece International Conference. TMREES Conference Series. Technologies and Materials for Renewable Energy, Environment and Sustainability. European Academy for Sustainable Development. "EURACA". 04-06 septiembre de 2019, Atenas – Grecia.
- Estado: Aceptado y presentado.


Decision-making tools for sustainable planning and conceptual framework for the energy-water-food nexus

Enrique Rosales-Asensio[a,b], Álvaro de la Puente-Gil[a], Francisco-José García-Moya[a], Jorge Blanes-Peiró[a] and Miguel de Simón-Martín[a,*]

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Abstract

The impact assessment of energy strategies, more specifically those that promote an integrated approach on resource management in other sectors such as water and food, requires knowledge related to the evaluation of the quality and knowledge that may be estimated by quantitative means. The present paper makes enquiries into those knowledge requirements in addition to review the means used to obtain it—including the required entries and the results they provide. In response to the recognized problems in knowledge, this paper introduces a basic reference structure underlying a system to evaluate the way that a progressive development of inexhaustible energies in a particular geographical region can affect the demand of water and food. Then, the proposed conceptual framework constitutes a novel approach for energy policy makers which only consider partial impacts of the energy management. By considering the nexus of energy, water and food, energy management policies may be redefined and differences with current policies must be investigated.

7.1.2. Resultados de presentar el Capítulo 3 en conferencias internacionales

Por su parte una de las publicaciones que forman parte del capítulo tercero, cuyo título es: Energía renovable como catalizador de sinergias en sistemas con alto riesgo de escasez de agua también fue presentado durante la conferencia internacional del Congreso: Tmrees19-Greece International Conference.

- Autores: Rosales-Asensio, Francisco José García-Moya, Alberto González-Martínez, David Borge-Diez and Miguel de Simón-Martín.
- Título: Stress Mitigation of Conventional Water Resources in Water-Scarce Areas through the use of Renewable Energy Powered Desalination Plants: An Application to the Canary Islands.
- Tipo de participación: Poster.
- Congreso: Tmrees19-Greece International Conference. TMREES Conference Series. Technologies and Materials for Renewable Energy, Environment and Sustainability. European Academy for Sustainable Development. “EURACA”. 04-06 de Septiembre de 2019, Atenas – Grecia.
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7.2. Publicaciones resultantes de esta Tesis Doctoral

7.2.1. Publicación de Resultados del Capítulo 2 en revistas de alto factor de impacto

7.2.1.1. Publicación primera parte del Capítulo 2

- Autores: David Borge-Diez, Francisco José García-Moya, Enrique Rosales-Asensio.
- Titulo: Water, Energy, Food Nexus Analysis and Management Tools: a Review.
- Revista: Energies 2022, Volumen 15, número 3, 1146.
- Factor de impacto: 3.004.
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Review

Water Energy Food Nexus Analysis and Management Tools: A Review

David Borge-Diez [1], Francisco José García-Moya [1] and Enrique Rosales-Asensio [2,*]

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Abstract: In order to eradicate water–energy–food poverty, Sustainable Development Goals (SDG) proposed milestones to overcome the feeding problem. The development of water–energy–food (WEF) nexus management tools, and approaches has increased during last years. The aim of this research is to review WEF nexus management methods, tools, and examples to identify gaps, goals, or future development that arise when modelling goods management issues for designing a sustainable development framework. It is also presented the food-biofuel competition for resources problem focusing in threatened systems. In addition to the resource trade-off quantification issue, it proposed an analysis for WEF systems management from economic, environmental, and practical points of view with the aim of identifying results, challenges, gaps, or assumptions for nexus. The renewable energy highlights as an enabler for sustainable development.

Keywords: sustainable management; Water Energy Food Nexus; WEF; synergies improvement; analysis of strategies; Millennium Development Goals

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1. Introduction

It is a fact that human activity induces negative effects on the environment. From transport, energy generation, and others that generate GHG (Green House Gas) emissions [1], joint to increasing needs on developing countries, provokes increasing climate change impacts. In parallel, over recent decades, increasing world population has led to an increase in requirement of global food production [2]. According to Ortiz-Bobea et al. [3] anthropogenic climate change provokes among others impacts that precipitation events become more intense and frequent. In addition, precipitation variability on regional scales will likely intensify. From an environmental and economic point of view, increasing food production has repercussions in other sectors, mainly with the energy and water sectors, and either agriculture and livestock farming. Even if human-related GHG emissions stop, climate change impacts will continue. Rising warming rates and magnitudes accompanied by ocean acidification, increase the risk of severe, pervasive, and in some cases, irreversible detrimental impacts.

In order to boost human development, the international community proposed the MDG (Millennium Development Goals) [4]. Among these goals were to eradicate poverty and hunger by 2030. Efforts for feeding a growing population provoked sustainable development concerns. In the light of this growing interest, UN released the 2030 Agenda for Sustainable Development [5]. One of the outstanding objectives is to achieve food security. According to Alexandratos et al. [6] to maintain the current nutrition levels, an increase of 70–100% in the food supply chain is needed. From an environmental and economic point of view, food production has repercussions in other sectors, mainly with the

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7.2.1.2. Publicación segunda parte del Capítulo 2

- Autores: Enrique Rosales-Asensio, Álvaro de la Puente-Gil, Francisco José García-Moya, Jorge Blanes-Peiró and Miguel de Simón-Martín.
- Título: Decision/making tools for sustainable planning and proposal of a novel conceptual framework for the energy-water-food nexus.
- Revista: Energy Reports. Volumen 6, Suplemento 6, noviembre de 2020, Páginas 4-15.
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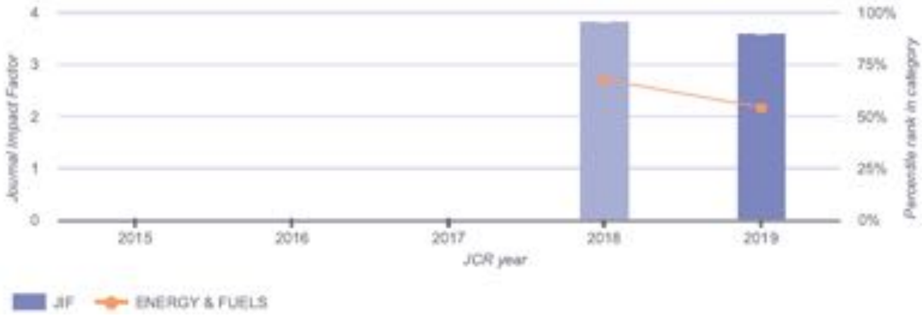
2019 Journal Impact Factor & percentile rank in category for: Energy Reports

3.595

2019 Journal Impact Factor



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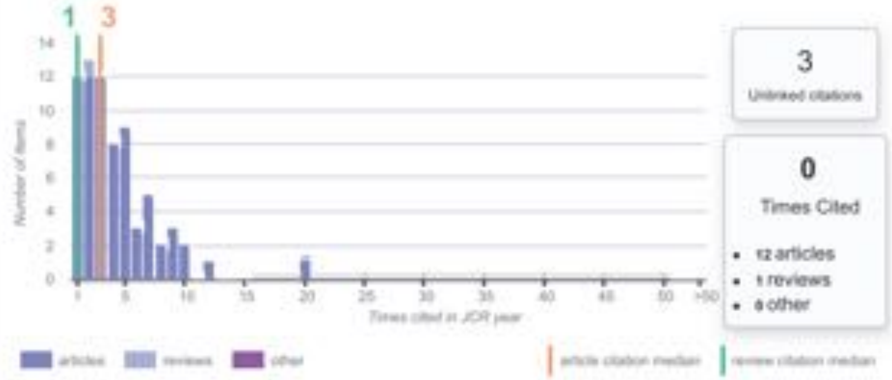

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Rank

Rank

JCR Impact Factor

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	Rank	Quartile	JIF Percentile
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2018	34/103	Q2	67.476

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Tmrees, EURACA, 13 to 16 April 2020, Athens, Greece

Decision-making tools for sustainable planning and conceptual framework for the energy–water–food nexus

Enrique Rosales-Asensio[a,b], Álvaro de la Puente-Gil[a], Francisco-José García-Moya[a], Jorge Blanes-Peiró[a], Miguel de Simón-Martín[a,*]

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Abstract

The impact assessment of energy strategies, more specifically those that promote an integrated approach on resource management in other sectors such as water and food, requires knowledge related to the evaluation of the quality and knowledge that may be estimated by quantitative means. The present paper makes inquiries into those knowledge requirements in addition to review the means used to obtain it—including the required entries and the results they provide. In response to the recognized problems in knowledge, this paper introduces a basic reference structure underlying a system to evaluate the way that a progressive development of inexhaustible energies in a particular geographical region can affect the demand of water and food. Then, the proposed conceptual framework constitutes a novel approach for energy policy makers which only consider partial impacts of the energy management. By considering the nexus of energy, water and food, energy management policies may be redefined and differences with current policies must be investigated.

Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2020.

Keywords: Energy strategies; Management of resources; Water, food and energy nexus; Renewable energy; Decision-making tools

1. Introduction

Often, political decisions are taken without the necessary coordination of different administrations and without considering the impact that a political decision in one activity may have on additional ones [1,2]. A deficiency in coordination arises between different branches at the same or different hierarchy levels in the public administration. Literature reflects clearly the fact that government tend to approach in an "isolated" way frequently results in policies that cannot be maintained at the current rate [3]. In this sense, there is a growing consensus about the importance

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Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2020.

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7.2.2. Publicación de Resultados del Capítulo 3 en revistas de alto factor de impacto

7.2.2.1. Publicación primera parte del Capítulo 3

- Autores: Francisco José García-Moya, Enrique Rosales-Asensio.
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2	J CLEAN PROD	ENVIRONMENTAL SCIENCES	JA	170352	9,297
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Comprehensive assessment of Gran Canaria water-energy-food nexus with GIS-based tool

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ABSTRACT

Society's increasing demand for resources creates an urgent need of resource allocation strategies. This research analyzed how alternative renewable-based energy plans affect a sustainability index related to the Water-Energy-Food nexus in a region highly dependent on desalted water. 50 water bodies of the island of Gran Canaria were analyzed for evaluating a pumping hydro energy storage strategy to support a renewable energy plan. The storage uses water from desalination plants which allowed to increase water and energy in the system. With the restrictions imposed, the Spanish island of Gran Canaria could store from 11.44 GWh/mcm to 30.76 GWh/mcm. Results showed that, depending on the specific renewable energy plan and on the factor of operation in the desalination plant, the stress in the water subsystem would be reduced from 8 mcm to 20 mcm. A system analysis strategy to control the water index was proposed to support the decision-making strategies.

1. Introduction

Over the last centuries resource consumption has increased in such a way that compromises the planet's ability to provide them in a sustainable manner (Bansel et al., 2015). Activities related to economic development have led to impacts in the environment. These include stress and contamination of water, land, fishing, and GHG emissions related to the economic activity. Manufacturing, growing vegetables, electricity generation, feeding animals, or international trade are some of the most resources-taking activities. The increasing needs of energy has led international organizations to face this problem. In this sense, Brundtland Commission (World Commission on Environment and Development, 1973) stated in 1973 that sustainable development consists in securing water, energy and food supplies for current and future generations, while maintaining a healthy and unharmed environment. Not only UN alerts and gives indications with sustainable development goals (Nations, 2020a), but also researchers investigate the water, energy, and food (WEF) nexus for a better understanding of the synergies and trade-offs. All of them together are intended to provide a decision framework to ease the decision-making process (Keairns et al., 2016).

Food production requires land, water and energy; transporting and treating water requires energy; and energy production requires water and land as well, and even food (Mohtar et al., 2012), and other resources. Water is needed for irrigation as well as for human consumption, but also in industry or for energy electricity generation. In addition, energy, in its multiple forms, is required for food production processes, including tree felling, harvest, fertilizer production, and transport (Chamas et al., 2021). Fig. 1 describes how components enter and leave a closed system, and how they are related through the components of which they are composed. Furthermore, it must be taken into account the CO_2 that is generated during these activities.

It stands out that, at the current rate of population growth, the agricultural sector is challenged with doubling food production by 2050 (Organization for Economic Co-operation and Development OECD-IEA and Bhaduri, 2010). It is highlighted that 71% of current world water withdrawals are attributed to the agricultural sector (Charting Our Water Future, 2009). By 2010 the energy sector consumed around 15% of the global water withdrawals (International Energy AgencyIEA, 2012) and contributed two-thirds of global GHG emissions (International Energy AgencyIEA, 2020). Overall, the EU produces and supplies more food than its population needs – producing 3416 kcal/inhabitant/day. This is far more than the 2000 kcal/inhabitant/day to 2600 kcal/inhabitant/day average daily energy intake requirement set by the EFSA (European Food Standard Agency) (European Union, 2015).

To enhance synergies between systems and increase environmental sustainability, some institutions encourage innovation projects that optimize the resource management process. European Commission

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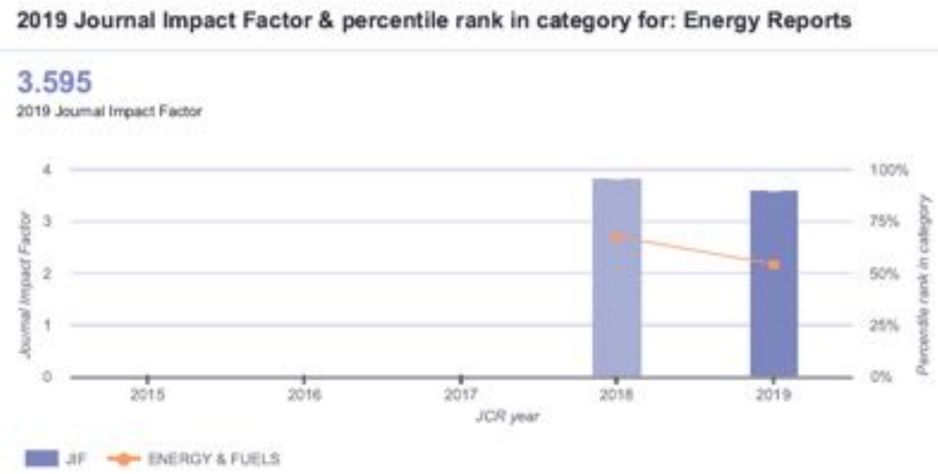
7.2.2.2. Segunda Publicación segunda parte del Capítulo 3

- Autores: Enrique Rosales-Asensio, Francisco José García-Moya, Alberto González-Martínez, David Borge-Diez and Miguel de Simón-Martín.
- Título: Stress Mitigation of Conventional Water Resources in Water-Scarce Areas through the use of Renewable Energy Powered Desalination Plants: An Application to the Canary Islands.
- Revista: Energy Reports. Volumen 6, suplemento 3. Febrero 2020. Páginas 124-135.
- Factor de impacto (año 2020): 3.595.
- Estado: Aceptado y publicado.



InCites Journal Citation Reports

Rank

Rank

JCR Impact Factor

JCR Year	ENERGY & FUELS Rank	Quartile	JIF Percentile
2019	52/112	Q2	54.018
2018	34/103	Q2	67.476

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Stress mitigation of conventional water resources in water-scarce areas through the use of renewable energy powered desalination plants: An application to the Canary Islands

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Abstract

Climate change conditions in the last decades have derived in a significant reduction of rivers' levels, irregularity of rainfall and, thus, difficulties in accessing to drinkable water. This situation is especially dramatical in islanded environments, such as the Canary Islands in Spain, where these restrictions to water resources have conducted to an overexploitation of aquifers and wells, with the deterioration of the environment that this fact entails. For this reason, desalination plants have become essential, and efforts must be done to reduce their impact and costs, as the involved processes for water desalination are high energy intensive. In this research paper, an optimized size hybrid wind and solar photovoltaic power plant is proposed to feed a desalination plant under the approach of not only feed the desalination process, but also provide the power grid with clean energy, taken advantage of the surplus electricity production. This way, not only the water resources stress is mitigated (through the desalting water production), but also the grid benefits from the integration of a distributed renewable energy source (DRES). Moreover, the business model is improved as the cost of drinkable water production is reduced and the power plant owner receives extra incomes from the water sales. Optimization results for a case study in Gran Canaria island shows that, considering the power dispatch in the island, the remuneration limits for power delivery and the remuneration for provided water, the optimal DRES associated with a desalination plant providing 5600 m^3/day of desalted water and a maximum annual electricity injection to the power grid of 5.88 GWh/year, an hybrid solar PV and wind generation installation with electrochemical storage is a feasible solution that makes the Levelized Cost of Electricity (*LCOE*) achieve a singular reduced value despite considering the additional costs of the desalination plant, although financial help must be provided to reduce the Payback Time.

Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2019.

Keywords: Water stress; Desalination; Renewable energy; Solar photovoltaics; Wind energy; Hybrid power plant

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Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2019.

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7.2.3. Publicación de Resultados del Capítulo 4 en revistas de alto factor de impacto.

7.2.3.1. Primera publicación que forma parte del Capítulo 4

- Autores: David Borge-Diez, Francisco José García Moya, Pedro Cabrera Santana, Enrique Rosales-Asensio.
- Título: Feasibility analysis of wind and solar powered desalination plants: An application to islands Desalination Plants: An Application to the Canary Islands.
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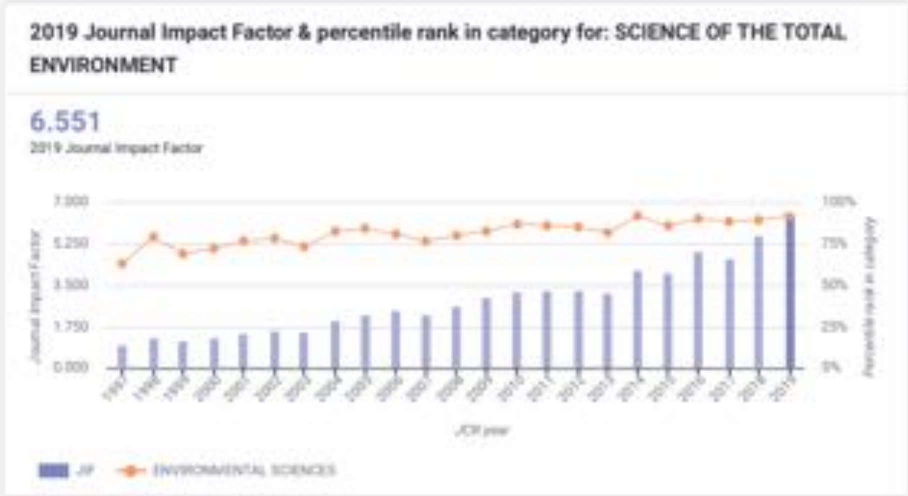

JCR Impact Factor

JCR Year	ENVIRONMENTAL SCIENCES		
	Rank	Quartile	JIF Percentile
2019	22/265	Q1	91.887
2018	27/251	Q1	89.442
2017	27/242	Q1	89.050
2016	22/229	Q1	90.611
2015	32/225	Q1	86.000
2014	18/223	Q1	92.152
2013	40/216	Q1	81.713
2012	31/210	Q1	85.476
2011	29/205	Q1	86.098
2010	26/193	Q1	86.788

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Feasibility analysis of wind and solar powered desalination plants: An application to islands

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HIGHLIGHTS

- Analysis of renewable energy driven desalinization plants in islands is presented.
- Reverse osmosis plant has been compared with respect to a novel pilot plant.
- Solution is economically profitable only under certain conditions of conceded grants.
- The sales of water and energy are highlighted as a limiting factor.
- LCOE might be similar than the Spanish generation, depending on the loans.

GRAPHICAL ABSTRACT

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ABSTRACT

Economic surveillance for securing water projects driven by non-conventional energy sources is a challenge. The carrying out of these initiatives in economies based on liberalized markets faces governments against the need for guaranteed profits. As water availability has become a relevant global problem, and desalination an energy-intensive demand solution, it is common to combine both kinds of technologies, renewable energy systems and desalination plants. This research investigates the influence of grants, investment rates, and energy and water sales on the commercialization of two desalination technologies. A performance analysis has been carried out taking into account different scenarios. Following this approach, a simulated reverse osmosis desalination plant has been compared with respect to an already granted novel pilot plant. Results show a better fulfillment of the non-economic objectives, and economically profitable not only under certain conditions of conceded grants, and investor's expected benefits but also of sales of water-energy, that highlighted as a limiting factor. The Levelized Cost of Energy might be similar than the Spanish generation means, depending on the cost escalation rate of the loans, and conceded grants. It was found a reduction of 11 euro cents under the average price that could be achieved, for the standard scenario.

1. Introduction

Among the 17 UN sustainable development goals (United Nations, 2020) to achieve a better and more sustainable future, we found the goal of reaching affordable and clean energy next to clean water and sanitation. Water scarcity affects more than 40% of the global population. Energy is central to nearly every major challenge and opportunity the world faces today. Be it for jobs, security, climate change, food production or increasing incomes. Additionally, among the European objectives included in the Lisbon Treaty (2007), it highlights the article 194: *to improve competitiveness, achieve security of supply of energy,*

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Rosales-Asensio, E., García-Moya, F.J., González-Martínez, A., Borge-Diaz, D., de Simón-Martín, M., 2019b. Stress mitigation of conventional water resources in water-scarce areas through the use of renewable energy powered desalination plants: an application to the Canary Islands. Energy Rep. 6, 124–135. https://doi.org/10.1016/j.egyr.2019.10.031.

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7.3. Patentes resultantes de los trabajos en esta Tesis Doctoral

Durante el trabajo de investigación llevado a cabo durante el proceso de redacción de esta Tesis Doctoral, se detectó la posibilidad de realizar un esquema que controlase de forma combinada el recurso. Este fue presentado como esquema patentable, el cual, tras un informe de estado de la técnica positivo, está a la espera de su publicación.

- Autores: Enrique Rosales-Asensio, Francisco José García-Moya, David Borge-Diez
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Título:	SISTEMA PARA EL CONTROL DEL RECURSO HÍDRICO Y ENERGÉTICO EN PLANTAS DESALADORAS
Solicitud No.	202031150
Solicitante:	UNIVERSIDAD DE LEÓN
Asunto:	**Informe sobre el Estado de la Técnica (IET)**

1. Contenido del informe

En el IET, el examinador busca documentos relacionados con la presente invención y acompaña el informe con su opinión escrita, donde hace una valoración preliminar acerca de la patentabilidad de las reivindicaciones y de otros aspectos de la solicitud.

Adjuntamos copia de este informe, donde se señalan los documentos relevantes encontrados durante la búsqueda y la categoría de los mismos. También incluimos copia de dichos documentos.

En este caso, el examinador ha citado documentos con categoría "A" (es decir no relevantes para la patentabilidad de la invención).

Dado que el IET es favorable, es de esperar que la OEPM emita próximamente la concesión de la patente, una vez realizado el examen sustantivo y dado el traslado del mismo.

Madrid, a 23 de marzo de 2021

Traslado del Informe sobre el Estado de la Técnica de la solicitud de Patente Nacional 202031150

La Oficina Española de Patentes y Marcas (OEPM), en cumplimiento con lo dispuesto en el artículo 36 de la Ley 24/2015 de Patentes y el artículo 26 de su Reglamento de Ejecución, le traslada el Informe sobre el Estado de la Técnica (IET) que incluye la Opinión Escrita correspondiente a la solicitud 202031150.

Los documentos citados en el Informe sobre el Estado de la Técnica y, en particular los documentos relativos a Literatura no Patente, pueden estar sujetos a Derechos de autor. La distribución de estos documentos ha de entenderse como parte de un procedimiento administrativo y como tal su transmisión debe entenderse a la luz del art. 31.bis 1 del Real Decreto Legislativo 1/1996, de 12 de abril, por el que se aprueba el Texto Refundido de la Ley de Propiedad Intelectual, regularizando, aclarando y armonizando las disposiciones legales vigentes sobre la materia y que establece que "No será necesaria autorización del autor cuando una obra se reproduzca, distribuya o comunique públicamente con fines de seguridad pública o para el correcto desarrollo de procedimientos administrativos, judiciales o parlamentarios".

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ANEXO A: REVISIÓN DE HERRAMIENTAS EVALUADAS

Tabla A0-1 Revisión de herramientas sobre el nexo evaluadas.

	Criterio de revisión					
Herramienta y referencia	1.a) Entradas fundamentales	2.a) Energía	2.b) Agua	2.c) Comida	2.d) Emisiones de efecto invernadero	2.e) Economía
CLEWs	Gran cantidad de datos necesarios. Parámetros técnicos y económicos de centrales térmicas, maquinaria agrícola, cadena de suministro de agua, terminales de desalinización, producción de fertilizantes, etc.	Balance energético, incluida la generación de electricidad y el refinado Energía para la alimentación Energía del exterior (virtual)	Balance hídrico Suministro de agua y desalinizació n Bombeo de agua W→F W→F (energía hidroeléctric a, estación generadora de frío, combustible derivado inmediatame nte de plantas cultivadas de materia viva)	Tecnologías de riego Uso de fertilizantes Uso de maquinaria agrícola	Restringido a una zona concreta y a las emisiones extranjeras Vertidos de GEI acumulados	Indicadores económicos seleccionado s
FME 2.0: orientar la planificación y la toma de decisiones integradoras sobre los recursos	Información local y características de la WLES Producción local de WEF (por tecnología) Datos políticos que tienen en cuenta las circunstancias particulares	Consecuencias de la producción de alimentos en la comercialización de la energía Energía utilizada en el agua (bombeo, tratamiento, desalinización) Energía utilizada para la alimentación (labranza, producción de fertilizantes, distribución y recolección)	Consecuenci as de la fabricación de sustancias nutritivas en un área particular restringida	Grado de producción regional de diversos tipos de sustancias nutritivas	Consecuencias de la fabricación de sustancias nutritivas en los vertidos de GEI	Gastos de fabricación de sustancias nutritivas
SEI (Stockholm Environment Institute) Modelización del agua y la energía	Requiere una gran cantidad de datos Información técnico-económica sobre equipos energéticos	Examen exhaustivo de la disfunción eréctil y sus transformaciones EB	Zona o región drenada por un río, sistema fluvial u otra masa de agua que concibe Simulación de las	/	Vertidos de GEI del sector energético	Incluye un módulo financiero

			necesidades y provisiones de agua Agua retenida bajo tierra en el suelo o en los poros y grietas de la evaluación de la roca Evaluación de las características del agua Evaluación del almacenamiento y la hidroelectricidad			
Herramienta de la Organización de las Naciones Unidas para la Agricultura y la Alimentación	Evaluación del país estudiado para clasificarlo por tipología	Específicos de cada tipo de intervención	Específicos de cada tipo de intervención	Específicos de cada tipo de intervención	/	Específicos de cada tipo de intervención
WBCSD nexus tool	Descripción de la naturaleza o características distintivas del sector energético Representaciones diagramáticas de áreas de terreno basadas en el SIG Caracterización del agua necesaria para agua-energía Datos sobre la mano de obra necesaria además de la disponibilidad de la máquina	Energía necesaria para el agua Energía necesaria para la alimentación (para el riego, la fabricación de fertilizantes o los dispositivos para realizar trabajos)	Agua necesaria para la generación de energía Agua necesaria para la producción de alimentos	Producción de alimentos	/	/
MuSIASEM	Requiere una gran cantidad de datos Indicadores socioeconómicos, incluida la evolución de la mano de obra Disponibilidad de suelo Evaluación del impacto del cambio climático	Evaluación de los flujos de energía en la sociedad	Evaluación de los flujos de agua en la sociedad	Evaluación de los flujos alimentarios en la sociedad	Implicaciones de todos los flujos en las emisiones	Costes y valores añadidos
Herramientas de diagnóstico para la inversión en agua para la agricultura y la energía	Conjunto completo de datos necesarios para caracterizar el suministro local de agua a la tierra o a los cultivos para ayudar al crecimiento y a las empresas de energía hidroeléctrica	Efecto de las empresas hidroeléctricas en la mejora de la calidad de vida Porcentaje de personas en una zona determinada que tienen un acceso relativamente sencillo y estable a la electricidad	Administración del agua Uso del agua para (i) la agricultura, que incluye el cultivo de la tierra para la obtención de cosechas y la cría de animales para obtener	Disponibilidad de alimentos y accesibilidad de los individuos a los mismos, donde la accesibilidad incluye la asequibilidad y la fabricación agrícola	Efecto del suministro de agua a la tierra o a los cultivos para ayudar al crecimiento, normalmente mediante canales y energía hidroeléctrica, en los vertidos de GEI	Contribución de la agricultura al producto interior bruto y a la producción de beneficios Requisitos de gasto Efecto del suministro de

			alimentos, lana y otros productos; y (ii) a la generación de energía derivada de la utilización de recursos físicos o químicos			agua a la tierra o a los cultivos para ayudar a las empresas en crecimiento en la mejora de la calidad de vida local
MARKAL/TIMES	Requiere una gran cantidad de datos Información tecnoeconómica sobre tecnologías energéticas Caracterización del RENS	Esquematización de la energía con un amplio grado de aspectos técnicos específicos EB Eficacia de la política energética	Uso del agua en el sector energético	/	Emisiones del sector energético	Gastos generales de la ES, con la provisión de agua necesaria

Tabla A0-2 Revisión de herramientas sobre el nexo evaluadas

Herramienta y referencia	Criterio de revisión				
	2.f) Tierra	3.a) Accesibilidad	3.b) Nivel geográfico nacional	3.c) Aplicable a zonas geográficas diferentes	3.d) Sin complejidad, aunque capaz de proporcionar una evaluación preliminar, incluyendo entradas políticas explícitas
CLEWs	Cultivos para biocombustibles Tipos de terreno según las circunstancias	Es posible que algún desarrollador trabaje en la herramienta	Nacional Global	Puede aplicarse a geografías distintas. Sin embargo, requiere muchos recursos.	/
WEF 2.0: orientar la planificación y la toma de decisiones integradas sobre los recursos	Tierra para alimentos	Es concebible que algún desarrollador trabaje en la herramienta	Nacional	Puede aplicarse a zonas geográficas diferentes	Marco de referencia simple Incluye políticas de importancia para un índice de sostenibilidad
SEI (Stockholm Environment Institute) Modelización del agua y la energía	/	Es posible que algún desarrollador trabaje en la herramienta Sin cargo para los países en desarrollo	National Global	Puede aplicarse a zonas geográficas diferentes	/
Food and Agriculture Organization of the United Nations tool	Específicos de cada tipo de intervención	Es posible que algún desarrollador trabaje en la herramienta	Nacional Subnacional	Mediante el uso de diferentes tipologías se puede utilizar en diferentes geografías	Una evaluación rápida del nexo no es complicada y depende de los índices listos para usar. La adopción de la categorización por naciones y los índices de proposición para cada tipo de intervención facilita su uso.
WBCSD nexus tool	Uso del suelo	Es posible que algún desarrollador trabaje en la herramienta	Nacional Global Regional Local	Puede utilizarse en zonas geográficas diferentes	/

MuSIASEM	Uso del suelo	Es posible que algún desarrollador trabaje en la herramienta	Nacional	Puede utilizarse en zonas geográficas diferentes. Sin embargo, requiere muchos recursos.	/
Herramientas de diagnóstico para la inversión (DTI) en agua para la agricultura y la energía	Tierras cultivadas	Es posible que algún desarrollador trabaje en la herramienta Se podría utilizar para las naciones dispares	National	Puede aplicarse a geografías distintas. Sin embargo, requiere muchos recursos.	/
MARKAL/TIMES	/	Aplicable a cualquier país	Nacional Global Regional Local	Se puede utilizar en zonas geográficas distintas. Sin embargo, requiere muchos recursos.	/

ANEXO B: CAPACIDAD DE DESALACION, TECNOLOGIAS, Y LOCALIZACION EN GRAN CANARIA

Tabla B0-1 Capacidad instalada en Gran Canaria, y características de las tecnologías de desalación.

Technología	**Consumo de Potencia**	**Producción De Salmuera**	**Instalada Capacidad m^3/día**	**Uso interior de la zona**	**Inversión Coste/m^3**	**Coste Operacional**
SHAMS-Titanium MED desalination	Bajo	Si		No	Alto	Moderado
AD and MED+AD TEchnology	Bajo	Si		No	Alto	Moderado
TNO Netherlands	Bajo	Si		No	Alto	Moderado
Dutch Pyramic/Seawater seawater Greenhouse	Bajo	Si		Si	Alto	Moderado
Aqua.abib water solutions	Bajo	No		Si	Alto	Moderado
Multi Stage Flash	Alto	Si	38.000	No	Moderado	Bajo
Multi Effect Distillation	Alto	Si		No	Moderado	Bajo
Thermal Vapour Compression MED	Alto	Si	5.200	No	Bajo	Bajo
Mechanical Vapour Compression	Alto	Si		No	Bajo	Bajo
Reverse Osmosis	Alto	Si	94.800	No	Moderado	Moderado

Tabla B0-2 Localización de la capacidad de desalación instalada en Gran Canaria.

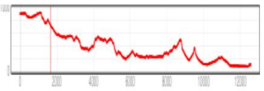
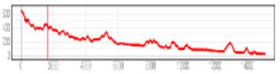
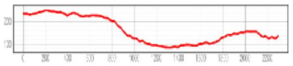
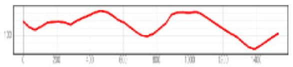
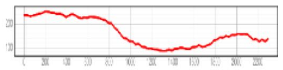
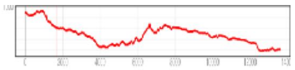
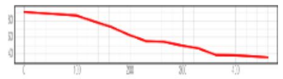
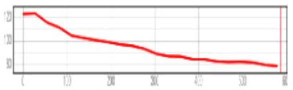
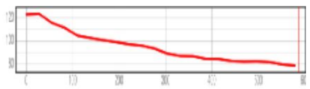
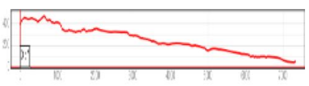
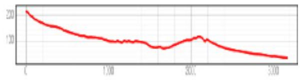
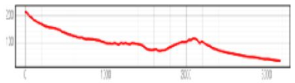
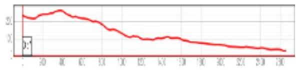
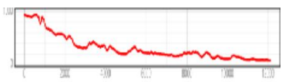
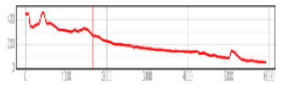
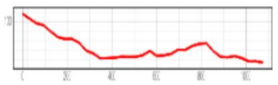
Planta Desaladora	Localización	Sistema	m³/día
Gáldar-Agaete I	Gáldar	OI	3.000
Agragua	Gáldar	OI	10.000
Guía I	Guía	CV	1.500
Arucas-Moya I	Arucas	OI	4.000
Granja Ag. Experimental	Arucas	CV	500
Las Palmas I	Jinámar	MEF	20.000
Las Palmas II	Jinámar	MEF	18.000
Las Palmas III	Jinámar	OI	36.000
Unelco	Jinámar PS	CV	1.000
Salinetas, S.A.	Salinetas	OI	600
Airport I	Airport G.C.	OI	1.000
Airport II	Airport	OI	500
Mando Aéreo de Canarias	Gando	OI	1.000
Sureste I	Santa Lucía	OI	10.000
Bonny	Juan Grande	OI	8.000
Elmasa II	Las Burras	OI	7.500
Elmasa III	Las Burras	OI	7.500
Unelco	Bco. Tirajana	CV	500
Anfi del Mar	Bco. La Verga	OI	200
Puerto Rico I	Puerto Rico	CV	1.200
Puerto Rico II	Puerto Rico	CV	1.000
Coagrisan	Bco. La Aldea	OI	5.000

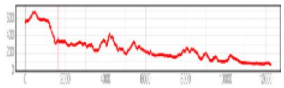
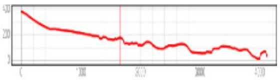
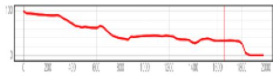
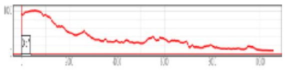
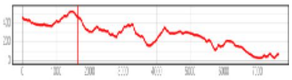
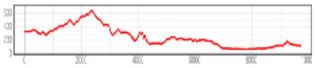
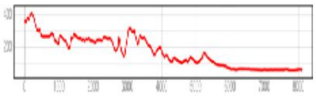
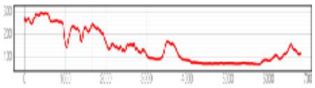
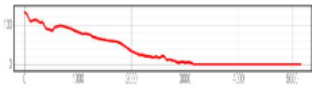
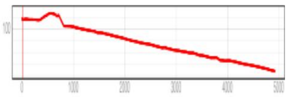
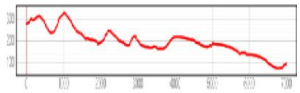
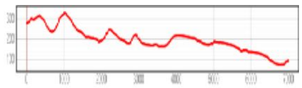
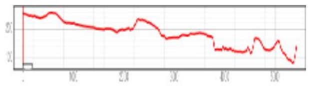
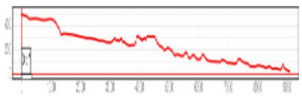
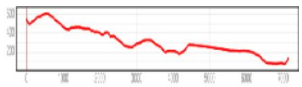
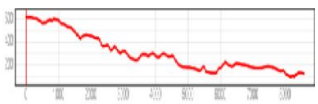
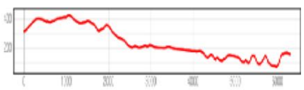
ANEXO C: RESTRICCIONES Y RESULTADOS DEL ANÁLISIS GEOMORFOLÓGICO

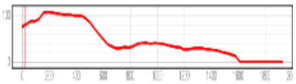
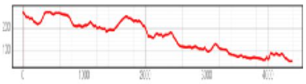
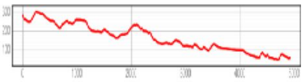
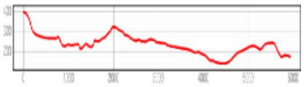
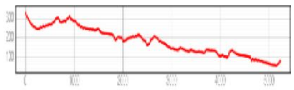
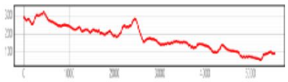
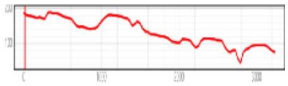
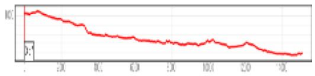
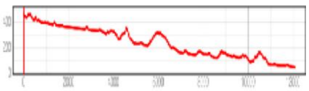
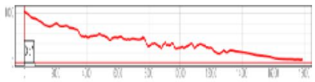
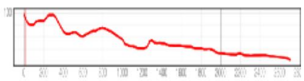
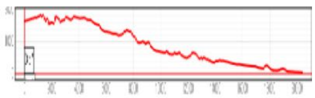
Tabla C0-1 Restricciones para análisis geomorfológico.

Restricción Propuesta	Razón	Restricción impuesta
Cuerpos de Agua en Gran Canaria	Capacidad de Almacenamiento	Cuerpos de agua más representativos de Gran Canaria
Distancia a plantas desaladoras	Problemas. Pérdidas de carga, cruce de carreteras, y propiedades	10 km como máximo
Proximidad a centales de generación térmica como restricción	A pesar de que pueda ser transportada, la red está mejor preparada en esta región	Distancia se fija en 20 km, porque la electricidad puede ser transportada a través de la red
Proximidad a la red	Trabajos para desarrollar la red	10 km
Cantidad de energía a ser almacenada	Para facilitar la programación de la operación del esquema PHS	El esquema debe proporcionar al menos 2 horas ininterrumpidad de operación a máxima capacidad.
Restricción Normativa	Para cumplir los requerimientos de las leyes relacionadas con: planificación y ordenación urbanística, paisajística, medioambiental y de seguridad aérea.	Cumplimiento de la normative que podría provocar problemas relacionados con el desarrollo de parques eólicos y del esquema de almacenamiento hídrico
Proximidad a áreas densamente pobladas	Dificultad para desarrollar el esquema en un periodo de tiempo corto	
Caminos	Dificultad para desarrollar el esquema en un periodo de tiempo corto	No pueden contener picos superiores a la altura inicial, ni cruzar núcleos poblados

Tabla C0-2 Resultados del Análisis Geomorfológico.

Coordenadas Geográficas	Herramienta Perfil	Energía (MWh)
437.058,3 308.7042,37		232,75
434.468,76 3.087.023,62		147
436.249,07 3.077.169,51		53,9
436.891,72 3.072.192,99		44,1
437.135,89 3.077.624,02		53,9
436.906,09 3.086.941,75		208,25
437.377,2 3.115.500,81		22,05
436.780,24 3.114.874,68		29,4
436.340,58 3.073.256,54		29,4
436.253,31 3.077.209,02		98
436.096,48 3.111.267,15		49
435.994,63 3.086.900,52		49
435.972,44 3.073.649,11		49
435.994,53 3.086.883,19		232,75
435.034,87 3.104.167,94		98
434.487,99 3.072.114,42		29,4

434.544,43 3.087.059,04		122,5
434.524,22 310.896,46		98
433.570,51 3.113.684,32		24,5
433.094,42 3.098.816,71		24,5
431.390,95 3.081.329,34		98
431.339,2 3.096.481,69		49
430.110,42 3.094.797,34		91,875
428.348,42 3.095.300,53		61,25
459.344,57 3.091.543,76		31,85
454.762,63 3.083.927,05		24,5
451.910,28 3.104.898,76		66,15
451.925,62 3.105.303		66
451.622,32 3.105.641,37		53,9
451.640,12 3.103.133,09		98
451.352,61 3.103.470,95		110,25
451.055,21 3.102.963,45		147
45.109.635 3.105.445,3		73,5

449.591,06 3.074.889,37		22,05
449.707,91 3.107.718,15		53,9
449.475,63 3.107.522,01		66,15
449.372,69 3.106.512,67		98
449.303,65 3.106.290,65		73,5
449.303,65 3.106.290,65		68,6
446.270,55 3.111.028,68		46,55
444.418,76 3.097.757,1		24,5
444.167,81 3.083.682,02		100,45
442.797,43 3.090.237,22		24,5
441.631,91 3.073.386,37		24,5
441.498,29 3.093.332,3		39,2
Energía Total (MWh)		3.076,22

ANEXO D: IMPACTOS DE LAS FUENTES DE ENERGÍA, Y COMPETITIVIDAD DEL SECTOR ALIMENTARIO

Tabla D0-1 Emisiones de las fuentes de energía. [18][19][20]

Technologia	Impactos en el terreno
Biomasa	T /MWh
CO_2 emisiones	1,5
Carbón	T/MWh
CO_2 emisiones	1,01
SO_2 emisiones	0,0005 – 0,014
NOx	0,0003 – 0,003
PM	0,0001 – 0,003
Nuclear	T/MWh
GHG (CO_2 -eq)	0,0037 – 0,1
Gas Natural	T/MWh
CO_2 de CCCTs	0,35 – 0,4
CO_2 de CTs	0,55 – 0,68
Solar	T/MWh
CO_2 emisiones equivalentes	0,02 – 0,06
Eólica	T/MWh
CO_2 emisiones equivalentes	0,014

Tabla D0-2 Análisis DAFO y de competitividad económica del subsector alimentario de Gran Canaria

Debilidades	Vulnerabilidad a las condiciones climáticas, características morfológicas del terreno que dificultan la mecanización, bajas cotizaciones de diversificación de las exportaciones y vulnerabilidad a las condiciones cambiantes del mercado. Precios más altos frente a los competidores. Saturación del mercado debido a: falta de planificación de los tipos de producción Las importaciones de: alimentos para el ganado, semillas, piensos, envases, la escasa diversidad y volumen de la gama de productos limita la competitividad, la dependencia de la financiación debido a los elevados costes de producción.
Amenazas	La liberalización implica competencia, menor financiación pública, aumento del suelo rústico para el turismo, regulación local, pérdida de coordinación entre administraciones. Alto poder de negociación de los agentes, falta de estrategias de coordinación productiva, excesiva dependencia de las importaciones de combustibles fósiles que encarece el suministro de agua (por su interrelación). Y la agricultura: fragilidad del ecosistema frente a las plagas, erosión del suelo.

Fortalezas	Buen clima que permite cultivar a lo largo del año, Valor añadido de los productos frescos locales, prestigio y alta calidad de algunos productos, a mayor turismo, mayor promoción de los productos, aumento de la rentabilidad de las explotaciones, con productos y actividades. Existencia de diferentes mercados para la comercialización. Región libre de transgénicos.
Oportunidades	Organización de los mercados de exportación, valor añadido y mayor rentabilidad en los cultivos diversificados, pisos bioclimáticos que permitan diferentes tipos de cultivos, a menor mecanización menores impactos, región ultraperiférica. Financiación de la UE. Nuevas tendencias, mejora de la imagen, recuperar el paisaje agrario con los beneficios asociados, fomento del asociacionismo. Planificación de la producción para sostener los precios bajando los efectos negativos del mercado; aprovechamiento de la marca Canarias. Nuevos métodos de mejora de la gestión del recurso hídrico.

Tabla D0-3 Competitividad económica del subsector alimentario de Gran Canaria

Año	2015		2010		2008		2005		2000	
PIB (Producto Interior Bruto)	Mill€	%	Mill €	%	Mill €	%	Mill €	%	Mill €	%
Agricultura, ganaderia y pesca	581	1,4	613	1,5	614,5	1,44	571,5	1,55	455,2	1,7
Trabajadores	744.000		729.000		740.900		771.800		792.500	
Valor Añadido Bruto a precios de mercado	223,8	1,6	237,88	1,6	240,8	1,62	227,66	1,75	211,99	2,12

ANEXO E: LOCALIZACIÓN DE LOS EMPLAZAMIENTOS PROPUESTOS

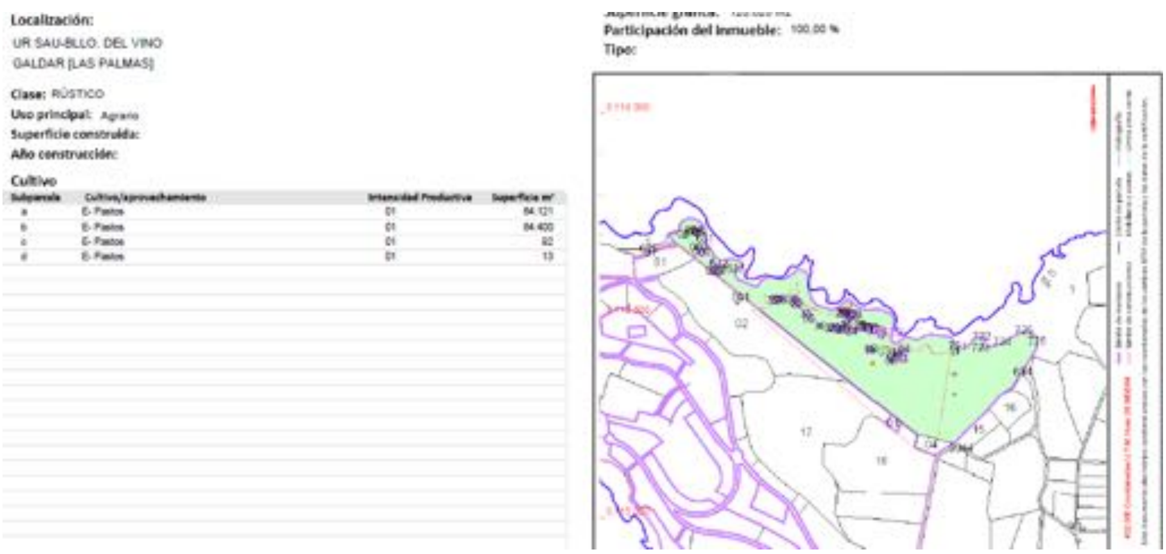


Figura E0-1 Emplazamiento Propuesto: Galdar. [16]

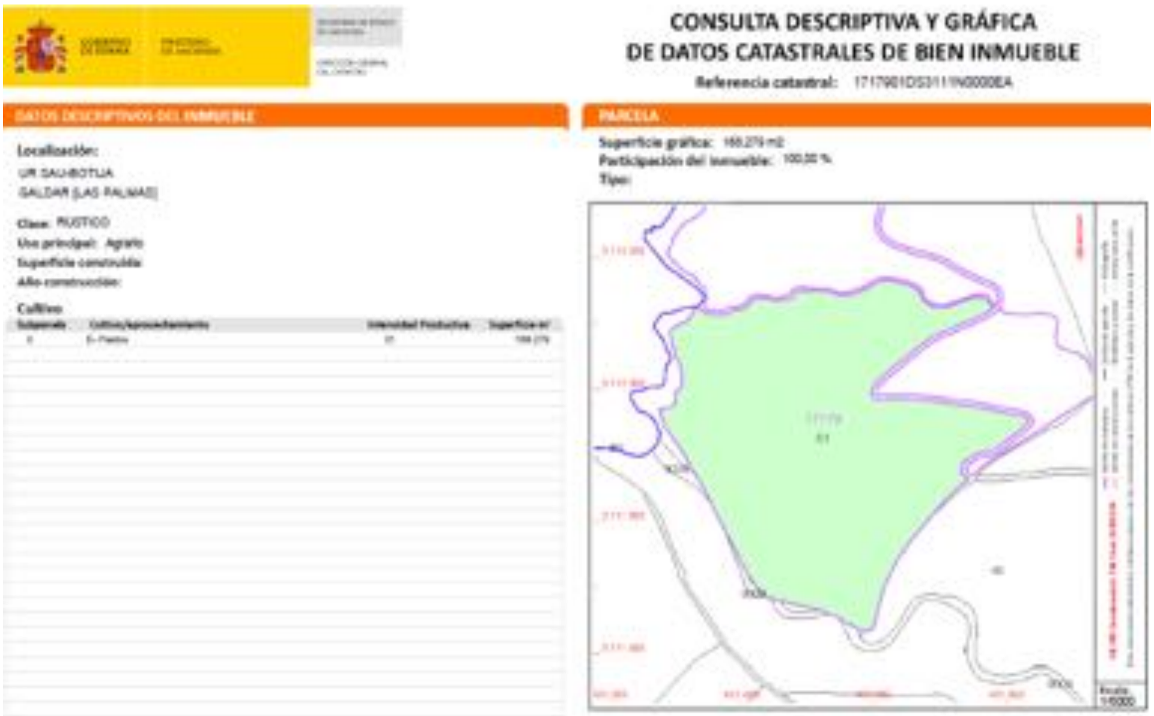


Figura E0-2 Emplazamiento propuesto: Galdar (Botija). [16]


CONSULTA DESCRIPTIVA Y GRÁFICA
DE DATOS CATASTRALES DE BIEN INMUEBLE
Referencia catastral:

DATOS DESCRIPTIVOS DEL INMUEBLE

Localización:
GALDAR (LAS PALMAS)
Clase: RÚSTICO
Uso principal: Agrario
Superficie construida:
Año construcción:
Cultivo

PARCELA

Superficie gráfica:
Participación del inmueble:
Tipo:

Figura E0-3 Emplazamiento propuesto: Galdar (del vino). [16]


CONSULTA DESCRIPTIVA Y GRÁFICA
DE DATOS CATASTRALES DE BIEN INMUEBLE
Referencia catastral:

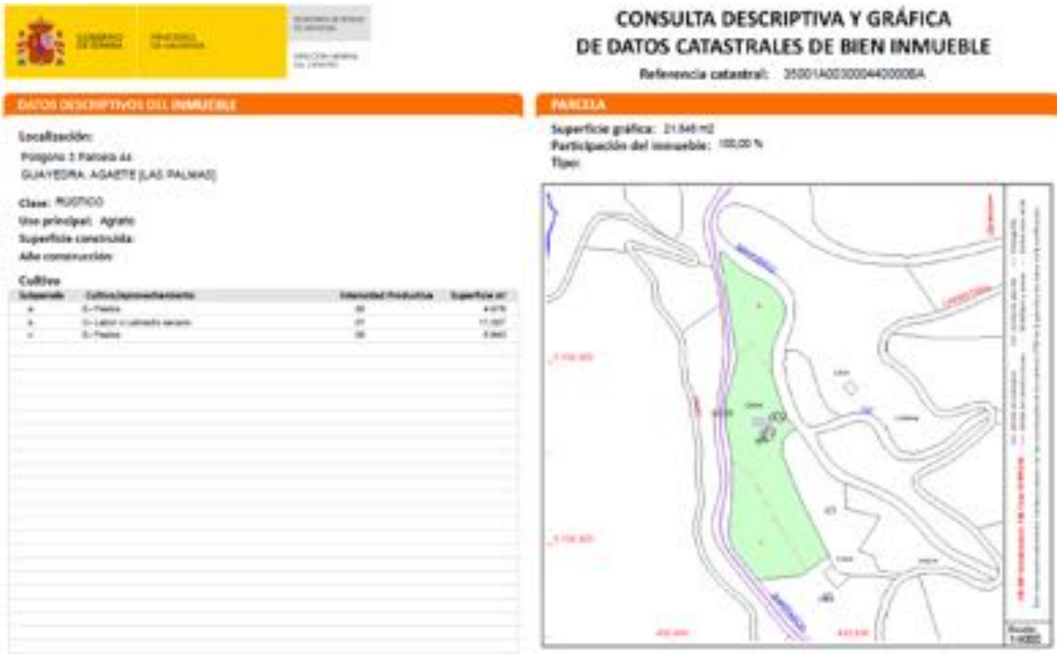
DATOS DESCRIPTIVOS DEL INMUEBLE

Localización:
Polígono 1 Parcela 111
SAN ANTONIO. SANTA LUCIA DE TIRAJANA (LAS PALMAS)
Clase: RÚSTICO
Uso principal: Agrario
Superficie construida:
Año construcción:
Cultivo

PARCELA

Superficie gráfica:
Participación del inmueble:
Tipo:

Figura E0-4 Emplazamiento propuesto: San Antonio. [16]



CONSULTA DESCRIPTIVA Y GRÁFICA
DE DATOS CATASTRALES DE BIEN INMUEBLE

DATOS DESCRIPTIVOS DEL INMUEBLE

Localización:
Polígono 3 Parcela 44
GUAYEDRA. AGAETE [LAS PALMAS]

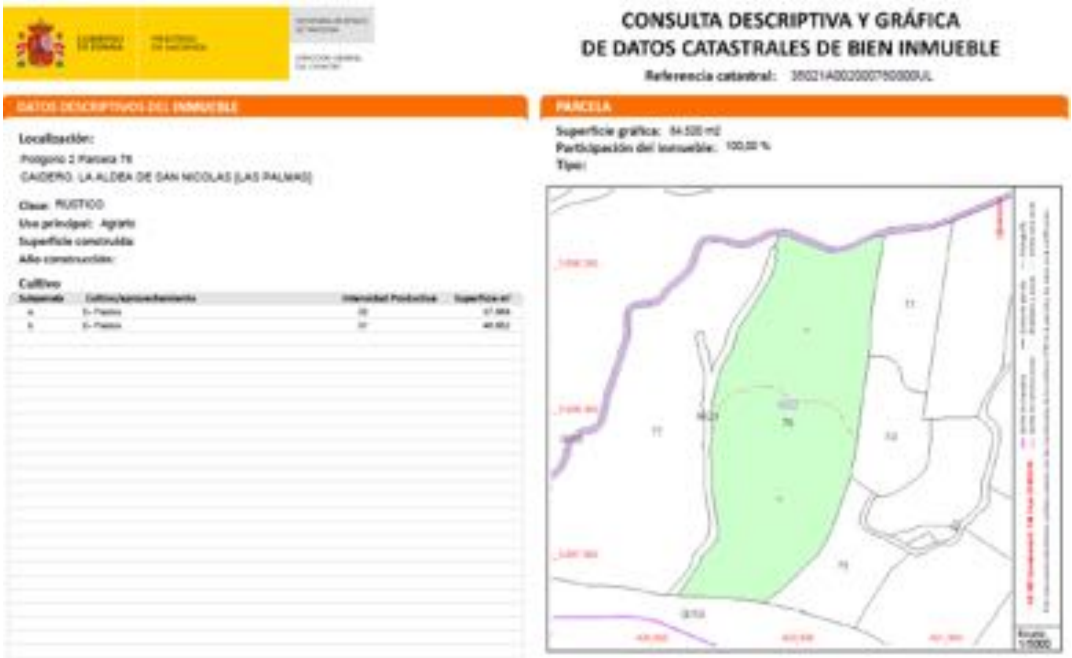
Clase: RUSTICO
Uso principal: Agrario
Superficie construida:
Año construcción:

Cultivo

PARCELA

Superficie gráfica:
Participación del inmueble: 100,00 %
Tipo:

Figura E0-5 Emplazamiento propuesto: Agaete. [16]



CONSULTA DESCRIPTIVA Y GRÁFICA
DE DATOS CATASTRALES DE BIEN INMUEBLE

DATOS DESCRIPTIVOS DEL INMUEBLE

Localización:
Polígono 2 Parcela 76
CAIDERO. LA ALDEA DE SAN NICOLAS [LAS PALMAS]

Clase: RUSTICO
Uso principal: Agrario
Superficie construida:
Año construcción:

Cultivo

PARCELA

Superficie gráfica:
Participación del inmueble: 100,00 %
Tipo:

Figura E0-6 Emplazamiento propuesto: La aldea de San Nicolás. [16]

Figura E0-7 Emplazamiento propuesto: La aldea de San Nicolás. [16]

Figura E0-8 Emplazamiento propuesto: Santa Lucia de Tirajana. [16]

ANEXO F: FLUJO DE CAJA DEL PROYECTO

Tabla F0-1 Flujo de Caja del Proyecto

Año	**Coste Planta de Desalinización (€)**	**Coste Baterias (€)**	**Coste Eólico (€)**	**Coste Solar (€)**	**Coste Electricidad (€)**	**Ventas Agua (€)**	**Ventas Electricidad (€)**
0	981.600	871,71	4.099.337	90.930	0	0	0
1	14.752	871,71	163.973	90.930	953,11	49.312,8	725.362,4
2	14.752	871,71	163.973	90.930	953,11	49.312,8	725.362,4
3	14.752	871,71	163.973,49	90.930	953,11	49.312,8	725.362,4
...	...	...	...	...	...	...	...
23	14.752	871,71	163.973.49	90.930	953.11	49.312,8	725.362,4
24	14.752	871,71	163.973,49	90.930	953.11	49. 312,78	725.362,37
25	14.752	871,71	163.973,49	90.930	953.11	49 .312,78	725.362,37

* Se ha adoptado como hipótesis que los costes de reemplazamiento de los componentes están incluidos en los costes anuales de operación y mantenimiento

ANEXO G: PARÁMETROS DE SIMULACIÓN, CARACTERÍSTICAS DE LOS CASH-FLOW Y RESULTADOS DE SIMULACIÓN

Tabla G0-1 Análisis de las características de las subvenciones propuestas

Ayuda	SME Phase 2 [31]	IDAE TEC/1380/2018 [32]
1. Objetivos	Claro, medible, realista y alcanzable dentro de la duración del proyecto. Breve presentación de la estructura general del plan de trabajo. Diagrama de Gantt + diagrama de Pert + KPI	Potencia instalada superior a 800 kW Asignación presupuestaria: 80 M € Incompatible con otras subvenciones Ámbito: ayudas propuestas para la inversión en proyectos de electricidad en los territorios no peninsulares. La potencia real instalada debe calcularse según definición de la normativa española: artículo 3 de: Real Decreto 413/2014, de 6 de junio.
2. Relación con el programa de trabajo	Explicar el estado actual de desarrollo del proyecto de innovación empresarial. Alcance material :	Alcance material: Ámbito geográfico: Disponible hasta el 31 de Diciembre.
3. Ambición	- Describa el punto de conflicto para el cliente identificado. ¿Cuál es la necesidad empresarial, el reto tecnológico o la oportunidad de mercado? - ¿En qué consiste su innovación? - ¿Cuál es el estado del arte del mercado? ¿Cómo se compararía su innovación con las soluciones, prácticas o productos disponibles (por ejemplo, rendimiento, costes, facilidad de uso, dimensión de género, cambio climático o aspectos medioambientales, beneficios para la sociedad)?	Obligaciones: Las empresas que cumplan con los requisitos relacionados más la Ley 24/2013 Sistema de contabilidad adicional, para registrar todas las transacciones relacionadas con cada operación a cofinanciar.
1. Impactos esperados:	Discusión. Entrar en el mercado ¿Quiénes son los usuarios y/o clientes objetivo y por qué querrán comprar el producto/servicio (punto de venta único)? ¿Son nuevos o ya forman parte de su base de clientes? ¿Cuál es el mercado en términos de tipo (por ejemplo, nicho, /alto volumen, nuevo/maduro, tasa de crecimiento), tamaño (por ejemplo, volumen, valor, ámbito geográfico) y crecimiento? ¿Quiénes son los principales competidores directos e indirectos de la invención propuesta? (Competidores, sustitutos y alternativas). ¿Cuáles son las barreras de entrada? ¿Cómo piensa superarlas?	Resultados esperados, esperados en POPE: C030: Capacidad adicional de generación de electricidad a partir de FER (MW). Reducción de las emisiones de GEI en toneladas de CO_2 equivalente/año. El factor de conversión a emisiones de CO_2 de la energía no renovable a utilizar debe ser 0,521 kg CO_2/kWh de energía final. La energía final se evaluará disminuyendo la energía generada en el nodo en un 4%.

	• Describa su modelo de negocio, incluyendo el modelo de ingresos y su plan de comercialización con un plazo aproximado de comercialización o despliegue. • ¿Por qué es escalable su modelo? ¿Cómo piensa ampliarlo y llegar a los mercados europeos y/o mundiales?	
2. Modelo de negocio		
	Financiación Indique las necesidades de financiación estimadas y el calendario para alcanzar la fase de comercialización de su innovación. ¿Cómo piensa financiar el 30% de la tasa de cofinanciación? Describa sus planes para garantizar la posterior financiación de su innovación (próximas rondas, financiación complementaria, etc.).	
Implementación		
Plan de trabajo	Breve presentación de la estructura general del plan de trabajo. Diagrama de Gantt + Diagrama de Pert + Hitos	Mostrar al IDAE la información económica así como la trayectoria financiera del proyecto.
Estructura y procedimientos de gestión	Describa la estructura organizativa y la toma de decisiones. Explique por qué la estructura organizativa y el mecanismo de toma de decisiones son adecuados para la complejidad y la escala del proyecto. Describa, si procede, cómo se abordará la gestión eficaz de la innovación en la estructura de gestión	Se debe presentar un presupuesto financiable

Recursos a comprometer	La información de esta sección coincide con los costes indicados en el presupuesto. • ¿Qué tiene de único su enfoque, comparado con el de otras empresas? • ¿Por qué ahora? Explique la evolución histórica de su categoría y defina las tendencias recientes que hacen posible su solución. • ¿En qué fase de desarrollo se encuentra su innovación? Consulte los niveles de preparación tecnológica (TRL) o algo análogo para las innovaciones no tecnológicas • ¿Qué hitos han conducido a la actual fase de desarrollo (por ejemplo, prueba de concepto completada, primeros ensayos de campo en curso)? Describa los resultados obtenidos sobre la viabilidad tecnológica, práctica y económica de la innovación. • ¿Cuáles son las siguientes etapas y actividades necesarias para comercializar su innovación?	Dentro de los procesos de contratación relacionados con los gastos bancarios: Aportar al menos 3 ofertas de diferentes proveedores previamente al compromiso de contratación para la ejecución de la instalación, así como mantener su documentación, incluyendo la justificación de la oferta seleccionada. Todos los servicios contratados deben ser demostrables. Demostrar la realización de la actividad, y someterse a verificación y control Ajustar los costes a lo establecido en el presupuesto, dejando que el organismo controle el desarrollo. Cumplir con los requisitos de publicidad y difusión según la Ley 38/2003 (arts. 18.4) Conservar los documentos que justifican el proyecto, incluidos los procedimientos de gestión y control que garantizan un buen uso de las subvenciones propuestas, así como proporcionar los documentos a posteriori.

Tabla G0-2 Resultados de Simulación

Parámetro	Simulación Resultados (kW)	Inversión (€)	O & M (€)		Ventas (€)
Planta Solar	1	1.050	84		
Planta Desaladora		981.600	73.487	Agua	21.408
Planta Eólica	2.499,9	2.499.967,7	32.000		
Bateria	0,83	750,22	75		
Costes de Electricidad			3.891	Electricidad	385.724
Tasas de electricidad (7%)					-20.831
Total		3.483.367,8	109.537		386.301

ANEXO P1: COPIA DE LA PUBLICACIÓN CIENTÍFICA "WATER ENERGY FOOD NEXUS ANALYSIS AND MANAGEMENT TOOLS: A REVIEW"

energies

MDPI

Review

Water Energy Food Nexus Analysis and Management Tools: A Review

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Abstract: In order to eradicate water–energy–food poverty, Sustainable Development Goals (SDG) proposed milestones to overcome the feeding problem. The development of water–energy–food (WEF) nexus management tools, and approaches has increased during last years. The aim of this research is to review WEF nexus management methods, tools, and examples to identify gaps, goals, or future development that arise when modelling goods management issues for designing a sustainable development framework. It is also presented the food–biofuel competition for resources problem focusing in threatened systems. In addition to the resource trade-off quantification issue, it proposed an analysis for WEF systems management from economic, environmental, and practical points of view with the aim of identifying results, challenges, gaps, or assumptions for nexus. The renewable energy highlights as an enabler for sustainable development.

Keywords: sustainable management; Water Energy Food Nexus; WEF; synergies improvement; analysis of strategies; Millennium Development Goals

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1. Introduction

It is a fact that human activity induces negative effects on the environment. From transport, energy generation, and others that generate GHG (Green House Gas) emissions [1], joint to increasing needs on developing countries, provokes increasing climate change impacts. In parallel, over recent decades, increasing world population has led to an increase in requirement of global food production [2]. According to Ortiz-Bobea et al. [3] anthropogenic climate change provokes among others impacts that precipitation events become more intense and frequent. In addition, precipitation variability on regional scales will likely intensify. From an environmental and economic point of view, increasing food production has repercussions in other sectors, mainly with the energy and water sectors, and either agriculture and livestock farming. Even if human-related GHG emissions stop, climate change impacts will continue. Rising warming rates and magnitudes accompanied by ocean acidification, increase the risk of severe, pervasive, and in some cases, irreversible detrimental impacts.

In order to boost human development, the international community proposed the MDG (Millennium Development Goals) [4]. Among these goals were to eradicate poverty and hunger by 2030. Efforts for feeding a growing population provoked sustainable development concerns. In the light of this growing interest, UN released the 2030 Agenda for Sustainable Development [5]. One of the outstanding objectives is to achieve food security. According to Alexandratos et al. [6] to maintain the current nutrition levels, an increase of 70–100% in the food supply chain is needed. From an environmental and economic point of view, food production has repercussions in other sectors, mainly with the energy and water sector and either agriculture and livestock farming. This leads to a substantial correlated impact in the water resource consumption, as well in the CO_2 associated emissions. It is especially important to consider the food industry water impact because it is the largest world's freshwater user. Accounting for 70% of total global water withdrawals [7], this sector is also responsible of 30% of the global energy consumption along food supply chains [8], as well as of its correlated GHG emissions [9]. Food security is potentially affected by climate change from food production, to access, use, and price stability.

Agriculture is among the most climate-vulnerable sectors, impacted by further drying water-scarce regions, and region-specific changes in crop productivity. Despite its critical consideration, water perspectives globally show a 40% gap in fresh water demand in 2030 [10]. As fresh water is needed for citizens' consumption, irrigation, processing, and packaging in the agri-food industry, its supply is basic to achieve the aforementioned sustainable development goals. Climate change conditions have derived difficulty in accessing drinkable water. In the 21st century global population, suffering from water scarcity is projected to increase with the level of warming. In addition, it is also projected that renewable surface water and groundwater resources reduce in most dry subtropical regions. Changes in precipitation in a warming world will not be uniform: extreme precipitation events become more intense and more frequent as global mean surface temperature increases, and precipitation variability on regional scales will likely intensify. In most developing countries, population is highly dependent on agriculture. Despite the high percentage of total labor force involved in agriculture [11] only six percent of the 2.9 million smallholder farmers in Kenya is irrigated showing decoupled WEF systems. In order to assess the performance of previous actions taken either at local, regional, national, or international level case studies are necessary, for evaluating in the medium and long term.

Adaptation, mitigation, and sustainability development highlight the most outstanding strategies for managing climate change risk concerns. When sustainable—synergized with the water and food system—renewable energy becomes an enabler to lower the anthropogenic climate change impacts. In the complex and uncertain climate change environment, effective decision-making tools and risk management is mandatory for resource-use maximization.

In order to face the objectives to globally increase environment sustainability, the UN proposed 17 SDGs (sustainable development goals) for a sustainable global growth [12]. In this sense, the water–energy–food (WEF) nexus management tools and approach explore synergies for designing a sustainable environment. These are intrinsically connected at different levels. Either at resource management, infrastructure development, or political measures needed level; either at regional, or national level these three subsystem goals are linked. Defining and accounting tradeoffs between systems is basic for a better understanding of interconnections. According to Dyllick et al. [13] a central meaning for sustainability is the triple bottom line approach for increasing the performance of the network through the economic, environmental, and social dimensions where the minimum performance of a network can be achieved. Bigs et al. [14] analyzed the importance of a sustainable approach for the water–energy–food nexus at a small scale. The synergies between water, energy, and food systems provokes that the deterioration of one factor will cause a series of chain reactions among them. Gulati et al. noted that food production needs groundwater and energy consumption, a fact that leads to changes in regional climate, which affect food production [15,16]. Stylianopoulou et al. [17] reviewed Water–Energy–Food indicators and ratios for addressing security and sustainability in water, energy and food challenges, highlighting land use, GHG emissions, crop water productivity, energy consumption for crops, among others.

Where feeding the world population is concerned, it is highlighted by WEF management tools. Because of its importance, WEF Nexus have their specific SDGs. Three out of the 17 objectives refer specifically to food, SDG 2 (food); 6 (water), and 7 (energy). According to Fader et al. [18] the greatest synergies are likely to occur where conflicting resource needs appear. Depending on the synergies between systems and their integration degree, the consequences of a not synergized systems management threat SDG fulfillment. A joint resource management would be essential not only for SDG's fulfillment, but also for sustainable growth. Some discussed interlinkages between water, energy, or food SDG's objectives, with others SDG's. Nilsson et al. [19] developed a systematic path to map out target interactions for policy makers. Coopman et al. [20] developed a methodology to analyze the implications of policy measures needed for achieving SDGs although did not consider inputs needed for achieving certain targets, and infrastructure costs and labor needed were not considered. Table 1 shows the most outstanding sustainable objectives for water, and energy, as well for food security nexus approach. Across these objectives, it is assessed how tools deals with systems trade-offs and linkages, for boosting SDG success.

Table 1. Objectives for a Sustainable Nexus Approach [19].

Sustainable Water	Sustainable Energy	Food Security
Access to water resources	Access to modern energy services	Food Availability
Sustainable use and management of water resources	Increase efficiency of energy use	Food Access and Supply
Resilient societies and ecosystems to water-related disasters	Energy is clean/renewable and reliable	Utilization & Nutrition
		Stability of Prices

In order to increase environmental sustainability, WEF tools will benefit from synergies between systems, through the development of solutions that boost multiple objectives. For assessing trade-offs and interconnections, it highlights boundaries and scenario definition. This fact will lead to the development of tools, and approach for enabling identification of possible interventions, or new policies on the natural environment. Endo et al. [21] reviewed the identification of water, energy, and food nexus multiple trade-offs at different levels. Flamini et al. [22] assessed the WEF nexus, and focused on sustainable energy as the main enabler for nexus improvement, noting that the impacts will be observed on economic, social, and environmental goals. When evaluating the anthropogenic climate change contribution, quantifying trade-offs between systems is basic for a proper impact assessment. It is a well-known fact that globally renewable energy deployment has increased over the last years, becoming an enabler for lowering climate change impacts of WEF systems. It is forecast that renewable electricity capacity will reach more than 4800 GW by 2026, increasing by over 60% between 2020 and 2026 [23]. On the other hand, since biofuels and crops production are competing for the same resource either water or land are becoming a great concern for food security. Table 2 presents different types of biofuels regarding to the production process [24].

Table 2. Types of biofuels.

Biofuel Generation	Production Process
First	Fermentation (starch + sugar) and oil transesterification
Second	Thermo/Bio chemical
Third	Microbiological
Fourth	Thermochemical and hydro-processing

By reviewing tools, as well as examples of WEF nexus systems assessment and management, this research analyses how WEF nexus systems research deal with resource allocation problem, and proposes a methodology for evaluating scenarios with WEF nexus systems analysis tools. First, it is defined by the overarching methodology adopted in this review paper, outlining the food security problem, and presenting the most outstanding tools employed for WEF systems—tradeoffs accounting. Secondly, examples and actions taken for increasing WEF nexus system management perspectives are presented. These are analyzed to figure out how they account trade-offs, what are the actors involved in nexus management, and identify gaps, errors, and future development. This is followed by a brief discussion to identify the performance of reviewed tools, as well goals, and fails of actions taken. It is proposed as a methodology for increasing the sustainable performance of WEF systems according to a technological, practical, economic, and environmental point of view actions taken in the short, medium, and long term.

2. Analysis of Actions and Examples

This section reviews the most outstanding WEF systems analysis tools, and approaches since they fulfil the following criteria: include all three nexus resources, have been recently used, and are among top cited articles. It also presents examples, and actions taken for boosting sustainable WEF management of threatened systems focusing in renewable energy deployment as a synergies' facilitator. Through a methodologic analysis of how tools define the problem, and what the aim of the approach is, this research proposed an innovative approach for a sustainable management of systems. As can be seen in Figures 1–3, the area used for crops production with an extension higher than 100,000 Ha in Asia, Africa, and America has exponentially grown since 1980. It is worth mentioning that the Asia-Pacific area takes up two-thirds of the global food supply and uses about 60% of the world's fresh water.

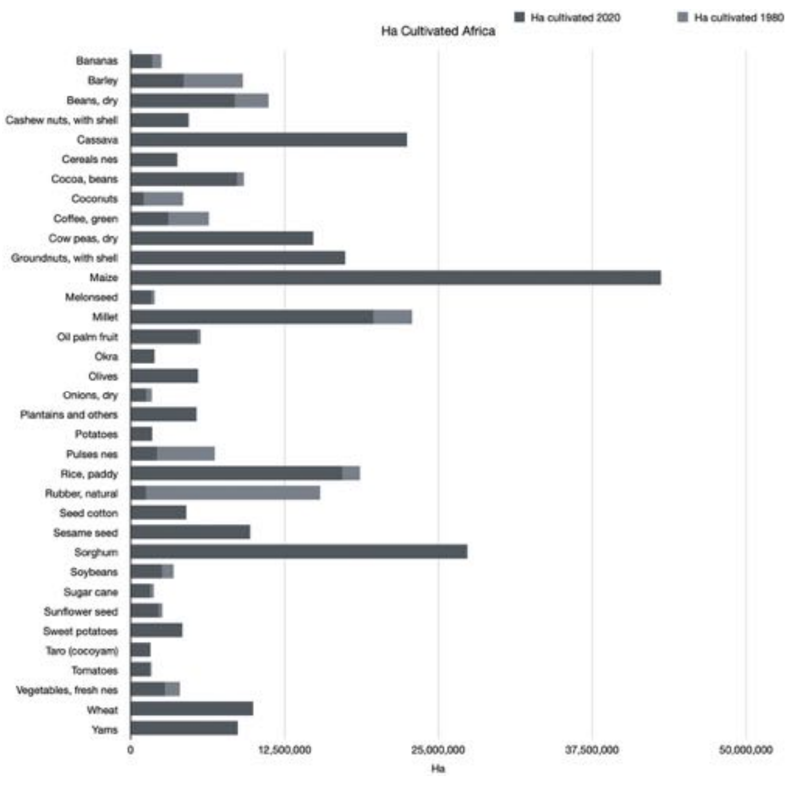

Figure 1. Crops production with an extension higher than 100,000 Ha in Africa, adapted from [25].

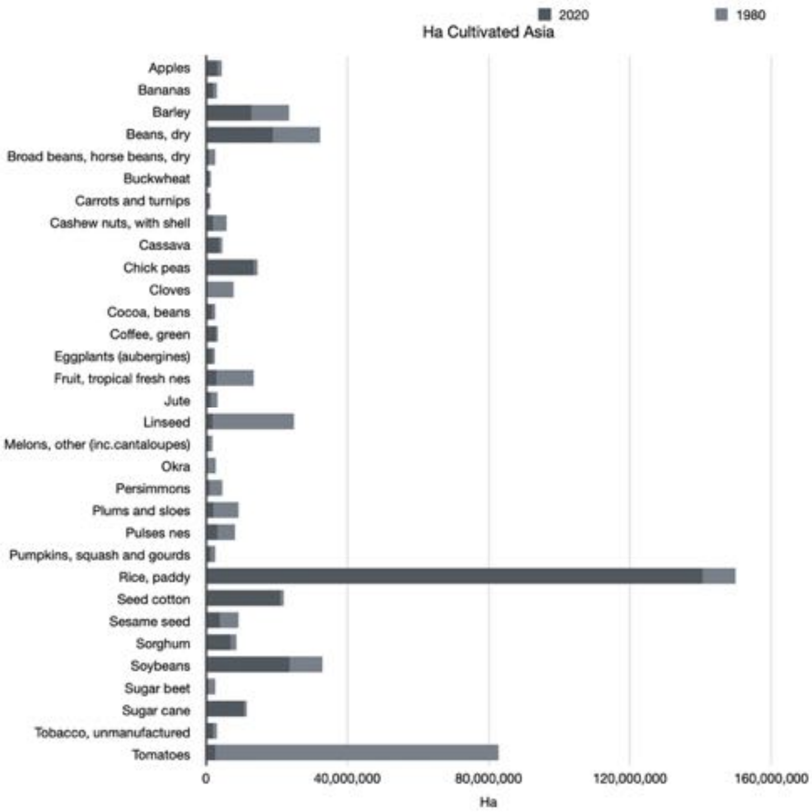

Figure 2. Crops production with an extension higher than 100,000 Ha in Asia, adapted from [25].

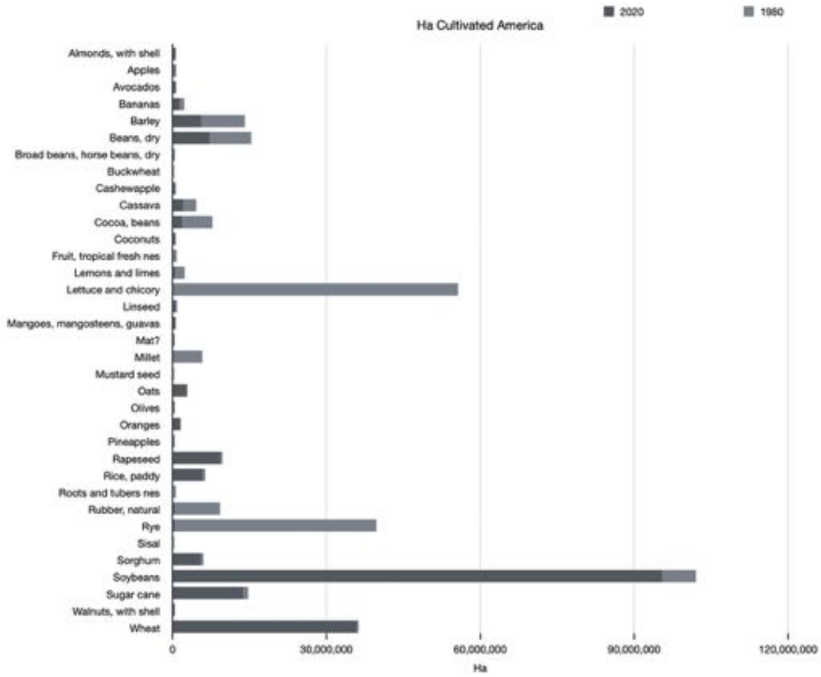

Figure 3. Crops production with an extension higher than 100,000 Ha in America, adapted from [25].

WEF management tools' final goal is to define synergies, and trade-offs' quantification between systems for a complete understanding of how these systems are linked. Through definition and quantification, these tools intend to boost a system's sustainable management. While some tools use quantitative approach for accounting these tradeoffs, qualitative approach include social assessment, opinions through surveys for evaluating deployed, or proposed policies within the nexus. A feasibility assessment of proposed actions was unbundled for analyzing technological, economical, sustainability, and practical feasibility of proposed actions within the nexus. In addition, it is to identify gaps, future development, or new research approach.

2.1. WEF Analysis Tools

Concerns about SDG's achievement have promoted the development of tools for synergies analysis, and trade-offs' quantification. When the analysis relies on realistic models and accurate data it is easier to achieve their goals. Research on WEF systems initially focused on correlations between two systems, and how do they account system externalities such as changes in climate through GHG related emissions or population increases, although challenges increased for studying the interconnection of the three elements of the nexus.

Table 3 shows WEF nexus assessment tools considered in this research. Among these, it highlights WEF Nexus Tool 2.0 [26]. In this tool, the user identifies data inputs from the systems' food, water, and energy portfolios, agricultural conditions, and food import–export data for assessing requirements of the systems among other indicators. Developed for Howels et al. [27] CLEWs (Climate, Land-use, Energy–Water strategies) this open-source tool investigates how a changing sector influence other. This is done by indices development, scenario making, and forecasting. Focusing in small islands, the KTH Royal Institute of Technology investigates these interconnections [28]. It is also to mention the Nexus Assessment framework [29] that looks at power irrigation, bioenergy, hydropower, or water desalination interventions to evaluate water, energy, food, labor, and cost components. They proposed the Nexus Rapid Appraisal tool for indices development. Among quantitative tools, it highlights MuSIASEM that focuses in water, energy, and food systems, in relation to socio-economic and ecological variables. Giampietro et al. [30] analyzed the 'metabolic pattern of energy, food, and water' for land-use changes evaluation, population dynamics, or GHG emissions. According to this approach MuSIASEM [31] provides quantitative information for discussing constraints such as feasibility to refer to the availability of natural resources, or environmental services in relation to the required supply and sink capacity. The viability concerns in this tool consist of internal constraints imposed through the metabolic pattern by the human socioeconomic system. Allwood et al. [32] designed the Foreseer Tool. By using Sankey diagrams, this tool allows users to track water, energy, and land resources through the production chain. Developed by Stockholm Environment Institute, two software models [33] for supporting and analyzing the water–energy nexus: WEAP (Water Evaluation and Planning System) and LEAP (Long Range Alternatives Planning System). It is also to highlight the integrated Sustainable Development Goals Planning Model (iSDG Planning Model) consisting of a tool for evaluating trends towards achieving SDGs according to defined scenarios [34]. Only by focusing on quantitative data, Rosales et al. [35] built a sustainability index for quantitative analysis of water consumption, and CO_2 evaluation of different energy electricity generation programs. Among the quantitative–qualitative approach is to highlight the European project: "Moving Towards Adaptive Governance". It proposed the Quantitative Story-Telling (QST) approach [36] that uses narratives to elucidate different points of view about the analyzed system highlighting implicit assumptions and uncertainties. This analysis also relies on multi-scale resource quantifications for evaluating nexus interconnections. In addition, it includes the opinions of involved actors for of building narratives. First it maps actors for narratives identification. It quantifies nexus relations through quantitative tools. Other tools included in this approach are: socio-institutional analysis, media analysis, interviews, coding, and surveys to farms and food industries to be included. In the next step, an analysis is developed for quantitative and quantitative data to build feedback on narratives. From the mixed analysis of narratives, it presents different storylines. In a next step, they are assessed under different scenarios. Finally, a longitudinal analysis and synthesis of results infers lessons and policy impacts that can be assessed. QST draws upon qualitative issues only when the analysis includes constraints to the system and trade-offs between systems [37]. Cabello et al. [38] used the narratives of involved actors for identifying convergences. SDG's also used qualitative and quantitative considerations. First: a pair of (water, energy, or food) SDG targets are selected, assigning a number for identifying when the objectives compete for the same resource.

Table 3. WEF Tools performance reviewed in this research [31–38].

Objective	Calculation Tool	Model Capacity	
Forecasting and analysis of scenarios	WEF Nexus Tool 2.0	Quantitative	
Forecasting and analysis of scenarios, index calculation	CLEWs	Quantitative/	Qualitative
Calculation of performance assessment considering five different parameters	Nexus Rapid appraisal	Quantitative	
Scenario analysis and forecast scenarios model	MuSIASEM	Quantitative	
Water, energy and land trade-offs prediction	Foreseer Tool	Quantitative	
Forecasting and analysis of scenarios	WEAP-LEAP	Quantitative/	Qualitative
Forecasting and analysis of scenarios	iSDG Planning Model	Quantitative/	Qualitative
Energy and climate mitigation models	Sustainability tool	Quantitative	
Multi indicator analysis	WEF nexus indicator	Quantitative	
Analysis of policies and narratives on governance.	QST	Quantitative/	Qualitative

2.2. WEF Analysis Examples

The complexity of systems involved include among others, different grades of economic development, climatic regions, development of energetic systems that makes it more difficult to model the systems. Analysis of WEF systems analysis examples lets one find gaps, future development, as well as goals. Wang et al. [39] analyzed WEF nexus synergies in a water scarce region of China, from 2005 to 2017. They focused in population, arable land, energy consumption for analysing the problem. On the other hand, qualitative study such as the one developed by Yuan et al. [40] discussed urban priority development strategies in Amsterdam, Eindhoven, Taipei, and Tainan. They highlighted the importance of renewable energy for WEF nexus systems' sustainable management.

Some are the actions that aim to lower environmental threat. The problem of the lack of effective and efficient water pumping technology for smallholder farmers. The problem of sugar beet can be included for synergies analysis. Some like Silversands Ethanol company [41] produces ethanol from sugar beets in South Africa. These crops need 530 mm of water for crop maturing, which is equal to the annual rainfall in the region. The problem appears under lack of water scenarios, when irrigation is needed under droughts scenarios. Sugar beet's water efficiency is around 60 m^3/GJ compared to sugar cane's water efficiency of 110 m^3/GJ for ethanol production. From a quasi-qualitative manner, this example created 31 jobs in 2009. The incentives for a nexus approach include economic efficiency, resource efficiency, and improved livelihood options [42,43]. Cheng-Ting et al. [44] analysed the economic performance of different crops deployment joint to the operation of a wind turbines, and proposed small-scale and renewable based irrigation systems could provide a viable alternative to polluting fossil-fuel powered generators. Brazil's biofuel industry is based on sugar molasses for bioethanol while crops for food production increase. In addition, in India's incorporate non-edible oil for biodiesel production. These processes are not competing with land and water resources. Since it is a residue of the sugar industry, bioethanol from molasses does not add further stress on land and water resources [45]. Water conflicts for agricultural activity and energy generation exist in Ethiopia, as they do throughout Asia and Africa [46–48]. By exploring WEF nexus synergies within the Shenzhen region, Li et al. [49] proposed stabilizing water supplies, coordinating energy exports and reducing crop sowing areas for improving synergies. Bian et al. [50] built a methodology and frameworks to find study linkages between water, energy, food, and other components, in Asia, Europe, America, and Africa. They also classified the studies according to water–energy, water–food, water–energy–food, water–energy–land–climate nexus approach. Zhang et al. [51] analyzed the complex WEF relationships in the Manas River Basin which is located in the inland arid area of northwest China. Through an analysis of main productions and consumptions of agricultural, animal husbandry, and industry statistics he highlighted that water footprints of agriculture and livestock products is much higher than the water footprints of energy consumption.

A renewable-powered desalination plant involves interconnected systems that synergies between WEF systems increase as long as they make use of more energy than in standard water supplying techniques, and renewable energy intends to reduce this energy environmental impact. As long as the system provides water for crop production, the synergies between systems increase as well. Provided that the facility shares the surpluses of generated energy, synergies will increase as well. According to this scheme, Rosales et al. [52] found a standard water cost of 0.5 to 0.6 EUR/m^3. As desalinated water demand increases costs and emissions as well, leading to a higher climate change risk itself. This fact threatens the achievement of sustainable development goals in these regions. The scheme combining renewable energies with the amount of water resource provided by desalination plants can be used to compensate for the intermittent nature of primary renewable energy sources. improve the manageability of this "combined resource" water–energy in a region that its managed. In isolated systems like islands, they suffer more than any other WEF system although these are well-defined systems, where inputs/outputs enter only by plane or ship that WEF systems trade-off analysis becomes easier. They cannot receive water transfers provoking harder conditions for agriculture, or livestock, becoming even more difficult in those at high water scarcity risk. In addition, the more synergies between water and energy systems, the more joint development that can be achieved. In systems where the desalination industry is essential provokes higher prices in agriculture, livestock, among others. Independent of the desalination technology, it accounts for 60–75% of total costs increasing water and energy WE synergies. As previously mentioned, synergies between the water and energy systems let one reduce water costs only by implementing renewable energy generation means in the pumping, and/or in the desalination process. Borge et al. [53] proposed a strategy for locating facilities that increase a sustainable operation of desalination plants. They also analyzed the economic performance of a hybrid renewable powered desalination plant for testing market profitability as well as the economic and environmental consequences [54].

3. Analysis

This section discusses what the challenges are when facing WEF sustainable management of the systems. The final goal is to investigate the feasibility of solutions for increasing the synergies between resources for lowering climate change associated impacts. Institutions such as UNECE (United Nations Economic Commission for Europe), International Renewable Energy Agency (IRENA), or Food and Agriculture Organization of the United Nations (FAO) [55–57] analyzed ecosystems nexus synergies from a sustainable approach. Some proposed tools comparison charts to compare different tools and identify relationships and synergies between sectors [29]. Dargin et al. [58] classified tools according to a complexity index that intended to model their complexity and suitability. Due to the amount of population, and warming rates MENA (Mediterranean and north Africa) region is among the most threatened areas that also increase water restrictions. In order to develop a complete assessment of proposed actions, these tools must assess the technological, economic, or environmental development in the short, medium, and long-term.

3.1. Feasibility Assessment

Through proper synergies' definition, these tools intend to find a solution for joint management of these three resources [24]. Innovation highlight as a facilitator for taking advantage of synergies between systems although their implementation will face risks also related to the grade of synergies development. The feasibility of actions taken, or scenarios tested with WEF nexus evaluation tools should be assessed, in the short as well in the medium and long term. In order to analyse the deployment of WEF nexus innovations, it is important to investigate the technologic, economic, practical, and environmental performance in the short, medium, and long term. Figure 4 show how to evaluate strategies that hypothetically increase synergies. The multiple point of view approach must include a technological, environmental, and economic evaluation of the proposed actions, or the actions to take. Risks, opportunities, as well other issues for citizens, firms, and governments must be investigated for identifying gaps, errors, that decrease sustainable management. Through case study analysis, it is possible to inform not only the quantitative results of actions taken, but also of qualitative aspects at policy and social level

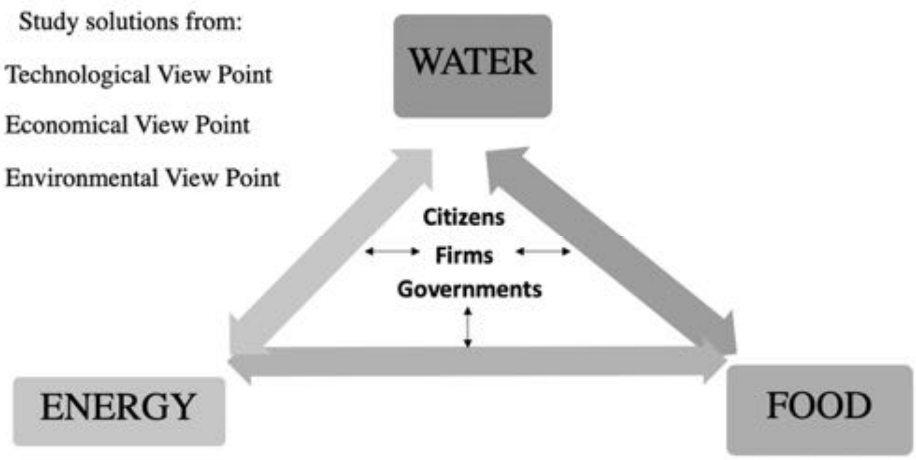

Figure 4. Environmental approach for WEF systems management.

3.1.1. Technological Evaluation

At the technological level it is mandatory to assess the performance of the innovations that increase the sustainable operation of WEF systems. The system analysis with WEF tools depicts the interactions to be further developed for increasing synergies. These must be technologically assessed for detecting innovations that increase synergies.

3.1.2. Economic Analysis

As long as sustainable approach in synergized systems include investment, among the objectives for the evaluation of innovations that boost synergies it is mandatory to evaluate its economic behavior. Target fulfilment in one subsystem would ultimately require share investment with other systems, and if properly developed, it must be properly evaluated. An economic feasibility assessment should be developed in order to verify their economic performance, and to identify shortage of customers for the generated products by the type of business.

3.1.3. Practical Application

It is a well-known fact that adaptation can reduce climate change impacts risks. The potential for adaptation, as well as constraints and limits to adaptation, varies among sectors, regions, communities, and ecosystems. Actions taken, or that to be taken also must be analyzed from a practical point of view. The sustainable narratives that explore synergies are analyzed including risks management issues at a short, medium, or long-term, or because of the deficient development of the various information systems associated with the innovation.

3.2. Involved Actors

Different actors are involved in WEF nexus synergies. Citizens not only strongly impact in environment sustainability, but also suffer from water scarcity, water resource access problems, longer droughts periods, food, and energy security problems, but they do not have influence in the food production system. Involved actors can direct, or indirectly affect the actions that tools suggest. Table 4 defines the influence they have in nexus management issues.

Table 4. Relationships between involved actors.

	Governments	Firms	Citizens
Technological	Directly	Indirectly	Indirectly
Practical	Indirectly	Directly	Directly
Economic	Directly	Directly	Indirectly
Environmental	Indirectly	Directly	Directly
Water System	Directly	Directly	Directly
Energy System	Directly	Indirectly	Directly
Food Production System	Indirectly	Directly	No Influence

Among these relationship highlights:

- Governments are the actors who own the power to influence in management issues through politics, plans, programs, taxes, bills. Governments "own" the power to define, and regulate relationships between firms and environment: mainly water, land, or emissions. Additionally, they promote innovation investment programs to boost technology knowledge in different areas, although often did not focus on the interlinkages.
- Firms mainly impact the environment through the productive system, the supply chain, and their relationship with costumers. In addition, they indirectly have influence in politics, as long as they participate in a free-market scenario. In addition, transport companies strongly impact environment. As firms are expected to improve their economic performance, they are affected by sub-systems trade-offs quantification either at the local, national, or international level. The interconnection between these levels also provokes consequences in the systems that they are trading with. In addition, investors are not attracted to using integrated methods like the WEF nexus because existing subsidizations do not focus on the nexus as one system.
- Citizens are those who consume goods and resources, and decide what governments may promote, and might be influenced with. Small systems, such as neighborhoods, small towns, or islands among others own high-qualitative knowledge about regional concerns.

4. Discussion

Methods for nexus assessment depends on the scales, goals, and data availability. As can be seen, tools intend to model system or creating narratives for the management of the systems. It is clear that quantitative tools offer further insight into the nexus, simplifies policy evaluation, and a guidance to stakeholders. Although food industry GHG emissions is often focused in food transport, these are also due to agriculture, and livestock farming in related processes. Saladini et al. [59] evaluated freshwater withdrawals in agriculture production, although GHG emissions of the agri-food sector should be further evaluated for a better understanding of the problem [60]. Similarly, methodologies for estimating biomass and biofuel emissions from combustion [61] should be further investigated for increasing trade-offs knowledge. Joined to estimating emissions from transport, energy generation, others complete GHG emissions estimations, and future development can be used to completely assess the sustainable performance of actions proposed. The SDG (Sustainable Development Goals Index) [62–64] must rely on real and accurate information. Despite most OMC's countries develop sustainable programs for decades; governments as well in different economic conditions may provoke change of proposed actions. Regions are not equally prepared for adopting different solutions. Botai et al. [65] reviewed the overall change in WEF management approach in Africa for analysing how they varied.

It is worth mentioning that greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits. It is especially important to quantify trade-offs between water–energy–food systems for a proper modelling system [66,67] that increases the understanding of the problem. It is especially important to provide urgent solutions for threatened systems like those presented here. Specifically, Gulati et al. [15] identified challenges and opportunities for food security in South Africa. As QST [37] combines quantitative as well qualitative indicators for nexus assessment leads to a better definition of trade-offs between systems this tool stands out as a solution for sustainable management. Similarly, software development with agile tools that mixes quantitative indicators fulfilment with qualitative opinions of developers, QST permits an increasing flexibility when actions and politics are revised. On the other hand, QST do not assess the interlinkage level between sub-systems. As renewable energy electricity deployment is increasing globally, it opens a medium- and long-term synergy development scenarios at either technological, economical, and environmental points of view. Figures 5–7 propose an approach for actions that can be taken for WEF systems sustainable management.

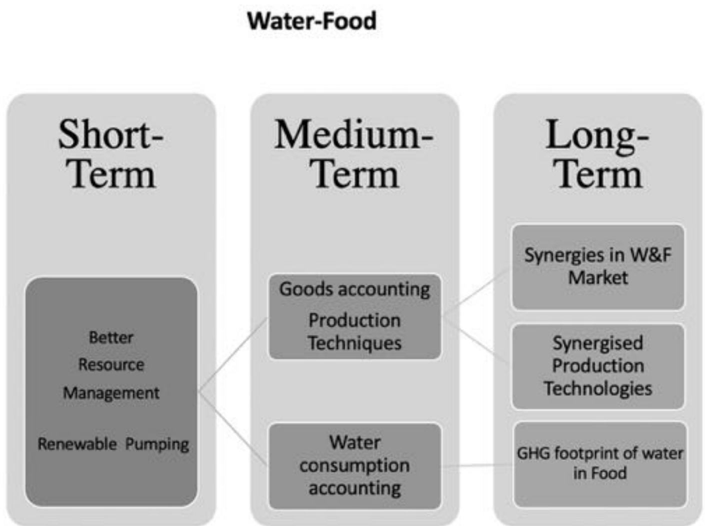

Figure 5. Sustainable environment approach for WEF systems management.

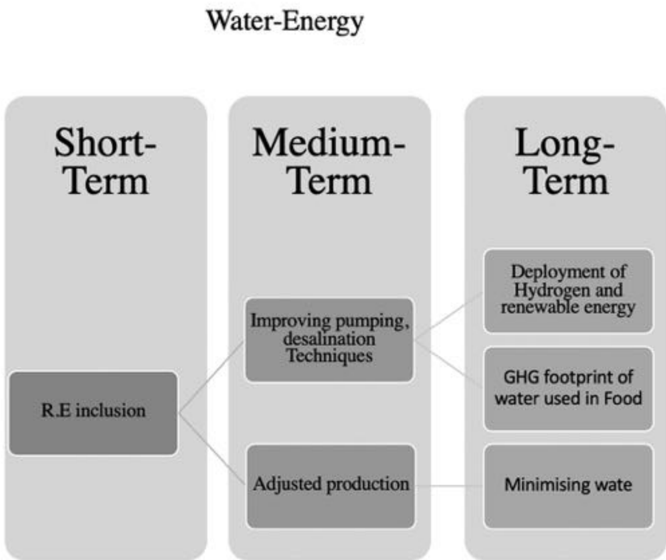

Figure 6. Sustainable environment approach for WEF systems management.

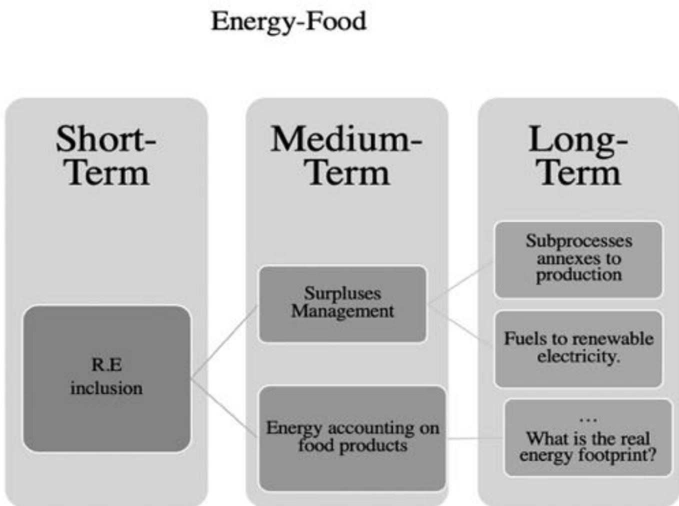

Figure 7. Sustainable environment approach for WEF systems management.

Synergies sometimes becomes risks when different SDG's are competing for the same scarce resource. Actions taken in one subsystem might lead to higher risks in other sectors. For example, environmental costs of water pumping between facilities with a high-share resource degree is reduced when they are closely located. Biofuel crops have certainly environmental advantages including improved sequestration of carbon in the soil, reduced soil erosion. On the other hand, dedicated energy crops are competing for the same resource, land, and water. First generation biofuels' production leads to water depletion and scarcity for agriculture, leading to an increased competition for water, affecting negatively their food security [60,61]. Among the additional environmental impacts associated with feedstock cultivation include biodiversity loss, water consumption, and reduced water flows, water quality and effluent run-off problems, and land degradation. As can be seen in Figures 1–3, the exponential growth of cultivated surface in these regions may lead to systems overexploitation. Increasing demand for biofuels impact these systems as well. On the one hand, as competition for water and land resources increase, price is expected to increase as well. This fact may lead to food security problems. Only two countries, USA and Brazil took up 460 million tons of maize and sugarcane, respectively, for producing biofuel [24]. On the other hand, when processed from agricultural residue crops outstands as a solution to produce biofuels because there are no requirements for additional water and land. Generally, perennial trees do not need dedicated inputs and can even promote land restoration, although harvesting these crops is generally harder than dedicated crops. In a short–medium term energy management is supposed to play an important role for increasing renewable energy use. It is basic accounting in ways for managing or storing electricity surpluses from renewable energy generation. The excess of energy to power chemical batteries, produce hydrogen are examples for the medium- or long-term deployment to be analysed from the aforementioned perspectives. It is mandatory to investigate how to take advantage of the water, energy, and food system joint operation. Rosales et al. [68] investigated how to reduce water stress in regions at high water scarcity risk with desalinated water, leading to increase synergies between subsystems.

On the other hand, the strategy proposed does not account for the positive effects of synergies with sectors such as capital goods, steel, etc. that also interfere with WEF management, but others at an early stage of development such as big data, information technologies, artificial intelligence, and real time information development. Despite most tools including a quantitative approach for assessing tradeoffs, real data of resource generation and consumption still remains uncounted. Among other impacts, it would allow regions forecasted of water scarcity to develop sustainable businesses models, in addition to the positive effects on the income effect, the push and pull effect on related sectors, upstream or downstream. Synergies between electricity and water markets can be analysed from different perspectives in the long term. The evaluation relies on the implementation of a decision-making system that control the "combined resource", acting in markets under different rules, where the water resource provision surrounding orchards and population. Only by exhaustive water accounting would it be able to assess the amount of water comprised in the food system, in the energy industry, and in the food processing industry. It could be mandatory to include in food labels the accounted amount of energy for processing the product. This issue let to classify products according their energy, and eventually GHG related emissions. Through interlinkages matrices nexus tools can evaluate synergies and trade-offs. For setting sustainability indicators either at local, national, or international level it is mandatory to account for data from different organizations or initiatives, such as from FAO. These indicators are basic for assessing the sustainability of the ecosystem.

Among others examples of opportunities in related-systems to be analyzed include lowering food wastage, as well as municipal water leakage. These actions engage citizens, firms as well as governments. A complete understanding of the environmental consequences of increasing yields on large-scale versus crop production in smallholder farms must be assessed for governments, researchers, and firms. Similarly, increasing transport fuel efficiency, or increasing penetration of electric and hybrid vehicles draws directly on the same actors, although highly dependent on citizens decisions. Improving irrigation techniques, or water use in power plants also relate directly or indirectly to different actors. Only by analyzing the economic, technological, practical, and environmental performance of these and other opportunities could the sustainability of actions taken or to take be assessed. The more synergized the system, the more the reduction in GHG gas emissions can be achieved through combined operation of the systems. Only by locating facilities near each other lets reducing energy consumption of the sustainable-synergized system. Sustainability performance of renewable powered desalination plants that provide water for crops can be improved reducing the distance between facilities. On the other hand, WEF Nexus sustainable management faces problems when competing with world trade agreements. When synergizing WEF systems it is important to figure out total costs of food products because this offers governments extra information for eventually taxing products according to their sustainable performance. How to evaluate environment threat concerns versus social advantages of job creation must be further investigated. Depending on the initial conditions of the systems it may be desirable to boost one action, or another.

Citizens do not have influence on crops production techniques, although they decide the products they consume. This results in a complex decision structure that selling techniques or environmental concerns of citizens must be considered despite different objectives to meet.

5. Conclusions

In light of the developed analysis, difficulties and gaps for sustainable management of WEF systems are identified. Assumptions made in these were analyzed for a better understanding of sustainable WEF problem. Scarce resource use optimization concerns cause the appearance of WEF systems analysis tools. By identifying and defining the interlinkages and relationships between these systems, tools intend to improve resource allocation management strategies. Either at the system design stage, or to analyze the performance of actions taken, the presented scheme intends to take advantage of synergies between water, energy, and food systems for increasing the sustainable performance of the system.

Because the complexity of interconnections, synergies, and actors in multiple levels, and scales, different WEF-nexus tools and approach define the synergies between systems under multiple points of view. Mainly focused on quantitative and qualitative concerns, as lessons from its implementation are drawn, and relationships between systems further defined, these tools must be constantly improved. Only by increasing the knowledge of synergies and through the development of resources, and trade-offs accounting systems, tools and frameworks might lead to a complete understanding of WEF systems that allow corporations, whether public, or private to compare between alternatives when evaluating the water–energy–food problem. Depending on the scale of a WEF analysis, involve different actors such as key decision-makers, companies, and inhabitants in a participatory environment over a short, medium, and long term. Although, tools lack a sustainable actions definition and performance evaluation tools for improving WEF sustainable management. Through WEF indexes, evaluation could be assessed for the WEF sustainability performance of food products that may lead to political proposals for markets based not only in monetary decisions. Specially this is important in poorer, and water scarce regions, such as developing countries in Africa and Asia that also have less laws for environmental protection. Not only analyzing proposed actions from a technological, economic, or environmental point of view across actors involved in the nexus management issues, but also from lessons learned, can proposed strategies for increasing positive synergies impact that constantly improve scarce resource utilization. Tracking energy costs of food products is mandatory for offering costumers the total costs of the products they are they are consuming.

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Nomenclature

BAU	Business-as-usual scenarios
CLEWs	Climate, Land-use, Energy-Water
FAO	Food and Agriculture Organization of the United Nations
GHG	Green House Gas
Ha	Hectare
IRENA	International Renewable Energy Agency
iSDG	Integrated Sustainable Development Goals
LEAP	Long Range Alternatives Planning System
MDG	Millennium Development Goals
MENA	Mediterranean and north Africa
QST	Quantitative Story-Telling
SDGs	Sustainable development Goals
UN	United Nations
UNECE	United Nations Economic Commission for Europe
WEAP-LEAP	Water Evaluation and Planning System
WEF	Water, Energy, and Food

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ANEXO P2: COPIA DE LA PUBLICACIÓN CIENTÍFICA "DECISION-MAKING TOOLS FOR SUSTAINABLE PLANNING AND CONCEPTUAL FRAMEWORK FOR THE ENERGY-WATER-FOOD NEXUS "

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Decision-making tools for sustainable planning and conceptual framework for the energy–water–food nexus

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Abstract

The impact assessment of energy strategies, more specifically those that promote an integrated approach on resource management in other sectors such as water and food, requires knowledge related to the evaluation of the quality and knowledge that may be estimated by quantitative means. The present paper makes inquiries into those knowledge requirements in addition to review the means used to obtain it—including the required entries and the results they provide. In response to the recognized problems in knowledge, this paper introduces a basic reference structure underlying a system to evaluate the way that a progressive development of inexhaustible energies in a particular geographical region can affect the demand of water and food. Then, the proposed conceptual framework constitutes a novel approach for energy policy makers which only consider partial impacts of the energy management. By considering the nexus of energy, water and food, energy management policies may be redefined and differences with current policies must be investigated.

Keywords: Energy strategies; Management of resources; Water, food and energy nexus; Renewable energy; Decision-making tools

1. Introduction

Often, political decisions are taken without the necessary coordination of different administrations and without considering the impact that a political decision in one activity may have on additional ones [1,2]. A deficiency in coordination arises between different branches at the same or different hierarchy levels in the public administration. Literature reflects clearly the fact that government tend to approach in an "isolated" way frequently results in policies that cannot be maintained at the current rate [3]. In this sense, there is a growing consensus about the importance

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Nomenclature

C→E	Cost per energy
CF	Conceptual framework
CI	Cost index
CO_2	Carbon dioxide
E	Energy
EB	Energy balances
E→E	Emissions for energy
ED	Energy demand
EP	Entry point, input
ES	Energy sector
FE	Food and energy
GHG	Greenhouse gas emissions
GIS	Geographic information systems
L→E	Earth for energy
LI	Land index
NS	Nexus sectors
NT	Water, energy, food nexus tools
P&DI	Policy and data input
p.u.	Per unit
RENS	Reference energy system
W→E	Water for energy
W→F	Water for food
WEF	Water, energy and food
WI	Water index
WLES	Water, land and energy systems

of the water, energy, and food security nexus and the need to devise and implement policies and actions in an integrated manner [4].

Integrated resource management can be defined as "the coordinated development and management of water, land, and related resources to maximize economic and social well-being in an equitable manner without compromising sustainability", and it has been so-called in recent times as "integrated water resource management" [5]. The first United Nations Water Conference, held in Mar del Plata, Argentina (1977), recommended greater attention to an integrated resources management, emphasizing that water plans should not only consider economic aspects but also ensure the optimal social benefit of water resources, as well as environmental protection [6]. The concept, popularized by the Dublin Declaration on Water and Sustainable Development (1992), promotes an integrated vision for resource management [5]. It stated that the management of water resources is an effective approach to address global challenges related to water management, restoration of degraded lands, adaptation to climate change, and the fight against hunger [7]. Some international bodies, such as OECD [8] or the World Bank [9] already recommend integrated resource management through these related methodologies.

The adoption of management based on the water, energy and food nexus requires a more appropriate perception of the associated benefits and exposure to danger for each of the nexus sectors, as well as an analysis of interactions between them in order to facilitate integrated planning and decision making [10]. In this sense, analytical frameworks are used to assess the impact of policies on different sectors [11] and inform policies by quantifying resource exchanges and providing an assessment through which the potential and unexpected risks associated with the nexus are identified [11–13].

After a deep review in the literature, it has been found that, even though some institutions and researchers, such as the FAO [14], World Bank [15], Pollit et al. [16] and Tol [17] have proposed some preliminary tools, they have been designed as frameworks for in-depth nexus analysis, not as simple, easy-to-use tools for conducting basic evaluations. These wide-ranging tools are intensive in terms of the information, time, capacities, and funding needed. To our knowledge, there is no tool available in the scientific literature that, having energy as an entry point (EP) or input and incorporating inputs relative to the specific explicit context, can be considered as simple. In order to address this gap, and as novel approach, apart from a deep review of existing models in the literature, this article presents a conceptual framework focused in the joint management of three fundamental resources: water, food and energy, but in this case, mainly focused on the energy as an EP related with the other resources, in a single of two ways relationship. This conceptual framework intends to be easy to apply but efficient at the same time.

The reminder of this paper is structured as follows. Section 1 states the objectives of the research article and provides an adequate background. Section 2 describes the review and selection criteria used to conduct the research. Section 3 proposes the conceptual framework for a tool that can conduct preliminary assessments of the basic impacts of the energy policy nexus. Finally, Section 4 explores the significance of the results and states the major outcomes.

2. Definition of frameworks to model nexus interactions

The frameworks used to model nexus interactions can be based on both quantitative and qualitative methods [18, 19]. Although this paper focuses on quantitative tools, qualitative tools can also provide important information. The methodology used by the FAO to assess the nexus combines both tools [14]; while other institutions such as the United Nations Economic Commission for Europe (UNECE) together with the KTH Royal Institute of Technology use other methodologies that are mainly qualitative [20].

The modeling tools for nexus integration can assist decision making and identify local objectives that are in line with broader sustainable development objectives [21].

Although fully integrated planning is preferable, assessing water requirements against an energy strategy could provide very useful initial information for other water end-uses. Some of the available methods used, such as the one proposed by Food and Agriculture Organization [22] or the one proposed by Mohtar and Daher [23], adopt food as an EP; variants, such as the one proposed by the United Nations Economic Commission for Europe and Royal Institute of Technology [20], adopt hydric resources as an EP; additional tools, like [24], employ the power derived from the utilization of physical or chemical resources as an EP. This paper will, for the most part, be centered in an "energetic" view.

The intersectoral nature of the nexus indicates the importance of perceiving the intended meaning resulting from the interrelationships among water, energy, and food through scenario simulation [22]. In this sense, the development of scenarios from quantitative tools is adopted to explain a number of several and probable events that will or are likely to happen in the future [22]. In fact, these scenarios constitute reasonable gradual developments to the present circumstances which, according to the way the elements of the nexus evolve and interact, may serve to assess the implications of certain policy decisions [22]. For instance, some policies advantageous for the energy and food sectors might exert excessive stress on the hydrological plans of countries with drought problems by promoting excessive use of water due to affordable pumping. In order to address these risks, several analytical frameworks have been developed within the context of the water, energy, and food nexus [14,20,25,26].

The quantitative tools that analyze the impacts of energy policy on the nexus may vary in terms of their completeness, as shown in Fig. 1. The first block represents an "isolated" way of dealing with the situation, in which "political" and other data relevant to the energy sector (such as the resulting energy balance) are provided without considering the influence that it can have on the remaining elements of the nexus. Conversely, an alternate way of dealing with a larger content of scope (in the middle) would consist of a water, energy, food nexus tools with the essential facts serving as a receptacle for quantities relating to the energy sector but as too important data relating to water and food and land—in this case, providing outputs on the essential remaining nexus assets required for the policies.

Since the 2011 Bonn Conference [27], several frameworks have been developed and evolved [28–32]. The existence of different purposes has resulted in diverse boundaries for frameworks that have been developed at different levels — from a regional level [29,31] to a global level [33,34]. This variety of frames of reference with different inputs, outputs, and analytical characteristics has its origin in the complexity of the nexus [35]. The inputs are employed to characterize the schemes studied and their circumstances. With respect to the outputs, a set of tools focus only on one component of the nexus; other tools describe additional components, and the remaining

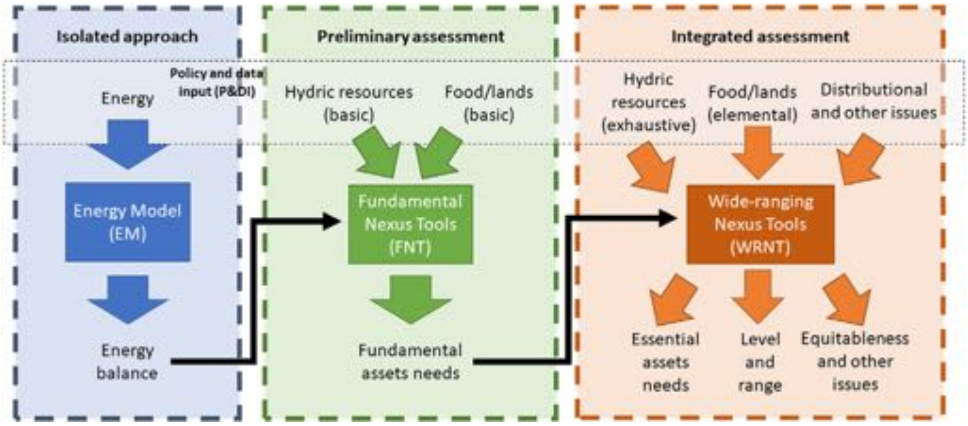

Fig. 1. Conceptual scheme of the modeling levels considering the water–energy–food nexus for energy policy. *Source:* Own elaboration.

ones show additional elements, such as available land area, minerals or GHG. Finally, the fundamental analytical characteristics of the tools may, in addition, be dissimilar. Although the kind of information necessary can change depending on the tools used, most of them depend on a large amount of data (inputs) that are often not available on a large scale [36]. This is because much of the data needed for nexus evaluations are not centrally located under the authority of a single agency and practices related to data management of different agencies often differ [35].

3. Review of integrated planning tools

The conducted review only includes tools that meet the following specific selection criteria:

(a) The tool deals with a minimum of two out of three essential features of the nexus.
(b) The tool permits to conduct evaluations at a wide-state level.
(c) The tool is, to a large degree, accessible and available for use or it is open access.

The examination principle by which tools are to be judged have been arranged into three groups—required inputs, proportionate outputs (and, as a result, replied queries), and analytical aspects. It should be noted that this research does not assess aspects such as in what way the tools can be employed to characterize scenarios and that an exhaustive analysis of the advantages and deficiencies of every tool is beyond its scope.

The specific review criteria are described below:

1. **Entry requirements**
   Main entries: these entries constitute the principal data in the examination, either with regard to facts and statistics collected for reference or analysis. These entries would, as a rule, have to be supplied by the user of the tool. Examples could be the amounts and types of energy available for the studied nation, the quality of being able to be used or distinct kinds of water being obtainable, access to land for cultivation, or the expenses associated to distinct energy or water technologies.
2. **Exits/inquiries replied to:** The standard of examination inside this category gives facts about what exits might be predicted from the tool and, as a consequence, what queries could possibly be answered with it.
   Policies on energy, water, or food and land use are not possible to be carried out separately from climate change for the reason that the impacts are clear and show two-way directions; each of the three nexus subdivisions produce and discharge a considerable amount of GHG and will be influenced by climate change. Even though considering the impact of climate change on the nexus' essential features is beyond the outlook of this research, a number of the revised tools consider the impacts of the policies evaluated or the schemes on GHG. A detailed nexus tool might allow the evaluation of the give-and-take that might happen among carbon dioxide emissions and the essential parts of the nexus.
   Because financial examination is essential to political decision-making, a number of tools are capable of supplying an assessment of the financial consequences of the schemes analyzed (in particular, the incurred

costs). The addition of non-financial expenses (i.e., consequences of an industrial or commercial activity which affects other stakeholders without this being reflected in market prices) might be important to consider the financial worth of ecosystem services (for example, maintaining areas with a large number of trees, land not used could lead to the capture of some of the CO_2 discharges and thus make the externalities connected with them smaller).

Moreover, some countries do not have a restriction on the surface of the land to be used, whereas other countries do so. A number of the revised tools are capable of supplying relevant information on the previously mentioned aspects.

3. **Analytical characteristics of the tools:** The standard of examination inside this arrangement describes a number of analytical characteristics of the tools that are treated as significant for this research such as its accessibility, allowed analysis or geographical restrictions application.

Built on the revised principles listed before, Tables A.1(a) and A.1(b) present an examination of the tools, showing the various principles included in the evaluated tools. Tables A.1(a) and A.1(b) have been outlined to supply an imaged explanation of the problems associated with each tool considering that if a criterion has not been assessed for a particular tool, the corresponding box within Tables A.1(a) and A.1(b) is left blank.

4. Conceptual framework definition

It has been proposed a frame of reference aiming to address some of the gaps previously identified—its main output being the assessment of the basic requirements of a given resource (such as the volumes of water in addition to land surfaces) combined by a number of particular actions for the power derived from the utilization of physical or chemical resources. The presented tool can (i) accommodate inputs that are particular to a given context; (ii) yield results in a useful and convenient layout; (iii) be uncomplicated from an analytical point of view, while also supplying a basic view of the situation.

The proposed conceptual framework is based on an approach based on situations in which the nation's energy balances (EB) are paramount for all the schemes. This allows the user to build a number of schemes by altering the EB connected to various energy policies (such as, for example, a higher adoption of inexhaustible energies) in addition to examining the rising effects on the water, energy, and food nexus. Despite the fact that this article focuses on renewables, the proposed tool deals with the full EB as, among other factors, a further development of inexhaustible resources would typically impact the remaining components of the nexus in consequence of the replacement of different kinds of energy that would otherwise be required.

In order to depict these replacements, it is necessary to consider the complete energy balance. The majority of nations collect the information of their EB as a division of their country-level data; while the International Energy Agency (IEA) does the same through a standardized structure for the processing, storage, and the display of data [37], which represents an essential benefit for the CF put forward.

The first step in using the proposed tool would be to provide an energy balance corresponding to a base scheme. Such an EB might depict either a current or a prospective energy scenario built on forecasts.

The next step would be to supply a substitute EB representing the energy policy scenario to be examined from the point of view of the nexus (e.g., by placing more attention on inexhaustible energies). Such an EB should reflect changes in the use of technologies and be consistent with energy policies that remain unchanged (the proposed tool estimates the accumulative EB simply by deducting the substitute and reference energy balances). The accumulative EB would depict the alterations in the energy circumstances as a result of the policy examined.

A following phase of the arranged tool would be to assess the implications of the incremental energy balance in terms of water, land, emissions, and cost. The tool would multiply the accumulative EB by the matrix data they describe. In this case, with regard to every kind of energy (energy balance vertical arrangements) and for each energy supply chain scenario (energy balance rows), it would result in (i) the quantity of water, (ii) land needed per unit of energy, (iii) the quantity of discharges expelled in each of these scenarios, or (iv) the unit expenses provoked. This way of proceeding is depicted in Fig. 2, in which every of the above-mentioned matrices has been named, correspondingly (i) W→E, (ii) L→E, (iii) E→E, and (iv) C→E. These data matrices are external data and are, generally, nation specific. The outcome of this phase is the elemental accumulative employment of water and land assets (such as capacity of water or earth surface), accumulative expenses or accumulative discharges originated by the energy policy examined.

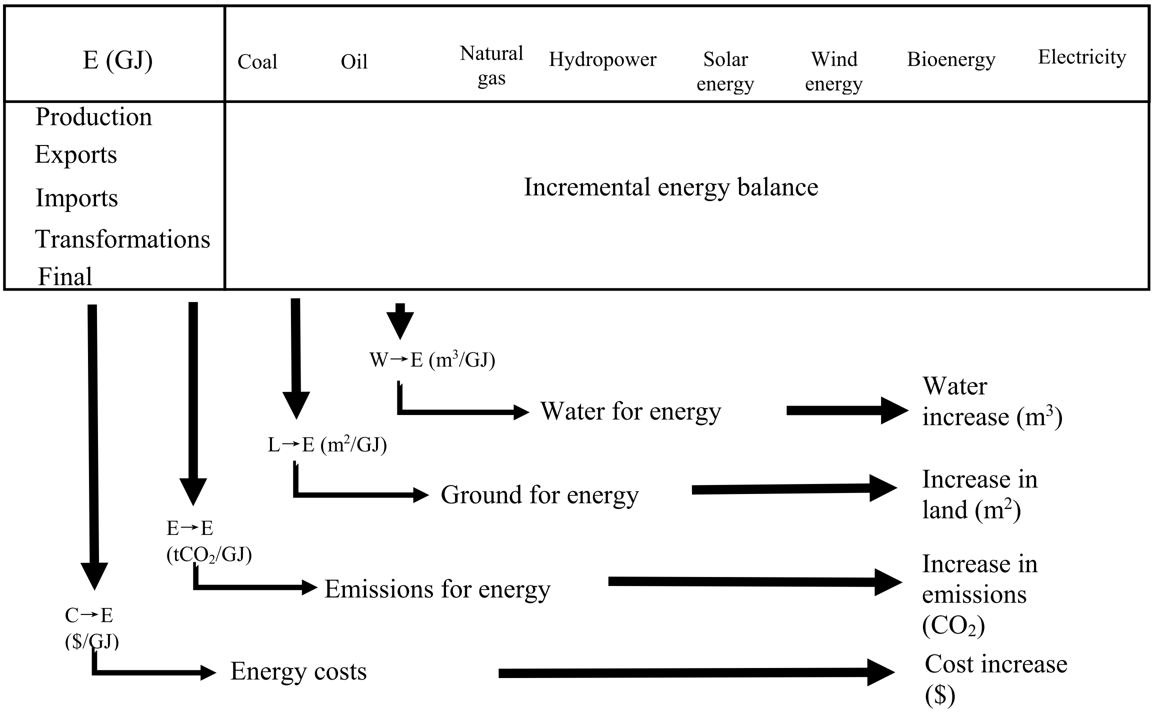

Fig. 2. Estimation of the implications of water, land, emissions and cost of the energy policy evaluated. *Source:* Own elaboration.

The proposed tool yields data around the meaning of the examined policy nexus, not about the way the policy should be planned to curtail those connotations of the nexus. On the other hand, and as mentioned before, this perspective exclusively supplies data around the essential resources needed, not the characteristics, allocation, or opposing employment of these resources (this would serve as a possible future improvement of the analysis).

The final step in the suggested CF would be to evaluate whether an accumulative employment of assets or discharges is tolerable. As discussed above, a given principle of action adopted may have the same performance in two different contexts but can be acceptable in only one of them [14].

As shown in Fig. 3, contrasting these tolerable levels with those of the EB available as another possibility (base scenario + accumulative) would generate four fragmentary indices (WI, LI, CI, and EI), each of which are indicated in p.u. values. In the case one or some of these indices show an index higher than the unit, it would signify that the satisfactory maximum has been surpassed. Lastly, the fourth fractional index shall be added to a general index according to the political significance that each feature has in the nation to be evaluated—in countries where a resource is considered critical, legislators may decide that its corresponding index is of greater importance.

The outputs resulting from the suggested CF might provide a basis for comprehensive qualitative and quantitative examinations. Although a particular number of qualitative features are satisfied by way of the data supplied by end-users in various phases of the suggested tool, comprehensive evaluation is necessary.

5. Conclusions

Today, most policy decisions with potential consequences for the water, energy, and food nexus are made through different institutions (such as distinct government departments or distinct positions in the public hierarchy of the government in power) without the necessary degree of coordination. The challenges facing the water, energy, and food nexus are, in part, a consequence of this "fragmented" policy applied to interrelated resources.

Access to data is a key challenge. In order to carry out a proper assessment of the water, energy, and food nexus, it is necessary to have access to both data from each of these sectors and data able to express the quantity of their mutual connections. The compilation of standardized data might serve to succeed in dealing with issues in

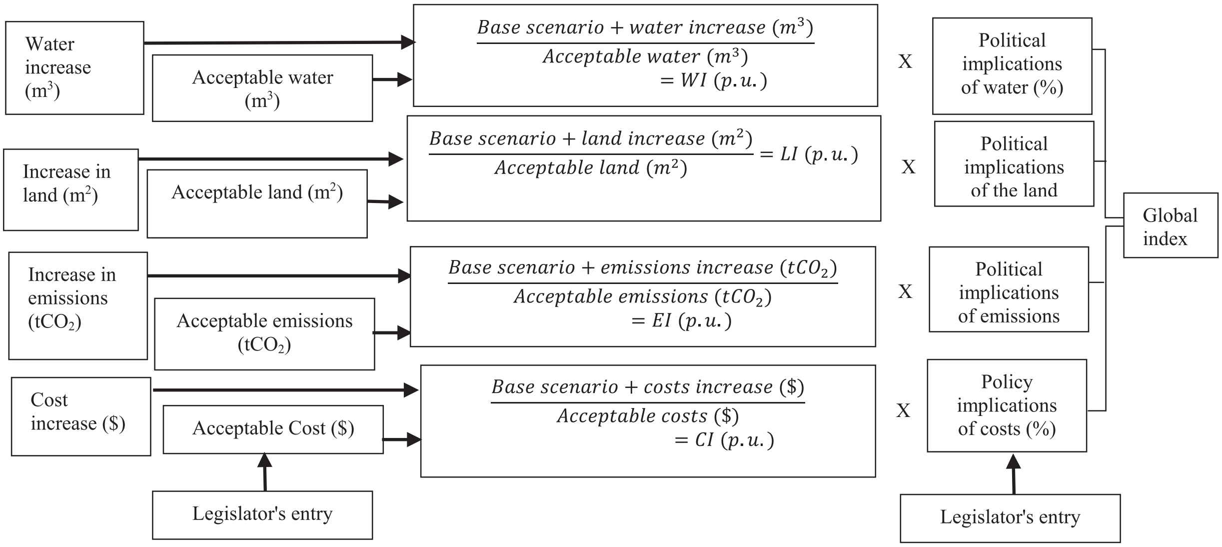

Fig. 3. Adoption of policy and data input to assess the water, land, emissions and cost likely consequences of the energy policy decisions examined for incorporation into a context-specific global index.
Source: Own elaboration.

existence at the current time related to consistency, comparability, and scale in addition to the absence of statistical information that are collected, observed, or recorded at regular time intervals.

- Most of the tools able to be used or obtained for people responsible for or involved in formulating policies nowadays are comprehensive and complex and require a significant amount of data, human resources, time, and economic sufficiency.
- Similarly, this research has identified the necessity for exploratory tools able to yield extremely useful basic estimations that could provide a basis for further (more complex) developments.

The reference frame put forward in this paper aims to propose an exploratory tool that has energy as an EP, which in turn provides a starting point that can ultimately support the integration of energy within the so-called nexus of water, energy, and food. The CF could present "snapshots" of the impact of renewable energy development (in addition to alternative approaches) on related resources such as water and land occupation.

For the proposed tool, every outcome constitutes a group of different energy policy decisions in which EB is accepted as key information. In this case, the tool put forward could roughly calculate or judge the value of the water, land, emissions, and cost involvements of every outcome in order to "combine" them into a global indicator that specifically regards the principle of actions proposed by the governments' choices for each particular circumstance.

The "product" presented by the tool put forward in this research might comprise an early step in the direction of a further exhaustive examination of the impact of the development of inexhaustible energies on the water, energy, and food nexus for several circumstances.

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.

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Table A.1(a). Review of evaluated nexus tools.
Source: Own elaboration.

Tool and reference	Standard of review					
	1.(a) Fundamental entries	2.(a) Energy	2.(b) Water	2.(c) Food	2.(d) Greenhouse discharges	2.(e) Economy
CLEWs [38]	Large amount of data required. Technical and economic parameters of thermal power plants, agricultural machinery, water supply chain, desalination terminals, fertilizer production, etc.	Energy balance, including electricity generation and refining Energy for food Foreign energy (virtual)	Water balance Water supply and desalination Water Pumping W→F W→F (hydroelectric power, generating station refrigeration, fuel derived immediately from living matter cultivated plants)	Irrigation Technologies Use of fertilizers Use of agricultural machinery	Restricted to both a particular area and foreign emissions Accumulated GHG discharges	Selected economic indicators
WEF 2.0: guiding integrative resource planning and decision-making (Daher & Mohtar, 2015) [39]	Local information and features of WLES Local production of WEF (by technology) Policy data taking into account particular circumstances	Consequences of food production on the commercialization of energy Energy used in water (pumping, treatment, desalination) Energy used for food (tillage, fertilizer production, distribution and harvesting)	Consequences of nutritious substances manufacturing on a restricted particular area	Degree of regional production of various kind of nutritious substances	Consequences of nutritious substances manufacturing on GHG discharges	Expenses of nutritious substances manufacturing
SEI (Stockholm Environment Institute) Modeling water & energy (LEAP/WEAP, 2014) [40]	Requires a large amount of data Techno-economic information on energy equipment	Comprehensive examination of ED and its transformations EB	Area or region drained by a river, river system, or other body of water devising Simulation of water requirements and provisions Water held underground in the soil or in pores and crevices in rock evaluation Water characteristics evaluation Storage and hydroelectricity evaluation	/	GHG discharges from the energy sector	Includes a financial module
Food and Agriculture Organization of the United Nations tool [16]	Evaluation of the country studied in order to classify it by typology	Specific to each type of intervention	Specific to each type of intervention	Specific to each type of intervention	/	Specific to each type of intervention

(*continued on next page*)

Table A.1(a) (*continued*).

Tool and reference	Standard of review					
	1.(a) Fundamental entries	2.(a) Energy	2.(b) Water	2.(c) Food	2.(d) Greenhouse discharges	2.(e) Economy
WBCSD nexus tool [33]	Description of the distinctive nature or features of the energy sector Diagrammatic representations of areas of land based on GIS Characterization of the water needed for FE Data on the required workforce in addition to machine's availability	Energy needed for water Energy needed for food (for irrigation, fertilizer manufacturing or devices for performing work)	Water needed for power generation Water needed for food production	Food production	/	/
MuSIASEM (Giampietro et al. 2009) [41]	Requires a large amount of data Socio-economic indicators, including workforce evolution Land Availability Climate change impact assessment	Assessment of energy flows in society	Assessment of water flows in society	Assessment of food flows in society	Implications of all flows on emissions	Added costs and values
Diagnostic Tools for Investment (DTI) in water for agriculture and energy [42]	Complete set of data needed to characterize local supply of water to land or crops to help growth and hydroelectric power enterprises	Effect of hydroelectric power enterprises on bettering quality of life Percentage of people in a given area that have relatively simple, stable access to electricity	Water administration Use of water for (i) farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products; and (ii) to the generation of power derived from the utilization of physical or chemical resources	Availability of food and individuals' accessibility to it, where accessibility includes affordability and agricultural manufacturing	Effect of supply of water to land or crops to help growth, typically by means of channels and hydroelectric power on GHG discharges	Agriculture's contribution to gross domestic product and profit production Expenditure requirements Effect of supply of water to land or crops to help growth enterprises on improving local quality of life
MARKAL/ TIMES (Loulou et al. 2005) [20,43–55]	Requires a large amount of data Techno-economic information on energy technologies Characterization of the RENS	Energy outlining with a large degree of technical specific aspects EB Effectiveness of energy policy	Water use in the energy sector	/	Emissions from the energy sector	Overall expenses of the ES, containing the necessary water provision

Appendix

See Tables A.1(a) and A.1(b).

Table A.1(b). Review of evaluated nexus tools.
Source: Own elaboration.

Tool and reference	Standard of review				
	2.(f) Earth	3.(a) Accessibility	3.(b) National geographical level	3.(c) Applicable to dissimilar geographies	3.(d) Uncomplicated although capable of providing a preliminary assessment, including explicit policy entries
CLEWs [38]	Biofuel crops Types of land according to the circumstances	It is possible that some developer works on the tool	National Global	It might be applied to dissimilar geographies. However, it is resource-intensive.	/
WEF 2.0: guiding integrative resource planning and decision-making (Daher & Mohtar, 2015) [39]	Land for food	It is conceivable that some developer works on the tool	National	Can be applied to dissimilar geographies	Simple reference frame Includes policies of importance for a sustainability index
SEI (Stockholm Environment Institute) Modeling water & energy (LEAP/WEAP, 2014) [40]	/	It is possible that some developer works on the tool Without charge for developing nations	National Global	Can be used to different geographies	/
Food and Agriculture Organization of the United Nations tool [16]	Specific to each type of intervention	It is possible that some developer works on the tool	National Subnational	Through the use of different typologies can be used in different geographies	A quick assessment of the nexus is uncomplicated and depends on the ready for use indexes. The adoption of nation categorization and the proposition indexes for every kind of intervention facilitates their use.
WBCSD nexus tool [33]	Land use	It is possible that some developer works on the tool	National Global Regional Local	Can be used to dissimilar geographies	/
MuSIASEM (Giampietro et al. 2009) [41]	Land use	It is possible that some developer works on the tool	National	It might be applied to dissimilar geographies. However, it is resource-intensive.	/
Diagnostic Tools for Investment (DTI) in water for agriculture and energy [42]	Cultivated land	It is possible that some developer works on the tool It might be used to dissimilar nations	National	It might be applied to dissimilar geographies. However, it is resource-intensive.	/
MARKAL/TIMES (Loulou et al. 2005) [20,43–55]	/	Applicable to any country	National Global Regional Local	It can be used to dissimilar geographies. However, it is resource-intensive.	/

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ANEXO P3: COPIA DE LA PUBLICACIÓN CIENTÍFICA "COMPREHENSIVE ASSESSMENT OF GRAN CANARIA WATER-ENERGY-FOOD NEXUS WITH GIS BASED TOOL."

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Comprehensive assessment of Gran Canaria water-energy-food nexus with GIS-based tool

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A R T I C L E I N F O

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A B S T R A C T

Society's increasing demand for resources creates an urgent need of resource allocation strategies. This research analyzed how alternative renewable-based energy plans affect a sustainability index related to the Water-Energy-Food nexus in a region highly dependent on desalted water. 50 water bodies of the island of Gran Canaria were analyzed for evaluating a pumping hydro energy storage strategy to support a renewable energy plan. The storage uses water from desalination plants which allowed to increase water and energy in the system. With the restrictions imposed, the Spanish island of Gran Canaria could store from 11.44 GWh/mcm to 30.76 GWh/mcm. Results showed that, depending on the specific renewable energy plan and on the factor of operation in the desalination plant, the stress in the water subsystem would be reduced from 8 mcm to 20 mcm. A system analysis strategy to control the water index was proposed to support the decision-making strategies.

1. Introduction

Over the last centuries resource consumption has increased in such a way that compromises the planet's ability to provide them in a sustainable manner (Bassel et al., 2015). Activities related to economic development have led to impacts in the environment. These include stress and contamination of water, land, fishing, and GHG emissions related to the economic activity. Manufacturing, growing vegetables, electricity generation, feeding animals, or international trade are some of the most resources–taking activities. The increasing needs of energy has led international organizations to face this problem. In this sense, Brundtland Commission (World Commission on Environment and Development, 1973) stated in 1973 that sustainable development consists in securing water, energy and food supplies for current and future generations, while maintaining a healthy and unharmed environment. Not only UN alerts and gives indications with sustainable development goals (Nations, 2020a), but also researchers investigate the water, energy, and food (WEF) nexus for a better understanding of the synergies and trade-offs. All of them together are intended to provide a decision framework to ease the decision-making process (Keairns et al., 2016).

Food production requires land, water and energy; transporting and treating water requires energy; and energy production requires water and land as well, and even food (Mohtar et al., 2012), and other resources. Water is needed for irrigation as well as for human consumption, but also in industry or for energy electricity generation. In addition, energy, in its multiple forms, is required for food production processes, including tree felling, harvest, fertilizer production, and transport (Chamas et al., 2021). Fig. 1 describes how components enter and leave a closed system, and how they are related through the components of which they are composed. Furthermore, it must be taken into account the CO_2 that is generated during these activities.

It stands out that, at the current rate of population growth, the agricultural sector is challenged with doubling food production by 2050 (Organisation for Economic Co-operation and Development OECD-IEA and Bhaduri, 2010). It is highlighted that 71% of current world water withdrawals are attributed to the agricultural sector (Charting Our Water Future, 2009). By 2010 the energy sector consumed around 15% of the global water withdrawals (International Energy AgencyIEA, 2012) and contributed two-thirds of global GHG emissions (International Energy AgencyIEA, 2020). Overall, the EU produces and supplies more food than its population needs – producing 3416 kcal/inhabitant/day. This is far more than the 2000 kcal/inhabitant/day to 2600 kcal/inhabitant/day average daily energy intake requirement set by the EFSA (European Food Standard Agency) (European Union, 2015).

To enhance synergies between systems and increase environmental sustainability, some institutions encourage innovation projects that optimize the resource management process. European Commission

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Nomenclature

AI	Artificial Intelligence
As	Alternative Scenario
ASAI	Average Service Availability System
ASR	Acceptable Stress Resource
AWU	Acceptable Water Use
AEU	Acceptable Emissions Use
BU	Baseline Use
BEU	Baseline Emissions Use
BWU	Baseline Water Use
CAIDI	Customer Average Interruption Duration
CC	Combined Cycle
CLEWS	Climate, Land, Energy, and Water Strategies
Coeur	Euro cent
COW	Cost of water
CO_2	Carbon Dioxide
DP	Desalination Plant
DS	Deployment Scenario
EEG	Energy Electricity Generation
EFSA	European Food Standards Agency
EP	Entry Point
ESC	Energy Storage Capacity
ESP	Energy Storage Potential
EU	European Union
GC	Geographical Coordinates
GHG	Green House Gas
GVC	Global Value Chain
GWh	Gigawatts-hour
G	Gravitational acceleration (9.8 m/s^2)
H	Head (m)
ICT	Information Communication Technology
IS	Information System
IEU	Incremental Emissions Use
IWU	Incremental Water Use
Inhab	Inhabitant
LCOE	Levelized Cost of Energy
LEAP	Long-range Energy Alternatives Planning System
mcm	1 Million Cubic Metre
MENA	Middle East and North Africa
MPHS	Micro Pumped Hydro Storage
MSF	Multi Stage Flash
MuSIASEM	Multi-Scale Integrated Analysis and Ecosystem Metabolism
MW	Megawatts
NOx	Nitrogen Oxide
O&M	Operating and Maintenance
PHES	Pumping Hydro Energy Storage
PV	Photovoltaic
REE	Red Eléctrica España (Electrical Network of Spain, Spanish TSO)
RES	Renewable Energy Sources
RO	Reverse Osmosis
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
ST	Steam Turbine
SWOT	Strengths, Weakness, Opportunities, Threats
UN	United Nations
US	United States
VC	Vapor Compression
V	Volume to be stored (m^3)
WEAP	Water Evaluation and Planning
WB	Water Bodies
WEF	Water Energy Food
WR	Water Requirements
Ww	Water Withdrawal
ρ	Water density (kg/m^3)

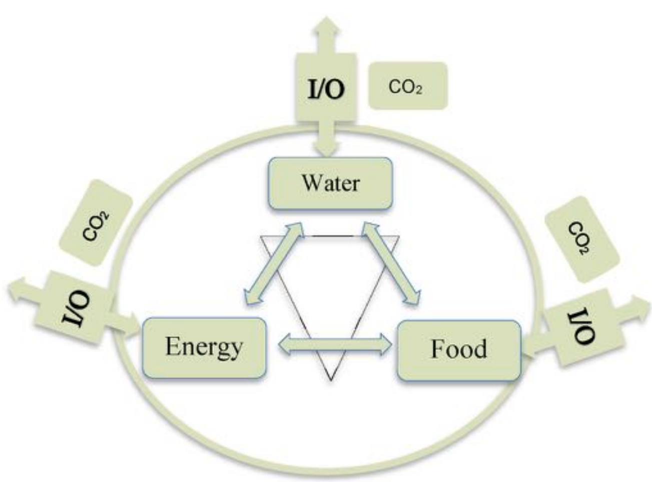

Fig. 1. WEF nexus.

proposed the SME-Phase II (European Commission, 2019) in order to provide funding for innovation projects that get involved in the process of sustainability, and green economy. Borge-Diez et al. (2020) analyzed techno-economic issues of those facilities finding relationship between grants and water and energy sales. As long as strategies and policies are not aligned, and are carried out individually, it will be more difficult to meet the growing demand for resources. To deal with this situation, a comprehensive nexus approach is developed (Bonn, 2014) to sustain the decision-making process of the resource management strategies. There are several frameworks that investigate the WEF nexus. Among the proposed tools are highlighted: WEAP (Water Evaluation and Planning) (Stockholm Environment Institute, 2014), for an integrated approach to water resources planning. LEAP (Long-range Energy Alternatives Planning System) (Stockholm Environment Institute, 2013), for energy policy analysis and climate change mitigation assessment. MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) (Food and Agriculture Organization of the United Nations, 2018) proposed a method to characterize flows within society. Agrawal et al. (2018) analyzed different scenarios with LEAP and WEAP to forecast the water and energy supply system of the power sector. And Liu et al. (2021), who developed an approach to conduct an input-output analysis of the WEF system.

Due to their isolated and water scarce nature, small islands are a promising candidate to investigate the sustainability of WEF nexus. This research uses a nexus analysis tool to evaluate Gran Canaria, an Island where alternative methods for water supplying are needed. It analyzed the consequences of a long-term renewable-EEG (Electrical Energy Generation) strategy combined with a Pumped Hydro Storage deployment scheme to support the manageability of renewable EEG plants. Zhao et al. (2015) highlighted the problems of EEG systems that a renewable energy deployment might comprise, including frequency deviations in cases of sudden changes in supply or demand. PHES is a feasible option for large-scale storage in Europe, accounting for an installed capacity of around 42.6 GW in the EU members (Gimeno-Gutiérrez and Lacal-Arántegui, 2015). Jawahar et al. (Jawahar and

Michael, 2017) reviewed the most suitable turbines, and found that they mainly depend on the flux and height. Notton et al. (Notton and et al., 2018) highlighted this energy storage system for the management of renewable energy. Increasing the manageability of the electricity system is especially important in isolated systems due to their generally lower interconnection ratio, and fuel supply difficulties (Hall and Lobina, 2004). As it was combined with small or medium sized desalination plants, this research assumed a micro-pumping energy system storage deployment combined with the desalted water from desalination plants. The PHES schemes are easily scheduled for production, and allow accounting the stored energy. The high efficiency in the energy conversion process, often higher than 90%, makes it a sustainable and efficient means to support the intermittent nature of renewable energies. Additionally, the energy that is stored becomes renewable when the energy used for pumping comes from renewable sources. Cabrera et al. (2018) proposed this energy storage option to achieve a 70% renewable EEG system in Gran Canaria.

This research analyzed Gran Canaria Island's 50 most representative water bodies to depict a sustainable-oriented strategy taking advantage of water from desalination plants to support renewable energy electricity generation. Notton et al. (2017) studied the electricity peak-shaving capacity of a pumping scheme to schedule the stored energy in high-demand hours. Rosales-Asensio et al. (2021) proposed a method to optimize the size of renewable powered desalination plants. This research proposed a sustainable-oriented algorithm to find the best candidates' locations, and investigated the sustainability of the strategy.

This study analyzed the energy potential storage capacity with a GIS (Geographical Information System) tool. In the scientific literature Fitzgeral et al. (Fitzgerald et al., 2012) implemented a method to find the potential to support small-scale renewable energy plans, and to locate the best sites for the upper reservoir. Those included a topographical as well as a constraints analysis. Among these, it highlights distance between reservoirs, minimum head, and distance to the electricity transmission grid. Note that one of the outstanding differences between fossil-fuel and renewable energy sources consists in its transport, provoking the deployment of renewable technologies problems, like grid stability in the region where the resource is higher. This research did not assume those constrains as a grid stability study would be out of the scope for the research here presented. Soha et al. (2017) followed similar restrictions to evaluate the potential in a region of Hungary. Ghorbani et al. (2019) estimated the potential of a region from four different topologies to evaluate the candidate sites for implementing a feasible PHS strategy. Lacal et al. (Lacal Arántegui et al., 2012) proposed a methodology regarding a regional approach, with constrains focused the conditions that a site must fulfil to be chosen.

Most of the techniques to provide water from non-conventional sources require a high energy consumption (see Table A1). It implies increasing water costs, and consequently, higher agricultural production costs. Other less energy-intensive techniques, but less able to deliver high desalination fluxes also stand out (Aqua, 2020) (Paton and Davies, 2004). In Gran Canaria, RO (Reverse Osmosis), MSF (Multi Stage Flash), and VC (Vapor Compression) technologies account for an installed desalination capacity of 138000 m^3/day (Athidrotecnia, 2018). A common approach to reduce high operating costs is renewable energy self-consumption, and sales of electricity. Although it provokes problems, including intermittency, or optimization of the available resource these strategies must deal with (Van Meerwijk et al., 2016). In the scientific literature Liu and Fernandez (LiuMei et al., 2018) (Fernandez Prieto, 2019) proposed strategies for the integration of renewable-based technologies in the techno-economical system.

Several analytical frameworks have been developed to undertake the WEF nexus analysis. Some focused in the WE nexus, analysing the design and operation of these systems (Endo et al., 2017) (Simpson Gareth and Jewitt Graham, 2019) (Mimoune Hamiche, 2016) (Zhang, 2016). This variety of frameworks and approach, with different inputs, outputs, and viewpoints has its origin in the complexity of the nexus (Goldstein et al., 2010). Variants, such as the one proposed by the United Nations Economic Commission for Europe and the Royal Institute of Technology adopted hydric resources as an entry point (United Nations Economic Commission for EuropeUNECE, 2017) (Nations, 2020b). Welsch et al. (2013) considered a CLEWS (Climate, Land-use, Energy, and Water Systems) approach to analyze Mauritius island, and highlighted the importance of a dynamics system analysis. As tool needed input data, the baseline water consumption scenario was depicted. This included energy electricity, human consumption, agriculture, and livestock water consumption. The analysis did not take into account inputs and outputs through the system boundary, because tracking component's footprints through system boundary in a globalized market, tracking the value chain of all components, and their transport exceeds the scope of the analysis.

Since these tools measure the sustainability of the system, a consumption parameter must be given to compare different scenarios. This research analyzed the water index results of implementing alternative renewable-based energy strategies combined with a PHS scheme linked to desalination plants. Within the scheme, the energy is stored by pumping water from the desalination plant lower reservoir to an upper reservoir to support three strategies to reach in the long-term the objective of 1 GW of renewable energy. The additional water storage capacity affects the WEF indices as well, enabling the linkage to the water-food subsystem. The materials and methods section introduced the WEF analysis tool, as well the initial conditions in the systems. Furthermore, it presents the alternative renewable energy plan as well the GIS analysis to find locations for the pumping energy storage strategy. The next section presents the results of the WEF analysis. It also presents the GIS analysis results that support that plan highlighting the most promising locations. The next section discusses the implications for the subsystems of the nexus, and a system is proposed to control water production through the control of the desalination plant's operating factor.

2. Material and methods

A monitoring framework should assess the resource costs of energy policy plans (Nations, 2015) (Commision, 2015). This work analyzed the consequences of deploying various alternative energy plans with a resource monitoring tool. In this tool, the energy balance is given as an exogenous input, independently of its feasibility. This section shows the baseline energy balance, that corresponded to EEG in Gran Canaria, and proposed some alternative energy balances—based on assumptions made to boost renewable energy systems—to investigate the consequences on a designed water index.

This research used a tool that estimated the water (land, emissions) costs that an alternative energy plan might cause. The output of the tool is an index that evaluates the costs of water (land, emissions) associated to the deployment of the proposed energy plan. The baseline water scenario accounted for human consumption, crop irrigation, cattle feed, and consumption from different power generation technologies in the island.

2.1. Footprints of the systems

To conduct the sustainability analysis of the system, this section reviews the water and emission costs of the food, as well of the EEG system in Gran Canaria. The human average water consumption per inhabitant in the Canary Islands is assumed to be 160 L per day (Tenerife, 2020). Provided that the inhabitants of Gran Canaria are 845000 (Canary Islands Institute of StatisticsISTAC, 2020), it implies a total water consumption of 49.35 mcm/year. Furthermore, Gran Canaria's food production subsystem footprint did not account products imports, or exports. The water costs depend on the type of product grown, and the type of production. Gerbens-Leenes et al. studied the water footprint of different agrarian products (UNESCO-IHE Institute for Water Education, 2018). In Gran Canaria, 37% (11884 Ha) of the agricultural land is cultivated, and the total production in 2006 reached a maximum, and lowered until 309600 t in 2011 (Canary Islands Institute of Statistics ISTAC, 2017). A SWOT analysis for Gran Canaria (Canary Islands) food sector is presented in Table D1.

Table 1 presents the total water, and emission footprint as well the baseline scenario in Gran Canaria's food production system. Additionally, the analysis left apart sectors such as industry, or gardening due to the difficulty of accounting these costs. Given the low share of industry in the island's economy (Canary Islands Institute of Statistics ISTAC, 2017), it will not have a major effect in the index depiction. A correction factor of 1.2 was applied to account for system losses.

The impacts that the EEG system has on the elements of the nexus (water, land, emissions) includes the impacts generated during the following operations and phases: fuel cycle, extraction, processing and transport, as well as the components associated. Also, those related to the construction of the plant, its operation, and its decommissioning. As far as PV is concerned, the key drivers of the lifecycle GHG emissions from PV systems include: location, system lifetime, mounting type, upstream electricity fuel mix, performance ratio, and the efficiency of the PV cell. A lot of factors interfere in the process highlighting lifetime, radiation level, and efficiency degrading rate. Besides, the impacts of operating PV, and wind power stations is negligible. On the other hand, technologies such as coal, nuclear, natural gas cycles might cause higher impacts due to the impact during the operation. As previously mentioned, this research assumed all the impacts inside the system. More information about emissions is presented in Table C1.

Table 2 shows the water withdrawals, and the CO_2 equivalent emissions associated to the most remarkable EEG, including the baseline scenario related to the system.

2.2. Sustainability index depiction

The sustainability index (eq. (1)) is a ratio of different use values, and thus dimensionless (p.u). In order to facilitate the evaluation of different energy plans, water, land, emissions, or costs index can be used. They normalize usage quantities by relating them to AU (Acceptable Use), a goal to achieve. As Rosales et al. (Decision-making tools for sustainable planning and conceptual framework for the energy-water-food nexus Rosales-Asensio, 2020) indicated, an acceptable scenario corresponded to a target entry, either politicians, researchers, or others. Table 3 shows the water consumption baseline scenario as well the CO_2 equivalent emissions actual rates in the studied system. According to equation (1), this research analyzed the water, and emissions index.

Likewise, the baseline scenario shows the initial conditions of the water (land, emissions) system related to the WEF system. IU (Incremental Use) reflects the consequences that the deployment of different energy plans had on those indexes. Equation (2) divides the qualitative indicator into various terms that would help for target entry estimation. To calculate the (BU) baseline use scenario this research included the EEG subsystem, water consumption in agriculture, livestock farming, and water consumption of the region's inhabitants. From this baseline scenario, the incremental use implications of the alternative energy plans presented in the following section were analyzed. IU (Incremental Use) corresponded to the incremental use regarding the deployment of those alternative EEG-energy plans.

Table 2
Life-cycle water withdrawal on Energy Sources. Source: Adapted from (Whitaker et al., 2012; Shires et al., 2009; Frankl et al., 2005; Construction and Solar, 2012; Vattenfall Wind Power Cer, 2010):

Technology	Water impacts (m^3/MWh)	Baseline Scenario (mcm)	Emissions Impacts (gCO_2/kWhe)	Baseline Scenario (t CO_2)
Biomass				
Wet Cooling	1.89–2.271		650	
Might be saved with Dry Cooling, reduced	0.378			
For dedicated energy crops:	151.4–378.5			
Coal				
Thermal Power Station	15.16		888	
Fuel				
Thermal Power Station	14.13	21.37	780	1243200
Nuclear				
Nuclear Power Station	41.69		24.2	
Natural Gas				
Simple circuit	15.918	12.21	499	352500
Combined cycle	8.34		250	
Solar				
Photovoltaic	3.79	0.22	300	17250
CSP	34.11			
Wind				
Wind powered power plant (Onshore)	0.985	0.245	123.7	2013
TOTAL		34.04		1614963

Table 3
Indexes associated with a renewable-based energy deployment strategy.

$$AWU = \sum_{i=0}^{n} Raingaugesvalues + \sum_{i=0}^{n} Desaltedwater \times C.F + \sum_{i=0}^{n} Capacityofreservoirs \quad (2)$$

Index	Incremental Use	Baseline Use	Acceptable Use
Water index	IWU (mcm)	BWU (mcm)	AWU (mcm)
	Alternative EP	313.8	321.8
Emissions index	**IEU (t of CO_2)**	**BEU (t of CO_2)**	**AEU (t of CO_2)**
	Alternative EP	1616253.23	Target entry

Table 1
Water footprint of Food Production System (No Imports). Source (Heinonen et al., 2020; Fry et al., 2018; Berndes, 2010; Manomet Center for Conservation Sciences, 2010; Bryngelsson et al., 2016):

Product	Water footprint (l/kg)	Baseline Scenario (mcm)	Emissions footprint (CO_2/kg)	Baseline Scenario (t CO_2)
Tomatoes	180	30.6	1.4	238
Potatoes	250	7	0.5	14
Pork	4800	23.3	7	33.98
Chicken	3900	9.98	6	15.35
Apple/pear	700	70	0.4	40
Banana	800	68	0.7	59.5
Milk	250	22	3	264
Human Consumption		49.34		
Total consumption		280.22		664.83

$$\frac{BU + IU}{AU} = Sustainability\ Index\ (p.u) \tag{1}$$

As the analysis of the WB of the island, Gran Canaria harbours more than 69 big reservoirs with a total storage capacity of 78 mcm, and more than 110 small basins (Insular council of waters of Gran Canaria, 2020). The average yearly rainfall in Gran Canaria approximates to 300 mm, the evapotranspiration 195 mm, the water infiltration 57 mm, and the water runoff 43 mm. The water subsystem is complemented by a desalination capacity on the island of 138000 m^3/day (Paton and Davies, 2004). The predominant desalination system on the island is RO, accounting for an 80% of the installed capacity (see Table B2). With this capacity the RO plants must work 45.28 days to fill the storage system.

According to the presented data, the AWU (acceptable water use) term comprises, the total capacity of reservoirs, 78 mcm of water, plus the rainfall in the cultivated land of the island, the 37% of the surface, it is 173.16 mcm, and water infiltration in the rest of the island's surface, it is 43.19 mcm. This system is complemented with the RO desalination plants working at a 30% of operation factor (14.49 mcm), and the proposed extra storage system of desalted water (5 mcm) which implies an increase in the operating factor of the desalination plants of 12.3%. Those accounted for a total AWU of 313.8 mcm.

2.3. Alternative EEG-Plans

As the total of EEG installed power of Gran Canaria Island, thermal groups involve 1024 MW (Canarias, 2020). The proposed renewable energy plan intends to reach in the long-term 1 GW of installed power from renewable sources (Hernández, 2018) supported by the PHS scheme. The analysis was conducted in two steps to reach the proposed energy objective. The short-term plan intended to reach half the power proposed for the long-term strategy.

As can be seen in Table 4, the majority of the energy generated on the island comes from fuel ST (Steam Turbine), and CC (Combined Cycle). It also presents the water costs associated with the seven alternative scenarios (AS) proposed. These scenarios are related to the deployment of a full wind renewable energy plan (I and IV), a half solar-wind energy plan (II and V), and a full-solar energy plan (III and VI). These six alternative plans virtually replaced CC power stations in the EEG system of the island. Finally, the alternative scenario (VII) virtually replaced VT power stations with wind power stations, for the long-term strategy. It also shows the initial conditions of power generation in the Gran Canaria system.

2.3.1. Hydro-pumping supporting strategy

This section presents the strategy adopted for the evaluation of the 50 candidate sites to support the proposed energy plan. The energy storage potential of the 50 proposed sites was evaluated (see supplementary material). Despite the fact that the turbine selection to develop this method of energy storage depends on the altitude as well on the work-flux, this research analyzed a crossflow turbine (Cink hydro-energy, 2020). This turbine might provide a flow between 0.03 m^3/s to 16 m^3/s, at 85% of efficiency, and a power of 7 MW. The deployment of the PHES strategy was assessed through a geo-morphological analysis of the 50 Gran Canaria's water bodies (Decision-making tools for sustainable planning and conceptual framework for the energy-water-food nexus Rosales-Asensio, 2020).

The geo-morphological analysis is developed with a GIS software (QGIS) (QGIS license of operation, 2019) that analyzed the energy capacity of the system, and applied the constraints that the locations must fulfil in the short-term strategy. QGIS is a software that used data downloaded from information providers (Geospatialdata, 2020) to conform the model, and by means of applying physical and energetic constraints find the locations that fulfil them. In the scientific literature, Bocin-Dumitriu et al. (Bocin-dumitriu, 2012) distinguished constraints related to the regional approach, and a wider analysis. In order to find the sites that better support the short-term strategy, additional restrictions (see Table B1) were imposed. Table 5 shows the steps given to develop the geo-morphological analysis that locate and find the maximum potential energy that could be achieved.

The energy storage capacity that those schemes may achieve was solved with the general statement given in eq. (5) (Portero et al., 2015).

$$ESC \times 3600 = \rho \times g \times V \times h \times 10^{-6}(\mathrm{MWh}) \tag{5}$$

As previously mentioned, the energy plan proposes a total of 1 GW of EEG from renewable sources in the long term. It should be taken into account the already installed power from renewable energy sources (Canarias, 2020), and the power from the aforementioned microturbine in the 50 WB. In this sense, the proposed EEG plan must require 454.2 MW of new renewable installed capacity.

As previously mentioned, it was developed in two stages. Fig. 2 proposes the algorithm to perform the GIS analysis as from the 50 WB, the sites of the desalination plants, and thermal power stations.

3. Results

This section presents the results of the short-term strategy analysis for implementing the proposed PHES scheme that supported the full renewable energy plan deployment. Fig. 3 shows the locations according to the analysis depicted in Table 5. It shows WB (Water Bodies) as Green points, RO Desalination Plants, as points in orange, and Thermal Power Stations as purple points. Those locations were manually georeferenced and added to the GIS model to develop the GIS analysis. The DEM (Digital Elevation Model) was used to analyze the total energy as well the paths from the WB to the desalination plants. The maximum energy that could be obtained from the storage system under study was,

Table 5
Analysis steps. Source: Adapted from (Spanish service of cartography website, 2020).

STEP	ACTION
1	Include *DEM* (Digital elevation model) of Gran Canaria
2	*Locations* of WB (green), fossil-fuel power stations (purple), and desalination plants (orange) (Fig. 3)
3	Analysis of the maximum potential energy. Distance - head between WB and sea level (see supplementary material).
4	GIS Analysis of the locations. See Fig. 2.

Table 4
EEG structure, generated energy, and water withdrawal of the different scenarios. Source: adapted from (Frankl et al., 2005; Construction and Solar, 2012; Vattenfall Wind Power Cer, 2010; Decision-making tools for sustainable planning and conceptual framework for the energy-water-food nexus Rosales-Asensio, 2020; Insular council of waters of Gran Canaria, 2020; Canarias, 2020; Hernández, 2018; Red Eléctrica España, 2018).

Technology	Energy (GWh)	AS (I) Ww (mcm)	AS (II) Ww (mcm)	AS (III) Ww (mcm)	AS (IV) Ww (mcm)	AS V) Ww (mcm)	AS (VI) Ww (mcm)	AS (VII) Ww (mcm)
Steam Turbine (fuel)	1409.83	21.37	21.37	21.37	21.37	21.37	21.37	0
Combined Cycle	1464.89	6.1	6.1	6.1	0	0	0	10.81
Wind Power	248.97	0.77	0.35	0.125	1.44	0.69	0.245	1.38
Solar Power	57.53	0.22	1.33	2.77	0.22	2.67	5.55	0.0002
Total	3181.2	28.46	29.15	30.36	23.03	24.73	27.16	12.19

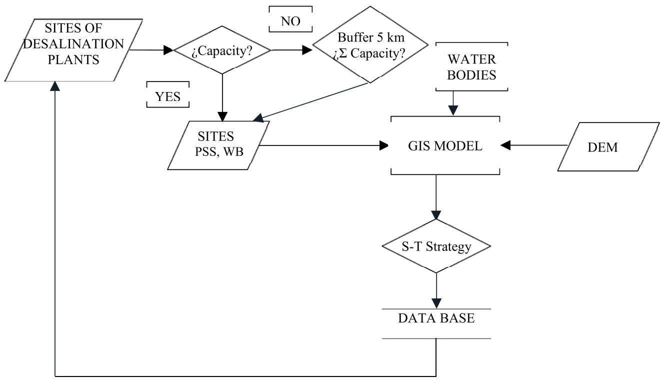

Fig. 2. Strategy for a renewable-PHES EP GIS analysis.

according to equation 5 and 3076 MWh (see supplementary material).

The locations that fulfilled the desalination capacity restriction were: Gáldar, Arucas-Moya, Telde, Jinámar, San Bartolomé de Tirajana, Puerto Rico, and Barranco la Aldea (see table A2). As can be seen in Table 6 the energy storage potential reached 11441.5 kWh/mcm in 15 locations. With the proposed turbine placement, it would mean 105 MW of extra power. The days needed to fill the upper reservoirs with 0.1 mcm/location depended on the desalination capacity of the surrounding desalination plants, varying from 8 days to 44 days.

Fig. 4 shows some locations that fulfilled the restrictions imposed in Table B1. Those showed better energetic characteristics to implement the proposed scheme. A complete list of these sites with complete land registry information can be consulted in supplementary material.

3.1. *WEF index*

This section presents the results that the alternative energy plans provoked on the other nexus' systems. As the presented scenario (BWU, and AWU), it reviewed the consequences on the index in the short, as well in the long term, of the deployment of the energy plans (I to VII). Results in Table 7 showed that higher reduction was achieved for the full wind deployment scenario. In the long term, the water consumption reduction varied from 8.11 mcm to 20 mcm depending on the renewable scenario. It should be underlined that the greatest GHG emission reductions were achieved through the virtual closure of steam turbine power plants. In addition, the virtual closure of the plants that implements the Rankine thermodynamic cycle caused the greatest reduction in the water index.

The CO_2 emissions could be converted into € by applying an exchange ratio. It should be noted a sharp increase in the European cost of emission allowances from 5.65 €/t in 2017 to 55 €/t in 2025 (European

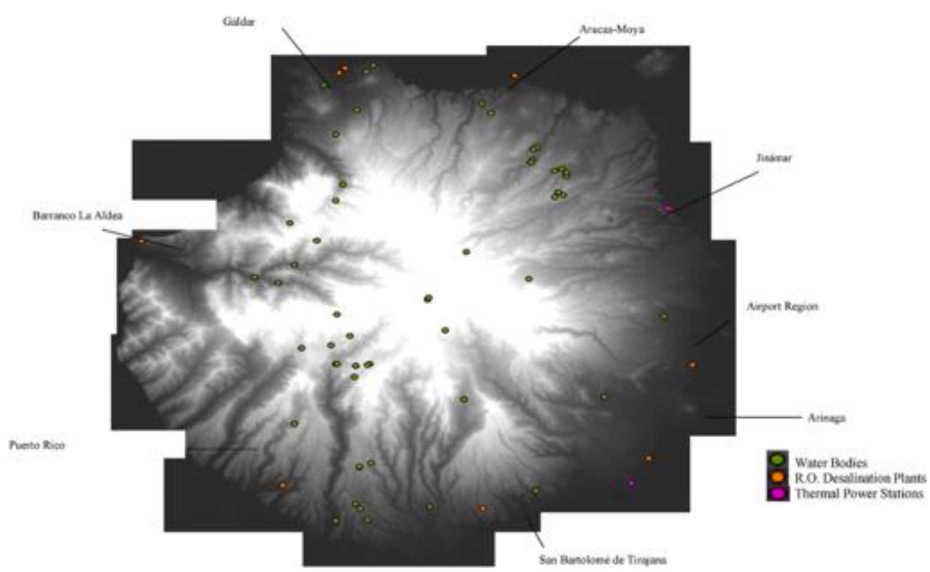

Fig. 3. WB, RO-DP, and Fossil-fuel based power plants allocation.

Table 6
Short-term strategy location.

Location	ESP (kWh/m^3)	GC	PHES Power (MW)	Actual Desalination installed capacity (m^3/day)	Days to fill the system
Gáldar	2229.5	(28003960, −15.565170) (27.990896, −15.696931) (27.854928, −15.696845) (27.775084, −15.665645) (28.157664, −15.627693)	35	13000	38.46 (11.1%)
Barranco la Aldea	2266.25	(27.981545, −15.729954) (27.976116, −15.714086) (27.990896, −15.696931) (28.013100, −15.680323)	28	5000	80 (22.8%)
Arucas-Moya	759.5	(28.123522, −15.545828) (28003960, −15.565170)	14	4500	44.4 (12.6%)
San Bartolomé de Tirajana	980	(27.784249, −15.592656) (28.051019, −15.498437) (27.87701, −15.567520)	21	15000	20 (5.71%)
Jinámar	245	(27.879005, −15.460156)	7	11500	8.69 (2.4%)

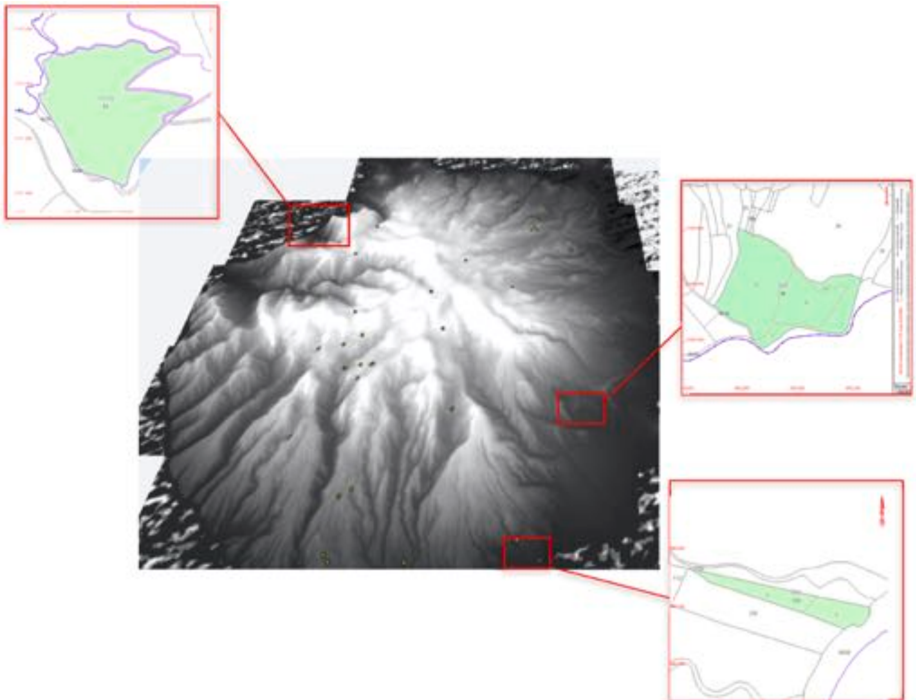

Fig. 4. Location siting proposal.

Table 7
Calculation of water and land indexes associated with a PHS scheme.

Energy Plan	Incremental Water use (Mill m^3)	Long-term Water index	Short-term WI Change (%)	Long-term WI Change (%)	L-T GHG emission Reduction (t of CO_2)	Short-term EI Change (%)	S-T GHG emission Reduction (t of CO_2)
(I) and (IV)	−10.71	$\frac{-10.71+313.8}{321.66}=0.9422$	−2.65	−3.4	1120.89	−0.78	560.44
(II) and (V)	−8.81		−2.3	−2.8	960	−0.647	480
(III) and (VI)	−8.11	$\frac{-8.11+313.8}{321.66}=0.950$	−2.3	−2.6	686.8	−0.601	343.4
(VII)	−20	$\frac{-20+313.8}{321.66}=0.913$	−3.1	−6.2	2750.35	−1.43	1385

Central Bank, 2020). Taking this into account, the proposed scheme comprises savings of more than 68.75 M€/year in the EEG system, as well as making progress towards the fulfilment of the objectives for GHG emission reduction internationally defined (The Paris agreement, 2015). From this point of view, it would be more advisable to reduce fuel-fired power plants, as there is a greater reduction in emissions than in combined cycle power plants.

4. Analysis and discussion

To ease the decision-making process that affects interrelated systems for a long period of years, the increase of the internal knowledge, as well trade-offs between the systems might ease the analysis of the consequences of the decisions taken. Rosales et al. (Rosales-Asensio et al., 2019a) proposed measures to overcome the barriers that the deployment of renewable energies found in Spain, and reviewed the wind technologies, and economic conditions in the Spanish market (Rosales-Asensio et al., 2019b). The analysis here developed tested different EEG plans, allowing the decision makers to estimate the consequences on other elements of the nexus.

The GIS analysis is concerned reservoirs with high energy potential were located around the South-East region of Gran Canaria, but they did not fulfil the restriction of distance to densely-populated areas. Parallel, a PHS facility of 220 MW of power (Chira-Soria System, 2019) was under construction in the South-west of Gran Canaria, and due to this fact, it was left out of the analysis in this research. Both the northwest and southeast regions of the island stand out for their energy potential to develop the scheme. That region houses several small reservoirs, and low population density. Among the most promising locations shown in Fig. 4, it stands out the two top and bottom site pairs of Galdar (28.147753, −15.676610; 28.105238, −15.666484), and Arinaga (27.844697164511746, −15.416003505490197; 27.87939235559117, −15.459578157904248). A total of 307600 kWh/m^3 of energy storage could be achieved from the site system to sea level in the long term, about 30% of the daily generated energy in Gran Canaria (see supplementary material). Note that the desalination capacity could not afford enough desalted water to fill the system in a day and, since it did not meet the constraints of the short-term strategy, it cannot be easily implemented. As the daily desalination capacity of the island, it will take 36 days to pump water to the upper reservoirs system. However, extra water from surrounding aquifers could be added to the desalted water upper storage site, lowering the number of days to fulfil the system. It must be highlighted that, to maximize water-energy system synergies, water should be delivered at different heights to take advantage of bioclimatic floors (Council of Gran Canaria, 2018). The closer the WB are (Fig. 3 and 4), the more difficult to control the synergies between systems. Furthermore, paths should be further investigated, not only to find the best suitable paths, but also to clarify synergies the surrounding areas.

According to the long-term renewable energy plan considerations, it comprised 454.2 MW of installed power. Taking into account a 0.32 of wind capacity factor (Canary Islands Government, 2019), for Gran Canaria, and scenarios IV and VII, it was predicted 1220.89 GWh/year of energy generation –the 83% of the baseline scenario generated energy–. In addition, the storing scheme must work 1.05 h/day to supply the 17% that the deployed energy plan could not provide. Besides, for 0.18 of expected solar P–V capacity factor, it was expected 960 GWh (scenario V), and 686.8 GWh (scenario VI) of energy. As a consequence, the back-up system should work 1.21 h, and 1.7 h respectively. Secondly, in the short-term strategy 15 locations were found. This fact comprised 105 MW of installed power for the proposed scheme. It was expected 610.44 GWh of energy for the full wind deployment, 41.5% of the energy generated in the thermal power station of the system, 481.91 GWh in the half wind-solar deployment, and 343.37 GWh for the full solar deployment. In the short-term energy strategy, the PHES option allowed the addition of a maximum storage capacity of 114415 kWh/m^3.

It must be taken into account that seawater desalination approximately consumes 9% out of the total electricity demand on Gran Canaria Island; despite the fact that RO desalination energy consumption evolved from 22 kWh/m^3 to 2 kWh/m^3 in 2010 (Berenguel-Felices et al., 2020). To face this high energy cost, it is common to build hybrid renewable energy-governed desalination plants. Rosales et al. (Rosales-Asensio et al., 2019c) analyzed the consequences on the LCOE, as well in the LCW (levelized cost of water) of a hybrid desalination plant, and found that an appropriate location allowed both indicators to be reduced. The proposed scheme is likely to further improve these indicators; although other costs, like the pumping process energy consumption, should be accounted.

Both desalination capacity (controlled by the operating factor), and rainfall data in the island are inputs of the proposed system. The sustainability tool easily assessed different energy strategies. It is important to figure out how different situations affect sustainability, especially in an increasing climate change threat scenario. In spite of its simple design, the proposed index becomes an easily-implemented general approach to analyze many WEF systems. Specifically islands usually suffer from interconnection problems that increase not only monetary, but also environmental costs. On the one hand, the WEF nexus is stressed because it needs water from non-conventional sources. As previously mentioned, RO desalination stresses WEF nexus because it needs energy, and becomes a source of waste that threatens sustainability itself. In addition, in the studied system, high tourism rates stands out (Tourism board of Gran Canaria Island Council of Gran Canaria, 2018). In order to analyze the consequences of different plans in variable scenarios, is highly valuable a rapid evaluation through an agile tool. On the other hand, results of research could be improved not only by tracking all water and carbon components footprints along the global value chain of all inputs and outputs in the system, but also taking into account all the tourists that enter, and leave the system.

Fig. 5 represents the water index dynamic behaviour in this WEF analysis. The model incorporated energy and food subsystems water footprint, and left apart others such as industry, or gardening because the little they meant in the analyzed system. Especially on islands, where desalination is needed, maximizing synergies between desalination plants, power generation system and the agricultural sector is essential to make the island sustainable. The global water index can be controlled just by increasing, or decreasing the operating factor of desalination plants. The better the system is modelled, the easier it is to plan the WEF system. This will lead to an index management enhance that help to face the water footprint environmental and social consequences (Gerbens-Leenes and Hoekstra, 2008).

Since agriculture accounts for 2% of Gran Canaria Island economy (see Table D2), it would be desirable to boost this economic sector (Council of Gran Canaria, 2018). The control through the water index system would provide scope for enabling water for agriculture in case of low-precipitation scenarios. Sustainability optimization often take into account constraints like feed demand or planetary boundaries models

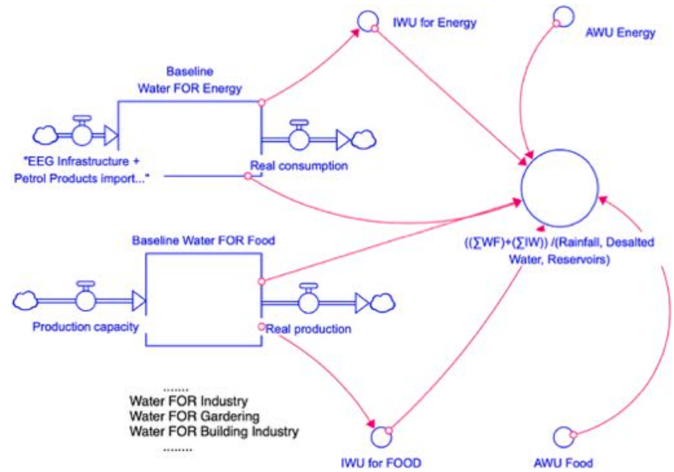

Fig. 5. Proposed Control System of the WE nexus.

for the analysis (Tourism board of Gran Canaria Island Council of Gran Canaria, 2018). Increasing, or decreasing the operating factor of desalination plants might allow to maintain the water index near a fixed sustainability index in a region, or closed system.

Once the water is used to generate electricity in high-demand hours, it would be used to irrigate crops, to feed animals in the surrounding areas, and it would be pumped from the locations of the desalination plant taking advantage of the surpluses of renewable energy during the valley of the daily energy consumption curve. In such an interconnected WEF system, the proposed water-energy storage strategy would allow to control energy as well water to maintain a given sustainability index. Furthermore, as long as it is suited for small microgrids, the proposed scheme gives a perspective for the management of the systems that would lead to social inequities such as energy, or water transport (Gerbens-Leenes and Hoekstra, 2008). In this sense, the better the transfer function is defined, the better will be the development of the water index control system. The system development should include management services data, because these improve the water-energy system. In this process, services such as weather forecasting IS (Information Systems), or AI (Artificial Intelligence) systems will play an important role through data analysis for a further development and scheduling of water and energy resources.

5. Conclusions

This study analyzed the consequences of different renewable-based energy plans on a sustainability index. In order to increase the manageability of renewable energy sources, and to support them, it proposed an energy-oriented hydro storage strategy. This research developed a decision-making process to locate the best energetic and technological sites for the short, as well for the long term. Within the applied constraints of the short-term strategy, it was found a total energy storage potential of 11.44 GWh/mcm in the 15 candidate sites that best fulfilled the constrains. For the long-term strategy, it was found 28.7 GWh/mcm of energy storage capacity in the given system. For the capacity factor of the proposed renewable energy sources, the long-term energy plan was not able to generate the same energy that the power plants aimed to replace. Although, only working 1 h/day, the PHS scheme was able to support the renewable energy plan. The system of reservoirs needed more than 10 working hours a day to generate the same energy that was generated in thermal power plants. Once established the initial conditions in Gran Canaria island, the sustainability tool evaluated the consequences of the deployment of renewable-based energy plans, helping in the decision-making problem of choosing between different energy strategies. The index analysis showed a water consumption reduction from 8.11 mcm to 20 mcm, depending on the renewable strategy. The higher water index reduction in alternative scenario (VII) reduced more than 6% from actual water withdrawals. Sustainable energy plans allowed the decision-making process to investigate rural micro-grid boosting strategies with greenhouses, or crops in a closed system. The control of desalination plants, linked to the energy strategy, allowed the development of sustainable-integrated control. Given the dual use of water-energy resources, indexes could be lowered letting the proposed energy plan to reduce the installed power from renewable sources.

CRediT authorship contribution statement

David Borge-Diez: Conceptualization, Methodology, Software, Writing – original draft, Data curation. **Francisco José García-Moya:** Conceptualization, Methodology, Software, Writing – original draft, Data curation. **Enrique Rosales-Asensio:** Conceptualization, Methodology, Software, Writing – original draft, Data curation.

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.jclepro.2021.129197.

Appendix

Appendix A. *Installed capacity in Gran Canaria, and characteristics of desalination technologies*

Table A1
Technologies and desalination capacity installed in Gran Canaria. Source: Adapted from (Bosch et al., 2019)

Technology	Power Consumption	Brine Production	Installed Capacity m^3/day	Inner Area Use	Investment Cost/m^3	Operational Costs
SHAMS-Titanium MED desalination	Low	Yes		No	High	Moderate
AD and MED + AD TEchnology	Low	Yes		No	High	Moderate
TNO Netherlands	Low	Yes		No	High	Moderate
Dutch Pyramic/Seawater seawater Greenhouse	Low	Yes		Yes	High	Moderate
Aqua.abib water solutions	Low	No		Yes	High	Moderate
Multi Stage Flash	High	Yes	38000	No	Moderate	Low
Multi Effect Distillation	High	Yes		No	Moderate	Low
Thermal Vapor Compression MED	High	Yes	5200	No	Low	Low
Mechanical Vapor Compression	High	Yes		No	Low	Low
Reverse Osmosis	High	Yes	94800	No	Moderate	Moderate

Table A2
Locations and desalination capacity installed in Gran Canaria. Source: Adapted from (Aqua, 2020)

Desalination Plant	Location	System	m^3/day
Gáldar-Agaete I	Gáldar	OI	3000
Agragua	Gáldar	OI	1000
Guía I	Guía	VC	1500
Arucas-Moya I	Arucas	OI	4000
Granja Ag. Experimental	Arucas	CV	500
Las Palmas I	Jinámar	MEF	20000
Las Palmas II	Jinámar	MEF	18000
Las Palmas III	Jinámar	OI	36000
Unelco	Jinámar PS	CV	1000
Salinetas, S.A.	Salinetas	OI	600
Airport I	Airport G.C.	OI	1000
Airport II	Airport	OI	500
Mando Aéreo de Canarias	Gando	OI	1000
Sureste I	Santa Lucía	OI	10000
Bonny	Juan Grande	OI	8000
Elmasa II	Las Burras	OI	7500
Elmasa III	Las Burras	OI	7500
Unelco	Bco. Tirajana	CV	500
Anfi del Mar	Bco. La Verga	OI	200
Puerto Rico I	Puerto Rico	CV	1200
Puerto Rico II	Puerto Rico	CV	1000
Coagrisan	Bco. La Aldea	OI	5000

Appendix B. GIS Restrictions for a Short-Term full renewable-PHS EP strategy

Table B1
Adopted Restrictions for the Short-Term full renewable-PHS EP strategy.

Restriction Proposed	Reason	Restriction imposed
WB in Gran Canaria	Storage Capacity	Most representative WB of Gran Canaria
Distance to desalination plants	Problems. Load losses, crossing roads, and properties	10 km at the most
Proximity Thermal power stations as restriction	Despite it can be transported, the grid is better prepared in that region	Distance is fixed in 20 km, because electricity can be transported through the grid
Proximity to grid	Works to develop Grid	10 km
Amount of energy to be stored	To easily schedule the operation of the PHS scheme	The scheme must provide at least 2 h of uninterrupted operation at maximum capacity
Law restriction	In order to fulfil the requirements of laws relating to: spatial planning and the environment, air safety	Fulfil laws that might provoke disputes related to the deployment of the wind park and the PHS system.
Proximity to densely populated areas	Difficulty for developing the scheme in a short period of time	
Path	Difficulty for developing the scheme in a short period of time	Cannot contain peaks higher than the starting height, neither cross populated areas.

Appendix C. Energy sources on emissions

Table C1
Emissions impacts of EEG technologies. Source: Adapted from: (Fry et al., 2018; Berndes, 2010; Manomet Center for Conservation Sciences, 2010; Bryngelsson et al., 2016; Whitaker et al., 2012; Shires et al., 2009; Frankl et al., 2005; Fthenakis et al., 2008)

Technology	*Emissions impacts*
Biomass	*T/MWh*
CO_2 emissions	*1.5*
Coal	***T/MWh***
CO2 emissions	1.01
SO2 Emissions	0.0005–0.014
NOx	0.0003–0.003
PM	0.0001–0.003
Nuclear	***T/MWh***
GHG (CO_2-eq)	*0.0037–0.1*
Natural Gas	***T/MWh***
CO_2 from CCCTs	*0.35–0.4*
CO_2 from CTs	*0.55–0.68*
Solar	***T/MWh***
CO_2 equivalent emissions	*0.02–0.06*
Wind	***T/MWh***
CO_2 equivalent emissions	*0.014*

Appendix D. SWOT analysis & economic competitiveness of the food subsector in Gran Canaria

Table D1
SWOT analysis of the food sector of Gran Canaria. Source: Adapted from (Council of Gran Canaria, 2018)

Weakness	Vulnerability to weather conditions, morphological characteristics of terrain that difficulties the mechanization, low exports diversification quotes and vulnerability to market changing conditions. Higher prices vs competitors. Saturation of market due to: no planning of types of production Imports of: cattle food, seeds, feed, packaging, low diversity and volume of the product range limits competitiveness, funding dependency because of the high production costs.
Threats	Liberalization implies competition, lower public funding, increasing rustic land for tourism, local regulation, loss of coordination between administrations. High negotiation power of agents, lack of production coordination strategies, excessive dependency of fossil fuel imports that increases the prices of water supply (due to its interlinkage). And agriculture: fragile ecosystem facing plagues, land erosion,
Strengths	Good climate that let cultivate along the year, Added value of local fresh products, prestige and high quality of some products, the more tourism, the more promotion of the products, enhancement of the profitability of farms, with products and activities. Existence of different markets for the commercialization. Transgenic-free region
Opportunities	Organization of exports markets, added value and better cost-effectiveness in diversified crops, bioclimatic floors that allow different types of crops, the lower mechanization the lower impacts, outermost region. UE funding. New tendencies, image enhanement, recover the agricultural landscape with the related benefits, promotion of association. Production planning to sustain prices lowering the negative market effects; exploitation of Canarias trademark. New improvement methods of water managing water resource.

Table D2
Economic competitiveness of the Food sector in Gran Canaria. Source: Adapted from: (Tenerife, 2020) (Council of Gran Canaria, 2018)

Year	2015		2010		2008		2005		2000	
GDP (Gross Domestic Product)	Mill €	%	Mill €	%	Mill €	%	Mill €	%	Mill €	%
Agriculture, livestock and fishery	581	1.4	613	1.5	614.5	1.44	571.5	1.55	455.2	1.7
Workers	744000		729000		740900		771800		792500	
Gross Value Added at market prices	223.8	1.6	237.88	1.6	240.8	1.62	227.66	1.75	211.99	2.12

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ANEXO P4: COPIA DE LA PUBLICACIÓN CIENTÍFICA "STRESS MITIGATION OF CONVENTIONAL WATER RESOURCES IN WATER-SCARCE AREAS THROUGH THE USE OF RENEWABLE ENERGY POWERED DESALINATION PLANTS: AN APPLICATION TO THE CANARY ISLANDS "

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Stress mitigation of conventional water resources in water-scarce areas through the use of renewable energy powered desalination plants: An application to the Canary Islands

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Abstract

Climate change conditions in the last decades have derived in a significant reduction of rivers' levels, irregularity of rainfall and, thus, difficulties in accessing to drinkable water. This situation is especially dramatical in islanded environments, such as the Canary Islands in Spain, where these restrictions to water resources have conducted to an overexploitation of aquifers and wells, with the deterioration of the environment that this fact entails. For this reason, desalination plants have become essential, and efforts must be done to reduce their impact and costs, as the involved processes for water desalination are high energy intensive. In this research paper, an optimized size hybrid wind and solar photovoltaic power plant is proposed to feed a desalination plant under the approach of not only feed the desalination process, but also provide the power grid with clean energy, taken advantage of the surplus electricity production. This way, not only the water resources stress is mitigated (through the desalting water production), but also the grid benefits from the integration of a distributed renewable energy source (DRES). Moreover, the business model is improved as the cost of drinkable water production is reduced and the power plant owner receives extra incomes from the water sales. Optimization results for a case study in Gran Canaria island shows that, considering the power dispatch in the island, the remuneration limits for power delivery and the remuneration for provided water, the optimal DRES associated with a desalination plant providing 5600 m^3/day of desalted water and a maximum annual electricity injection to the power grid of 5.88 GWh/year, an hybrid solar PV and wind generation installation with electrochemical storage is a feasible solution that makes the Levelized Cost of Electricity (*LCOE*) achieve a singular reduced value despite considering the additional costs of the desalination plant, although financial help must be provided to reduce the Payback Time.

Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2019.

Keywords: Water stress; Desalination; Renewable energy; Solar photovoltaics; Wind energy; Hybrid power plant

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Nomenclature

DRES	Distributed Renewable Energy Source
LCOE	Levelized Cost of Electricity
LCW	Levelized Cost of Water
GWh	Gigawatts per hour
PV	Photovoltaic
MW	Megawatts
kW	Kilowatts
kWh	Kilowatts per hour
RES	Renewable Energy Source
EC	European Council
CO_2	Carbon Dioxide
EU	European Union
M€	Million euro

1. Introduction

Broadly speaking, it can be said that the climate of the Canary Islands is characterized by very scarce and irregular rainfall [1], which, together with the intensification of agriculture, the increase in population and the development of tourism [2], has led to overexploitation of the aquifer [3,4]. Note the fact that, according to Falkenmark and Lindh [5] a consumption of 20% of total renewable water resources is considered as the limit of over-exploitation of a system. According to this criterion, and taking the average annual contributions as total resources, the basins of the Canary Islands (with a consumption/spending ratio greater than 60% [6]) clearly exceed the limit of overexploitation. In this sense, desalination has made possible in the last fifty years the settlement of populations, the growth of tourism and the development of arid geographical areas [7].

The Canary Islands currently have a population of about 2 188 519 inhabitants, with Tenerife (906 854 inhabitants), Gran Canaria (845 676 inhabitants) and Lanzarote (141 437 inhabitants) being the most populated. The least populated island is El Hierro with 10 960 inhabitants [8]. In this sense, it is predicted that, if current trends continue, the Canary Islands will have a population increase of 17.2% in the next 15 years, being the second Spanish autonomous community where the population is expected to increase the most during this period [9]. In terms of tourist arrivals, there has also been a rapid increase in recent years, from 10 432 046 tourists in 2010 to 15 975 507 in 2017 [10].

In this sense, the desalination of water in the Canary Islands is necessary due to (i) some natural limitations and (ii) others of a strictly economic nature. The former derives from the hydrogeological balance itself, which determines, in simplistic terms, that the increase in extraction above natural recharge leads to a systematic decrease in groundwater levels and, at the same time, in the yield of the exploitations [11]. The immediate consequence is the need to divert capital towards refilling works that do not generate new resources and towards the search for water in aquiferous areas of inferior quality [11]. Furthermore, once a certain maximum density of exploitations has been reached, the new ones will divert flows from the existing ones rather than from untapped deposits [11]. In economic terms, on the other hand, the effects are translated into a systematic reduction in the profitability of the uses and thus, into an increase in the price of the water that these uses extract [11]. In some cases, this decrease in profitability also stems from the worsening of water quality, which makes water use more limited [11].

The research presented here will focus on the area of Arinaga, belonging to the municipality of Agüimes (island of Gran Canaria). This population is currently insufficiently supplied (with an average net supply of 95 l/h-d) and it is supplied with groundwater (losses in the network are in the order of 30%) [12]. Due to the natural, economic and population increase limitations mentioned above, a seawater desalination plant will be needed in this area to supply the increased consumption of drinking water and to give a rest to the (over) exploited water resources. Due to the abundance of wind and solar resources in the area [13], a possible technology to be used to power the facility would be solar and/or wind energy-in this sense, the right combination of a renewable energy source with a desalination technology may be the key to meeting the demand for energy and water in an economic, efficient and environmentally friendly manner [14].

Table 1 shows the total volume of desalinated water in the Canary Islands. On the other hand, Table 2 represents the number of desalination plants and the total percentage of desalinated water by islands.

Table 1. Total annual volume of desalinated water in the Canary Islands.
Source: [15].

Hm^3/year	Lanzarote	Fuerteventura	Gran Canaria	Tenerife	La Gomera	El Hierro	Total
Public	34.24	23.95	62.01	24.17	0.00	1.50	145.87
Private	9.02	13.02	59.95	13.09	0.73	0.49	96.30
FCCA estimates (not officially inventoried)	10.74	17.34	59.95	32.23	0.73	0.49	121.48
Total (official)	43.25	36.97	121.96	37.26	0.73	1.99	**242.16**
Total according to FCCA estimates	44.98	41.29	121.96	56.40	0.73	1.99	**267.34**

Table 2. Number of desalination plants and total percentage of desalinated water by islands.
Source: [16].

Concepts	Lanzarote	Fuerteventura	Gran Canaria	Tenerife	La Gomera	El Hierro	La Palma
Total number of desalination plants	49	66	135	46	0	2	1
% of the total volume of water consumed on the island	99%	86%	52%	9%	0%	19%	0%

As it can be seen, the total water consumed in Lanzarote is now desalinated, also in Fuerteventura (where the first desalination plant began operating in 1970) [17]. In Tenerife, an island with more water resources, they are increasingly dependent on desalination: it accounts for 47% of household consumption, with an annual increase in desalination of more than 16% since 2000 [17]. In Gran Canaria, 86% of water for human consumption is desalinated, and 52% of the total supplied is desalinated [17]. There are currently 319 desalination plants in the Canary Islands with a drinking water production capacity greater than 660 000 m^3/day [18] of which more than 100 are located on the island of Gran Canaria [19]. Due to these circumstances, and as far as the Canary Islands are concerned, Gran Canaria is the most suitable island for the assessment of the proposed investigation. Gran Canaria's estimated actual production is about 40% of all desalinated water in the Canary Islands, which exceeds the desalinated water forecasts contained in the island's hydrological plan [20]. On this island, desalination plants are atomized and distributed along the entire coastline [20]. This is due to several factors: that the investment has been made in a staggered manner, that the orography of the island is quite rugged, that a dispersed model has been preferred in the face of potential contamination of the coastline and that distribution costs are saved [20]. On the contrary, the costs resulting from the scale increase [20].

In the scientific literature, it is possible to find a large number of research papers that have mapped water needs and renewable energy sources as a strategic tool for planning new desalination systems. Among the most notable may be those carried out by Shatat et al. [21] who presented an economic and comparative evaluation study for a small scale solar powered water desalination system; Padrón et al. [22] who modelled hybrid systems with base in the renewable energy to compare many different design options based on their technical and economic merits; Mahmoudi et al. [23] who evaluated a brackish water greenhouse desalination unit powered by wind energy for desalting groundwater for irrigation purposes; Poompavai and Kowsalya [24] who presented various control strategies carried out in solar PV and wind energy-based water pumping systems; Mokheimer and Sahin [25] who modelled and simulated a hybrid wind/solar powered reverse osmosis desalination system; Gude and Nirmalakhandan [26] who presented a sustainable phase-change desalination process driven solely by solar energy without any reliance on grid power; Abdelshafy et al. [27] who presented a grid-connected hybrid renewable energy integrated with a reverse osmosis desalination plant to provide fresh water for a residential community; Ismail et al. [28] who presented a theoretical investigation of the performance of two sequential desalination systems, multi-effect distillation and mechanical vapour compression: Zhangab et al. [29] who developed a novel framework for optimization of hybrid systems in remote areas; Li et al. [30] who designed a sustainable and reliable hybrid renewable energy system coupled with a desalination system, considering different operational scenarios with fluctuating renewable energy supply, and changeable water demand; Novosel et al. [31] who evaluated the impact of desalination in a combination with pump storage that utilizes the produced brine on the penetration of intermittent renewable energy sources in an energy system; Cherif and Belhadj [32] who elaborated an energy and water production estimation on a large-scale time from Photovoltaic–Wind hybrid system coupled to a reverse osmosis desalination unit; or the investigation conducted by Ali et al. [33], who presented a specific class of standalone battery-less PV/Wind-reverse osmosis desalination system.

However, the proposal of sites in arid zones, currently not supplied through desalination plants, which can potentially see their water stress reduced through the use of desalination plants powered by renewable energy have not been given the same attention, so a study that addresses them is necessary. From a deep survey of grey literature and updated literature related to the topic addressed here, it was possible to find that – even though there are plenty deal of different approaches – this paper undoubtedly contributes to the pool of existing knowledge by giving the aforementioned perspective (to our knowledge, so far not addressed). By performing this thorough literature review, we ensure the originality of the idea here presented (so far not explicitly shown to our knowledge in any scientific paper).

This first section briefly discussed the possibilities of renewable energy-driven desalination technologies; in the second section, the method used to conduct the research will be exposed; in the third section, a case study on the implementation of the proposed technology will be presented. The fourth section is reserved for conclusions, where the economic and environmental consequences resulting from the implementation of the outlined project in the third sections are presented.

2. Materials and methods

This study will focus on the dimensioning of a desalination plant and its consumption, for which a wind system with the necessary capacity to feed the plant will also be dimensioned. In addition, a study will also be carried out on the excess electrical energy generated by the photovoltaic wind/solar system.

Thus, the sections of this research work will be those listed below, separated into two large groups. First, the sections of the desalination plant, which are:

- Location of the desalination facilities.
- Calculation of the daily production required to supply the target populations (plant capacity).
- Calculation of the specific consumption of the desalination plant.

Second, the sections of the wind/photovoltaic solar system, which are as follows:

- Location of the wind turbines.
- Calculation of the photovoltaic wind/solar potential at the location of the wind turbines and solar panels.
- Study of energy production and evaluation of energy use, evaluating the excess of wind/solar PV energy.
- As a design condition, it has been assumed that the annual excess of energy cannot be higher than the energy demanded by the desalination plant.

In terms of location, the following conditions have been established:

1. The desalination plant will have to be located at a point close to the sea, in order to avoid high costs in the collection system.
2. The wind energy system must be located at a point with a high wind potential that is close to the desalination plant.
3. The photovoltaic solar energy system must be located at a point with a high solar resource that is close to the desalination plant.
4. In order to avoid interference of the desalination plant activities with the daily life of the inhabitants close to the plant site, the facilities shall be located in an area dedicated to industrial activity.
5. The population to be supplied must not have current access to the desalinated water supply.
6. The soil must be suitable for the construction of this type of facility.

Within the Canary Islands, the islands most dependent on desalinated water are Gran Canaria, Lanzarote and Fuerteventura. Due to the fact that (i) these last two islands use practically all of the desalinated water and (ii) the extension of the existing desalination plants is relatively simple, there is no real need for a new seawater desalination plant. Due to this, they were rejected, and the island of Gran Canaria was chosen for the investigation presented. Based on the conditions established in the Materials and Methods section, the Arinaga Industrial Estate has been selected as the site for the seawater desalination plant. This site is industrial land, close to the sea, without nearby desalination plants and has several towns nearby to supply.

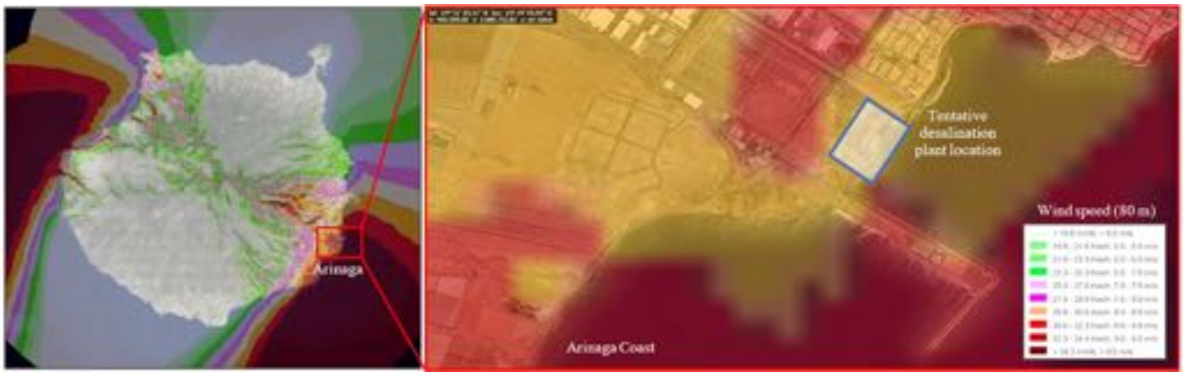

Fig. 1. Wind resource for Gran Canaria (left) and at the selected site, Arinaga (right) for 80 m height.
Source: Adapted from: [34,35].

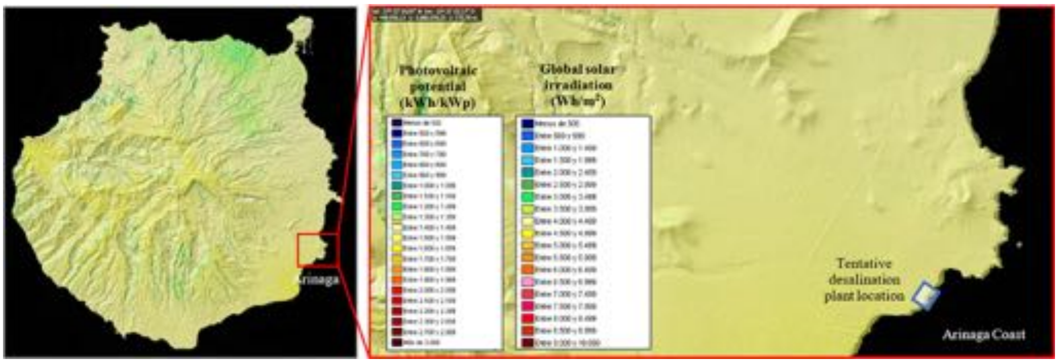

Fig. 2. Solar resource for Gran Canaria (left) and at the selected site, Arinaga (right).
Source: Adapted from: [34,35].

Figs. 1 and 2 represent, respectively, from the Territorial Information System of the Canary Islands - IDECanarias [34], the wind resource and photovoltaic potential (in kWh/kWp) for the island of Gran Canaria. As can be seen, the coastal areas close to the Arinaga industrial estate (see Figs. 1 and 2) have, respectively, one of the best wind resources at 80 m and solar for the island of Gran Canaria. It can be observed in both figures the proposed tentative location of the desalination plant.

The next step will be the study of the population nuclei near the Arinaga Industrial Estate, and how many people live in the area. Table 3 shows that, by 2018, the towns near the Arinaga industrial estate had a total of 21 214 inhabitants.

Table 3. Population of Arinaga for the year 2018.
Source: [36].

Playa de Arinaga	Cruce de Arinaga	Polígono residencial	Polígono industrial	Total
9721	10 384	1068	41	21 214

Once the location was decided, the next steps would be the dimensioning of the production capacity of the seawater desalination plant. In order to determine the definitive capacity of the plant, the number of inhabitants of the areas to be supplied will be studied (Cruce, Polígono and Playa de Arinaga). The objective is for the seawater desalination plant to be able to supply the inhabitants of these areas completely for a period of 10 years (until 2029), so as to be able to give rest to the local water resources currently exploited for this purpose.

The first step in this section is the search for the numbers of inhabitants in the nuclei that must be supplied, for which data from the National Statistics Institute have been consulted. From these data, it is concluded that the populations studied had, in 2017, a total of 21 214 (see Table 3). Considering the forecasts for the coming years and taking as a reference the 10 years prior to the economic crisis (1997–2007), it will be assumed that the annual population growth rate for the evaluated area will be 5% per year. As a result of the assumption of this 5% annual increase, it will be assumed that the populations studied will have, by 2029, a population of 34 555 inhabitants.

For water consumption, the average consumption per inhabitant for the Canary Islands will be used, which will be assumed to be invariable and situated at 160 litres per inhabitant per day [37].

Thus, assuming that for the area studied, for the year 2029 there will be a total of 34 555 inhabitants who will consume 160 litres of water per day on average, it will be possible to calculate the daily capacity of the seawater desalination plant through Eq. (1).

$$Capacity = Consumption \cdot inhabitants = 0.160\ \mathrm{m^3/day} \cdot 32\,944 = 5528.8\ \mathrm{m^3/day} \tag{1}$$

As a consequence, in order to cover the foreseeable demand for water for human consumption in the areas to be supplied, by 2029 a capacity of approximately 5600 m^3/day will be required for the proposed seawater desalination station. It should be borne in mind, however, that since more water is usually consumed during the summer months, it is good practice to design the desalination plant in excess.

Once the capacity of the necessary desalination plant is known, it is necessary to dimension the energy supply system of the seawater desalination plant, specifically by means of wind turbines and/or photovoltaic solar panels. To this end, the wind and solar resource of the area in which the wind/photovoltaic solar system will be implemented must be analysed, as it has been shown in Figs. 1 and 3 respectively.

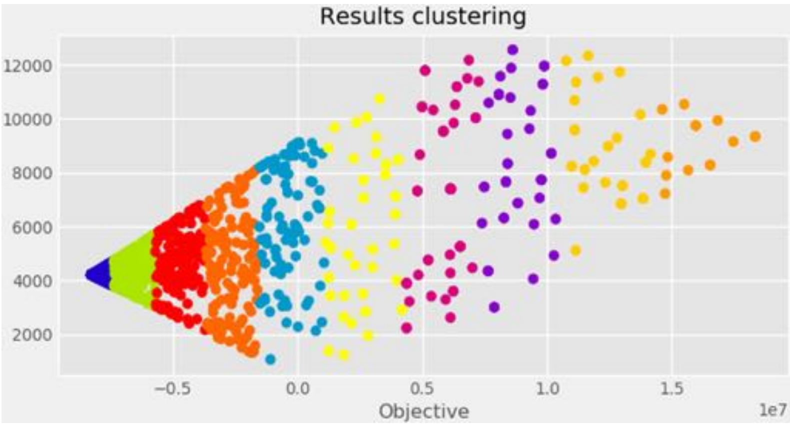

Fig. 3. Optimal results clustering (total installed capacity in kW vs. value of the optimization objective function). *Source:* Own elaboration.

Once the location of the wind turbine/photovoltaic solar panels was selected, the wind and solar resources were studied at this point. For this purpose, the resources available through the website of the Canary Islands Territorial Information System - IDECanarias [34] and the data included in the DesalinationPlant software (which uses data from this area as a default) [38] will be used. This software, specifically developed for this type of installations, will be used to carry out a techno-economic evaluation of the proposed scheme.

In this case, assuming, according to [51], that the consumption of the reverse osmosis desalination plant can be considered 3 kWh/m^3, the annual energy consumption over a year will be:

$$Annual\ consumption = 5600\ \mathrm{m^3/day} \cdot 3.0\ \mathrm{kWh} \cdot 350\ \mathrm{days/year} = 5.88\ \mathrm{GWh/year} \tag{2}$$

Note that, instead of 365 days a year, 350 days have been assumed because this is the typical number of operating days a year for a desalination plant of this type [52]. As a result of the above calculations it can be concluded that the proposed seawater desalination plant will have an annual consumption of 5.88 GWh/year. In this case, and considering the design conditions set out in the section on materials and methods (where it was indicated that the annual excess of energy could not exceed the energy demanded by the desalination plant), the annual energy produced by RES-based power station that supply the desalination plant may not exceed 11.76 GWh/year. This fact is due to some restrictions applied by Spanish's energy regulations, that limit energy electricity surpluses injections to the power grid. Selling electricity surpluses is allowed to lower their energy bills, but only some of the energy produced from the RES-based power station that they have installed to run the facility with. This restriction was the first to handle with.

As it has been previously mentioned, in this research the software desalination plant is used to size the facility. This software [38] uses a *"black stochastic optimization box"* to optimize the amount of RES (wind and solar) and electrochemical storage involved in the desalination plant operation in order to obtain, in this case, the maximum benefit for the operation of the plant. Among the options that the software uses to optimize it can be mentioned: the desalination plant, the solar and wind farm, as well as the energy storage option.

Considering a capacity factor of 0.32 for wind energy and 0.18 for solar-photovoltaic energy [53], an amount energy of 11.76 kWh/year implies that, for the aforementioned capacity factor, a maximum of 4.2 MW must be used for sizing the wind-farm in the software in order to run the optimization. Similarly, the solar farm must be sized in the range of 0 to 7.4 MW to fulfil this restriction [54]. The energy storage device must provide energy as long as the RES-based power station is not able to provide enough. Particularly, for the annual excess of energy of 5.88 GWh/year at the most as well as the energy for the facility to operate, this option must be sized between 0 and 1340 kW, capacity enough to cover the aforementioned energy restriction.

Table 4 shows all considered parameters for the conducted optimization. In addition, data of hourly wind speed (for a hub height of 80 m), solar global hourly irradiation and electricity spot market prices were also provided.

Table 4. Simulation parameters.
Source: Own elaboration.

Desalination plant							
Membrane pack	Auxiliaries Power (kW)	Water flow in (m^3/h)	Water flow out (m^3/h)	Cost/installed (€/kW)	Maintenance cost (%)	Equipment life	After life investment (%)
6 [39]	41.16	368	233	600	27 [40]	10 [41]	100
Water storage							
Relative Head (m)	Storage Capacity (m^3)	Water demand (m^3)	Water price (€/m^3)	Investment cost (€)	Maintenance cost (%)	Equipment life (years)	After life investment (%)
190	180 000	50 [42]	0.60	962 000	1	50 [43]	100
Desalination pumps							
Number of pumps	Nominal Power (kW)	Nominal Flow (m^3)	Cost/installed kW (€/kW)	Maintenance cost (%)	Equipment life (years)	After life investment (%)	
8	110	115	2000 [44]	26 [45]	15 [46]	100	
Solar photovoltaic power plant							
PV panel size (m^2)	Efficiency (%)	Installation cost (€/kWp)	Maintenance costs (%)	Equipment life (years)	After life investment (%)	Min./Max. power for sizing (kW)	
2 [47]	17	1050 [48]	8	25	80 %	1/7400	
Wind farm [49]							
Installation cost (€/kW)	Maintenance costs (%)	Equipment life (years)	After life investment (%)	Min./Max. power for sizing (kW)			
1000	4	25	80	1/4200			
Energy storage [50]							
Charging/ Discharging efficiency (%)	Min./ Max. SoC (%)	Installation cost (€/kW)	Maintenance costs (%)	Equipment life (years)	After life investment (%)	Min./Max. power for sizing (kW)	
98/98	20/95	900	10	10	80	1/1340	

Table 5. Results of the optimization process.
Source: Own elaboration.

Parameter	Optimal result	Parameter	Optimal result
Solar PV size (kW)	866	Storage cost (€)	871.70
Wind farm size (kW)	4 100	Investment costs (€)	5 991 109
Storage size (kWh)	1	Total cost (€)	12 783 098
Desalination plant cost (€)	981 600	Total income (€)	19 366 879
Solar PV installation cost (€)	909 300	Average yearly benefit (€/ year)	253 222
Wind farm installation cost (€)	4 099 337	*Costs-incomes ratio* (-)	0.795

3. Results and discussion

The optimum result of the developed simulation is shown in Table 5, as well as in Fig. 3, but results from different configurations carried out during the optimization process can be evaluated from every and each iteration that the software developed, highlighting the optimum result for the proposed scheme and given parameters, maximizing the benefit for the proposed problem.

Despite the wind profile is less consistent than the irradiation profile, the optimization results showed a wind-based configuration for the RES-based power station in this problem (due to the higher energetic benefit that can be achieved from this resource). In addition, the battery storage system is basically not used, as the algorithm found more profitable to obtain the electricity not provided by RES from the power grid and sell the surplus rather than storage it in expensive Li-ion batteries. As it can be seen from the results shown in Table 5 and with the aforementioned capacity factors, the maximum energy produced by the RES-based power station scarcely surpass the energy restriction of annual excess of energy (maximum energy that can be injected in the power grid) that must be lower than 5.88 GWh/year.

Table 6. Levelized costs of energy and water.
Source: Own elaboration.

Parameter	Results	Observations
Classic *LCOE* (€/MWh)	7.04	Only power generation facilities costs are included without considering water sales
Global *LCOE* (€/MWh)	7.34	All costs are included but also incomes from water sales
Classic *LCOE* injected electricity to power grid (€/MWh)	29.64	Only power generation facilities costs are included without considering water sales
Global *LCOE* injected electricity to power grid (€/MWh)	30.88	All costs are included but also incomes from water sales
LCW without considering electricity sales (€/m^3)	0.0353	Power generation facilities costs are included but not electricity sales
LCW considering electricity sales (€/m^3)	−0.0541	Costs are reduced by incomes from electricity sales
LCW without RES (€/m^3)	1.17	Equivalent desalination plant fed only by electricity from the power grid

It must be highlighted the value of the costs-incomes ratio, used as optimization parameter, which in this result means that each euro of income has a cost of € 0.795. This value must not be compared with the *LCOE*. Different approaches for *LCOE* can be seen in Table 6. Typical *LCOE*, which has been calculated considering only the power generation facility achieves the value of 7.04 €/MWh, which represents an 82.23% better value respect the cost of the power energy from the grid. On the other hand, if we consider the complete process, i.e. including the water desalination costs and incomes, the *LCOE* achieves 7.34 €/MWh. The obtained value for *LCOE* must be evaluated considering that it can vary by technology, country and project, based on the renewable energy resource, capital and operating costs, as well as the efficiency of the technology. It must be considered the associated costs with electricity consumption (see Appendix); and the costs of the associated desalination plant. In addition, it has been included the costs of the water storage deposit as well as the pumps. On the other hand, we should also consider that the costs of solar photovoltaic and wind energy technology have fallen during lasts years [53].

Table 6 also shows the Levelized Cost of Water (*LCW*) which achieves 0.0353 €/m^3 in classical terms (not considering the extra incomes from the electricity selling). This value means that producing water by this method is a 46.16% more expensive than the expected remuneration for it (process not economically feasible by itself without financial support), but if we consider the whole process and we include the extra incomes from the electricity selling, this value changes drastically up to −0.0541 €/m^3, which means that each m^3 of produced desalted water makes a net profit. These values must be considered in the context that the production of desalted water in an equivalent plant without renewable energy sources would conduct to a *LCW* greater than 1.1 €/m^3.

From the results shown in Table 5, the payback is known to be met in more than 11 years, due to the high investment costs of the project, affecting the viability of these facilities. In accordance with the provisions of article 10 of Law 24/2013, of 26 December, on the Electricity Sector, the electricity systems of non-mainland territories are subject to a singular regulation that considers the specificities deriving from their territorial location [50].

The peculiarities of electricity systems in non-mainland territories with respect to the mainland system, deriving fundamentally from their isolated nature and small size, make it more difficult to integrate electricity production from renewable energy sources due to their characteristics. While in the peninsular system the percentage of electricity production from renewable energy sources stood at 40.2% in 2016, in non-mainland territories this percentage stood at around 6% [55].

In order to make progress in meeting the binding objectives established in Directive 2009/28/EC [56] and its revision (European Union; Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources) it is considered advisable to set up wind and photovoltaic power station that contribute to the diversification of primary energy sources, as well as the reduction of energy dependence and the reduction of CO_2 emissions [57]. On the other hand, despite the fact that the activity of electricity production from renewable energy sources generates income from the sale of energy on the market, these are not sufficient to recover their investment costs and avoid a financing deficit, which makes it necessary to grant public aid. Based on the subsidiarity principle, established in the Lisbon treaty, article 5 [58], are the EU members that must fulfil this task.

Specifically, for this region, to ensure the implementation of electrical energy production facilities with wind and photovoltaic technology, the first calls for aid are established (for electrical energy production facilities with wind technology located in the Canary Islands and for investment in electrical energy production facilities with solar photovoltaic technology located in the Balearic Islands.). Now on, a comparison is made in Table 7 in order to clarify the feasibility of the project. The TEC Order 1380/2018 [59] is a thoroughly lost grant that is given in advance in order to help the investment of financeable projects. The projects that this aid will cover must fulfil some terms: first, the wind resource where the wind farm will be placed must be higher than 5.2 m/s. Second, the minimum amount of money to bankroll per project will be 500 k€. And, finally, the unitary investment price must be lower than 1.2 M€/MW. As of results shown in Table 5 can be observed the designed facility fulfil these requirements.

Table 7. Payback time periods comparison.
Source: Own elaboration.

Parameter	Results	Considering TEC 1380/2018
Wind farm cost (€)	4 099 337	2 307 337
Investment cost (€)	5 991 109	4 199 109
Payback time (years)	11.9	8.3

4. Conclusions

The water resources of the Canary Islands have suffered a serious deterioration throughout several decades, trying to supply the water consumption of the population and tourism, both in an unprecedented growth. Thus, the technology of seawater desalination has acquired a certain prominence in the economic development of the region, to the point of being responsible for a large part of the total energy consumption of the Canary archipelago, usually from fossil fuels, that have a negative impact on the environment. Thus, the combination of desalination by reverse osmosis with renewable energies, in this case, wind and solar photovoltaic, is a step towards sustainability and the reduction of dependence on fossil fuels. The capacity of the proposed plant, 5600 m^3/day, aims to supply the total population of Arinaga until 2029, which corresponds to the 10 assumed years of the expected life of the desalination plant membranes. During this time, the stress of the currently exploited conventional water resources will be mitigated, in this case obtaining drinking water for human consumption without supposing extra demand for the power grid, since its operation is based on self-sufficiency.

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Appendix. Project cash flow

Year	Desalination Plant cost (€)	Battery cost (€)	Wind cost (€)	Solar cost (€)	Electricity cost (€)	Water sales (€)	Electricity sales (€)
0	981 600	871.71	4 099 337.15	909 300	0	0	0
1	14 752	87.171	163 973.49	90 930	953.11	49 312.78	725 362.37
2	14 752	87.171	163 973.49	90 930	953.11	49 312.78	725 362.37
3	14 752	87.171	163 973.49	90 930	953.11	49 312.78	725 362.37
...	...	...	...	...	...	...	...
23	14 752	87.171	163 973.49	90 930	953.11	49 312.78	725 362.37
24	14 752	87.171	163 973.49	90 930	953.11	49 312.78	725 362.37
25	14 752	87.171	163 973.49	90 930	953.11	49 312.78	725 362.37

It has been adopted as hypothesis that components replacement costs are included in the yearly operation and maintenance costs.

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Anexo P5: Copia de la publicación científica "Feasibility Analysis of Wind and Solar Powered Desalination Plants: An Application to islands"

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Feasibility analysis of wind and solar powered desalination plants: An application to islands

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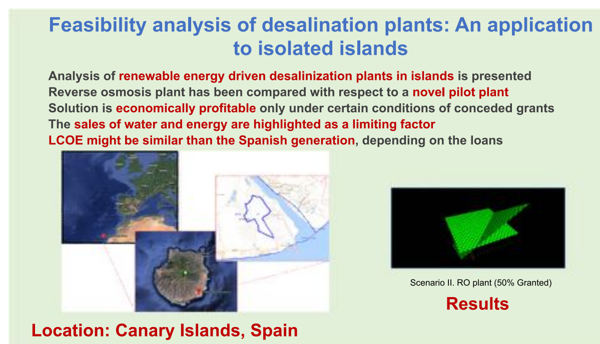
HIGHLIGHTS

- Analysis of renewable energy driven desalinization plants in islands is presented.
- Reverse osmosis plant has been compared with respect to a novel pilot plant.
- Solution is economically profitable only under certain conditions of conceded grants.
- The sales of water and energy are highlighted as a limiting factor.
- LCOE might be similar than the Spanish generation, depending on the loans.

GRAPHICAL ABSTRACT



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ABSTRACT

Economic surveillance for securing water projects driven by non-conventional energy sources is a challenge. The carrying out of these initiatives in economies based on liberalized markets faces governments against the need for guaranteed profits. As water availability has become a relevant global problem, and desalination an energy-intensive demand solution, it is common to combine both kinds of technologies, renewable energy systems and desalination plants. This research investigates the influence of grants, investment rates, and energy and water sales on the commercialization of two desalination technologies. A performance analysis has been carried out taking into account different scenarios. Following this approach, a simulated reverse osmosis desalination plant has been compared with respect to an already granted novel pilot plant. Results show a better fulfilment of the non-economic objectives, and economically profitable not only under certain conditions of conceded grants, and investor's expected benefits but also of sales of water-energy, that highlighted as a limiting factor. The Levelized Cost of Energy might be similar than the Spanish generation means, depending on the cost escalation rate of the loans, and conceded grants. It was found a reduction of 11 euro cents under the average price that could be achieved, for the standard scenario.

1. Introduction

Among the 17 UN sustainable development goals (United Nations, 2020) to achieve a better and more sustainable future, we found the goal of reaching affordable and clean energy next to clean water and sanitation. Water scarcity affects more than 40% of the global population. Energy is central to nearly every major challenge and opportunity the world faces today. Be it for jobs, security, climate change, food production or increasing incomes. Additionally, among the European objectives included in the Lisbon Treaty (2007), it highlights the article 194: *to improve competitiveness, achieve security of supply of energy,*

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Nomenclature

ASAI	Average Service Availability System
BAT	Best Available Techniques
CAIDI	Customer Average Interruption Duration
CCt	Capital costs
CCG	Combined Cycle Gas Station
CO_2	Carbon Dioxide
coeur	Euro cent
COW	Cost of water
CRF	Costs Recovery Factor
EBITDA	Earnings Before Interest Taxes depreciation and Amortization
EU	European Union
EEG	Energy Electricity Generation
FCCt	Fuel consumptions costs
GCC	Generation Control Center
GDP	Gross Domestic Product (GDP)
GHG	GreenHouse Gas
GWh	Gigawatts per hour
Hm^3	Cubic Hectometer
ICT	Information Communication Technology
IDAE	Institute for the Diversification and the Energy Savings
Ieff	Effective investment rate
Inhab	Inhabitant
kW	Kilowatts
kWh	Kilowatts per hour
KPI	Key Performance Indicator
LCOE	Levelized Cost of Energy
m^3	Cubic meter
MENA	Middle East and North Africa
MW	Megawatts
n	Number of years
NOx	Nitrogen Oxide
NPV	Net Present Value
O&M	Operating and Maintenance
PV	Photovoltaic
REE	Red Eléctrica España S.A.U. (Spanish Transmission System Operator)
RES	Renewable Energy Sources
RO	Reverse Osmosis
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
SME	European Innovation Council accelerator
SEC	Specific Energy Consumption
TEC	Ecologic Transition
TRL	Technology Readiness Levels
W	Watts
W&E	Water and electricity

sustainability in order to increase the installed capacity of primary renewable energy-based technologies.

Different scenarios developed by IEA (2018) suggest that energy demand could expand by 30% worldwide between today and 2040, where the convergence of cheaper renewable energy technologies, digital applications and the rising role of electricity is a crucial vector for change. So, EEG is supposed to increase significantly, putting affordable, universally available and cleaner electricity at the centre of strategies for economic development. Without decisive action, energy-related GHG emissions could more than double by 2050, and soil erosion and water scarcity will speed up all over the world. Due to this fact, Governments face the challenge of revert, palliate, or more properly be prepared to tackle these events. We cannot forget that worldwide, fossil fuels involve the vast majority of its energy consumption, and globally around 80% of global primary energy use still comes from fossil fuel (Strategic Energy Technologies Information System, 2018). Specifically, to fulfil their 2020 climate & energy package (Official Journal of the European Union, 2012), the EU institutions set three key targets: 20% cut in GHG emissions, 20% of EU final energy from renewables, 20% of improvement in energy efficiency, among other initiatives. Those will be a set of binding legislation. Moreover, in 2016 European Commission presented the package: “Clean Energy for all Europeans” (Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank. Clean Energy for All Europeans. COM/2016/0860 Final, 2016) in which several agreements have been made in order to move along this strategy, as the agreeing on setting in 32% the final energy consumption from renewable technologies by 2030 for the whole European Union with rising expectative. To boost this strategy new legislation has already come (Directive (EU) 2018/2001 of the European Parliament and of the Council on the Promotion of the Use of Energy From Renewable Sources, 2018) to enhance the development of renewable - based projects, that will help society to grow and thrive while lowering energy dependence, as well as the reduction of GHG emissions.

Despite the fact that 70% of earth's surface is covered by water, and 97% of it is in liquid phase water availability for safe consumption and agriculture has become a relevant problem around the world. For that reason, from the second half of the 20th-century, water desalination technologies were developed for areas under water scarcity risk. According to the World Resource Institute, water stress in 2040 would become extremely high in Spain, Greece, as well as in the MENA region.

Gómez et al. analysed the most used technologies of desalination in the Canary Islands. Among these, distillation methods such as multi-stage flash, multiple-effect distillation, vapour compression, and membrane processes such as electrodialysis reversal, membrane distillation, and reverse RO.

Van der Brugger et al. (2004) investigated the energy-intensive process that RO desalination comprises, focusing on the rate operation and the high pressure in this process. This produces -as long as fossil fuels are used for EEG- an associated environmental impact, and increasing prices of the desalted water resource, in regions that lack them, causing loss of competitiveness for agriculture, industry, or human usage. Provided that EEG costs in islands are higher due to its isolated nature, these issues become even more acute. The efforts focus on how to improve the efficiency of the desalination process. In fact, more than 80% investment costs of a RO desalination plant involve capital and electricity costs. Water desalination in Gran Canaria entails an energy electricity consumption of around 350 GWh/year, around a 10% of the total final energy consumption of the island. Energy costs are nearly 52% of operating and maintenance costs, and 39% of total cost (National Renewable Energy Laboratory, 2005).

In the Canary Islands, by 2012, the installed desalination capacity was 273,084 m^3/day, entailing 122 Hm^3/year. Especially in Gran Canaria, 86% of water for human consumption is desalinated, as well as the 52% of total supply (La Provincia, 2019). 62 Hm^3 out of them were desalinated in public desalination plants, and 60 Hm^3 from private property.

Ghalavand et al. (2014) analysed costs related to the involved technologies in the desalination process as well as costs of energy in the region where the desalination plant is located. Their isolated nature provokes a higher energy bill for desalting those 122 Hm^3. In order to improve the competitiveness of the process, to reduce costs, a dedicated RES-based power station has become an extended option to run these facilities to overcome electricity prices, lowering operational costs, while reducing associated GHG associated emissions. Rosales-Asensio et al. (2019a) analysed this scheme, and found that for a 6 c€/kWh of energy costs, the costs of water might be reduced by investing in the internal process of a private property RO Desalination plant (Lozano-Ruano, n.d.), while economic analysis advised the investment. Other proposed technology that comes from innovation process in desalination technologies is the thermo-solar water distillation (Aqua.abib, 2020a), a technology that harvest sunlight with a 70% of efficiency heating the air between two plastic layers and the hot air naturally rises until a vortex of a pyramid surpassing 100 °C, instantly evaporating sprayed seawater separating it due to its weight difference. The benefit of this project, apart from the fact that it offers goods as water, salt, is that it proposes low energy consumption. By the time of the redaction of this research was being developed the first pilot plant.

On the one hand, Governments have to face the issue of the integration of renewable technologies, trying to fulfil agreements made to face climate change, while solving the associated problem concerning the reduction of the competitiveness of the economy that itself comprises multiple actors. According to Spanish National Grid (Spanish Power Transmission Company, 2018), Gran Canaria, a region where just 10% of generated electricity comes from RES provokes a high rate of GHG emissions, existing concern about the economic competitiveness of these facilities, as well as the environmental impact of the energy used in the process. However, RES-desalination solutions appeared becoming feasible alternatives. González et al. (2019) focused on wind powered desalination systems. Colmenar-Santos et al. (2017) investigated actions to face these problems in the region of study, and years that came grants and benefits were highlighted. Shah et al. (2017) reviewed measures adopted by Governments in order to boost RES-based technologies of EEG, and how they affect the commercialization of these disruptive technologies.

In order to ensure the implementation of RES-based power stations – specially wind and photovoltaic technology – in the non-mainland territories of Spain, last years, calls for aid have been established in the Canary Islands, and for investment in EEG facilities with solar photovoltaic technology located in the Balearic Islands. Developed by TEC/1380/2018 order (Institute for the Energy Diversification and Saving (IDAE), 2019), it is incompatible with others proposed from European Union, or others, as well as, it is incompatible with the specific retributive regime (IET order 1045/2014 approval of retributive parameters for EEG facilities from renewable energy sources, 2014; Royal Decree 413/2014, regulating the activity for generating electricity from renewable energy sources co-generation, and waste plants, 2014; Royal Decree 738/2015 regulating the activity for generating energy electricity and clearance proceeding in non-mainland electric systems, 2015), given in order to reduce the extra costs of the facilities in the business of generation of electricity from RES. Spanish authorities, in order to lower the high costs of desalted water, let sales of surpluses of the generated electricity when operating those desalination plants, but with a maximum of twice the energy needed to run the facility. European authorities proposed the SME grant Phase 2 (European Commission, 2019): tool bound to innovation projects underpinned by a strategic business plan and feasibility assessment that focuses on the industrial, economic, and social problem to overcome, or the business opportunity of projects involving renewable energy technologies.

This research virtually granted two water desalination technologies following them and this scheme as a guide, and developed a techno-economic evaluation of these projects in order to decide if investment or not in a given project would be advisable. For evaluating projects, it is common using market and technical studies, economic evaluation, or the analysis and administration of risk. The aim of this paper is to find out what was the influence of parameters (grants, investment rates, W&E sales) over KPI for the investment decision regarding the commercialization of novel projects associated with water desalination.

In the scientific literature it is common to find reviews using the software HOMER to size desalination plants minimizing, or optimizing parameters. Khan Meer et al. (2018) studied the deployment of solar PV and wind energy sources to run a RO facility, and found a total water production cost between 0.45 and 0.89 €/m^3. Similarly, Eltawil et al. (2009) found those costs to be between 0.59 and 2.81 €/m^3 depending on the technology, the size of the facility, and the market that was acting in. Javed et al. (2019) conducted a techno-economic study of a hybrid solar-wind-battery for a stand-alone system, and investigated the influence of a low loss of power supply probability, finding that it had an enormous influence in direct, and O&M costs. Shallenberg et al. (2014) were interested in investigating the relationship between energy and desalination technologies, and focusing on the Canary Islands showed the energy and monetary costs of desalination.

In contrast, it is observed a lack of studies concerning the comparison of real investment scenarios of projects to develop an analysis of the investment decision. In the first stage, the characteristics of proposed grants were analysed: objectives, ambition, expected impacts, implementation, or measures to maximize impact stand out as of them. Secondly, it was analysed if the proposed technologies fulfilled the desired characteristics in order to apply for the proposed grants, facilities dimensioning, and what is its influence in the investment decision for its commercialization through a sensitive analysis that investigated if this business model would be profitable enough for private investors.

2. Material and methods

This section describes the two analysed RES-desalination systems and describes the method to find out what is the influence of grants, investment rates, W&E sales for the investment decision regarding the commercialization of novel projects associated with water desalination.

This research analysed the solar and wind profiles of the region with geographic information tools in order to find the RES potential of the region, letting explore the scalability/replicability. The Canary Islands are a Spanish archipelago located in the Atlantic Ocean, in a region known as Macaronesia, around 100 km off the northwest coast of Africa and about 1350 km from Europe (Cabrera et al., 2018). Despite its proximity to Africa, the Canarian archipelago is economically and politically European, as it is part of the European Union. The archipelago has seven main islands, with a population of around 2.1 million inhabitants and a density of 287.39 inhabitants per km^2 (Canary Islands Institute of Statistics, 2020). The Canary Islands is the eighth most populous administrative region Spain and its population is mostly concentrated in the two capital islands (Tenerife and Gran Canaria) (Canary Islands Institute of Statistics, 2020). The economy in the islands is based primarily on tourism, which represents around 30% of the Gross Domestic Product (GDP) in the islands. However, construction sector and tropical agriculture have been also drivers in the islands economy. Canary Islands have suffered an important lack of water resources along the history (Santamarta and Rodríguez-Martín, 2013). Water resources in the islands have been set in two systems of water collection, based on the location and climate of the involved islands (Santamarta and Rodríguez-Martín, 2013). Western islands contain high mountains and forests which retain the clouds in the north face of the islands. For this reason, the water resources of these islands are mainly the groundwater. Easter islands, by contrast, does not contains high mountains and forests and they are more arid. In these islands the desalination is the main source of water (Santamarta and Rodríguez-Martín, 2013). Since all economic sectors in the islands are intensive in the use of water, the water resources in the islands are overexploited (Santamarta and Rodríguez-Martín, 2013). This has motivated several initiatives from the governments to promote the desalination development on the islands and to control the water use (Gómez-Gotor et al., 2018).

In term of electricity and grid interconnection there are six islands electrically independent each other. Only two of the eastern islands (Lanzarote and Fuerteventura) are interconnected by a underwater connection. This insularity in electricity terms avoid synergies between isolated energy systems and generate additional costs which are proportionally spread out in the electricity bills throughout the country, to allow citizens in the islands to pay the same price per kWh as those who live on mainland Spain (Nuez and Osorio, 2019). Total installed electrical power in the islands was 3308,6 MW, at the end of 2018, with 18.5% as renewable energy (612.3 MW) (Canary Islands Government, 2018). These renewable energy sources (RES) are mainly wind (397.3 MW) and solar photovoltaic (186.5 MW). However, another RES as mini-hydraulic, hydropower and biogas are participating with 2.0 MW, 22.8 MW and 3.7 MW respectively (Canary Islands Government, 2018). In the Canary Islands there is a lot of potential for the exploitation of RES, mainly wind and solar and one of the priorities for the islands governments is to increase the level of RES in the electrical systems (Shallenberg et al., 2014).

Canary Islands is specially considered as an outermost region in the UE (European Commission, n.d.-a). Remoteness supposes to local manufacturers a number of constraints which push up the cost prices of their products, thereby making them uncompetitive with products from elsewhere (especially mainland Spain and the other EU Member States) (European Commission, n.d.-a). For these reasons, it has implemented specific measures, which, by means of tax exemptions or reductions for local products, are designed to: (i) encourage productive industrial activity, (ii) safeguard their competitiveness with outside products, and (iii) thus increase the proportion of the Canaries' GDP accounted for by industrial activity (European Commission, n.d.-a). In this sense, for instance, the harmonised rules on VAT do not apply to the Canary Islands (European Commission, n.d.-a). However, there is another local consumer tax known as the IGIC (Impuesto General Indirecto de Canarias - Canaries General Indirect Tax) applied at several different rates (European Commission, n.d.-a). Additionally, another consumer tax known as the AIEM is applied to a limited list of locally manufactured products specified in the *Decision 377/2014/EU* (European Commission, n.d.-b).

Focused in Gran Canaria. Cabrera et al. (Cabrera et al., 2018) noted that in the south east of that island, where it is located the "Barranco de Tirajana" thermal power station suffer all the aforementioned problems: water scarcity, high environmental impact (El Diario, 2019a) on population due to the high GHG emissions and loss of competitiveness. The location of the proposed site for the facility is shown in Fig. 1. Now on, the technologies that were proposed as candidates to ask for grants were analysed and dimensioned for a further analysis of its commercialization performance evaluation.

2.1. RO desalination plant

The first analysed technology is a RES-powered RO desalination plant, sized with the software Desalination Plant (Desalinationplant, 2018). Colmenar-Santos et al. (2018) analysed that only by optimizing three variables (wind energy, solar energy and energy storage) is able to provide a minimum operational cost for a RO plant, and for a given desalination capacity. Due to the fact that simulation of the desalination plant is coupled to a hybrid distributed energy resource is itself a complex task, Desalination Plant implements a quite complex economic metric. As Im and Park (2013) reviewed to obtain the variables, stochastic optimization algorithms have their own mechanisms to find the global optimum. They require a large number of evaluations to reach it, and to optimize the system, it is necessary to provide the wind and solar profiles of both, speed and irradiation data from the region of Gran Canaria (Canary Islands Institute of Statistics, 2020; Canary Islands Government, 2018).

Provided that the maximum amount of funding the SME instrument would provide was € 2.5 million per project, and it involved 70% of the total investment, € 3.5 million was the total budget for the design of the RES-powered desalination facility. According to Rosales-Asensio et al. (2019b), for a standard desalination plant it might be assumed to cost € 1 million (National Renewable Energy Laboratory, 2005) in order to perform the simulation. Similarly, it was assumed a total cost of 1000 € per installed kW of wind power (Stehly et al., 2017), fact that it implied that the wind installed power must be of 2.5 MW for dimensioning this facility within the Software. Similarly, for solar photovoltaic power it was assumed 1050 € per installed kW (Fu et al., 2017) it is: 2.33 MW. According to Spanish legislation, these facilities can sell a restricted amount of energy: the same amount that they are able to generate with the installed capacity to run the desalination plant (IET order 1045/2014 approval of retributive parameters for EEG facilities from renewable energy sources, 2014). Taking into account a capacity factor of 0.32 for wind energy, and 0.18 (International Renewable Energy Agency (IRENA), 2018) for solar-photovoltaic energy the expected EEG capacity to size the wind powered desalination plant could be calculated.

$$\text{Expected energy capacity} = 2500\ \text{kW} \times 2803\ \text{h/year} = 7,008,000\ \text{kWh/year}.$$

$$\text{Expected capacity (water)} = 3,504,000\ \text{kWh/year} \times 1\ \text{m}^3/3\ \text{kWh} \times 1\ \text{year}/350\ \text{days} = 3337\ \text{m}^3/\text{day}.$$

The specific energy consumption (SEC) considered in this study for the water treatment (3 kWh/m^3) was determined as the average value of different RO desalination plant installed in The Canary Islands (Arenas-Urrea et al., 2019).

From these results, the expected capacity for sizing the associated desalination plant resulted in 139 m^3/h of capacity in the associated desalination plant. The rest of the necessary data to develop the simulation can be consulted in Appendix A.

2.2. The aqua.abib project

This second facility to be analysed is a novel distillation facility joint to a RES-based Power Station. The aqua.abib project applied for a grant of the SME Instrument H2020 program, and received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 739468 of the Small and Medium sized Enterprises Instrument program (phase II) of the European Commission. As we previously mentioned, incomes consisted in W&E sales for the desalination plant, and water, electricity and salt sales for the aqua.abib project. The cost of this project was set at 2.4 million € (European Commission, 2020), and as can be seen in Table 2 funding will be provided by different sources. The system offers a flux of 25,000 m^3/year, enough water for 1200 people (71.41 m^3/day). In addition it is able to generate 875 mTon of NaCl. The website of the project (Aqua.abib, 2020b) shows that European Commission granted around 50% of the total cost, it is said: 1.4 million €. Provided that the deployment of wind power was mandatory to opt for the grant, this research assumed it for the associated renewable plant of the aqua.abib pilot plant, for the same region. The necessary amount to fulfil the 3.5 million € condition was proposed as wind deployment to the desalination plant. Provided that this pilot plant is in its early stages of technological development, the 0-50-100% analysis of the grant departed from the already 1.4 million € granted.

2.3. Analysis of commercialization

As from the analysis of the characteristics, and conditions that proposed grants demanded highlight: feasibility of the project, summarizing measures to maximize impact, or uses (research, commercial, social, or environmental investment). Once the facility perceives the grant, it is demanded an extra accounting system to record all dealings (transactions). Variable costs related to the increasing administrative tasks imply increasing costs, which additionally would demand more agile structures of information management systems (Appendix B). Furthermore, these facilities must subscribe to insurance, and an economic guarantee of 20,000 € per installed MW, extra-costs that were accounted as 1% of the total project costs (Baca Urbina, 2015). On the other hand, taxes, workforce, environmental impact studies, and studies to find out the wind resource, geotechnical studies, security and health plans, as well as promotion costs will not be financeable. In order to

Fig. 1. Proposed placed (in line blue) for the allocation of the plant (Land Registry website, 2019). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

boost wind-powered technologies, TEC order 1380/2018 (Institute for the Energy Diversification and Saving (IDAE), 2019), for instance, demanded more than 800 kW of installed wind power. Furthermore, the region to locate the wind power station must have a wind resource speed higher than 40% of the maximum resource for this region, namely 13 m/s at 60 m high. In addition, it demanded requirements of state air safety agency, nearness node of connection to the grid, with a minimum voltage value.

This research conducted a commercialization analysis following a flux diagram (Fig. 2): it varied the amount granted, the Ieff of the rest of the amount invested, and calculated parameters that were taken into account in order to explore its commercialization performance. The amount of conceded grant to build the facility varied from 0% to 100%, and the effective investment rate (Ieff) of the cost recovery factor (CRF) between 3.5% and 24%.

In order to understand how the profit-earning capacity was affected, it was distinguished between the EEG facility and the desalination plant because of the importance of the annual capital costs. These vary depending on the amount and characteristics of the loans conceded to build the facility, and how are they yearly capitalized. Among the most used ways, this research opted for the same amount of yearly money payment as shown in (2) (Baca Urbina, 2015), under the assumption all investment came from loans at a specific Ieff.

Among the most widely used parameters that indicate the performance competitiveness of these facilities we can name the levelized cost of energy (LCOE) and cost of water (COW). LCOE is an economic assessment of the average total cost; including: capital, operating and maintenance, as well as fuel costs to build and operate a facility over its lifetime divided by the total energy output over the lifetime of the facility under a specific Ieff. Gökçek and Gökçek (2016) predicted (for a wind-powered RO desalination plant, connected to the grid) a LCOE from 0.068 €/kWh to 0.14 €/kWh, and a COW from 0.7 to 2.46 €/m^3.

These variations depended on the size of the desalination plant, the region where it is located, and on the technology involved in the process. Feo García et al. (2013) studied the region where this research is focused in, and gave an average price for water of 0.6 €/m^3. Karunathilake et al. (2020) used a fuzzy logic-based optimization process to discover the optimal system capacities and energy mix. This technique is also used by other authors in chemical process for another purposes (Palacio-Morales et al., 2019).

$$LCOE = \frac{\sum_{i=1}^{n} \frac{CCt + OMCt + FCt}{\left(1 + I_{eff}\right)^{n}}}{\sum_{i=1}^{n} \frac{Electricity}{\left(1 + I_{eff}\right)^{n}}} \tag{1}$$

$$CRF = C.C \frac{I_{eff}\left(1 + I_{eff}\right)^{n}}{\left(1 + I_{eff}\right)^{n} - 1} \tag{2}$$

The project was analysed for 20 years of return of investment, varying the amount of sold electricity, as well water sales from 70% to 200% in order to investigate the capacity of both facilities to achieve the economic KPI, and for a better understanding of its commercialization performance.

Specifically, to achieve this task, this research calculated the net cash flow of each year (net utility) with data from Appendixes 2 and 3. The general statements (see Fig. 3) consisted in developing a balance of all the costs and incomes generated during a whole year (Baca Urbina, 2015), starting with the marginal utility, or predicted earnings before interests, taxes, depreciation and amortization (EBITDA). On the other hand: capital, operating, taxes, and administrative costs as shown in Appendix C. In the calculus of the NPV, it was used 6% as inflation rate (company earnings are limited to maintain its real purchasing value)

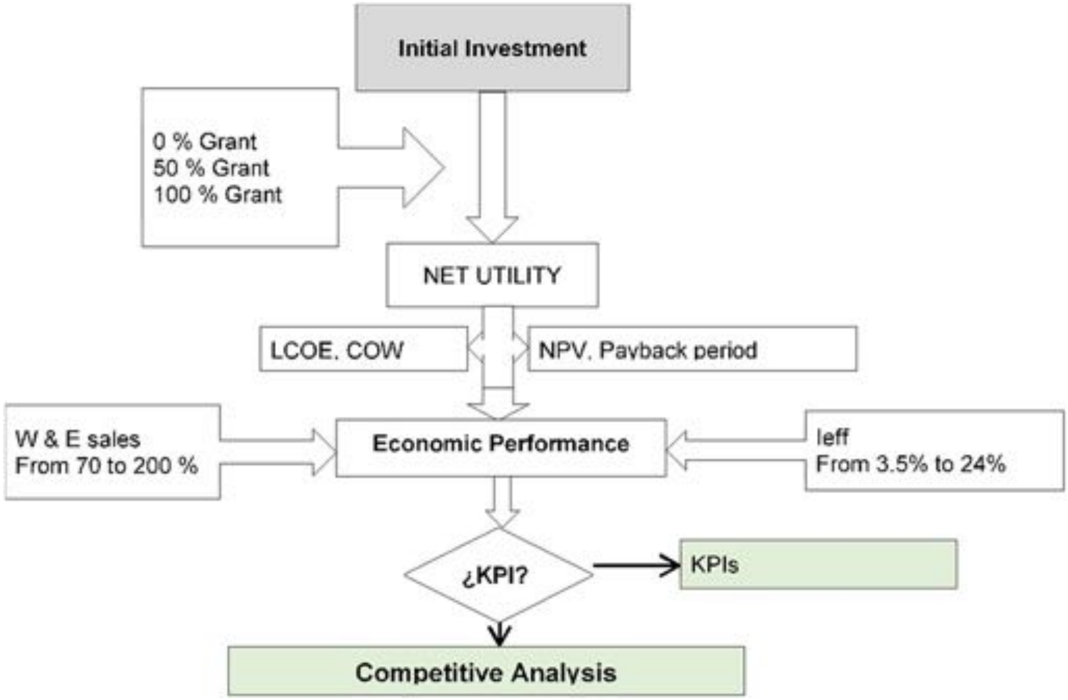

Fig. 2. Flux diagram of the commercialization analysis.
Source: own elaboration.

instead of calculating the profitability of the facility as a whole with an investor choice, provided that it was accounted in the CRF.

Table 2 shows the key performance indicators (KPI) related to this research, and to provide a success metric. Among these, this research focused on economic analysis. It is the energy and GHG emissions, water costs and related jobs.

3. Results and discussion

As can be seen in Figs. 4 and 5, the deployment of renewable technologies for EEG in Gran Canaria is far from the mentioned EU objectives of renewable deployment. With a population of approximately 850,000 inhabitants (Canary Islands Institute of Statistics, 2020), the ratio wind power/inhabitant in the island was lower than 100 W/inhab, far from the mean of Spain, 495.8 W/inhab, and far from the EU members mean: 301.1 W/inhab (Spanish Power Transmission Company, 2018), and this without taking into account that during 2019, more than 4.5 million tourists visited the island (Tourism board of Gran Canaria Island Council of Gran Canaria, 2018).

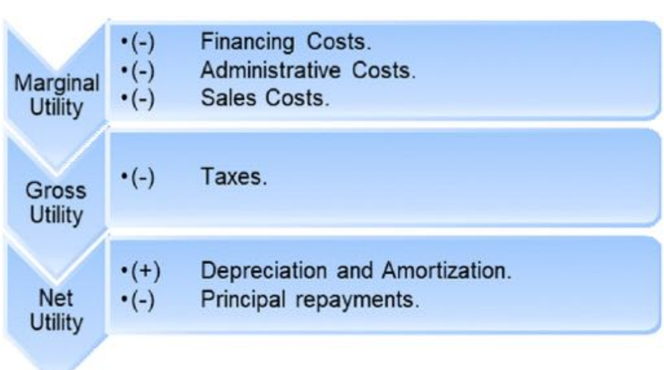

Fig. 3. Net cash flow.
Source: own elaboration.

Similarly, the photovoltaic installed power ratio of 85.9 W/inhab in Canary Islands versus the Spanish mean of photovoltaic capacity per inhabitant of 103.4 W/inhab, even lower than in EU: 197.8 W/inhab (EurobservER, 2017).

The percentage of uploaded energy from RES-based technologies varies within the year, finding maximum rates of 21% in July, and minimum of 5.4% in October (Canary Islands Government, 2018). On the other hand, the rainfall in this region was found to be lower than 0.150 m^3/year (Gómez-Gotor et al., 2018), and as a consequence it could be considered as a desert climate. Due to fact, this location was found to be a "laboratory of research" for other places with difficult agricultural, economic, and climatic conditions, making it a suitable candidate to opt for the grant through the proposal of an integrated solution that might contribute to improve the economic, societal, and environmental situation of regions suffering from draught problems.

As we have previously mentioned, the wind resource must be higher than 40% of the maximum resource for this region, namely 13 m/s at

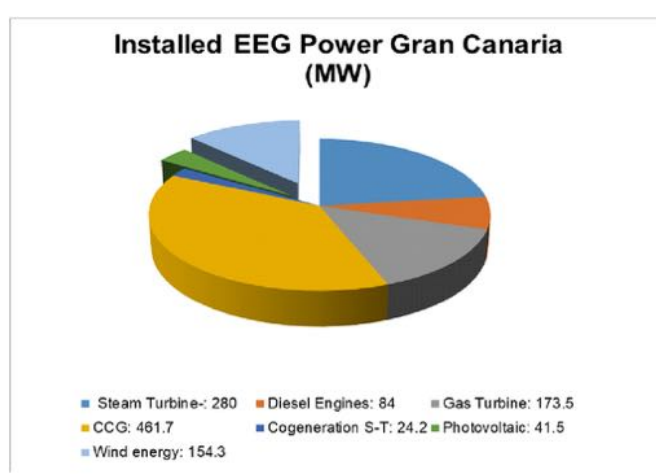

Fig. 4. EEG installed power in Gran Canaria (Aqua.abib, 2020b).

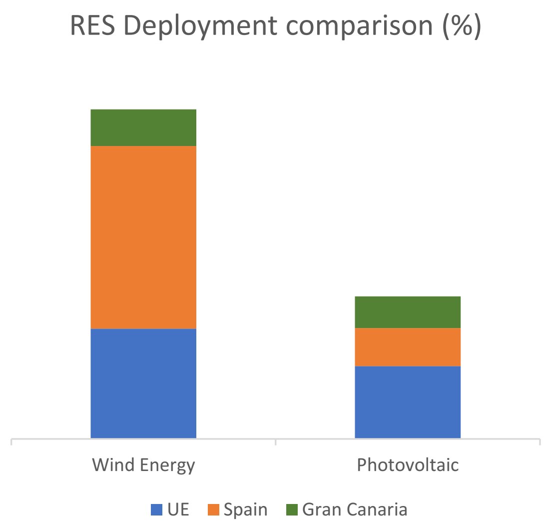

Fig. 5. RES % deployment comparison (Spanish Power Transmission Company, 2018).

60 m high (Canary Islands Government, 2019a), so that, higher than 5.3 m/s. The proposed region (see Figs. 6 and 7) fulfilled the requirements for wind resource as well as the potential of solar photovoltaic energy for this region: 1500–1600 kWh (see Fig. 7) (Canary Islands Government, 2019b) that grants demand.

3.1. Techno-economic results

The simulation results for sizing the RES powered RO desalination plant used the costs-incomes ratio as optimization parameter, obtaining as a result, a profitability index of 0.784 for the operation of the facility as a whole. Moreover, results showed an energy deployment where PV and battery storage were almost null, while the wind farm reached the maximum sizing power (2500 kW). The rest of simulation results can be consulted in Appendix C, including annual costs to run the facility, as well as the incomes of simulated operations during one year. (In a standard decision-making problem costs of operating the solar photovoltaic plant, and the storage device that the simulation showed would have been left apart because of its small size). These showed that average year wages from W&E sales were 407,132 €/year, and the global O&M costs reached 123,737 €/year, resulting in an EBITDA of 297,595 €.

On the other hand, for the operation of the distillation plant as well as for those related to the wind farm were assumed proportional O&M costs. The revenues came from water, salt, and electricity sales with the same simulated pricing of the desalination plant, resulting in an EBITDA of 100,551 € (Appendix C).

The results of the analysis depicted in Fig. 2 are shown in Tables 3a and 3b, respectively for both facilities, and for the aforementioned grant conditions. Firstly, the CRF of the necessary loan to build the facility, obtained as previously explained (see Eq. (2)). It also included the performance parameters LCOE, and the COW of both schemes.

As can be observed, the distillation plant showed positive net utility only when half grant was conceded (1.400 + 0.55 million €) (see Table 1), and under advantageous Ieff conditions. On the other hand, when the RO plant perceived half grant (1.25 million €) it showed a positive net utility up to 10% of Ieff condition. The sensitive analysis included the NPV and the payback period calculation, for different investment rates, and for the different options of conceded grants. As can be observed, most scenarios showed a negative NPV, marked with X when it is tremendously negative, advising against the investment. The best NPV result advised the investment in the aqua.abib project only when whole grant (2.5 million €) was conceded, but for up to 6% of Ieff, (note that money came from different institutions, probably under different investment rates conditions), although the discounted payback period remained higher than 15 years in this case. Note that despite more profitability margin appeared for the RO plant, the NPV became null even at an Ieff lower than 3.5%, for a not-conceded grant scenario, setting the limit of the investment decision. Also, when half grant was conceded, it became negative above 12% Ieff.

Finally, for a whole conceded grant scenario the Ieff that set this limit was found to be above 24%. In addition, it highlights that only when half grant was conceded, and for an Ieff of 7.5% a reduction of 11 coeur under the average 0.6 €/m^3 was achieved, while the aqua.abib project showed a price higher than 3 €/m^3.

To deepen the understanding of the economic performance of the facilities, Figs. 8–13 showed the influence that the variation of the incomes derived from W&E sales from 75% to 200% of expected incomes, had for achieving the net utility KPI objective (200,000 €) in both facilities. It was done through the deployment of 3 scenarios: 0, 50, and 100% of granted. Additionally, the Ieff of the rest of the money needed was varied between 3.5% and 24%. As from their analysis can be observed that:

First, in scenario (I) (Figs. 8 and 11) that no grant was conceded, the RO plant reached the economic objective only for a very low Ieff. This happened only when W&E sales increased over the 140% of capacity. Despite the fact that it started with 1400 k€ granted, the distillation plant did not achieve the economic KPI objective of 200,000 € of net utility.

Secondly, scenario (II) (Figs. 9 and 12) analysed the influence of half grant on the net utility of the plants. As can be seen, only the RO plant achieved the net utility KPI stated objective when W&E sales increased. In the light of the results the RO-plant would be able to provide an Ieff of

Fig. 6. Wind resource of Gran Canaria (a), and the selected site (b) at 80 m (Canary Islands Government, 2019a).

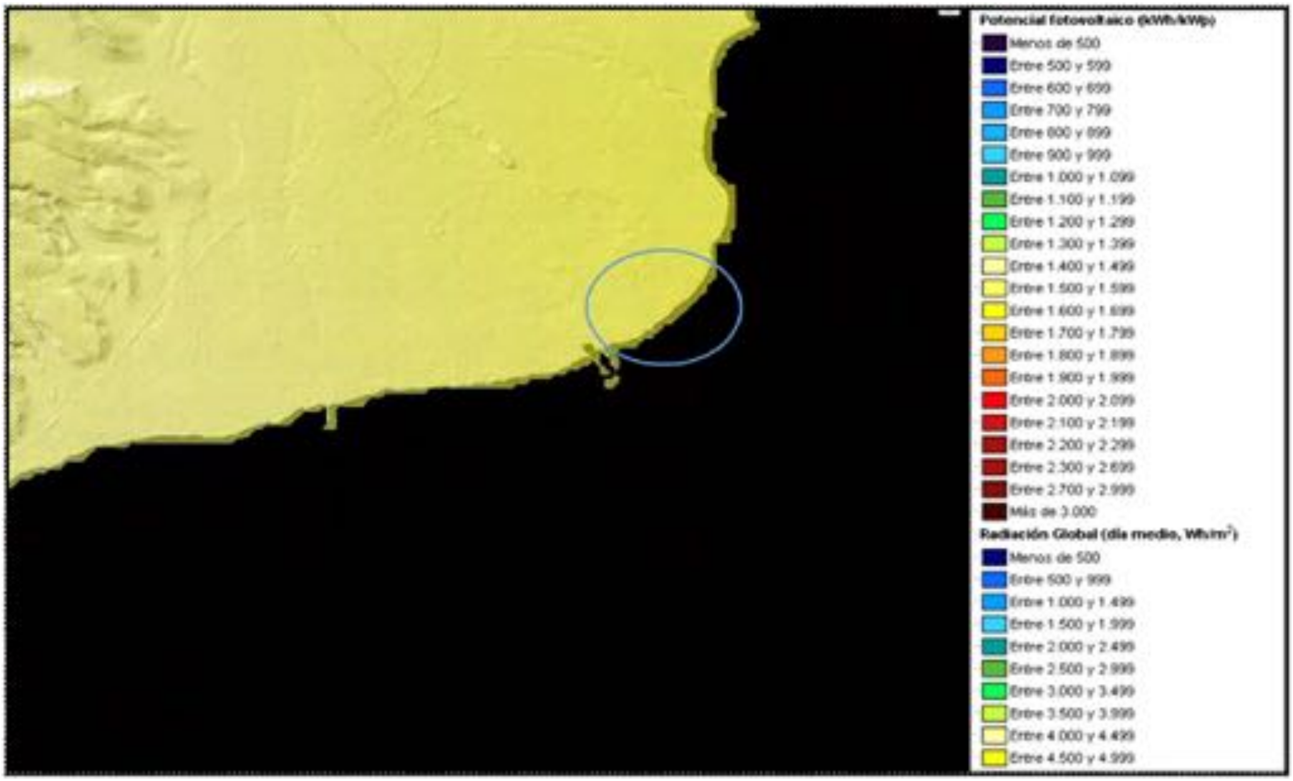

Fig. 7. Solar photovoltaic resource of the selected site (Canary Islands Government, 2019b).

20% when 200% of W&E were sold. On the other hand, the distillation plant did not reach the objective (Fig. 12).

Finally, scenario (III) (Figs. 10 and 13) compared both facilities with similar amounts of conceded grants. As can be observed the RO plant would provide benefits from 3.5 to 24% of Ieff, as W&E sales increased. This was the only scenario where the distillation plant reached the economic objective (Fig. 13), but only for 200% of increasing sales, and for specific conditions of low Ieff.

Among the cases that reached the economic objective, in scenario I (Figs. 8 and 11), the RO plant achieved it only for a very low Ieff, and only when W&E sales increased over 140% of capacity. Note that the RO plant simulation showed a near-zero battery deployment, and low electricity costs results, meaning that the plant operated at around 35% of its nominal capacity (see capacity factor of wind energy).

As can be seen in the scenario (II) (Figs. 9 and 12), only the RO plant achieved the objective from 3.5 up to 20%, as W&E sales increased. Only in the scenario (III) the distillation plant reached the economic objective (Fig. 13), but only for 200% of increasing sales, although it must be remarked that due to its working configuration this plant could not increase its capacity of selling water, so in essence it probably will not be achieved. As from these results, it did not advise the investment in the Distillation Plant due to its higher investment needs as well as its lower business capacity related to W&E sales. Although, for a scenario of low W&E demand, the difference among the profitability of these two facilities came near.

Table 1
Financing card (Aqua.abib, 2020b).

Funding source	Amount
European Commission	1400 k€
ENISA (Spanish public administration)	300 k€
Bank loan	200 k€
Private capital	1600 k€

Despite the better performance of the RO plant, both projects needed help to pay the loans to capitalize the project, if being attractive for private investment was expected. That the facility reached the objective for particular conditions might imply for policy makers that a specific water-energy deployment would let those facilities reach benefits allowing extra electricity sales. Analysing data of the RO plant performance it is highlighted that the smaller the size of the RO desalination plant the lower the competitiveness of its performance, and precisely it proportionally happened to the distillation plant that additionally would imply benefits to the environment. Precisely, in the region of study it can be found the Barranco de Tirajana thermal power station (Spanish Ministry of Environment, 2020) that consumed 233,713.47 tons of fuel oil, and 278,341.4 of non-automotive gas-oil in 2018 (last year of available data). For what GHG emission was concerned, it stressed: the methane, with total emissions of 16.82 Ton/year; CO: 224.341 tons/year, NO_x emissions of 2112.28 tons, and CO_2, with 1,620,654 tons/year, among others. The reduction of GHG emissions that this scheme achieved, accounted as 0.521 kg CO_2/kWh (see

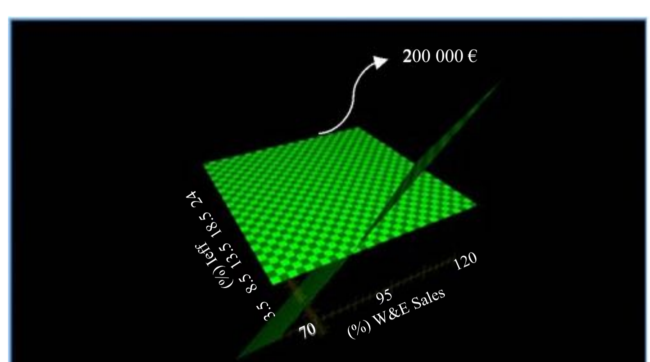

Fig. 8. Scenario I. RO plant (0% granted).

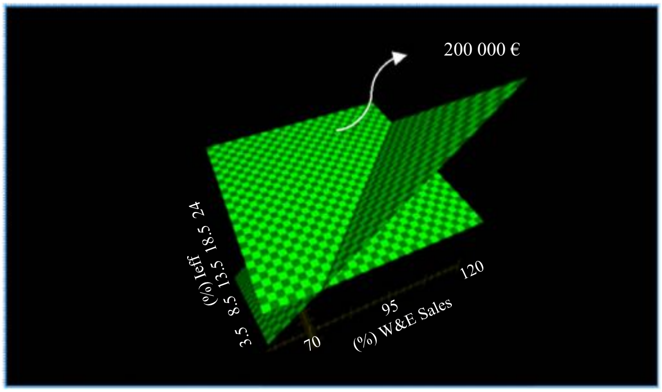

Fig. 9. Scenario II. RO plant (50% granted).

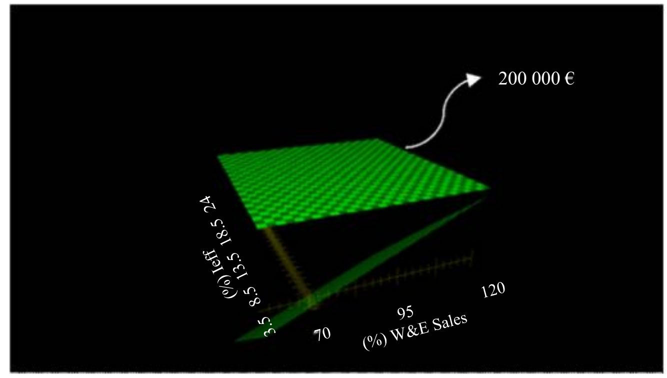

Fig. 11. Scenario I. aqua.abib project (0% granted).

Appendix B) was of 3651 tons/year for a 100% scenario of the RO plant, under the proposed objective, that only could be achieved when more electricity generation from this scheme were sold.

Although the activity generated incomes, most scenarios showed that these did not let recover their investment costs in a reasonable period of time for the aqua.abib project while providing profitability enough to avoid financing deficit, fact that force to grant public aid, or increase W&E sales in these facilities. In some of them, loans ought to be returned in less than 10 years. For a grant scenario that the RO plant perceived half grant (1.25 million €), results demonstrated that was able to achieve a discounted payback period of 10.26 years versus the aqua.abib project, that granted (1.4 million €) showed 33.74 at the same Ieff (7.5%) (Table 2).

Scenarios showed that the profitability could be achieved increasing the amount of demanded water, that was highly interconnected to activities such as cattle farming, agriculture, and others that eventually might demand increasing water, and therefore the economic activity itself. Market should be analysed in order to know if proposed scenarios were capable of absorbing such an amount of resource, specially in sectors like food industry, and energy management. These scenarios would provide resources to the market for society to grow and thrive, incomes that were not accounted in the economic balance.

Provided that the price of electricity generation from conventional sources in areas, like in islands, is higher, the gap between the costs of the deployment of these disruptive technologies and the traditional ones may be closed up with lesser economic impact. As Soshinskaya et al. (2014) indicated, costs of energy electricity (LCOE) vary within the year, and the region where the facility is located. Provided that this research assumed a year for the period calculation and the Canaria region for the calculus, in essence the market that is acting in might differ from others with different RES characteristics. In addition, other non-accounted costs are the hidden costs of these projects highlighting: water impacts, land impacts, and GHG emissions costs associated with the deployment of different energy strategies.

Similarly, NREL (2005) analysed the real competitiveness of hybrid powered RO desalination plants, predicting a COW around 1 €/m^3 for a 1.5 MW powered seawater desalination plant, in a grid-isolated topology, and a cost of 0.62 €/m^3 for a grid-connected topology with energy prices of 0.11 €/kWh. The developed analysis showed a lower COW up to 12% of Ieff, but only when half grant was conceded, a scheme that might lower the energy prices while providing benefits to investors. Eltawil et al. (2009) found a COW between 0.66 and 0.75 €/m^3 for RO desalination plants of similar capacity (2843 to 3720 m^3/day). Results demonstrated that even for high Ieff, the economic, and KPI COW reduction objective might also be achieved, although it must be noted (Hispagua, 2007) that water desalination depends on parameters such as salinity, or conductivity that could affect these costs as well. In comparison, the COW in the aqua.abib project was proven to be much higher, despite that it was calculated for 100% of plant capacity. Globally, in Gran Canaria only 11% of EEG comes from renewable sources yet (El Diario, 2019b), and that an optimal energy mix with a renewable energy penetration of 65% would be obtained without jeopardising grid reliability (Wind energy and electric vehicles Magazine (WEEV), 2013). Despite the different costs both schemes (it is expected to range between 750 kW and 5.0 MW) can be widely used to reach the 1.2 GW installed power from renewable energy sources needed to reach the optimal energy mix of this island while providing water at a lower cost.

This research highlighted the analysis of the economic objective in an investment decision, but variable weights could be given to each KPI (or others) of Table 2, depending on the demanded objectives. Notice that the profitability of the facility derived fundamentally from electricity sales, although it is important to note that due to the isolated nature, and the small size of the system (Uche-Soria and Rodriguez Monroy, 2018) might occur problems in the operation of the system, specially to maintain the necessary reliability indices (SAIFI, SAIDI,

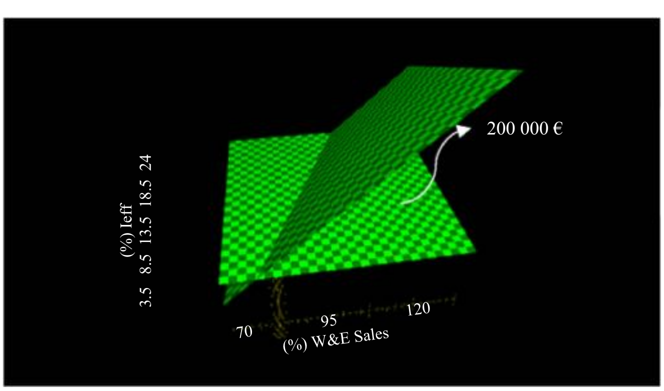

Fig. 10. Scenario III. RO plant (100% granted).

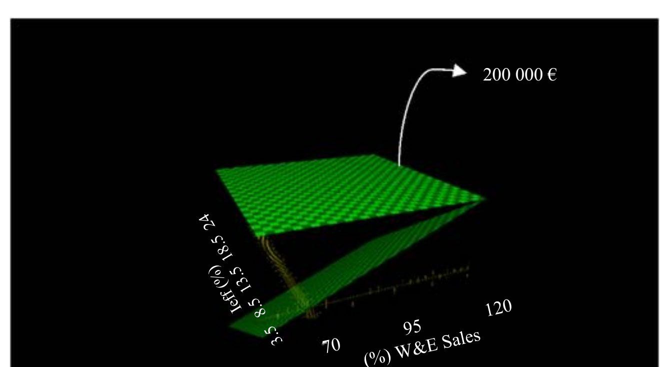

Fig. 12. Scenario II. aqua.abib project (50% granted).

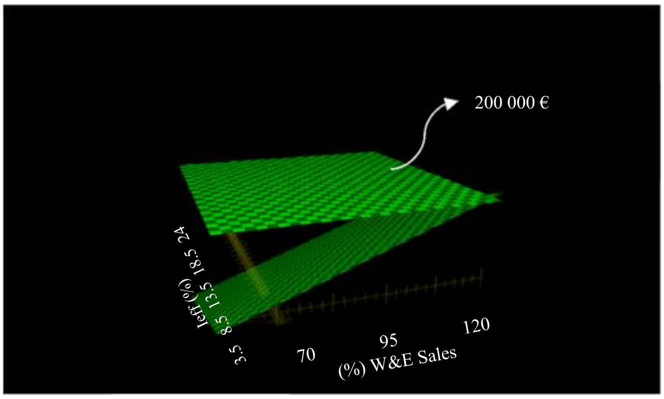

Fig. 13. Scenario III. aqua.abib project (100% granted).

CAIDI and ASAI), although, specially for these facilities there is also the possibility of storing the energy surpluses.

The energy electricity prices can be lowered from the current price to a considerably lower amount (note that the cost of EEG in the rest of Spain is 59 €/MWh) (Spanish Ministry of Environment, 2019). As long as more business opportunities related to these facilities are to come, specially linked to the electrification of the economy. For example, Dalton et al. (2019) presented Blue Growth, new related investment opportunities that would increase the profitability as further stages and activities that improve and commercialize the innovation appear. At this point, it would be expected that grants could be progressively retired. Provided that generating electricity in non-mainland regions – specifically in Spain– is a global "burden" for the economy that represents an extra cost in the Spanish case of € 900 million per year (Spanish Ministry of Environment, 2019), increasing the deployment of those systems will not lower the global competitiveness of the sector. Due to its outstanding wind resource and to the possibility of obtaining second-to-none capacity factors, (the highest wind capacity factor ever reported, a 52%, corresponded to a wind farm located in Gran Canaria) (Adwen, 2015; La Provincia, 2011) it is expected that those projects has as an outcome in the production of electricity from wind at a cost of roughly 7 coeur per kWh (International Energy Agency (IEA), 2012); and a LCOE for the whole scheme of 10 coeur per kWh—producing electricity in Gran Canaria has a cost of 190.7 €/MWh (Official Bulletin of the Canary Islands (BOC), 2008).The analysis of the competitiveness of facilities here developed offered a step forward in order to clarify the integration of combined-businesses models of renewable energy deployment. Results of the conducted research would allow decision makers (politics/investors) take a deeper view of the performance of facilities offering an extra decision point specially when interlinked with water systems.

Table 2
Key performance indicators.

Objective	Success metrics
Establishment of an optimal energy mix for a microgrid to make an abandoned farm profitable.	Software validation with assimilable experiences
Economic analysis	Design a micro grid scheme of about 2 MW resulting in an annual positive net cash flow of 200,000 €.
Social analysis	Job creation (direct or indirect)
Impact from the environmental point of view	Reduction of emission of 5000 tons of CO_2 to the atmosphere through the scheme
Reduction of water production costs in current desalination plants	To propose a configuration that reduces water production costs by 4 coeur/m^3 compared to previous assimilable experiences using the best available techniques (BATs)

Table 3a
Techno-economic results of RO desalination plant.
(Source: own elaboration)

Ieff (%)	3.5	5.5	7.5	12	24
No grant					
CRF (€)	175,123	209,398	245,423	334,736	608,429
LCOE (coeur/kWh)	5.7	6.5	7.4	9.6	16.3
Net utility	19,660	−28,057	−78,220	−202,598	−583,659
Discounted payback period (years)	15.82	20.12	31.74	Never	Never
NPV	−18,336	X	X	X	X
Half grant					
CRF (€)	87,623	104,765	122,798	167,486	304,430
LCOE (coeur/kWh)	3.6	4.0	4.4	5.5	8.8
Net utility	107,160	76,576	44,405	−35,348	−279,660
Discounted payback period (years)	9.11	10.26	11.88	22.57	Never
NPV	1,072,781	691,401	290,231	X	X
Full grant					
CRF (€)	68,712	82,154	96,292	131,357	238,725
COW (€)	0.44	0.48	0.52	0.62	0.91
Net utility	194,783	181,341	167,203	132,138	24,770
Discounted payback period (years)	3.66	3.84	4.05	4.59	7.78
NPV	2,165,433	1,997,813	1,821,513	1,384,138	45,385

4. Conclusions

In the years to come, as water scarcity increases, water supply will become a critical issue, so research such as the one presented here are of high importance to investigate how a sustainable way to provide water-energy might become economically attractive for investors not only in regions threatened with droughts, as the MENA region, but also others. This research provided a better understanding of the issue that the commercialization of these disruptive technologies involved, and demonstrated that despite that both schemes fulfilled the demanded characteristics of the grants, different economic scenarios appeared, although they were conditioned to the market conditions, and still to economic benefits from public institutions. In conclusion, apart from the cost-effective scenario that paves the way for an

Table 3b
Techno-economic results of distillation plant.
(Source: own elaboration)

Ieff (%)	3.5	5.5	7.5	12	24
No grant					
CRF (€)	41,615	62,640	86,400	144,720	321,408
LCOE (coeur/kWh)	5.7	6.5	7.4	9.6	16.3
Net utility	−27,479	−66,104	−105,715	−203,332	−560,097
Discounted payback period (years)	26.5	33.74	Never	Never	Never
NPV	X	X	X	X	X
Half grant					
CRF	20,807	31,320	43,200	72,360	165,204
LCOE (coeur/kWh)	3.6	4.0	4.4	5.5	8.8
Net utility	29,471	−3079	−34,079	−106,929	−299,129
Discounted payback period (years)	18.17	155	Never	Never	Never
NPV	X	X	X	X	X
Full grant					
CRF	41,615	62,640	86,400	144,720	321,408
COW	0.7	1.4	3.4	7.9	13.3
Net utility	49,271	28,271	7571	−38,729	−162,729
Discounted payback period (years)	15.3	19.34	29.26	Never	Never
NPV	211,905	19,021	X	X	X

economically-efficient investment, this research contributes by proposing the use of an optimal renewable energy mix to conduct the desalination needed to provide fresh water to orchards located in arid zones. Moreover, the possibility of selling surplus energy to the electric grid is suggested to allow the orchard's owner to achieve possible profitability. Additionally, this research demonstrated that the profitability of this scheme can be scheduled only letting more/less sales from this scheme, assessing a novel water operation strategy to take full advantage of the potential that can be reached from its use. As have been demonstrated, some scenarios achieved economic objectives, especially under conditions of more energy sales. Besides, the LCOE was found lower than the mean of EEG costs in Gran Canaria. Among the expected impacts of this scheme are some remarkable social-related effects. Firstly, important and improved availability, acceptance and use by local communities of innovative models of water management in difficult climate conditions and arid areas can be enabled. Secondly, reduced pressure on the environment, improved ecosystem services, water yields and sustainable food production are predictable. Thirdly, an enhanced innovation in water-energy nexus can be gotten, particularly supporting the sustainable use of water with less and affordable energy cost. This initiative can increase the water management capacity of local communities in rural, remote and arid areas. Additionally, the development of effective models of knowledge transfer in sustainable water management is reached. And, finally, an increase of socio-economic growth and stability of targeted areas could be attained. In overall terms, it was demonstrated that water costs can be reduced as well. Parallel, the benefits on the environment boost the green economy that will imply social benefits as well. The economic surveillance of these projects enables the penetration of renewable energies into the electricity network of Canary Islands to reach quotas that vary between 40% and 60%, depending on the amount of sold electricity, while a reduction of GHG emissions was achieved. Specifically, this research found a reduction of GHG emissions of 0.22% of the annual equivalent emissions of Tirajana Thermal Power Station where it was located. In the investment decision-making problem of disruptive technologies projects, grants resulted indispensable to develop those business-combined models.

CRediT authorship contribution statement

David Borge-Diez: Conceptualization, Methodology, Software, Writing - original draft, Data curation. **Francisco José García-Moya:** Conceptualization, Methodology, Software, Writing - original draft, Data curation. **Pedro Cabrera-Santana:** Conceptualization, Methodology, Software, Writing - original draft, Data curation. **Enrique Rosales-Asensio:** Conceptualization, Methodology, Software, Writing - original draft, Data curation.

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. Parameters of simulation. Source: own elaboration

Desalination plant

Membrane pack (Toray Membranes, Wilmington, NC, 2009)	Auxiliaries power (kW)	Water flow in (m^3/h)	Water flow out (m^3/h)	Cost/installed (€/kW)	Maintenance cost	Equipment life (American Membrane Technology Association, 2008)	After life investment (Stanford University, 2008)
6	41.16	219.58	139	600	27%	10	100%

Water storage deposit

Relative head	Storage capacity (m^3)	Water demand (m^3)	Water price (€/m^3)	Investment cost (€)	Maintenance cost	Equipment life (Jia et al., 2008)	After life investment
190	180,000	50	0.60	962,000	1%	50	100%

Plant pump group

Number of pumps	Nominal power (kW)	Nominal flow (m^3)	Cost/installed kW (€/kW) (Gülich, 2008)	Maintenance cost (Xylem Water Solutions, 2019)	Equipment life (Hunter Water Corporation, 2019)	After life investment
8	110	115	2000	26%	15	100%

Solar plant

Size of panel (SUNPOWER, 2019) (m^2)	Efficiency	Cost/installed kW (€) (Fu et al., 2017)	Maintenance cost	Equipment life	After life investment	Min. power for sizing (kW)	Max. power for sizing (kW)
2	17%	1050	8%	25	80%	1	7400

Wind farm (Stehly et al., 2017)

Cost/installed kW (€)	Maintenance cost	Equipment life	After life investment	Min. power for sizing (kW)	Max. power for sizing (kW)
1000	4%	25	80%	1	4200

Storage (Lazard, 2015; Hemmati, 2017; Anindito et al., 2019)

Charge efficiency	Discharge efficiency	Min./max. state of charge	Cost/installed kW (€/kW)	O&M (Weitzel et al., 2018)	Equipment life	After life investment	Min. power for sizing
98%	98%	20/95	900	10%	10	80%	1 kW

Appendix B. Analysis of the characteristics of proposed grants

Grant	SME phase 2 (European Commission, 2019)	IDAE TEC/1380/2018 (Institute for the Energy Diversification and Saving (IDAE), 2019)
1. Objectives	Clear, measurable, realistic and achievable within the duration of the project. Brief presentation of the overall structure of the work plan. Gantt chart + Pert chart + KPI	- Installed power higher than 800 kW - Budget allocation: 80 M € - Incompatible with other grants. - Ambit: aids proposed for investment in projects involving RES based technologies (PV-WD) for generating electricity in non-mainland territories. - The real installed power must be calculated according to definition from the Spanish regulation: article 3 of: Royal Decree 413/2014, June the sixth.
2. Relation to the work program	Explain the current stage of development of the business innovation project. Material scope:	- Material scope: - Geographic scope: - Available until December, the thirty-first.
3. Ambition	• Describe the identified customer pain point? What is the business need, technological challenge or market opportunity? • What is your innovation? • What is the market's state-of-the-art? How would your innovation compare with available solutions, practices or products (e.g. performance, costs, ease-of-use, gender dimension, climate change or environmental aspects, benefits to society)?	- Duties: - Enterprises who fulfil related requirements plus the 24/2013 law - Extra accounting system, to record all transactions related to each operation to be co-funded.
1. Expected impacts:	Discussion. Entering the market • Who are the targeted users and/or customers and why will they want to buy the product/service (unique selling point)? Are they new or already part of your customer base? • What is the market in terms of type (e.g. niche, high volume, new/mature, growth rate), size (e.g. volume, value, geographical scope) and growth? • Who are the main direct and indirect competitors to the proposed invention? (Competitors, substitutes and alternatives). • Which are the barriers to entry? How do you intend to overcome them?	Expected results, expected in POPE: - C030: Extra capacity of electricity generation from RES (MW). - Reduction of GHG emissions in tons of equivalent CO_2/year. - The conversion factor to CO2 emissions from non-renewable energy to be used must be: 0.521 kg CO_2/kWh of final energy. The final energy will be evaluated by lowering the generated energy in the node by 4%.
2. Business model	• Outline your business model, including the revenue model and your commercialization plan with an approximate time-to-market or deployment. • Why is your model scalable? How do you intend to scale-up and reach European and/or global markets? Financing • Indicate the estimated funding requirements and the timeline to reach the commercialization stage of your innovation. How do you intend to finance the 30% of cofinancing rate? Outline your plans to ensure the subsequent financing of your innovation (next rounds, top-up financing, etc.).	
Implementation		
Work plan	Brief presentation of the overall structure of the work plan. Gantt chart + Pert chart + Milestones	- Show to IDAE the economic information as well as the financial path of the project.
Management structure and procedures	Describe the organizational structure and the decision-making. Explain why the organizational structure and decision-making mechanism are appropriate to the complexity and scale of the project. Describe, where relevant, how effective innovation management will be addressed in the management structure	- Financeable budget must be presented.
Resources to be committed	Information in this section matches the costs as stated in the budget. • What is unique in your approach, compared to those of other companies? • Why now? Explain the historical evolution of your category and define recent trends that make your solution possible. • What is the current development stage of your innovation? Refer to Technology Readiness Levels (TRL) or something analogous for non-technological innovations • Which milestones led to the current development stage (e.g. proof of concept completed, early field trials under way)? Describe the results obtained on the technological, practical and economic feasibility of the innovation. • • What are the further stages and activities needed to commercialize your innovation?	Within the hiring processes related to bankable expenses: - Provide at least 3 different offers of different suppliers previously to the hiring commitment for the facility execution, as well as maintain its documentation, including the justification of the selected offer. - All contracted services must be demonstrable. - Demonstrate the accomplishment of the activity, and undergo to verification and control - Match the costs as stated in the budget, letting the organism control the development. - Fulfil the requirements of publicity and diffusion according to Law 38/2003 (arts. 18.4) - Preserve documents that justify the project, including management and control procedures that guarantee a good use of the proposed grants, as well as provide the documents ex-post.

Appendix C. Simulation results. Source: own elaboration

Parameter	Simulation results (kW)	Investment (€)	O & M (€)		Sales (€)
Solar farm	1	1050	84		
Desalination plant		981,600	73,487	Water	21,408
Wind farm	2499.96	2,499,967.68	32,000		
Battery	0.83	750.22	75		
Electricity costs			3891	Electricity	385,724
Taxes on electricity (7%)					−20,831
Total		3,483,367.8	109,537		386,301

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ANEXO P6: COPIA DE LA PUBLICACIÓN DE LA PATENTE "SISTEMA PARA EL CONTROL DE AGUA Y ENERGÍA EN PLANTAS DESALADORAS"

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(54) Título: **CENTRAL DE BOMBEO MIXTA Y MÉTODO DE GENERACIÓN Y ALMACENAMIENTO DE ENERGÍA**

(57) Resumen:
Central de bombeo mixta y método de generación y almacenamiento de energía.
Central de bombeo mixta que comprende una red de captación, tratamiento y abastecimiento de agua que comprende, al menos un depósito principal o de cabecera (5, 6) y al menos dos depósitos secundarios (7-12). El al menos un depósito principal (5, 6) y los al menos dos depósitos secundarios (7-12) están conectados entre sí mediante conducciones (24) y medios de válvula (23). El sistema comprende unos medios de conversión (26) de la energía potencial del agua en energía eléctrica, unos medios de bombeo y unos medios de control (33), en conexión con al menos unos medios de actuación (27), adaptados para el accionamiento de los medios de válvula (23), de los medios de conversión (26) y de los medios de bombeo (25).

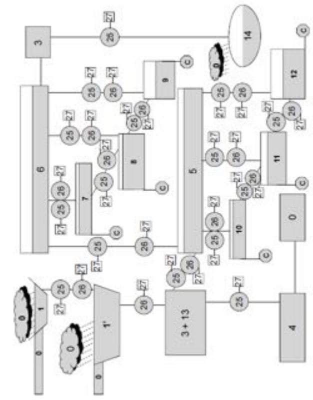

Fig. 1.

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DESCRIPCIÓN

Central de bombeo mixta y método de generación y almacenamiento de energía.

OBJETO DE LA INVENCIÓN

La presente invención está dirigida a una central de bombeo mixta y a un método para la generación y almacenamiento de energía eléctrica a partir de dicha central.

ANTECEDENTES DE LA INVENCIÓN

En la actualidad, existen muchos sistemas distintos para generar energía. En concreto, dentro del campo de la invención, i.e, la energía hidroeléctrica, existen centrales hidroeléctricas, que transforman la energía potencial de un fluido en energía eléctrica, y centrales de bombeo, que transforman la energía potencial de un fluido en energía eléctrica y viceversa, y la almacenan. Existen también centrales de bombeo mixtas, en las que además del flujo de agua entre el depósito y el contradepósito existe un flujo neto de agua entrante en el depósito superior y saliente del depósito inferior que corresponde a la aportación de un recurso hídrico externo, como por ejemplo un río.

El funcionamiento básico de estos sistemas se basa en la elección de un depósito y un contradepósito. Desde el primero se deja caer el fluido por gravedad hacia el segundo, aprovechándose la energía potencial de dicho fluido para producir energía eléctrica. Desde el segundo se puede bombear el fluido hacia el primero en un periodo en el que el coste de la energía eléctrica empleada para bombear sea más bajo, de modo que compense el beneficio por la energía generada en un periodo frente al gasto que supone bombear de nuevo el fluido en el otro periodo.

El documento WO07131305A describe una central hidroeléctrica con rellenado indirecto por hidro-acumulación, incluyendo una serie de bombas movidas por un molino de agua o similar, utilizando la energía cinética de la corriente de agua, manga de agua o conducciones a través de los cuales se bombea el agua hacia el depósito de hidro-acumulación.

El documento BR0305012 A hace referencia a un sistema de retorno de agua a un pantano, de modo que el agua que se pierde por los aliviaderos se hace retornar al pantano para que se aproveche para cumplir su función generadora de energía. Esto lo lleva a cabo con un bajo coste, ya que utiliza dispositivos existentes en el mercado (bombas comerciales, conducciones, norias, etc.).

No obstante, estos sistemas necesitan la construcción de una infraestructura *ad hoc*, siendo por tanto el coste de la infraestructura proporcional al número de elementos que se quieran construir. Además, debido precisamente a este coste, la capacidad de elección entre itinerarios para realizar los trasiegos se ve muy reducida. Tampoco se conoce ningún sistema que tenga en cuenta las pérdidas originadas por las fugas en las conducciones.

DESCRIPCIÓN DE LA INVENCIÓN

La presente invención propone una solución al problema anterior mediante un sistema según la reivindicación 1 y un método según la reivindicación 12. En las reivindicaciones dependientes se definen realizaciones preferidas de la invención.

En un primer aspecto inventivo se presenta una *central de bombeo mixta que comprende una red de abastecimiento de agua que comprende,*

- *al menos un depósito principal o de cabecera a una altura HP,*
- *al menos dos depósitos secundarios a una altura H1 y H2 respectivamente,*

en donde

- *el al menos un depósito principal y los al menos dos depósitos secundarios están conectados entre sí mediante conducciones y medios de válvula, y*

caracterizado porque comprende

- *al menos unos medios de conversión de la energía potencial del agua en su trasiego entre dos depósitos por gravedad, en energía eléctrica,*
- *al menos unos medios de bombeo de agua desde al menos un depósito hasta al menos otro depósito con una altura mayor, y*
- *unos medios de control en conexión con al menos unos medios de actuación, adaptados para*
    - *el accionamiento de los medios de válvula para permitir el trasiego por gravedad de un flujo de agua desde al menos un depósito hasta al menos otro depósito con una altura menor, y*

activación de los al menos unos medios de conversión para la producción de energía eléctrica a partir de dicho flujo de agua asociado durante un periodo de tiempo T1, y

- *el accionamiento de los medios de válvula y de los al menos unos medios de bombeo para permitir el trasiego de un flujo de agua por bombeo desde al menos uno de los depósitos hasta otro depósito a un altura mayor durante un periodo de tiempo T2.*

En el contexto de la presente invención, se entiende por depósito cualquier entidad capaz de almacenar agua, ya sea un depósito al uso, i.e, depósito de cabecera, depósito de cola, aljibe, etc., ya sea cualquier otra entidad de almacenamiento, como un pantano, un río, un acuífero, un lago o mar, etc.

En el contexto de la presente invención, se entiende por conducción cualquier medio de conexión que ponga en contacto fluido dos depósitos. Puede entenderse por tanto cualquier tubería, cañería o conducto enterrado o al aire libre, un surco, un canal, una cascada, etc.

En el contexto de la presente invención, se entiende que los medios de control están en conexión con los medios de actuación en el sentido de que los medios de control gobiernan los medios de actuación, enviando órdenes de activación o desactivación de los medios (medios de válvula, medios de conversión, medios de bombeo, etc.) sobre los que actúan dichos medios de actuación. Los medios de control utilizan, entre otros aspectos, para dicho gobierno la información que reciben por parte de los diversos sistemas de detección de la central.

En el contexto de la presente invención, la activación de los medios de válvula puede servir para diversas funciones, como por ejemplo para abrir o cerrar un conducto y reducir las fugas o como paso inmediatamente anterior a la activación de un medio de conversión o un medio de bombeo, o para hacer un bypass de un medio de conversión o de bombeo.

Ventajosamente con una central según la invención, se puede aprovechar una infraestructura que ya ha sido creada para el abastecimiento de agua y utilizarla para almacenar y obtener energía, de modo que ambos sistemas se benefician mutuamente: aprovechar la red de abastecimiento de agua permite al sistema de generación y almacenamiento de energía contar con una gran cantidad de depósitos y conexiones para realizar los trasiegos, y por otro lado, el hecho de poder generar energía permite abastecer de agua y energía de manera más eficiente a las localidades cuya generación y demanda de agua y energía sufre fuertes variaciones temporales tanto horarias como estacionales, y a cuya demanda no puede hacer frente el sistema actual de abastecimiento de energía. Además, una distribución planeada del agua permite que el agua de la que se dispone se distribuya entre núcleos de población de manera más eficiente que con los sistemas encontrados en el estado de la técnica.

En una realización particular de la invención, la altura HP es mayor que H1 y mayor que H2.

En una realización particular de la invención, la central comprende un sistema de detección de fugas para la detección de un nivel de fuga que comprende al menos dos sensores de caudal de medida directa o indirecta en al menos una conducción. Se entiende por medida directa la de aquellos sensores que miden directamente el caudal que atraviesa la sección donde están instalados. Se entiende por medida indirecta la de aquellos sensores que miden una magnitud que no es el caudal, pero gracias a la cual se puede calcular el caudal que atraviesa dicha sección.

En una realización particular de la invención, el sistema de detección comprende un conjunto distribuido de sensores de presión en al menos una conducción.

En una realización particular de la invención, los medios de control están en conexión con unos medios de actuación, estando adaptados dichos medios de control para el cierre de los medios de válvula y para la desactivación de los medios de conversión y los medios de bombeo en una conducción cuando el nivel de fuga en dicha conducción supera un umbral de fuga. Esto permite optimizar el funcionamiento de la central, teniendo en cuenta qué conexiones tienen un nivel de fuga demasiado elevado como para dejar de resultar ventajoso el hecho de utilizar esa conexión para realizar el trasiego.

En una realización particular de la invención, la central comprende al menos un sensor de detección de contenido de cloro para la detección de un nivel de contenido de cloro, y al menos un medio dosificador de cloro. En una realización particular de la invención, cada depósito comprende un sensor de detección de contenido de cloro. En una realización particular de la invención, cada depósito comprende un medio dosificador de cloro. En una realización particular de la invención, los medios de actuación están adaptados para activar el al menos un medio dosificador de cloro cuando el nivel de contenido de cloro está por debajo de un umbral de cloro. Esto permite que el agua recupere, en caso de ser necesario, sus propiedades de potabilidad si las pierde durante el trasiego, y pueda seguir siendo apta para el consumo de la población de las localidades abastecidas.
En una realización particular de la invención, al menos un depósito comprende un sensor de nivel.

En una realización particular de la invención, los medios de control están adaptados para llevar a cabo las siguientes acciones:

- recibir información relativa a valores históricos correspondientes a la época del año y el carácter laboral o festivo de la jornada y a los valores estimados de la demanda de agua de cada depósito durante un número de horas siguientes al comienzo del trasiego, y
- seleccionar, haciendo uso de dicha información recibida,
  - antes del periodo T1 al menos una conducción en la que se va a realizar trasiego de agua por gravedad, accionando los correspondientes medios de válvula y activando los medios de conversión, y
  - antes del periodo T2 al menos una conducción en la que se va a realizar el trasiego de agua por bombeo, accionando los correspondientes medios de válvula y activando los medios de bombeo.

Esto permite integrar la información sobre las necesidades de abastecimiento de agua de las distintas poblaciones abastecidas por los depósitos, de modo que además de aprovechar el agua para generar energía, se permite un mejor abastecimiento de las poblaciones.

En un segundo aspecto inventivo se presenta un *método de obtención y almacenamiento de energía eléctrica con una central de bombeo mixta según el primer aspecto inventivo, caracterizado por que comprende los siguientes pasos:*

- *durante un periodo de tiempo T1,*
  - *accionamiento de los medios de válvula para el trasiego por gravedad de un flujo de agua entre al menos un depósito y al menos otro depósito a una altura menor, y*
  - *accionamiento de los al menos unos medios de conversión para la producción de energía eléctrica a partir de dicho flujo de agua asociado,*
- *durante un periodo de tiempo T2,*
  - *accionamiento de los medios de válvula y*
  - *accionamiento de los al menos unos medios de bombeo para el trasiego de un flujo de agua desde al menos uno de los depósitos a otro depósito a un altura mayor.*

En una realización particular de la invención, el método comprende adicionalmente las etapas de:

- comprobar el nivel de fuga de una conducción, preferentemente por el sistema de detección de fugas, y
- si el nivel de fuga supera el umbral de fuga, desactivar los medios de conversión y los medios de bombeo en dicha conducción.

En una realización particular de la invención, la comprobación del nivel de fuga se realiza al menos una vez en al menos uno de los periodos de tiempo T1 o T2.

En una realización particular de la invención, el método se lleva a cabo tomando como referencia temporal un día, dividido en intervalos temporales, y un índice “n” que recorra dichos intervalos temporales dentro de dicha referencia temporal.

En una realización particular de la invención, los medios de control reciben información relativa a valores históricos correspondientes a la época del año y el carácter laboral o festivo del día de referencia y a los valores estimados de la demanda de agua de cada depósito durante dicho día de referencia.

En una realización particular de la invención, los medios de control realizan las siguientes acciones:

- antes de comenzar el día de referencia, seleccionar al menos una conducción en la que se va a realizar trasiego de agua por gravedad, accionando los correspondientes medios de válvula y activando los medios de conversión, y
- antes de comenzar el día de referencia, seleccionar al menos una conducción en la que se va a realizar el trasiego de agua por bombeo, accionando los correspondientes medios de válvula y activación de los medios de bombeo, en función de los valores estimados de la demanda de agua de cada depósito durante dicho día de referencia.

En una realización particular de la invención, los medios de control seleccionan para cada intervalo temporal n del día de referencia las conducciones entre las que se va a realizar el trasiego mediante la optimización de una función de coste C

$$C = \sum_{n,i,j} C_{n,i,j}, \qquad siendo\ C_{n,i,j} = \left(Q_{n,i,j} - F_{n,i,j}\right) \cdot g \cdot \left(h_{n,i} - h_{n,j}\right) \cdot \eta_{n,i,j} \cdot k_{n,i,j} \cdot T_{n,i,j} + F_{n,i,j} \cdot P \cdot T_{n,i,j}$$

Cubriendo i y j todos los pares de depósitos de la central, incluyendo los intercambios de agua con el ambiente y las aportaciones al consumo externo, y cubriendo n cada una de los intervalos temporales del día, y siendo cada uno de los términos:

$C_{n,i,j}$: coste del trasiego entre el depósito i y el depósito j
$Q_{n,i,j}$: gasto másico (en kg/s) que atraviesa la conducción en el trasiego entre el depósito i y el depósito j, constante durante el tiempo $T_{n,i,j}$.
$F_{n,i,j}$: gasto másico (en kg/s) que se pierde por fugas en el trasiego entre el depósito i y el depósito j, constante durante el tiempo $T_{n,i,j}$, y estimado por medio de datos históricos.
g: aceleración de la gravedad
$h_{n,i}$: altura media del nivel en el depósito i durante el intervalo temporal n
$h_{n,j}$: altura media del nivel en el depósito j durante el intervalo temporal n
$\eta_{n,i,j}$: rendimiento de la máquina, turbina o turbina-bomba en el caso de un trasiego por gravedad o bomba en el caso de un trasiego por bombeo, constante durante el intervalo temporal n.
$k_{n,i,j}$: coste de la electricidad, para vender en el caso de trasiego por gravedad (en cuyo caso tendrá un valor positivo) o para comprar en el caso de trasiego por bombeo (en cuyo caso tendrá un valor negativo). Se estima al comienzo de cada jornada en base a datos históricos y otras informaciones. Se considera que permanece constante durante el intervalo temporal n.
$T_{n,i,j}$: tiempo durante el cual tiene lugar el trasiego dentro del intervalo temporal n, será $T1_{n,i,j}$ en el caso del trasiego por gravedad o $T2_{n,i,j}$ en el caso del trasiego por bombeo.
P: precio del agua, constante.

en donde para la optimización de la función interviene la limitación de mantener el nivel mínimo de los depósitos, por motivos del uso del depósito; estando dado en los depósitos de consumo por las necesidades de abastecimiento, y en los depósitos naturales, por necesidades ecológicas.

Tanto la central de bombeo mixta como el método de generación y almacenamiento de energía, ambos objeto de la presente invención, aportan una solución que ofrece la ventaja de permitir la absorción de los picos de electricidad generados por fuentes de generación de energía discontinuas cuyos picos de generación no coinciden con los picos de demanda de energía, por ejemplo, la energía eólica. En cualquier momento la central puede almacenar energía en forma de energía potencial del agua en los depósitos más altos.

Los n intervalos temporales se establecen de modo que durante cada uno de ellos el precio de compra y el de venta de la energía permanezcan constantes como sucede por ejemplo durante los periodos de tarifa constante como pueden ser las consideradas horas valle y horas punta o como sucede por ejemplo cuando la oferta y la demanda energética de algunos sistemas se ajustan fijando un precio mediante subasta para periodos de tiempo prefijados como puede ser por ejemplo cada hora del día.

A lo largo de todo el documento, se debe entender como consumo externo cualquier consumo que se realice a partir de los depósitos, como por ejemplo, consumo humano, industrial, agrícola, ganadero, etc.

Todas las características y/o las etapas de métodos descritas en esta memoria (incluyendo las reivindicaciones, descripción y dibujos) pueden combinarse en cualquier combinación, exceptuando las combinaciones de tales características mutuamente excluyentes.

DESCRIPCIÓN DE LOS DIBUJOS

Estas y otras características y ventajas de la invención, se pondrán más claramente de manifiesto a partir de la descripción detallada que sigue de una forma preferida de realización, dada únicamente a título de ejemplo ilustrativo y no limitativo, con referencia a las figuras que se acompañan.

Figura 1 Esquema de un sistema según la invención, donde se observan todos sus componentes y las relaciones entre ellos.
Figura 2 Esquema de un método según la invención, realizado entre dos entidades genéricas.

EXPOSICIÓN DETALLADA DE LA INVENCIÓN

En la exposición que se va a realizar se han utilizado las siguientes referencias:

0: Río, mar, lluvia, ambiente, etc.
1, 1': Azud, pantano, etc.
3: ETAP, *Estación de Tratamiento de Agua Potable*
4: Desaladora con su depósito
5: Depósito de cabecera de baja cota
6: Depósito de cabecera de alta cota
7-12: Depósito de cola
13: Depósito de salida de la ETAP
14: Acuífero
C: Consumo externo

21: Entidad genérica 1
22: Entidad genérica 2
23: Medios de válvula
24: Conducción
25: Medios de bombeo
26: Medios de conversión
27: Medios de actuación
28: Sensor de caudal
29: Sensor de presión
30: Sensor de contenido en cloro
31: Medios dosificadores de cloro
32: Sistema de detección de fugas
33: Medios de control (no representados en las figuras)
34: Sensor de nivel

Del mismo modo, en las explicaciones también se hará referencia a las siguientes nomenclaturas:

n es el índice temporal, indica el intervalo temporal en el que tiene lugar cada una de las acciones. Se considera que las magnitudes permanecen constantes durante el periodo de tiempo indicado por el índice n. La suma en n de todos los intervalos da como resultado un día, que es la unidad que se toma como referencia, ya que las decisiones sobre cómo realizar los trasiegos se toman para cada día.

$h_{b,i}$ indica la altura a la que se encuentra la base de un depósito natural o artificial i: $h_{b,1}$ es la altura de la base del azud (1), $h_{b,5}$ es la altura de la base del depósito de cabecera de baja cota (5), etc. A su vez, $n_{n,i}$ indica el nivel de llenado en el intervalo temporal n de un depósito i, con respecto a su altura $h_{b,i}$: $n_{n,1}$ será el nivel de llenado del azud (1) con respecto a la altura de su base $h_{b,1}$, y así sucesivamente. También se define la altura en el intervalo temporal n del nivel de un depósito $h_{n,i} = h_{b,i} + n_{n,i}$

$Q_{n,i,j}$ indica el caudal que circula en el intervalo temporal n entre el depósito i y el depósito j. Así, $Q_{n,5,6}$ será el caudal que circula entre el depósito de cabecera de baja cota (5) y el depósito de cabecera de alta cota (6). $Q_{n,5,0}$ indica las pérdidas al ambiente (0) desde el depósito de cabecera de baja cota (5), y $Q_{n,5,C}$ indica el flujo de agua que se trasiega desde el depósito de cabecera de baja cota (5) al consumo externo.

$F_{n,i,j}$ indica las fugas en la conducción (24) que une las entidades i y j, con un criterio de nomenclatura análogo al del caudal: $F_{n,5,6}$ serán las fugas que presenta en el intervalo temporal n la conducción (24) que une el depósito de cabecera de baja cota (5) y el depósito de cabecera de alta cota (6).

Descripción de las figuras

En la figura 1 se puede observar una realización preferida de un sistema según la invención. En esta figura se observa la existencia de los siguientes elementos:

- Elementos de aporte natural de agua o de recogida natural de las pérdidas (0): un río, el mar, la lluvia, el ambiente, etc.
- Depósitos naturales (1), (1'): un azud, un pantano, etc.
- Dos depósitos principales, llamados también depósitos de cabecera: el depósito de cabecera de baja cota (5) y el depósito de cabecera de alta cota (6).
- Varios depósitos secundarios (7-12).
- Medios de conversión (26) situados en cada conducción (24).
- Medios de bombeo (25) situados en cada conducción (24).
- Medios de actuación (27) situados en los medios de conversión (26) y en los medios de bombeo (25).

En un ejemplo particular de realización, los medios de conversión son una turbina o una bomba utilizada como turbina o una turbina-bomba. Cuando lo que se utiliza es una bomba utilizada como turbina o una turbina-bomba, la reversión de su funcionamiento permite utilizarlos como medios de bombeo.

En la Figura 2 se observa un detalle del sistema con los elementos existentes entre una primera entidad genérica i (21) y una segunda entidad genérica j (22). Debe entenderse como entidades genéricas cualesquiera elementos naturales de aporte o recogida de pérdidas (0), depósitos naturales (1, 1’), depósitos de cabecera (5, 6), depósitos secundarios (7-12), el consumo externo (C).Entre estas dos entidades se muestran una serie de elementos:

- una válvula (23) en cada entidad;
- dos sensores de caudal (28) en cada conducción (24);
- dos sensores de presión (29) en cada conducción (24); y
- algunos de los elementos incluidos en la Figura 1, i.e., los medios de bombeo (25), medios de conversión (26) y medios de actuación (27).

El sistema de detección de fugas (32) utiliza la información recibida por los sensores de caudal (28) y los sensores de presión (29). Los sensores de caudal (28) son imprescindibles para la detección de las fugas, mientras que los sensores de presión (29) ofrecen un mayor detalle sobre la situación de la fuga, cuando ésta existe. Los valores de las fugas en los depósitos se miden comparando los caudales de salida y entrada del depósito con el volumen de agua almacenada que se conoce por medio de un sensor de nivel (34) que sirve además para el control de los niveles mínimos exigidos en cada depósito.

Estos niveles mínimos exigidos en cada depósito pueden venir impuestos por varias causas:

- El suministro de agua al consumo externo: este requisito impone que el nivel mínimo de un depósito sea el necesario para hacer frente a la demanda.
- El nivel mínimo por motivos ecológicos: este requisito impone que el nivel mínimo de un pantano, acuífero o cualquier otro depósito de estas características sea el imprescindible para que se cumplan las condiciones ecológicas establecidas por las autoridades competentes.

El nivel máximo admisible de fugas se establecerá de modo que si se supera dicho nivel, el trasiego no sea rentable. No obstante, esto no quiere decir que sólo se realicen trasiegos rentables en el sistema, ya que la exigencia del consumo externo puede obligar a realizar un trasiego por una conducción cuyo nivel de fuga sea superior al máximo admisible. Si dicho trasiego se realiza por gravedad, también se activan los medios de conversión para extraer energía.

Así las cosas, se lleva a cabo un ejemplo particular de un método según la invención, en el que intervienen los siguientes elementos y variables:

- Una primera entidad genérica i (21) y una segunda entidad genérica j (22), entre las que se va a realizar el trasiego, cada una de ellas con sus alturas de nivel ($h_{n,i}$, $h_{n,j}$), sus medios de válvula (23), sus sensores de detección de contenido de cloro (30), sus medios dosificadores de cloro (31).
- Las fugas de agua ($F_{n,i,j}$) que presenta el trasiego.
- Un tiempo $T1_{n,i,j}$ durante el cual se realiza un trasiego por gravedad de un caudal ($Q_{n,i,j}$) desde la primera entidad genérica i (21) a la segunda entidad genérica j (22), que se puede aprovechar o no para extraer energía por medio de unos medios de conversión (26), en particular una turbina.
- Un tiempo $T2_{n,i,j}$ durante el cual se realiza un bombeado de un caudal ($Q_{n,i,j}$) desde la primera entidad genérica i (21) a la segunda entidad genérica j (22), por medio de unos medios de bombeo (25).

En realizaciones particulares, $T1_{n,i,j}$ o $T2_{n,i,j}$ son cero, puesto que no existe la necesidad de realizar durante todos los intervalos temporales las dos operaciones de trasvasar un caudal por gravedad y volver a bombearlo.

Antes de iniciar el funcionamiento, los medios de control (33) reciben información relativa a valores históricos correspondientes a la época del año y el carácter laboral o festivo de la jornada y a los valores estimados de la demanda de agua de dichos depósitos durante el día de referencia. Estos datos proporcionan los niveles mínimos de ambas entidades mencionados anteriormente, que tendrán que respetarse durante ese día, ya que de otro modo se pondría en peligro el suministro de agua a las poblaciones.

Además de estos niveles mínimos necesarios en cada depósito, existe una segunda condición que proporciona al sistema los valores de $T1_{n,i,j}$ y $T2_{n,i,j}$. Esta es la maximización de una función de coste C:

$$C = \sum_{n,i,j} C_{n,i,j}, \qquad siendo\ C_{n,i,j} = (Q_{n,i,j} - F_{n,i,j}) \cdot g \cdot (h_{n,i} - h_{n,j}) \cdot \eta_{n,i,j} \cdot k_{n,i,j} \cdot T_{n,i,j} + F_{n,i,j} \cdot P \cdot T_{n,i,j}$$

Cubriendo i y j todos los pares de depósitos de la central, y cubriendo n cada una de los intervalos temporales del día, y siendo cada uno de los términos:

$C_{n,i,j}$: coste del trasiego entre el depósito i y el depósito j
$Q_{n,i,j}$: gasto másico (en kg/s) que atraviesa la conducción en el trasiego entre el depósito i y el depósito j
$F_{n,i,j}$: gasto másico (en kg/s) que se pierde por fugas en el trasiego entre el depósito i y el depósito j
g: aceleración de la gravedad
$h_{n,i}$: altura media del nivel en el depósito i durante el intervalo temporal n
$h_{n,j}$: altura media del nivel en el depósito j durante el intervalo temporal n
$\eta_{n,i,j}$: rendimiento de la máquina, turbina o turbina-bomba en el caso de un trasiego por gravedad o bomba en el caso de un trasiego por bombeo
$k_{n,i,j}$: coste de la electricidad, para vender en el caso de trasiego por gravedad (en cuyo caso tendrá un valor positivo) o para comprar en el caso de trasiego por bombeo (en cuyo caso tendrá un valor negativo). Se estima al comienzo de cada jornada en base a datos históricos y otras informaciones. Se considera que permanece constante durante el intervalo temporal n.
$T_{n,i,j}$: tiempo durante el cual tiene lugar el trasiego dentro del intervalo temporal n, será $T1_{n,i,j}$ en el caso del trasiego por gravedad o $T2_{n,i,j}$ en el caso del trasiego por bombeo.
P: precio del agua

Para optimizar esta función se tendrán en cuenta todos los posibles trasiegos entre depósitos (i,j), incluyendo

- los intercambios con el ambiente: el ambiente aporta a la central el agua de la lluvia, el agua de un río o del mar; por su parte la central cede al ambiente el agua que se evapora de cualquiera de sus depósitos, y
- las aportaciones al consumo externo.

A la hora de evaluar esta función, es necesario tener en cuenta las limitaciones antes señaladas:

- Los depósitos han de mantener en cada intervalo temporal un nivel mínimo determinado antes de comenzar el día de referencia, por motivos que dependen del depósito; en los depósitos de consumo externo serán exigencias de consumo; en los depósitos naturales, serán exigencias ecológicas.
- Se ha de satisfacer la demanda real de consumo de agua
- Se han de restringir las pérdidas de agua por fugas. El valor a usar para las fugas ($F_{n,i,j}$) será estimado por medio de valores históricos, no con los datos del sistema de detección de fugas (32), ya que la optimización de la función y la consecuente elección de los depósitos entre los cuales se va a producir el trasiego sucede antes de que se produzcan las fugas. Estos valores de fugas detectados por el sistema de detección de fugas (32) sólo se utilizan como alertas para advertir por ejemplo del hecho de un posible valor excesivamente bajo en el nivel de un depósito, y poder garantizar el suministro mínimo de agua exigido en todos los depósitos de la central.

No obstante, en el caso de que por necesidades de abastecimiento sea necesario utilizar una conducción que no sea rentable por cuestiones de fugas, primará el criterio de garantizar el abastecimiento.

En un ejemplo particular de realización, en los periodos en el que una variación de $Q_{n,i,j}$ no tiene influencia en el coste (debido a que el precio $k_{n,i,j}$ permanezca constante aunque se alargue el tiempo del trasiego), se fija $Q_{n,i,j}$ como el valor que maximiza el rendimiento de los medios de bombeo o de conversión colocados en la conducción que une los depósitos i y j.

Una vez recibidos y analizados esos datos y los datos de los niveles actuales de los depósitos para cada intervalo temporal n y para cada par de depósitos i,j, el periodo $T1_{n,i,j}$ comienza con el accionamiento, por parte de los medios de actuación (27) y tras la orden recibida desde los medios de control (33), de los correspondientes medios de válvula (23) de ambos depósitos i y j (21 y 22) y la activación de los medios de conversión (26). El periodo $T1_{n,i,j}$ concluye con la desactivación de los medios de conversión (26) y el cierre de los medios de válvula (23). Análogamente, el periodo $T2_{n,i,j}$ comienza con la apertura, por parte de los medios de actuación (27), de los correspondientes medios de válvula (23) de ambos depósitos i y j (21 y 22) y activando los medios de bombeo (25). El periodo $T2_{n,i,j}$ concluye con la desactivación de los medios de bombeo (25) y el cierre de los medios de válvula (23).

Además, en un ejemplo particular de realización, los medios de control (33) llevan a cabo las siguientes acciones al menos una vez al día:

- comprobar el nivel de fuga de una conducción (24), detectado por el sistema de detección de fugas (32), y

- si el nivel de fuga supera un determinado umbral de fuga predeterminado, no considerar esa conducción (24) para realizar los pasos indicados anteriormente en el método, no iniciando los periodos $T1_{n,i,j}$ ni $T2_{n,i,j}$.

REIVINDICACIONES

1.- Central de bombeo mixta que comprende una red de captación, tratamiento y abastecimiento de agua que comprende,

- al menos un depósito principal o de cabecera (5, 6) a una altura HP (hb5, hb6),
- al menos dos depósitos secundarios (7-12) a una altura H1 y H2 respectivamente,

en donde

- el al menos un depósito principal (5, 6) y los al menos dos depósitos secundarios (7-12) están conectados entre sí mediante conducciones (24) y medios de válvula (23), y

caracterizado porque comprende

- al menos unos medios de conversión (26) de la energía potencial del agua en su trasiego entre dos depósitos (5-12) por gravedad, en energía eléctrica,
- al menos unos medios de bombeo de agua (25) desde al menos un depósito (5-12) hasta al menos otro depósito (5-12) con una altura mayor, y
- unos medios de control (33), en conexión con al menos unos medios de actuación (27), adaptados para
    - el accionamiento de los medios de válvula (23) para permitir el trasiego por gravedad de un flujo de agua (Q) desde al menos un depósito (5-12) hasta al menos otro depósito (5-12) con una altura menor, y activación de los al menos unos medios de conversión (26) para la producción de energía eléctrica a partir de dicho flujo de agua (Q) asociado durante un periodo de tiempo T1, y
    - el accionamiento de los medios de válvula (23) y de los al menos unos medios de bombeo (25) para permitir el trasiego de un flujo de agua (Q) por bombeo desde al menos uno de los depósitos (5-12) hasta otro depósito (5-12) a un altura mayor durante un periodo de tiempo T2.

2.- Central de bombeo mixta según la reivindicación 1, caracterizado por que la altura HP es mayor que H1 y mayor que H2.

3.- Central de bombeo mixta según cualquiera de las reivindicaciones 1 o 2, que comprende un sistema de detección de fugas (32) para la detección de un nivel de fuga caracterizado por que comprende al menos dos sensores de caudal (28) de medida directa o indirecta en al menos una conducción (24).

4.- Central de bombeo mixta según la reivindicación 3, donde el sistema de fugas (32) comprende un conjunto distribuido de sensores de presión (29) en al menos una conducción (24).

5.- Central de bombeo mixta según cualquiera de las reivindicaciones 3 o 4, caracterizado porque los medios de control (33) están en conexión con unos medios de actuación (27) adaptados para el cierre de los medios de válvula (23) y la desactivación de los medios de conversión (26) y los medios de bombeo (25) en una conducción (24) cuando el nivel de fuga en dicha conducción (24) supera un umbral de fuga.

6. Central de bombeo mixta según cualquiera de las reivindicaciones anteriores, caracterizado porque comprende al menos un sensor de detección de contenido de cloro (30) para la detección de un nivel de contenido de cloro, y al menos un medio dosificador de cloro (31).

7. Central de bombeo mixta según la reivindicación 6, caracterizado porque cada depósito (5-12) comprende un sensor de detección de contenido de cloro (30).

8. Central de bombeo mixta según cualquiera de las reivindicaciones 6 o 7, caracterizado porque cada depósito (5-12) comprende un medio dosificador de cloro (31).

9.- Central de bombeo mixta según cualquiera de las reivindicaciones 6 a 8, caracterizado porque los medios de actuación (27) están adaptados para activar el al menos un medio dosificador de cloro (31) cuando el nivel de contenido de cloro está por debajo de un umbral de cloro.

10.- Central de bombeo mixta según cualquiera de las reivindicaciones anteriores, caracterizado porque al menos un depósito (5-12) comprende un sensor de nivel (34).

11.- Central de bombeo mixta según cualquiera de las reivindicaciones anteriores, caracterizado porque los medios de control (33) están adaptados para llevar a cabo las siguientes acciones:

- recibir información relativa a valores históricos correspondientes a la época del año y el carácter laboral o festivo de la jornada y a los valores estimados de la demanda de agua de cada depósito durante un número de horas siguientes al comienzo del trasiego, y
- seleccionar, haciendo uso de dicha información recibida,

- antes del periodo T1 al menos una conducción (24) en la que se va a realizar trasiego de agua por gravedad, accionando los correspondientes medios de válvula (23) y activando los medios de conversión (26), y
- antes del periodo T2 al menos una conducción (24) en la que se va a realizar el trasiego de agua por bombeo, accionando los correspondientes medios de válvula (23) y activando los medios de bombeo (25).

12.- Método de obtención y almacenamiento de energía eléctrica con una central de bombeo mixta según cualquiera de las reivindicaciones anteriores, caracterizado por que comprende los siguientes pasos:

- durante un periodo de tiempo T1,
  - accionamiento de los medios de válvula (23) para permitir el trasiego por gravedad de un flujo de agua ($Q_{i,j}$) entre al menos un depósito i (5-12) hasta al menos otro depósito j (5-12) a una altura menor, y
  - accionamiento de al menos unos medios de conversión (26) para la producción de energía eléctrica a partir de dicho flujo de agua ($Q_{i,j}$) asociado,
- durante un periodo de tiempo T2,
  - accionamiento de los medios de válvula (23) y
  - accionamiento de los al menos unos medios de bombeo (25) para el trasiego de un flujo de agua (Q) desde al menos uno de los depósitos (5-12) hasta otro depósito (5-12) a un altura mayor.

13.- Método de obtención y almacenamiento de energía eléctrica con una central de bombeo mixta según la reivindicación 12, caracterizado por que comprende adicionalmente las etapas de:

- comprobar el nivel de fuga de una conducción (24), detectado por el sistema de detección de fugas (32), y
- si el nivel de fuga supera el umbral de fuga, desactivar los medios de conversión (26) y los medios de bombeo (25) en dicha conducción (24).

14.- Método de obtención y almacenamiento de energía eléctrica con una central de bombeo mixta según cualquiera de las reivindicaciones 12 a 13, en el que la comprobación del nivel de fuga se realiza al menos una vez en al menos uno de los periodos de tiempo T1 o T2.

15. Método de obtención y almacenamiento de energía eléctrica con una central de bombeo mixta según cualquiera de las reivindicaciones 12 a 14, caracterizado porque se lleva a cabo tomando como referencia temporal un día, dividido en intervalos temporales, y un índice “n” que recorra dichos intervalos temporales dentro de dicha referencia temporal.

16.- Método de obtención y almacenamiento de energía eléctrica con una central de bombeo mixta según la reivindicación 15, caracterizado porque los medios de control (33) realizan las siguientes acciones:

- reciben información relativa a valores históricos correspondientes a la época del año y el carácter laboral o festivo del día de referencia y a los valores estimados de la demanda de agua de cada depósito durante dicho día de referencia.
- antes de comenzar el día de referencia, seleccionar, haciendo uso de la información recibida, al menos una conducción (24) en la que se va a realizar trasiego de agua por gravedad, accionando los correspondientes medios de válvula (23) y activando los medios de conversión (26), y
- antes comenzar el día de referencia, seleccionar, haciendo uso de la información recibida, al menos una conducción (24) en la que se va a realizar el trasiego de agua por bombeo, accionando los correspondientes medios de válvula (23) y activación de los medios de bombeo (25), en función de los valores estimados de la demanda de agua de cada depósito durante el día de referencia.

17.- Método de obtención y almacenamiento de energía con una central de bombeo mixta según la reivindicación 16, caracterizado porque los medios de control (33) seleccionan para cada intervalo temporal n del día de referencia las conducciones (24) entre las que se va a realizar el trasiego mediante la optimización de una función de coste C

$$C = \sum_{n,i,j} C_{n,i,j}, \qquad siendo\ C_{n,i,j} = \left(Q_{n,i,j} - F_{n,i,j}\right) \cdot g \cdot \left(h_{n,i} - h_{n,j}\right) \cdot \eta_{n,i,j} \cdot k_{n,i,j} \cdot T_{n,i,j} + F_{n,i,j} \cdot P \cdot T_{n,i,j}$$

Cubriendo i y j todos los pares de depósitos de la central, incluyendo los intercambios de agua con el ambiente y las aportaciones al consumo externo, y cubriendo n cada una de los intervalos temporales del día, y siendo cada uno de los términos:

$C_{n,i,j}$: coste del trasiego entre el depósito i y el depósito j

$Q_{n,i,j}$: gasto másico (en kg/s) que atraviesa la conducción en el trasiego entre el depósito i y el depósito j, constante durante el tiempo $T_{n,i,j}$.
$F_{n,i,j}$: gasto másico (en kg/s) que se pierde por fugas en el trasiego entre el depósito i y el depósito j, constante durante el tiempo $T_{n,i,j}$, y estimado por medio de datos históricos.
g: aceleración de la gravedad
$h_{n,i}$: altura media del nivel en el depósito i durante el intervalo temporal n
$h_{n,j}$: altura media del nivel en el depósito j durante el intervalo temporal n
$\eta_{n,i,j}$: rendimiento de la máquina, turbina o turbina-bomba en el caso de un trasiego por gravedad o bomba en el caso de un trasiego por bombeo, constante durante el intervalo temporal n.
$k_{n,i,j}$: coste de la electricidad, para vender en el caso de trasiego por gravedad (en cuyo caso tendrá un valor positivo) o para comprar en el caso de trasiego por bombeo (en cuyo caso tendrá un valor negativo). Se estima al comienzo de cada jornada en base a datos históricos y otras informaciones. Se considera que permanece constante durante el intervalo temporal n.
$T_{n,i,j}$: tiempo durante el cual tiene lugar el trasiego dentro del intervalo temporal n, será $T1_{n,i,j}$ en el caso del trasiego por gravedad o $T2_{n,i,j}$ en el caso del trasiego por bombeo.
P: precio del agua, constante.

en donde para la optimización de la función interviene la limitación de mantener el nivel mínimo de los depósitos, por motivos del uso del depósito; estando dado en los depósitos de consumo externo por las necesidades de abastecimiento, y en los depósitos naturales, por necesidades ecológicas.

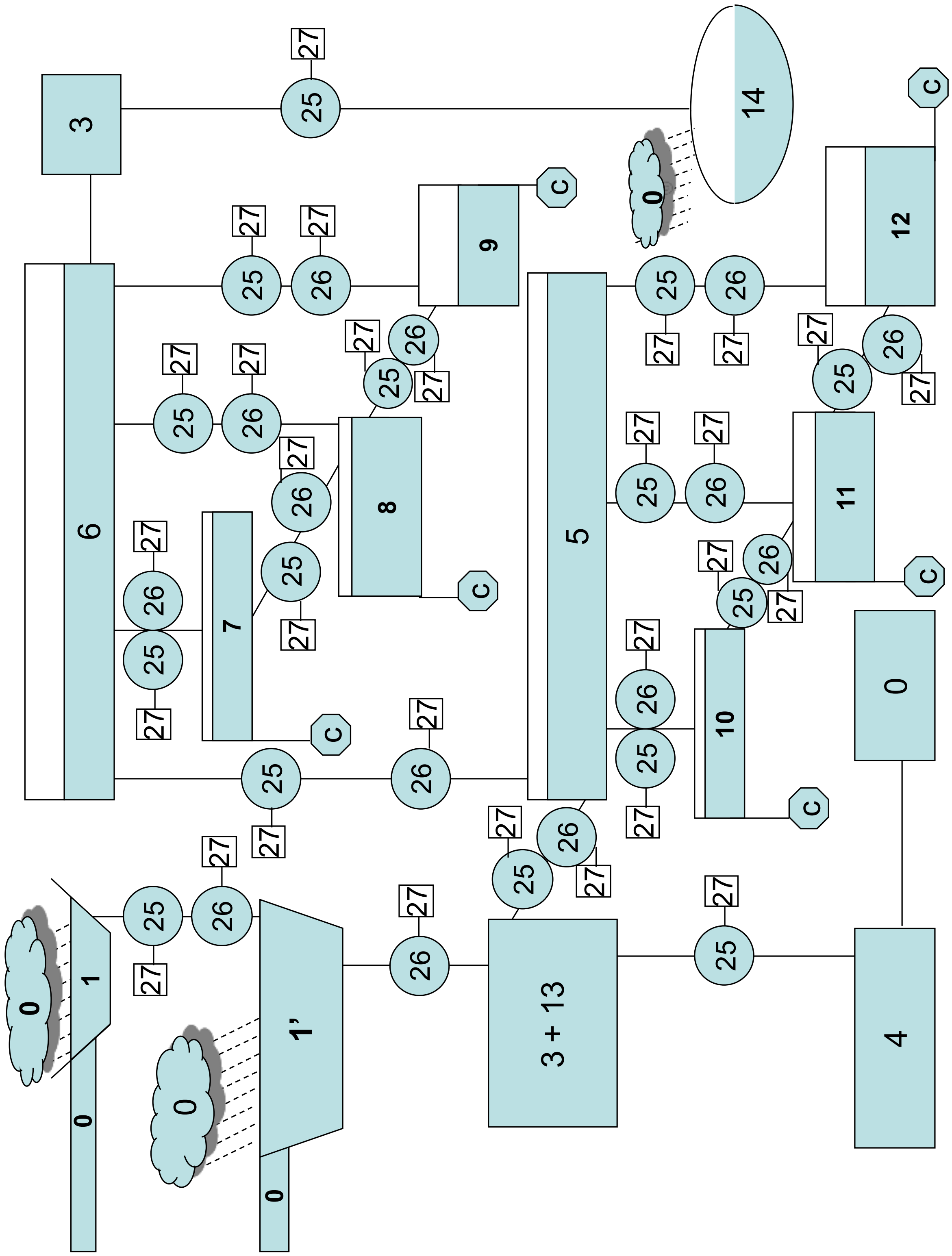
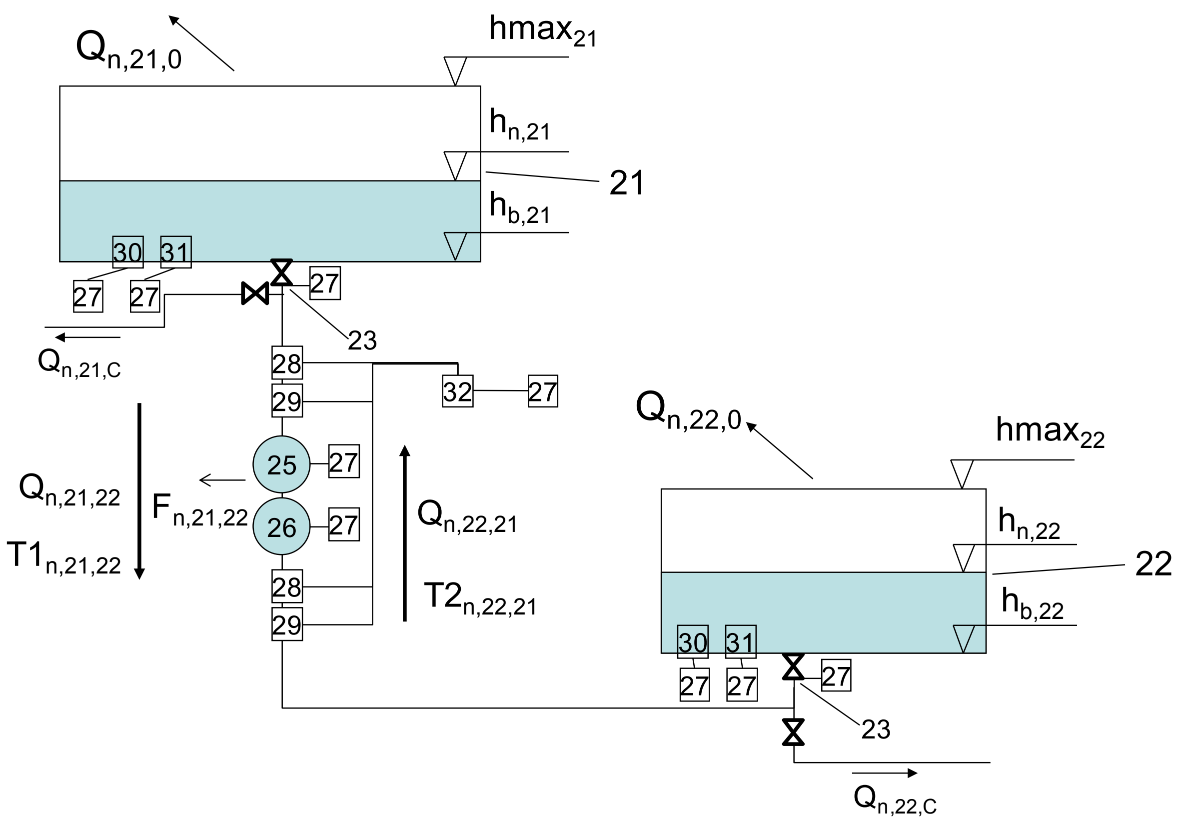


Fig. 1.


Qn,21,0
hmax21
hn,21
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Qn,21,22
Fn,21,22
T1n,21,22
Qn,22,21
T2n,22,21
Qn,22,0
hmax22
hn,22
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Qn,22,C

Fig. 2

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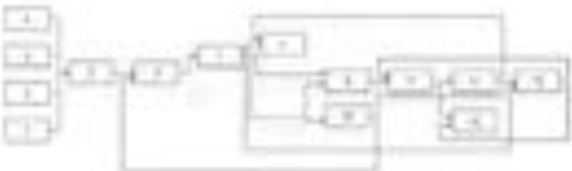
(54)发明名称

一种清洁能源储能蓄能与海水淡化联产系统

(57)摘要

本发明涉及能源利用领域，具体涉及一种清洁能源储能蓄能与海水淡化联产系统。本发明通过将风电、光伏发电、潮汐发电和海潮流发电先经过输变电系统进行调整，然后输送给电力蒸汽装置，将电力蒸汽装置产生的蒸汽发往发电系统进行发电从而获得电能质量较好的电能。本发明有效解决了风电、光伏发电、潮汐发电和海潮流发电的随机性和波动性的问题，使得联产的海水淡化系统能够稳定运行，同时本发明还将海水淡化系统与抽水蓄能系统进行了连接，将两者进行了有效互补，海水淡化系统产生的淡水可以为抽水蓄能系统提供水源，抽水蓄能系统产生的电能可以提供给海水淡化系统，提高了系统的运行效率，节约了资源。



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1.一种清洁能源储能蓄能与海水淡化联产系统,其特征在于:包括清洁能源系统,所述清洁能源系统通过输变电系统供电连接电力蒸汽装置,所述电力蒸汽装置通过第一气体输送装置提供蒸汽给蒸汽发电系统,所述蒸汽发电系统通过输电装置和第二气体输送装置分别给海水淡化系统提供电能和蒸汽,所述海水淡化系统产生的淡水通过液体输送装置提供给抽水蓄能系统;所述清洁能源系统至少包括如下系统中的一种:风电系统、光伏发电系统、潮汐发电系统和海潮流发电系统。

2.根据权利要求1所述一种清洁能源储能蓄能与海水淡化联产系统,其特征在于:所述海水淡化系统产生的淡水还提供给所述电力蒸汽装置。

3.根据权利要求1或2所述一种清洁能源储能蓄能与海水淡化联产系统,其特征在于:所述海水淡化系统包括第一海水淡化系统和第二海水淡化系统。

4.根据权利要求3所述一种清洁能源储能蓄能与海水淡化联产系统,其特征在于:所述第一海水淡化系统为低温多效蒸馏系统,所述第二海水淡化系统为蒸发系统。

5.根据权利要求4所述一种清洁能源储能蓄能与海水淡化联产系统,其特征在于:所述抽水蓄能系统包括高位水库、低位水库、水泵装置和水轮发电装置。

6.根据权利要求5所述一种清洁能源储能蓄能与海水淡化联产系统,其特征在于:所述蒸汽发电系统还供电连接所述水泵装置。

7.根据权利要求6所述一种清洁能源储能蓄能与海水淡化联产系统,其特征在于:所述蒸汽发电系统和所述水轮发电装置连接电网。

一种清洁能源储能蓄能与海水淡化联产系统

技术领域

[0001]　本发明涉及能源利用领域，具体涉及一种清洁能源储能蓄能与海水淡化联产系统。

背景技术

[0002]　沿海地区往往是风能、光伏能、潮汐能十分丰富的地方，但是此类能源都有一个问题，就是不可控，所发电能质量不高，波动性很大，输出功率很不稳定，而作为联产主要用户的海水淡化装置，一般需要持续而稳定的电源，如何解决这一矛盾，成为了清洁能源技术应用到海水淡化的一个研究重点。

[0003]　申请号201410480835的文件公开了一种"抽水蓄能式风能直接驱动海水淡化集成系统"，该系统直接使用风电抽取海水蓄能储能，再由海水利用其势能驱动反渗透装置制造淡水，整套装置原理非常简单，缺点是没有必要的备用电源，如果遇到风力发电机长时间无法供电，整套装置在运行一段时间后，也将停止运行，并且海水会对蓄水池造成腐蚀。

[0004]　申请号201610010059.8公开了"一种风—光—抽蓄—海水淡化复合系统能量管理方法"，该方法的特点是对风电、光伏发电、抽水蓄能、海水淡化进行分离式管理，在风电、光伏发电供应充足时，既海水淡化，又抽水蓄能，甚至供应常规负荷；当电能开始下降时，优先供应海水淡化，依次停掉抽水蓄能和常规负荷；当电能不足以为此海水淡化时，抽水蓄能开始发电保障海水淡化。

[0005]　该方法虽然使用淡水蓄能解决了蓄能设备的腐蚀问题，但是海水淡化系统和淡水蓄能系统是分离管理的，当淡化海水富余时，无法直接补充到淡水蓄能系统中，风电和光伏发电是直接供给海水淡化复合系统和常规负荷使用，中间没有必要的变电环节，不能满足海水淡化系统对电源持续性和稳定性的要求，影响海水淡化系统的正常运行。

发明内容

[0006]　本发明的目的是提供一种清洁能源储能蓄能与海水淡化联产系统，用以解决现有技术中清洁能源系统为海水淡化系统提供的电源不稳定的问题。

[0007]　为实现上述目的，本发明的方案提供了一种清洁能源储能蓄能与海水淡化联产系统，包括系统方案一，系统方案一包括清洁能源系统，所述清洁能源系统通过输变电系统供电连接电力蒸汽装置，所述电力蒸汽装置通过第一气体输送装置提供蒸汽给蒸汽发电系统，所述蒸汽发电系统通过输电装置和第二气体输送装置分别给海水淡化系统提供电能和蒸汽，所述海水淡化系统产生的淡水通过液体输送装置提供给抽水蓄能系统；所述清洁能源系统至少包括如下系统中的一种：风电系统、光伏发电系统、潮汐发电系统和海潮流发电系统。

[0008]　系统方案二，在系统方案一的基础上，所述海水淡化系统产生的淡水还提供给所述电力蒸汽装置。

[0009]　系统方案三，在系统方案一或者系统方案二的基础上，所述海水淡化系统包括第

一海水淡化系统和第二海水淡化系统。

[0010]　系统方案四，在系统方案三的基础上，所述第一海水淡化系统为低温多效蒸馏系统，所述第二海水淡化系统为蒸发系统。

[0011]　系统方案五，分别在系统方案四的基础上，所述抽水蓄能系统包括高位水库、低位水库、水泵装置和水轮发电装置。

[0012]　系统方案六，在系统方案五的基础上，所述蒸汽发电系统还供电连接所述水泵装置。

[0013]　系统方案七，在系统方案六的基础上，所述蒸汽发电系统和所述水轮发电装置连接电网。

[0014]　本发明的有益效果是：通过将风电、光伏发电、潮汐发电和海潮流发电先经过输变电系统进行调整，然后输送给电力蒸汽装置，将电力蒸汽装置产生的蒸汽发往蒸汽发电系统进行发电从而获得电能质量较好的电能，有效解决了风电、光伏发电、潮汐发电和海潮流发电的随机性和波动性的问题，使得联产的海水淡化系统能够稳定运行。

[0015]　本发明还将海水淡化系统与抽水蓄能系统进行了联产，将两者进行了有效结合，海水淡化系统产生的淡水可以为抽水蓄能系统和电力蒸汽装置提供水源，抽水蓄能系统产生的电能可以并入电网，提高了系统的运行效率，节约了资源。

附图说明

[0016]　图1是本发明所述系统的结构框图；

[0017]　图2是本发明所述系统中抽水蓄能部分的实际效果图；

[0018]　图3是本发明所述系统中抽水蓄能系统部分蓄水池防蒸发示意图；

[0019]　附图中：1、风电系统；2、光伏发电系统；3、潮汐发电系统；4、海潮流发电系统；5、输变电系统；6、电力蒸汽锅炉；7、蒸汽发电系统；8、电网；9、第一海水淡化系统；10、第二海水淡化系统；11、高位人造蓄能水库；12、水轮发电机；13、低位人造蓄能水库；14、饮用、灌溉等其他用途；15、检修人员通道；16、上水管道；17、水泵系统；18、检修通道支撑梁柱；19、厂房；20、厂房支撑梁柱；21、废热循环加热管；22、光伏发电板；23、光伏发电板基座；24、防蒸发布；25、边墙。

具体实施方式

[0020]　下面结合附图对本发明做进一步详细的说明。

[0021]　本发明提出了一种综合利用风电、光伏发电、潮汐发电和海潮流发电等清洁能源与海水淡化联产储能发电系统，可以有效解决风力发电、光伏发电、潮汐发电、海潮流发电的电能用于海水淡化时具有随机性、波动性的问题，能够实现有效蓄能和储能，同时能够解决工业化海水淡化所需的水、电、气等问题。

[0022]　如图1所示是风光潮汐海流电储能蓄能与海水淡化联产系统结构示意图，图中包括的风电系统1、光伏发电系统2、潮汐发电系统3、海潮流发电系统4，经过输变电系统5后接入电力蒸汽锅炉6，电力蒸汽锅炉6在电能的作用下，产生过热蒸汽推动蒸汽发电系统7进行发电。

[0023]　其中蒸汽发电系统7所发电能优先供应电网8，只有在电网8电能富余时，才向第一

海水淡化系统9和第二海水淡化系统10提供所需电能以及为抽水蓄能提供所需电能。

[0024] 蒸汽发电系统7产生的海水淡化所需废热分别供应第一海水淡化系统9和第二海水淡化系统10。

[0025] 第一海水淡化系统9和第二海水淡化系统10所产淡水优先供应电力蒸汽锅炉6，其次保证高位和低位人造蓄能水库11和13的用水，最后用于饮用和灌溉等其他用途14；高位人造蓄能水库11中水经过水轮发电机12将势能转化为电能用于并网，然后流入低位人造蓄能水库13。

[0026] 在另一种实施方式中蒸汽发电系统可以分为两套，包括第一发电系统和第二发电系统，电力蒸汽锅炉6产生过热蒸汽推动第一发电系统和第二发电系统进行发电。

[0027] 其中第一发电系统所发电能优先供应电网8，只有在电网8电能富余时，才向第一海水淡化系统9和第二海水淡化系统10提供所需电能以及给抽水蓄能提供所需电能。第二发电系统主要用于消耗光伏发电2产生的周期峰值电能，所发电能主要提供给海水淡化所需电能和抽水蓄能所需电能。

[0028] 第一发电系统和第二发电系统产生的海水淡化所需废热分别供应第一海水淡化系统9和第二海水淡化系统10，而第一发电系统和第二发电系统产生的海水淡化所需电能则完全供给第一海水淡化系统9。

[0029] 第一海水淡化系统9和第二海水淡化系统10所产淡水优先供应电力蒸汽锅炉6，其次保证高位和低位人造蓄能水库11和13的用水，最后用于饮用和灌溉等其他用途14；高位人造蓄能水库11中水经过水轮发电机12将势能转化为电能用于并网，然后流入低位人造蓄能水库13。

[0030] 如图2所示为抽水蓄能部分的实际效果图，图中当第一发电系统和第二发电系统提供电能时，水泵系统17抽取第一海水淡化系统9和第二海水淡化系统10所产生的淡水以及低位人造蓄能水库13的存水，补充到高位人造蓄能水库11中。

[0031] 当需要水轮发电机12并入电网8工作时，高位人造蓄能水库11可以保证水轮发电机12正常工作10小时以上，所排放淡水进入低位人造蓄能水库13。

[0032] 当第一海水淡化系统9和第二海水淡化系统10正常工作且水泵系统17没有工作时，所产淡水将流入低位人造蓄能水库13。

[0033] 第二海水淡化系统10可以不依赖发电系统提供电能，仅凭高位人造蓄能水库11流出的淡水，经过第二海水淡化系统10的冷凝器，凝结海水淡化所需废热加热的海水产生的水蒸气就可以制备淡水；而流经冷凝器的淡水也将流入低位人造蓄能水库13。

[0034] 为了减少高位和低位人造蓄能水库11和13的水汽蒸发，在水库中检修人员通道15上设置有光伏发电板基座23，光伏发电板基座23上设置可以起到遮光作用的光伏太阳能电池板22，同时为了方便检修这些光伏太阳能电池板22，在人造蓄能水库中设置有方便人员检修的通道15。

[0035] 对设置在厂房19顶棚的高位人造蓄能水库11中的检修人员通道15，有额外的工程要求，除满足正常的人员检修外，还应起到辅助加固高位人造蓄能水库11边墙的作用。

[0036] 在检修人员通道15下方，厂房支撑梁柱20上方延长出检修通道支撑梁柱18，支撑和固定检修人员通道15，再由检修人员通道15固定高位人造蓄能水库11的边墙。

[0037] 当第一发电系统和第二发电系统提供电能和热能时，第一海水淡化系统9和第二

海水淡化系统10开始将大批量海水淡化。此时水泵系统17启动，淡水从第一海水淡化系统9和第二海水淡化系统10及低位人造蓄能水库13抽取，经过上水管道16注入高位人造蓄能水库11。当水泵系统17停止工作时，淡水从第一海水淡化系统9和第二海水淡化系统10制取的淡水将顺着上水管道16下段排入低位人造蓄能水库13。

[0038] 需要水轮发电机12并入电网8工作时，高位人造蓄能水库11可以保证水轮发电机12正常工作10小时以上，所排放淡水进入低位人造蓄能水库13。

[0039] 第二海水淡化系统10可以不依赖发电系统提供电能，仅凭高位人造蓄能水库11流出的淡水经过第二海水淡化系统10的冷凝器，凝结海水淡化所需废热加热的海水产生的水蒸气，就可以制备淡水。而流经冷凝器的淡水也将流入低位人造蓄能水库13。

[0040] 如图3所示，为减少人造蓄能水库的水分蒸发，在高位和低位人造蓄能水库11和13的淡水液位上设置防蒸发布24，减少风能吹走水蒸气和日照蒸发水蒸气。

[0041] 由于人员检修通道15之间的间距空间较小，所以防蒸发布24的面积也不能制作非常大，这能有效的防止风吹破坏防蒸发布。

[0042] 以上给出了本发明涉及的具体实施方式，通过将风电、光伏发电、潮汐发电和海潮流发电先经过输变电系统进行调整，然后输送给电力蒸汽装置，将电力蒸汽装置产生的蒸汽发往发电系统进行发电从而获得电能质量较好的电能。

[0043] 但本发明不局限于所描述的实施方式，例如增加发电系统的数量或者海水淡化系统的数量，这样形成的技术方案是对上述实施例进行微调形成的，这种技术方案仍落入本发明的保护范围内。

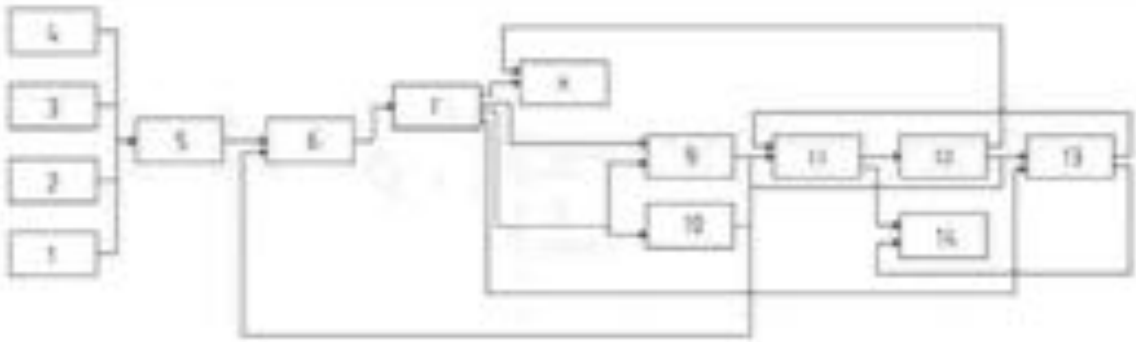
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图1

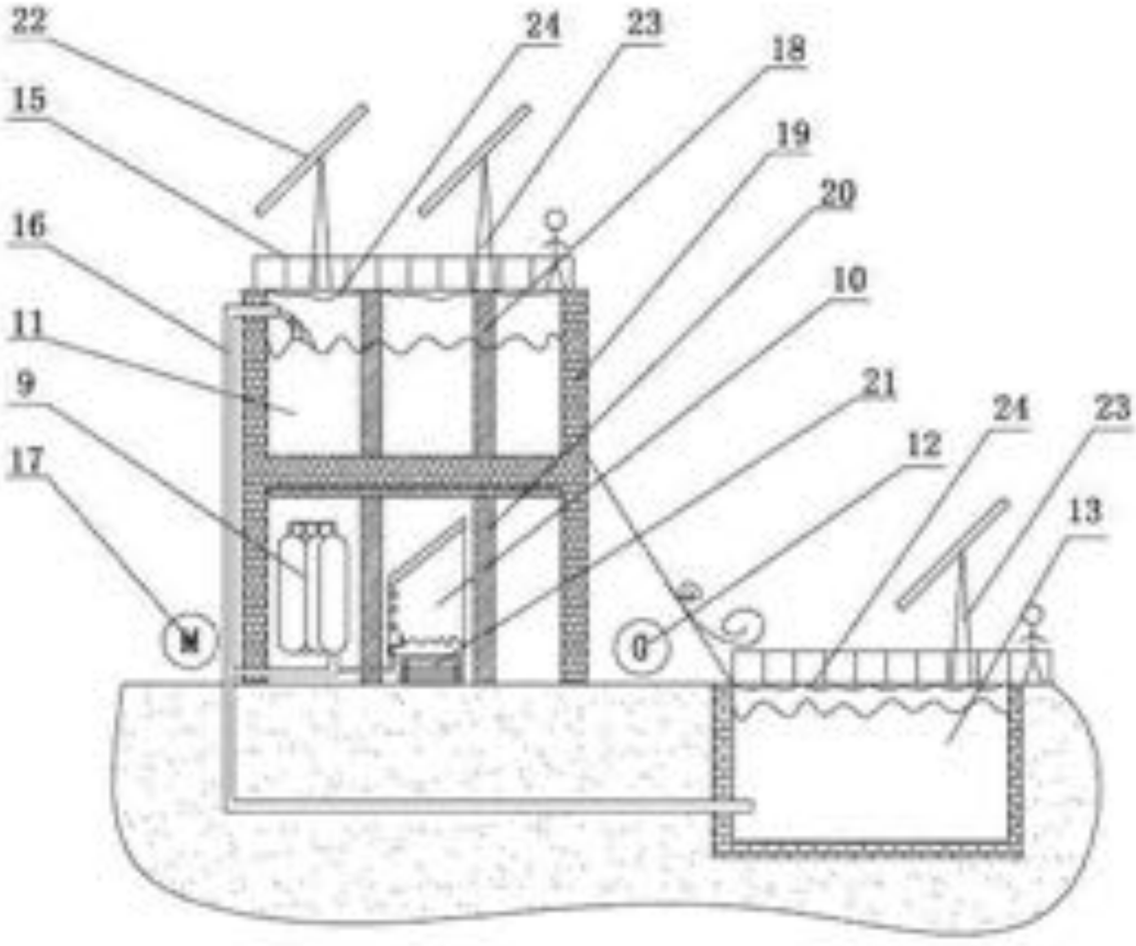
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图2

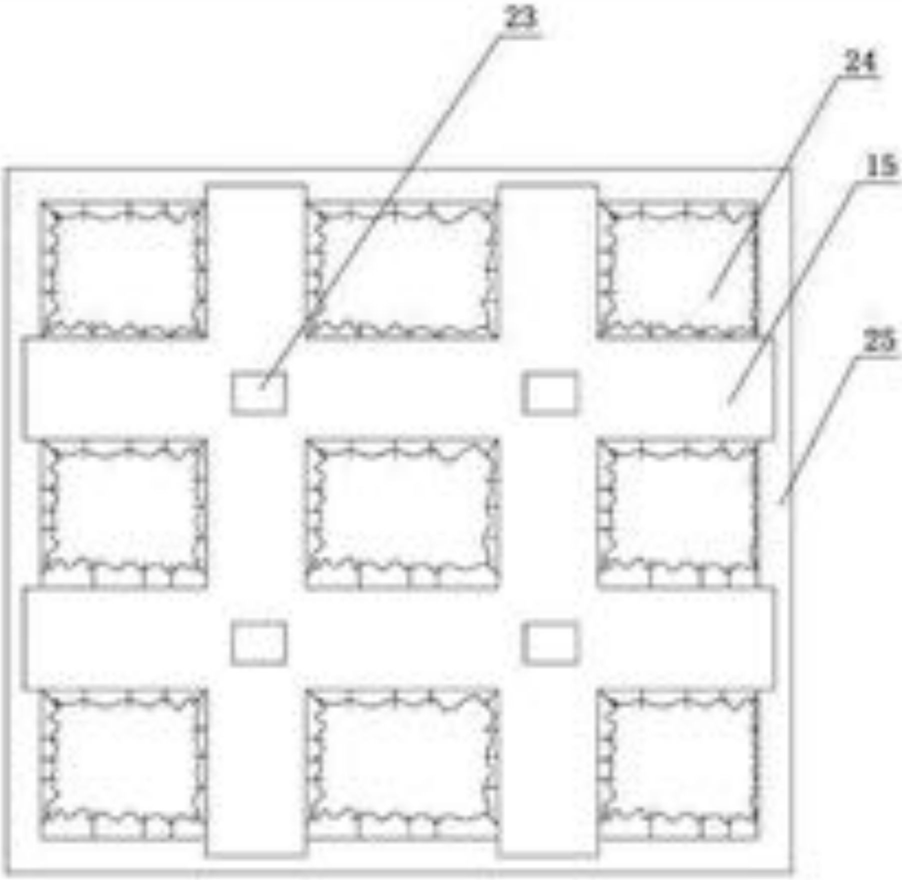

图3

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TI - Clean energy storage and seawater desalination system comprises clean energy systems and clean energy system is connected to the power steam device through the power transmission and transformation system

AB - NOVELTY : Clean energy storage and seawater desalination system comprises clean energy systems. The clean energy system is connected to the power steam device through the power transmission and transformation system. The electric steam device provides steam to the steam power generation system through the first gas delivery device. The steam power generation system supplies electric energy and steam to the seawater desalination system through the power transmission device and the second gas delivery device respectively. The fresh water produced by the seawater desalination system is supplied to the pumped storage system through the liquid delivery device. The clean energy system comprises at least one wind power system, photovoltaic power generation system, tidal power generation system or sea tidal power generation system.

- USE : Used as clean energy storage and seawater desalination system.
- ADVANTAGE : The system: solves the problems of randomness and volatility of wind power, photovoltaic power generation, tidal power generation and sea tide power generation; enables co-production seawater desalination system to operate stably; provides water for the pumped storage system; has high operating effect; and saves resources.
- DESCRIPTION OF DRAWINGS : The diagram shows a schematic representation of clean energy storage and seawater desalination system.

IW - CLEAN ENERGY STORAGE SEA DESALINATE SYSTEM COMPRISE CONNECT POWER STEAM DEVICE THROUGH TRANSMISSION TRANSFORM

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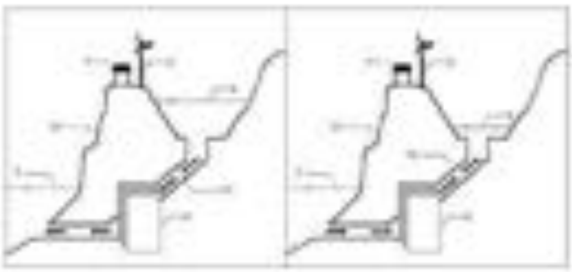
权利要求书2页 说明书5页 附图2页

(54)发明名称

一种集风能光能和海水蓄能于一体的反渗透海水淡化装置

(57)摘要

本发明涉及一种集风能光能和海水蓄能于一体的反渗透海水淡化装置，属于风光互补发电技术、海水抽水蓄能技术、海水淡化技术、智能控制技术等领域。光伏阵列包括若干个等间距分布的光伏发电板，风力发电机、光伏阵列均固定设置在地面上，风力发电机、光伏阵列分别电连接逆变器；逆变器电连接控制器。高位蓄水池开设在高于低位蓄水池的地方，高位蓄水池开设连通低位蓄水池的通道，通道上安装阀门，可逆式水泵水轮机组安装在通道上；逆变器、可逆式水泵水轮机组、负载、蓄电池分别电连接控制器，负载电连接蓄电池。本发明将抽水蓄能与风光互补发电系统结合，迅速转变的特性可弥补风力发电的不稳定性，为系统提供更多的调峰填谷容量和调频、调相、紧急事故备用电源，可靠性强。



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1.一种集风能光能和海水蓄能于一体的反渗透海水淡化装置,其特征在于,包括阀门,光伏阵列(1)、风力发电机(2)、逆变器(3)、控制器(5)、高位蓄水池(5)、低位蓄水池(7)、可逆式水泵水轮机组(6)、蓄电池(8),所述光伏阵列(1)包括若干个等间距分布的光伏发电板,所述风力发电机(2)、所述光伏阵列(1)均固定设置在地面上,所述风力发电机(2)、所述光伏阵列(1)分别电连接所述逆变器(3);所述逆变器(3)电连接所述控制器(5),所述高位蓄水池(5)开设在高于所述低位蓄水池(7)的地方,所述高位蓄水池(5)开设连通所述低位蓄水池(7)的通道,所述通道上安装所述阀门,所述可逆式水泵水轮机组(6)安装在所述通道上;所述逆变器(3)、所述可逆式水泵水轮机组(6)、所述蓄电池(8)分别电连接所述控制器(4)。

2.根据权利要求1所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置,其特征在于,所述高位蓄水池(5)的位置高于所述低位蓄水池(7)100-200米。

3.根据权利要求1所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置,其特征在于,所述可逆式水泵水轮机组(6)包括水泵工况(10)和水轮机工况(11),所述水泵工况(10)包括水泵、进水管和出水管,所述水泵的进水口通过所述进水管连通所述低位蓄水池(7),所述水泵的出水口通过所述出水管连通所述高位蓄水池(5);所述水轮机工况(11)包括水轮机,所述水轮机固定设置在所述通道上。

4.根据权利要求1所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置,其特征在于,包括反渗透海水淡化装置,所述反渗透海水淡化装置包括取水系统(13)、预处理模块(22)、反渗透脱盐模块(23)和后处理模块(24),所述取水系统(13)包括取水管、取水泵和取水箱(21),所述取水泵安置在所述取水管上,所述取水管的一端连通所述低位蓄水池(7),所述取水管的另一端连通所述取水箱(21),所述取水箱(21)连通所述预处理模块(22),所述预处理模块(22)连通所述反渗透脱盐模块(23),所述后处理模块(24)安装在所述反渗透脱盐模块(23)上。

5.根据权利要求4所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置,其特征在于,所述预处理模块(22)包括抽水管、给水泵(14)、多介质过滤器(15)和保安过滤器(16),所述取水箱(21)通过所述抽水管连通所述多介质过滤器(15),所述给水泵(14)安装在所述抽水管上,所述多介质过滤器(15)连通所述保安过滤器(16),所述保安过滤器(16)连通所述反渗透脱盐模块(23)。

6.根据权利要求5所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置,其特征在于,所述多介质过滤器(15)型号为HKY-DZL08;所述保安过滤器(16)为袋式过滤器。

7.根据权利要求5所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置,其特征在于,所述反渗透脱盐模块包括进水管、高压泵(17)、反渗透膜组件(18)和产水水箱(19),所述保安过滤器(16)通过所述进水管连通所述反渗透膜组件(18),所述高压泵安装在所述进水管上,所述反渗透膜组件(18)连通所述产水水箱(19)。

8.根据权利要求7所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置,其特征在于,所述后处理模块(24)包括能量回收装置(20),所述能量回收装置(20)为PX-45S正位移式压力交换器,所述保安过滤器(16)出水口、所述反渗透膜组件(18)出水口分别连通所述能量回收装置(20)进水口,所述能量回收装置(20)出水口连通所述反渗透膜组件

(18)进水口。

9.根据权利要求7所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置，其特征在于，所述反渗透膜组件(18)采用八个陶氏海水膜元件分装在四个压力膜壳内，四个压力膜壳依次从上向下叠加排列，所述高压泵(17)连通四个所述压力膜壳的左端，四个所述压力膜壳的右端连通所述产水水箱(19)。

10.根据权利要求9所述的一种集风能光能和海水蓄能于一体的反渗透海水淡化装置，其特征在于，所述陶氏海水膜元件为SW30HRLE-400型号；所述压力膜壳采用R8040C100S-4W，1000psi，4芯。

一种集风能光能和海水蓄能于一体的反渗透海水淡化装置

技术领域

[0001]　本发明涉及一种集风能光能和海水蓄能于一体的反渗透海水淡化装置，属于风光互补发电技术、海水抽水蓄能技术、海水淡化技术、智能控制技术等领域。

背景技术

[0002]　我国有很多偏离大陆的小型海岛(面积在500m2～5km2，约占全国海岛总数的98%)，电网很难到达，大部分地区采用柴油机发电，随着石油的短缺和油价的上涨，发电成本飞速上涨，电能的紧缺接制约了小型海岛的经济开发和居民的日常生活，有些岛屿甚至逐渐被荒废，大部分小型海岛都面临这种电力短缺及吃水困难等问题，而海岛地区风能资源丰富，为解决偏远地区用电提供了良好的先天条件，针对这些情况，现在的海岛多采用风能进行供电。

[0003]　目前的风光互补发电系统一般采用蓄电池蓄能，但蓄电池寿命短、成本高、有污染，且不能大量储存电能，而海水抽水蓄能不仅像常规抽水蓄能可以大量储存电能，调峰填谷，且启动迅速，爬坡卸荷速度快，运行灵活可靠，还具有不依赖淡水资源，建设成本低，能量生产可靠和环保等优点，其快速转变的灵活性可弥补岛上风能太阳能的随机性和不均匀性，为系统提供更多的调峰填谷容量和调频、调相、紧急事故备用电源等，因此，采用海水抽水蓄能对风光互补发电系统进行蓄能，由于抽水蓄能机组的启动和停止需要一定的时间，且可逆式水泵水轮机存在'S'不稳定区，在这时间段内，系统失电或者电能无法消耗，所以，系统配置一定量的蓄电池，既解决了上述问题，同时也可以平衡一定的系统能量。

[0004]　将海水淡化与可再生能源系统结合，能够有效解决岛上的用能、用水问题，且海水淡化具有很好的适应性和可调度性，能够解决负荷与出力的匹配问题，海水淡化具有可变负荷，可调节、高耗能的特点，与可再生能源结合，当出力大的时候，多产水；出力小的时候，少产水，能够一定程度上适应可再生能源的出力波动，在系统的能量平衡方面承担重要的角色。

发明内容

[0005]　本发明所要解决的技术问题是克服现有技术的缺陷，提供一种集风能光能和海水蓄能于一体的反渗透海水淡化装置。

[0006]　为达到上述目的，本发明提供一种集风能光能和海水蓄能于一体的反渗透海水淡化装置，包括阀门、光伏阵列、风力发电机、逆变器、控制器、高位蓄水池、低位蓄水池、可逆式水泵水轮机组、蓄电池和负载；所述光伏阵列包括若干个等间距分布的光伏发电板，所述风力发电机、所述光伏阵列均固定设置在地面上，所述风力发电机、所述光伏阵列分别电连接所述逆变器，所述逆变器电连接所述控制器，所述高位蓄水池开设在高于所述低位蓄水池的地方，所述高位蓄水池开设连通所述低位蓄水池的通道，所述通道上安装所述阀门，所述可逆式水泵水轮机组安装在所述通道上；所述逆变器、所述可逆式水泵水轮机组、所述负载、所述蓄电池分别电连接所述控制器，所述负载电连接所述蓄电池。

[0007]　优先地，所述高位蓄水池的位置高于所述低位蓄水池100-200米。

[0008]　优先地，所述可逆式水泵水轮机组包括水泵工况 和水轮机工况，所述水泵工况包括水泵、进水管和出水管，所述水泵的进水口通过所述进水管连通所述低位蓄水池，所述水泵的出水口通过所述出水管连通所述高位蓄水池；所述水轮机工况包括水轮机，所述水轮机固定设置在所述通道上。

[0009]　优先地，包括反渗透海水淡化装置，所述反渗透海水淡化装置包括取水系统、预处理模块、反渗透脱盐模块和后处理模块，所述取水系统包括取水管、取水泵和取水箱，所述取水泵安置在所述取水管上，所述取水管的一端连通所述低位蓄水池，所述取水管的另一端连通所述取水箱，所述取水箱连通所述预处理模块，所述预处理模块连通所述反渗透脱盐模块，所述后处理模块安装在所述反渗透脱盐模块上。

[0010]　优先地，所述预处理模块包括抽水管、给水泵、多介质过滤器和保安过滤器，所述取水箱通过所述抽水管连通所述多介质过滤器，所述给水泵安装在所述抽水管上，所述多介质过滤器连通所述保安过滤器，所述保安过滤器连通所述反渗透脱盐模块。

[0011]　优先地，所述多介质过滤器型号为HKT-DZL08；所述保安过滤器为袋式过滤器。

[0012]　优先地，所述反渗透脱盐模块包括进水管、高压泵、反渗透膜组件和产水水箱，所述保安过滤器通过所述进水管连通所述反渗透膜组件，所述高压泵安装在所述进水管上，所述反渗透膜组件连通所述产水水箱。

[0013]　优先地，所述后处理模块包括能量回收装置，所述能量回收装置为PX-45S正位移式压力交换器，所述保安过滤器出水口、所述反渗透膜组件出水口分别连通所述能量回收装置进水口，所述能量回收装置出水口连通所述反渗透膜组件进水口。

[0014]　优先地，所述反渗透膜组件采用八个陶氏海水膜元件分装在四个压力膜壳内，四个压力膜壳依次从上向下叠加排列，所述高压泵连通四个所述压力膜壳的左端，四个所述压力膜壳的右端连通所述产水水箱。

优先地，所述陶氏海水膜元件为SW30HRLE-400型号；所述压力膜壳采用R8040C1005-4W，1000psi，4芯。

[0015]　本发明所达到的有益效果：

(1)本发明中抽水蓄能装置能够大量储存电能，利用海水作为低位蓄水池，节约建设成本，且与常规抽水蓄能装置一样，可以调峰填谷，机组启停迅速，运行灵敏可靠，其迅速转变的特性可弥补风力发电的不稳定性，为系统提供更多的调峰填谷容量和调频，调相，紧急事故备用电源等，同时具有能量生产可靠和环保等优点；本发明巧妙地将抽水蓄能与风光互补发电系统结合，一方面可以代替蓄电池对整个系统进行储能，另一方面也提高了整个系统的稳定性；系统中仍配备了蓄电池，用来承担瞬时峰荷，增加了系统的稳定性；针对海岛中缺乏淡水的问题，该系统结合了海水淡化装置，有效地解决了海岛用淡水的问题。

[0016]　(2)本发明装置针对小型海岛上的常规能源匮乏、缺乏电能和淡水等问题，不仅能有效利用当地丰富的风能、太阳能资源和海水资源，利用风光互补发电，海水抽水蓄能电站与蓄电池结合储能，供给海水淡化装置产生淡水，在系统中风能和太阳能供给负荷有多余电能时，利用可逆式水泵水轮机的水泵工况进行抽水，将低位蓄水池的海水抽到高位蓄水池，将多余的电能变成水能储存起来；在风能和太阳能供给负荷电能不足时，利用可逆式水泵水轮机的水轮机工况进行发电，将水能变成电能，连接海水淡化装置供给负载，既解决当

地电能紧缺的问题，也能够为当地居民提供淡水，本系统稳定、环保，运行成本低。

附图说明

[0017]　图1是本发明的剖视图；

图2是本发明中反渗透海水淡化装置的原理框图；

图3是本发明中风能、光能和海水抽蓄一体化的示意图。

[0018]　图中，1-光伏阵列，2-风力发电机，3-逆变器，4-控制器，5-高位蓄水池，6-可逆式水泵水轮机组，7-低位蓄水池，8-蓄电池，9-负载，10-水泵工况，11-水轮机工况，12-高山，13-取水系统，14-给水泵，15-多介质过滤器，16-保安过滤器，17-高压泵，18-反渗透膜组件，19-产水水箱，20-能量回收装置，21-取水箱，22-预处理模块，23-反渗透脱盐模块，24-后处理模块，25-控制模块。

具体实施方式

[0019]　下面结合附图对本发明作进一步描述，以下实施例仅用于更加清楚地说明本发明的技术方案，而不能以此来限制本发明的保护范围。

[0020]　一种集风能光能和海水蓄能于一体的反渗透海水淡化装置，包括阀门、光伏阵列1、风力发电机2、逆变器3、控制器5、高位蓄水池5、低位蓄水池7、可逆式水泵水轮机组6、蓄电池8和负载9；光伏阵列1包括若干个等间距分布的光伏发电板，风力发电机2、光伏阵列1均固定设置在地面上，风力发电机2、光伏阵列1分别电连接逆变器3；逆变器3电连接控制器5，高位蓄水池5开设在高于低位蓄水池7的地方，高位蓄水池5开设连通低位蓄水池7的通道，通道上安装阀门，可逆式水泵水轮机组6安装在通道上；逆变器3、可逆式水泵水轮机组6、负载9、蓄电池8分别电连接控制器4，负载9电连接蓄电池8。

[0021]　进一步地，高位蓄水池5的位置高于低位蓄水池7达100-200米。

[0022]　进一步地，可逆式水泵水轮机组6包括水泵工况10 和水轮机工况11，水泵工况10包括水泵、进水管和出水管，所述水泵的进水口通过所述进水管连通所述低位蓄水池7，所述水泵的出水口通过所述出水管连通所述高位蓄水池5；所述水轮机工况11包括水轮机，所述水轮机固定设置在所述通道上。

[0023]　进一步地，负载9包括反渗透海水淡化装置，反渗透海水淡化装置包括取水系统13、预处理模块22、反渗透脱盐模块23和后处理模块24，取水系统13包括取水管、取水泵和取水箱21，取水泵安置在取水管上，取水管的一端连通低位蓄水池7，取水管的另一端连通取水箱21，取水箱21连通预处理模块22，预处理模块22连通反渗透脱盐模块23，后处理模块24安装在反渗透脱盐模块23上。

[0024]　海水淡化采用反渗透膜法，并采用模块化装置，如附图2所示，取水模块21：利用取水系统提取海水；预处理模块22：利用给水泵14将海水经多介质过滤器15和保安过滤器16过滤；反渗透脱盐模块23：利用高压泵7增加海水侧的压力，把海水中的水分子压到反渗透膜组件18中渗透膜的另一侧，产生淡水，送至产水水箱19；后处理模块24：利用能量回收装置有效回收海水淡化过程中的能量，达到节能效果；控制模块25：控制整个流程的进行；利用本装置可将海水变成淡水，用于生活用水。

[0025]　进一步地，预处理模块22包括抽水管、给水泵14、多介质过滤器15和保安过滤器

16，取水箱21通过抽水管连通多介质过滤器15，给水泵14安装在抽水管上，多介质过滤器15连通保安过滤器16，保安过滤器16连通反渗透脱盐模块23。

[0026]　进一步地，多介质过滤器15型号为HKY-DZL08；保安过滤器16为袋式过滤器。

[0027]　进一步地，反渗透脱盐模块包括进水管、高压泵17、反渗透膜组件18和产水水箱19，保安过滤器16通过进水管连通反渗透膜组件18，高压泵安装在进水管上，反渗透膜组件18连通产水水箱19。

[0028]　进一步地，后处理模块24包括能量回收装置20，所述能量回收装置20为PX-45S正位移式压力交换器，所述保安过滤器16出水口，所述反渗透膜组件18出水口分别连通所述能量回收装置20进水口，所述能量回收装置20出水口连通所述反渗透膜组件18进水口。

[0029]　所述保安过滤器16的出水管道流出的低压海水从一端进入所述能量回收装置20，所述反渗透膜组件18出口的高压浓盐水从另一端进入所述能量回收装置20，压力能量在所述能量回收装置20内进行交换后，低压海水转变成高压海水流出到所述高压泵17与所述反渗透膜组件18之间的进水管中。

[0030]　进一步地，反渗透膜组件18采用八个八英寸陶氏海水膜元件分装在四个压力膜壳内，四个压力膜壳依次从上向下叠加排列，高压泵17连通四个压力膜壳的左端，四个压力膜壳的右端连通产水水箱19。

进一步地，陶氏海水膜元件为SW30HRLE-400型号；压力膜壳采用R8040C100S-4W，1000psi，4芯。

[0031]　本发明的工作过程：

在小型海岛上距海边一定距离的高山上建一个蓄水池作为系统的高位蓄水池5，在山顶蓄水池周边风流条件较好处设置风力发电机2，在山坡向阳处铺设光伏电池板组成的光伏阵列1，利用海洋作为低位蓄水池7，在高位蓄水池5和低位蓄水池7之间连接通道上设置可逆式水泵水轮机组6，该可逆式水泵水轮机组6具有将所述的低位蓄水池7的水抽取到所述的高位蓄水池5中的水泵工况10以及将所述高位蓄水池的水下流到低位蓄水池7用于发电的水轮机工况11，形成的风能-光能-海水抽蓄一体化的发电系统，流程见附图3，再通过控制器4连接反渗透海水淡化装置。

[0032]　①风力发电部分是利用风力机将风能转换为机械能，通过风力发电机将机械能转换为电能，太阳能发电部分是利用光伏电池板的光伏效应将光能转换为电能，再通过控制器对蓄电池充电，经过逆变器对负载供电；

②海水抽水蓄能部分由可逆式水泵水轮机机组、高水位蓄水池、低位蓄水池和通道组成，当运行在水泵工况时可进行抽水，将低位蓄水池的海水抽到高位蓄水池，将电能变成水能蓄起来；运行在水轮机工况时，可利用高低水位海水蓄水池的水位差进行发电，将水能变成电能；在负荷低谷期，可逆式水泵水轮机运行在水泵工况，利用多余的电能将低位蓄水池的水抽到高位蓄水池，将电能变成水能储存起来；在负荷高峰期，可逆式水泵水轮机运行在水轮机工况，利用高低水位蓄水池的水位差发电，将水能变成电能。

[0033]　③逆变器把蓄电池中的直流电变成标准的220V交流电，保证交流电负载设备的正常使用，同时还具有自动稳压功能，可改善风光互补发电系统的供电质量；

④控制器4根据日照强度、风力大小及负载的变化，不断地对蓄电池8的工作状态进行切换和调节，首先是把风能、光能转化而来的电能送给负载，然后多余的风能、光能转化而

来的电能送往蓄电池存储，蓄电池电量存满后将剩余的风能、光能转化而来的电能用于可逆式水泵水轮机组运行抽水工况将电能变成水能储存起来。发电量不能满足负载需要时，控制器把蓄电池的电能送往负载，当蓄电池也不能满足负载时，控制器将可逆式水泵水轮机组的运行工况调整为水轮机工况进行发电供给负载，保证了整个系统工作的连续性和稳定性。⑦蓄电池部分由多块蓄电池组成，在系统中起到能量调节、平衡负载和承担瞬时负荷的作用，它将风光互补发电系统输出的电能转化为化学能储存起来，以备供电不足时使用。

[0034] 本发明采用海水抽水蓄能装置的四大优势：一是以海洋作为低位蓄水池，不需要额外建设低位蓄水池，也不依赖淡水资源，节约建设成本和淡水；二是储能，即将风力发电的多余电能储存起来；三是调峰，即根据负荷变化情况，调整机组频率，对系统进行调峰；四是调频，即依据系统频率的变化，当系统频率超出规定的正常范围时，增大或减小机组的出力，来达到新的平衡，在一定的范围内将控制系统的频率变化，从而保证系统的稳定，以海洋作为低位蓄水池能够充分的利用海水资源；储能的功能可以充分利用风能和太阳能资源；调峰和调频利用了水电机组启停迅速的特点。

[0035] 本发明在传统的风光互补发电系统的基础上进行改进，用海水抽水蓄能电站代替部分蓄电池，一方面增加了蓄电能力，另一方面也增加了系统的稳定性；在系统中配置模块化海水淡化装置，使系统不仅能满足小型海岛居民用电，而且能够提供淡水；同时，本发明能够利用海岛丰富的风能和海水资源，不仅节约了化石能源，而且更解决了常规抽水蓄能电站对淡水资源的依赖问题。

[0036] 以上所述仅是本发明的优选实施方式，应当指出，对于本技术领域的普通技术人员来说，在不脱离本发明技术原理的前提下，还可以做出若干改进和变形，这些改进和变形也应视为本发明的保护范围。

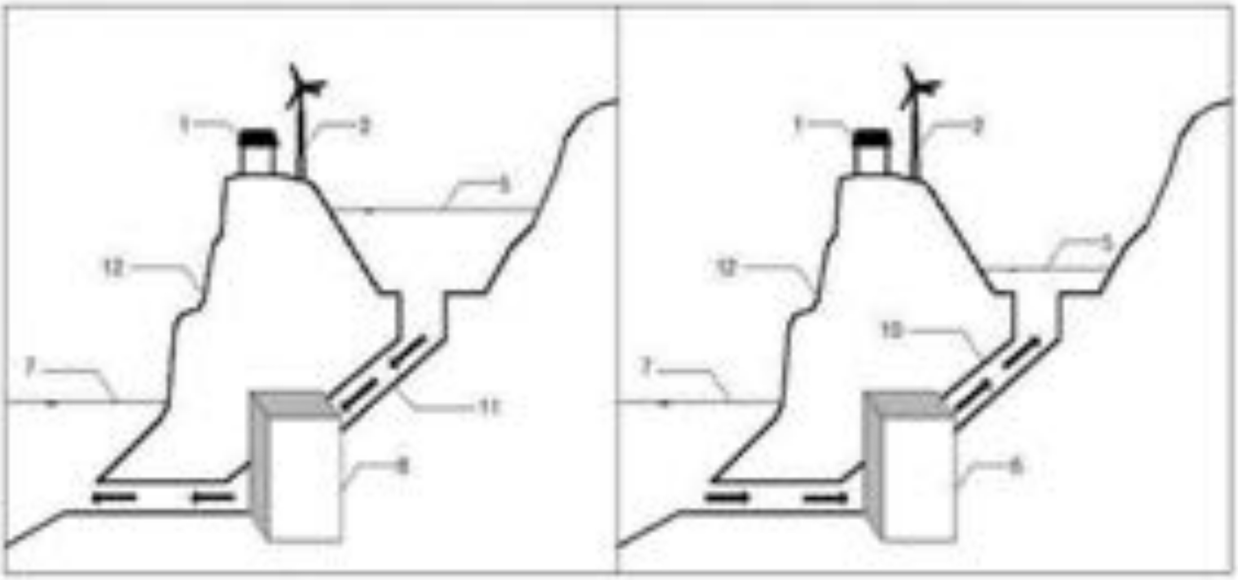

图1

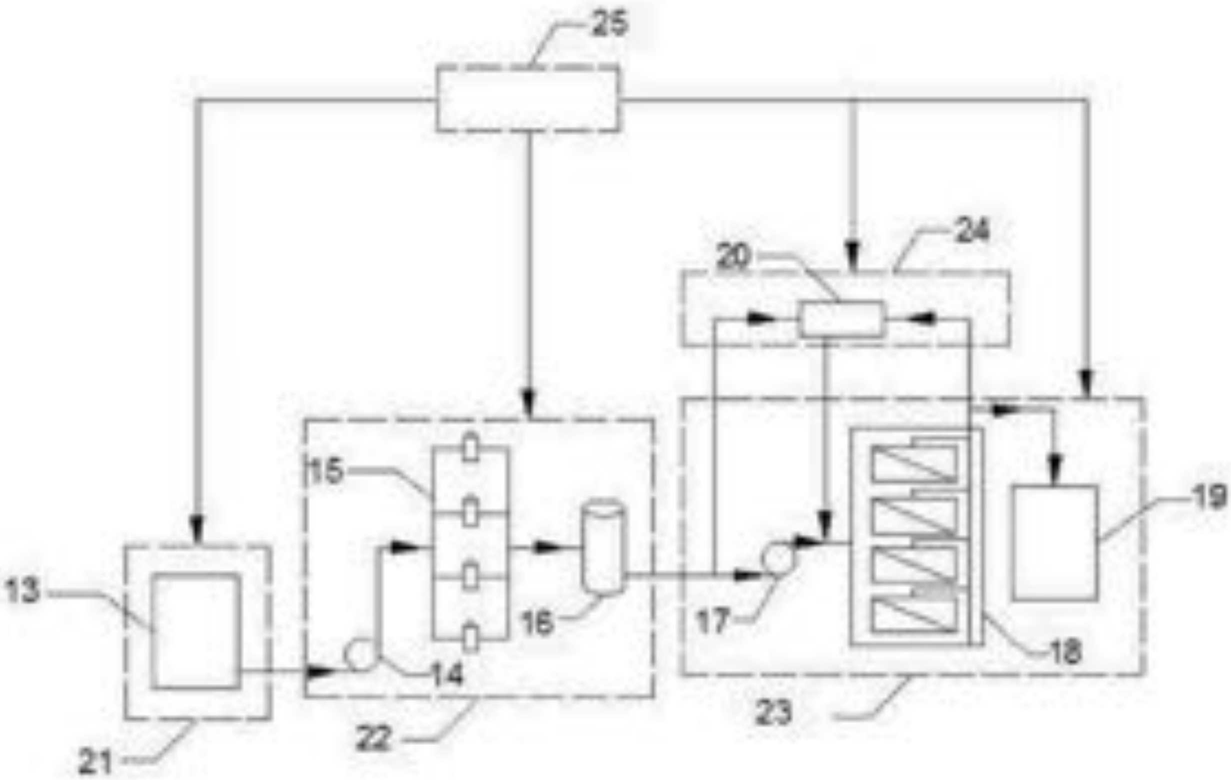

图2

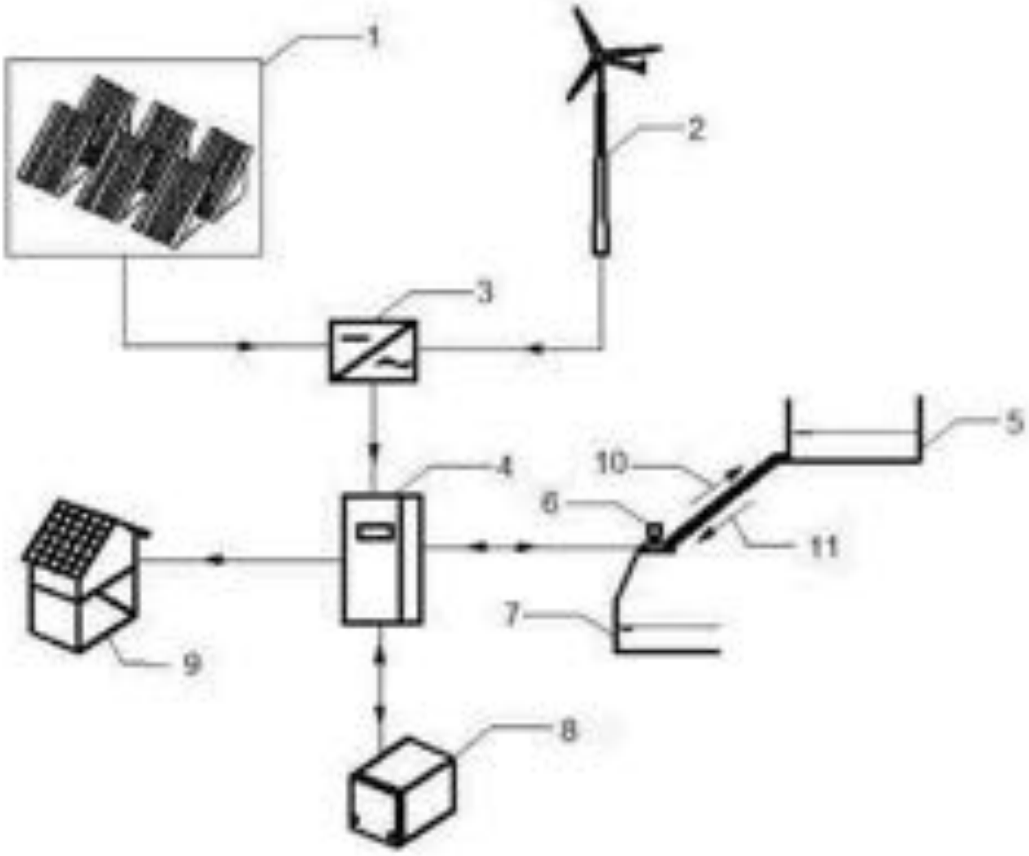

图3

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TI - Reverse osmosis seawater desalination device has reversible pump turbine unit which is mounted on passage, and inverter, reversible pump turbine unit, and battery which are electrically connected to controller respectively

AB - NOVELTY : The device has a photovoltaic array (1) which is provided with multiple equally spaced photovoltaic power generation panels. Wind power generator (2) and photovoltaic array are fixedly arranged on the ground. An inverter is electrically connected to a controller. Higher-level water reservoir (5) is provided with a passage communicating with lower-level water reservoir (7). Valve is mounted on the passage. Reversible pump turbine unit (6) is mounted on the passage. The inverter, reversible pump turbine unit, and battery (8) are electrically connected to a controller respectively.

- USE : Reverse osmosis seawater desalination device integrated with wind energy and seawater energy storage.
- ADVANTAGE : The rapid transformation of characteristics for instability of wind power generation is achieved, so as to facilitate peak shaving and valley filling capacity, frequency modulation, phase modulation and emergent backup power for the system, and strong reliability.
- DESCRIPTION OF DRAWINGS : The drawing shows a sectional view of the reverse osmosis seawater desalination device.

1 : Photovoltaic array
2 : Wind power generator
5 : Higher-level water reservoir
6 : Reversible pump turbine unit
7 : Lower-level water reservoir
8 : Battery

IW - REVERSE OSMOSIS SEA DESALINATE DEVICE PUMP TURBINE UNIT MOUNT PASSAGE INVERTER BATTERY ELECTRIC CONNECT CONTROL RESPECTIVE

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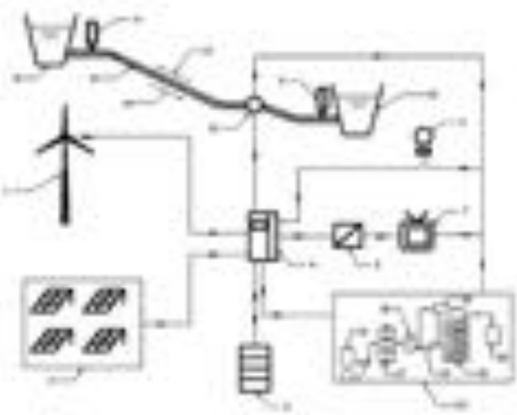
权利要求书 1 页 说明书 3 页 附图 2 页

(54) 发明名称

风光互补发电储能装置

(57) 摘要

本发明公开了一种风光互补发电储能装置，包括风力机、光伏列阵、控制器以及蓄电池，所述的风力机、光伏列阵以及蓄电池均与所述的控制器连接，在所述的控制器上还连接有一抽水蓄能发电装置，该抽水蓄能发电装置包括下水库、上水库以及连接该上水库和下水库的管路，在该管路上设置有可逆式水泵水轮机，该可逆式水泵水轮机具有将所述的下水库的水抽取到所述的上水库中的第一工况以及将所述上水库的水下流到下水库用于发电的第二工况。与现有技术相比，本发明利用抽水蓄能代替部分蓄电池进行蓄能，克服了蓄电池寿命短、成本高、有污染等缺点，同时能提高系统的可靠性和稳定性，并且环保。



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1. 一种风光互补发电储能装置，包括风力机、光伏列阵、控制器以及蓄电池，所述的风力机、光伏列阵以及蓄电池均与所述的控制器连接，其特征在于：在所述的控制器上还连接有一抽水蓄能发电装置，该抽水蓄能发电装置包括下水库、上水库以及连接该上水库和下水库的管路，在该管路上设置有可逆式水泵水轮机，该可逆式水泵水轮机具有将所述的下水库的水抽取到所述的上水库中的第一工况以及将所述上水库的水下流到下水库用于发电的第二工况。

2. 根据权利要求1所述的风光互补发电储能装置，其特征在于：在所述的控制器上还连接有海水淡化装置，该海水淡化装置包括：取水箱、给水泵、多介质过滤器、保安过滤器、高压泵、反渗透膜组件、产水水箱和管道，取水箱、多介质过滤器、保安过滤器、反渗透膜组件、产水水箱通过所述的管道依次串联，所述的给水泵一端与取水箱连接，另一端与所述的多介质过滤器连接，所述的高压泵设置在所述的反渗透膜组件的海水侧。

风光互补发电储能装置

技术领域

[0001]　本发明涉及风光互补技术、风力发电技术、太阳能发电技术、抽水蓄能技术、海水淡化技术、高效智能控制技术等技术领域，具体是一种风力发电和太阳能发电互补与抽水蓄能结合的发电装置。

背景技术

[0002]　在我国很多偏远海岛，电网很难到达，大部分地区采用柴油机发电，随着石油的短缺和油价的上涨，发电成本飞速上涨，电能的紧缺严重制约了这些地区的经济开发和居民或驻军的日常生活。而这些地区，往往有丰富的可再生能源，如太阳能、风能等，为解决偏远地区用电提供了良好的先天条件。针对这些情况，现在的海岛多采用风光互补系统进行供电。

[0003]　风光互补系统主要由风力发电机组、太阳能光伏电池组、控制器、蓄电池、逆变器、交流直流负载等部分组成，系统结构图见附图1。①风力发电部分是利用风力机将风能转换为机械能，通过风力发电机将机械能转换为电能，再通过控制器对蓄电池充电，经过逆变器对负载供电；②光伏发电部分利用太阳能电池板的光伏效应将光能转换为电能，然后对蓄电池充电，通过逆变器将直流电转换为交流电对负载进行供电；③逆变系统由一台或几台逆变器组成，把蓄电池中的直流电变成标准的220V交流电，保证交流电负载设备的正常使用。同时还具有自动稳压功能，可改善风光互补发电系统的供电质量；④控制部分根据日照强度、风力大小及负载的变化，不断对蓄电池组的工作状态进行切换和调节：一方面把调整后的电能直接送往直流或交流负载。另一方面把多余的电能送往蓄电池组存储。发电量不能满足负载需要时，控制器把蓄电池的电能送往负载，保证了整个系统工作的连续性和稳定性；⑤蓄电池部分由多块蓄电池组成，在系统中同时起到能量调节和平衡负载两大作用。它将风力发电系统和光伏发电系统输出的电能转化为化学能储存起来，以备供电不足时使用。在目前的风光互补系统中，一般采用蓄电池蓄能，但蓄电池寿命短、成本高、有污染，且不能大量储存电能。

发明内容

[0004]　技术问题：本发明所要解决的技术问题是针对上述现有技术的不足，而提供一种能永久储存更大能量的且无污染的风光互补发电储能装置。

[0005]　技术方案：为解决上述技术问题，本发明采用的技术方案是：一种风光互补发电储能装置，包括风力机、光伏列阵、控制器以及蓄电池，所述的风力机、光伏列阵以及蓄电池均与所述的控制器连接，其特征在于：在所述的控制器上还连接有一抽水蓄能发电装置，该抽水蓄能发电装置包括下水库、上水库以及连接该上水库和下水库的管路，在该管路上设置有可逆式水泵水轮机，该可逆式水泵水轮机具有将所述的下水库的水抽取到所述的上水库中的第一工况以及将所述上水库的水下流到下水库用于发电的第二工况。

[0006]　在所述的控制器上还连接有海水淡化装置，该海水淡化装置包括：取水箱、给水

泵、多介质过滤器、保安过滤器、高压泵、反渗透膜组件、产水水箱和管道，取水箱、多介质过滤器、保安过滤器、反渗透膜组件、产水水箱通过所述的管道依次串联，所述的给水泵一端与取水箱连接，另一端与所述的多介质过滤器连接，所述的高压泵设置在所述的反渗透膜组件的海水侧。

[0007] 本发明抽水蓄能发电系统能够大量储存电能，且启动迅速，爬坡卸荷速度快，运行灵活可靠，既能削峰又可填谷，其快速转变的灵活性可弥补风力发电和太阳能发电的随机性和不均匀性，为系统提供更多的调峰填谷容量和调频、调相、紧急事故备用电源等，同时具有能量生产可靠和环保等优点。因此，本发明巧妙地将抽水蓄能与风光互补系统结合，一方面可以代替蓄电池对整个系统进行储能，另一方面也提高了整个系统的稳定性。系统中仍配备了小容量的蓄电池，用来承担瞬时峰荷，增加了系统的稳定性。同时，针对海岛中缺乏淡水的问题，该系统结合了海水淡化装置，作为该系统的一个负荷，有效地解决了海岛用淡水的问题。

[0008] 本发明有效地将风能和太阳能进行互补发电，弥补了风能和太阳能的间歇性和不稳定性。同时，将抽水蓄能电站与风力发电和太阳能发电相结合，在系统中的风电和太阳能发电供给负荷有多余电能时，利用可逆式水泵水轮机的水泵工况进行抽水，将下水库的水抽到上水库，将多余的电能变成水能储存起来；在风电和太阳能发电供给负荷电能不足时，利用可逆式水泵水轮机的水轮机工况进行发电，将水能变成电能，供给负荷用电，将风力发电和太阳能发电与抽水蓄能电站结合起来，不仅能够大量储存电能，而且提高了系统的稳定性。将海水淡化装置作为系统负载的一部分，可以给居民提供淡水。

[0009] 有益效果：针对偏远海岛常规能源匮乏、缺乏电能和淡水等问题，利用本发明装置，不仅能有效利用当地丰富的风能和太阳能资源，解决当地电能紧缺的问题，而且能够为当地居民提供淡水。本系统稳定、环保，运行成本低。

附图说明

[0010] 图 1 是现有风光互补系统结构图。

[0011] 图 2 是本发明抽水蓄能装置示意图。

[0012] 图 3 是本发明海水淡化装置图。

[0013] 图 4 是本发明装置连接图。

具体实施方式

[0014] 抽水蓄能电站包括可逆式水泵水轮机（有两个工况，水泵工况和水轮机工况）、上水库、下水库，其示意图如附图 2 所示。在负荷低谷期，可逆式水泵水轮机运行在水泵工况，利用多余的电能将下水库的水抽到上水库，将电能变成水能储存起来；在负荷高峰期，可逆式水泵水轮机运行在水轮机工况，利用上下水库的水位差发电，将水能变成电能。

[0015] 海水淡化采用反渗透膜法，其装置图如附图 3 所示。装置由取水系统、给水泵、多介质过滤器、保安过滤器、高压泵、反渗透膜组件、能量回收装置、产水水箱和管道组成。利用取水系统提取海水，利用给水泵将海水送至过滤器，经多介质过滤器和保安过滤器过滤之后，给反渗透膜组件，利用高压泵增加海水侧的压力，把海水中的水分子压到渗透膜的另一侧，产生淡水，送至产水水箱，其中，能量回收装置可有效回收海水淡化过程中的能量，达

到节能效果。利用本装置可将海水变成淡水，可用于生活用水。

[0016] 工作原理：本发明装置如图4所示。该装置包括风力机、太阳能光伏阵列、可逆式水泵水轮机、上水库、下水库、海水淡化装置、控制器、逆变器、交流负载、直流负载及上述设备之间的连接装置。风力机将风能变成电能。太阳能光伏阵列将太阳能变成电能。可逆式水泵水轮机有两个工况，水轮机工况和水泵工况；运行在水轮机工况可利用上下水库的水位差进行发电，将水能变成电能；运行在水泵工况可进行抽水，将下水库的水抽到上水库，将电能变成水能蓄起来，可以通过控制器进行工况之间的转换。海水淡化装置可以将海水变成淡水。逆变器将直流电变成交流电，供给交流负荷。控制器可对风力机的运行状态、太阳能光伏阵列的倾角、蓄电池的充放电、可逆式水泵水轮机的工况、海水淡化装置的状态进行控制。交流负载和直流负载可根据用户需要进行配置，如电灯、电视、音响、冰箱、热水器等。数据采集系统对系统中各设备的运行状态和参数进行采集，给调度系统提供数据。

[0017] 控制器根据风速和太阳辐射控制风力机运行状态和光伏阵列的倾角，将电能供给直流负载，通过逆变器将直流电变成交流电供给交流负载，同时供给海水淡化装置用电。控制器根据风力发电量和太阳能发电量之和与负荷（包括直流负载、交流负载和海水淡化装置）之间的比较，判断电量是否能满足负荷需要，如果满足且有多余电能，则控制器判断蓄电池的状态，如果蓄电池处于欠压状态，则给蓄电池充电，如果当蓄电池充满电时，风力机和光伏阵列发的电能仍有剩余，则控制抽水蓄能电站的可逆式水泵水轮机运行在水泵工况进行抽水，将下水库的水抽到上水库；如果风力发电量和太阳能发电量不能满足负荷需要，则控制抽水蓄能电站的可逆式水泵水轮机运行在水轮机工况进行发电，供给负荷。

[0018] 本发明采用抽水蓄能装置的三大优势：一是储能，即将风电和太阳能发电的多余电能储存起来；二是调峰，即根据负荷变化情况，预先调整水电机组频率，对系统进行调峰；三是调频，即根据系统频率的变化，在系统频率超出规定的正常范围时，增加或减小水电机组的出力，从而达到新的平衡，将系统的频率变化限制在一定的范围内，从而维护系统的稳定。储能的功能能够充分利用风能资源和太阳能资源；调峰和调频利用了水电机组启停迅速的特点。

[0019] 本发明在原有风光互补系统的基础上进行改进，用抽水蓄能电站代替蓄电池，一方面增加了蓄电能力，另一方面也增加了系统的稳定性；在系统中配置海水淡化装置，使系统不仅能满足海岛居民用电，而且能够提供淡水；同时，本发明能够利用海岛丰富的风能和太阳能这两种可再生能源和清洁能源，不仅节约了常规能源，而且更环保。

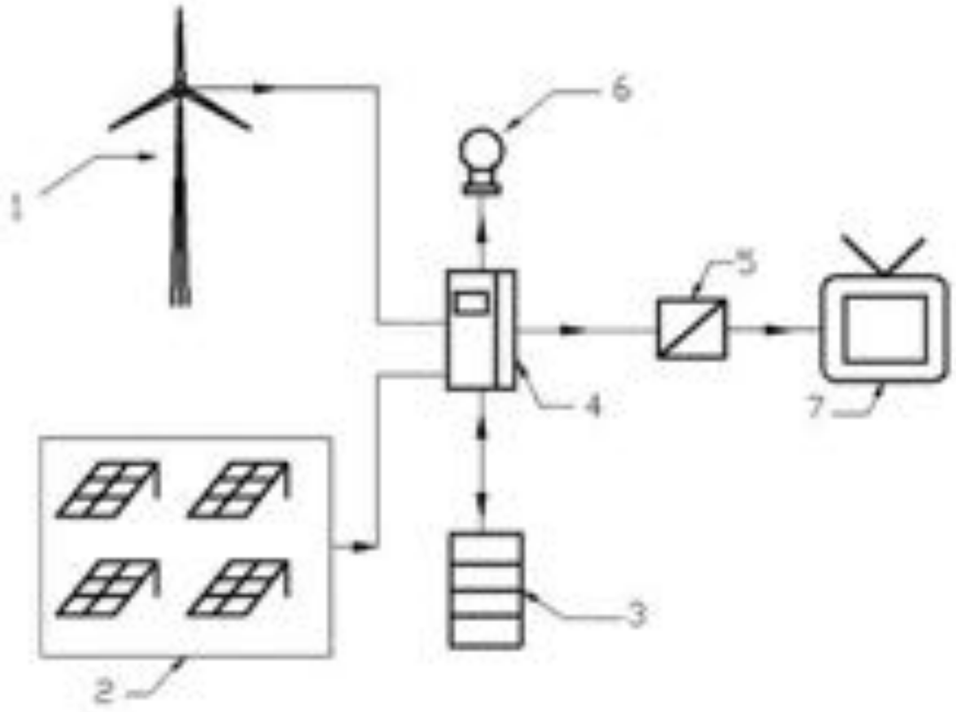

图 1

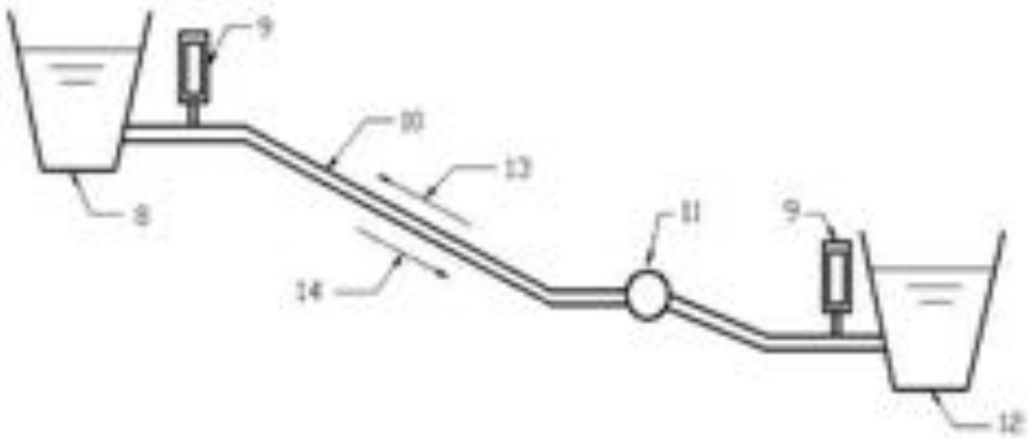

图 2

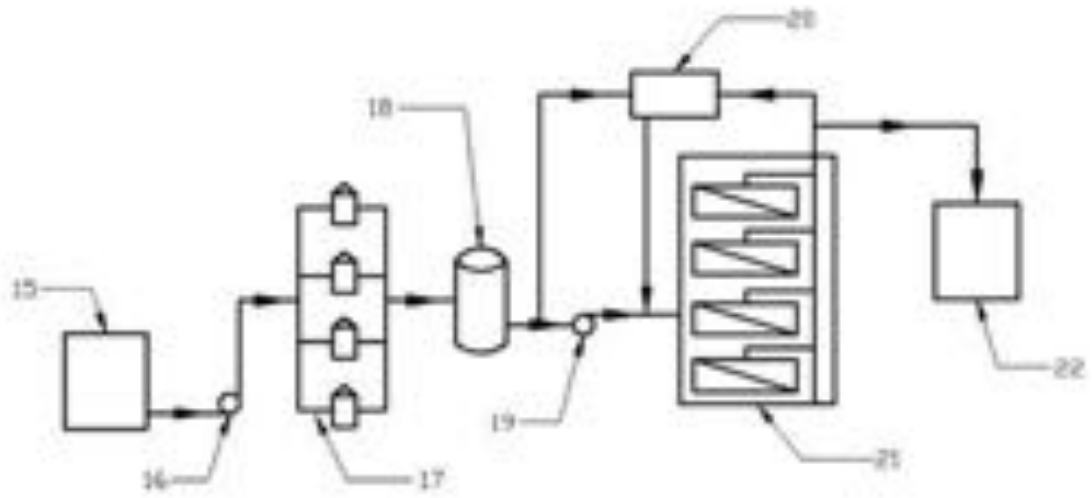
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图 3

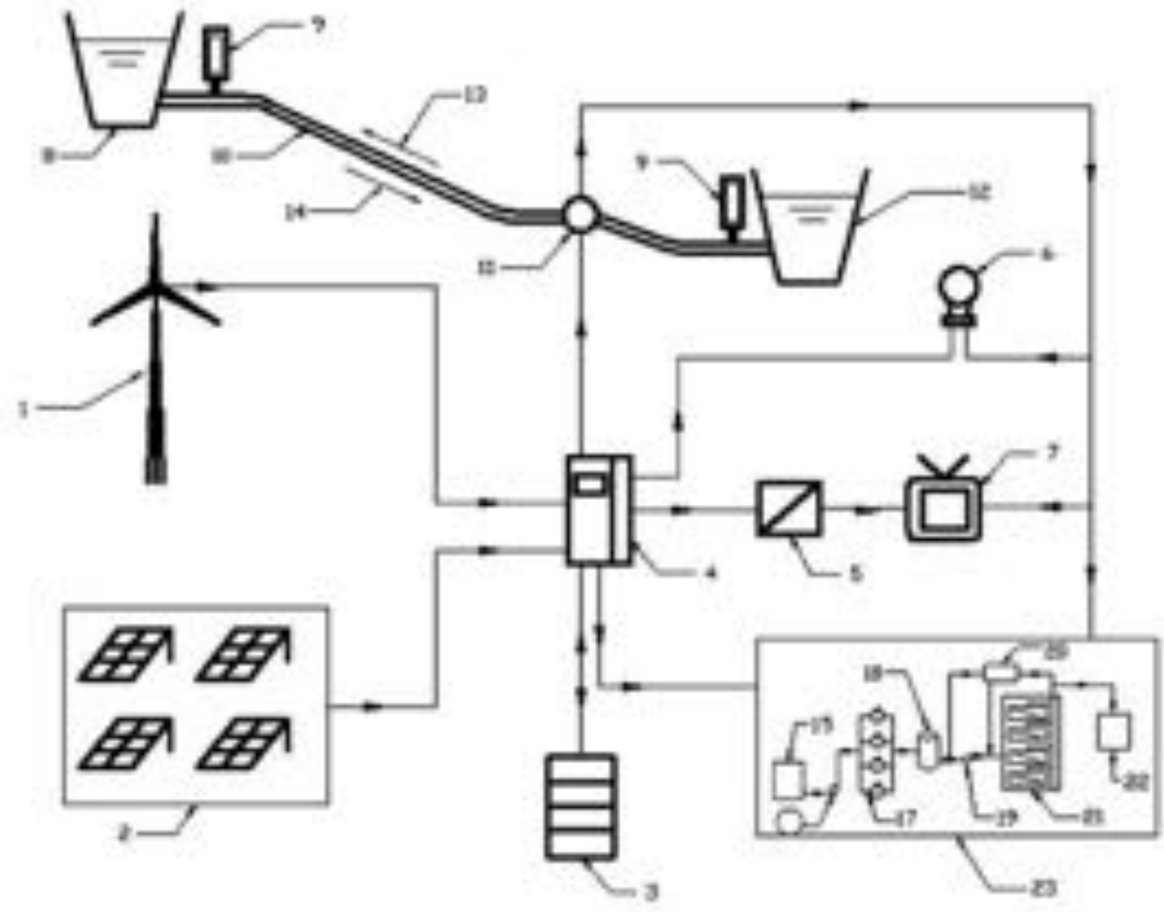
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图 4

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TI - Wind-light complementary generating energy-storing device comprises wind turbine, photovoltaic array, controller and battery

AB - NOVELTY :

A wind-light complementary generating energy-storing device comprises a wind turbine, a photovoltaic array, a controller and a battery. The wind turbine, the photovoltaic array and the battery are connected with the controller. The controller is further connected with a water pumping energy-accumulating generating device. The water pumping energy-accumulating generating device comprises a lower reservoir, an upper reservoir and a pipe for connecting the upper reservoir with the lower reservoir. The pipe is provided with a reverse water pump water turbine.

- DETAILED DESCRIPTION :

A wind-light complementary generating energy-storing device comprises a wind turbine, a photovoltaic array, a controller and a battery. The wind turbine, the photovoltaic array and the battery are connected with the controller. The controller is further connected with a water pumping energy-accumulating generating device. The water pumping energy-accumulating generating device comprises a lower reservoir, an upper reservoir and a pipe for connecting the upper reservoir with the lower reservoir. The pipe is provided with a reverse water pump water turbine. The reverse water pump turbine is provided with a first working condition for pumping the water of the lower reservoir to the upper reservoir and a second working condition for flowing the water of the upper reservoir to the lower reservoir to generate electricity.

- USE :

A wind-light complementary generating energy-storing device.

- ADVANTAGE :

The device accumulates energy through replacing part battery by water pumping energy accumulation to accumulate energy, avoids deficiencies of short service life, high cost and pollution of the battery, and can improve reliability and stability of system, and is environment-friendly.

- DESCRIPTION OF DRAWINGS :

The drawing shows a sectional view of a wind-light complementary generating energy-storing device.

IW - WIND LIGHT COMPLEMENTARY GENERATE ENERGY STORAGE DEVICE COMPRISE TURBINE PHOTOVOLTAIC ARRAY CONTROL BATTERY

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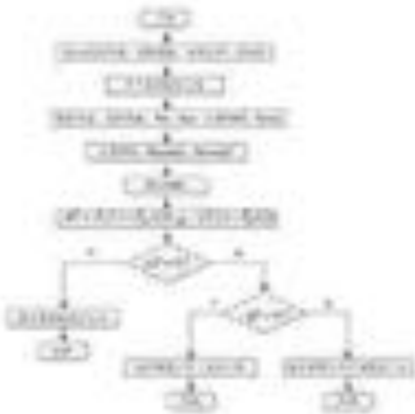
权利要求书3页 说明书7页 附图2页

(54) 发明名称

一种风－光－抽蓄－海水淡化复合系统能量管理方法

(57) 摘要

本发明公开了一种风－光－抽蓄－海水淡化复合系统的能量管理方法，风－光－抽蓄－海水淡化复合系统主要有四部分组成：风力发电部分、光伏发电部分、抽水蓄能电站、海水淡化系统。本发明的能量管理方法基于常规负荷大小、海水淡化机组负荷大小、用水需求量、可再生能源出力等因素确定剩余功率的大小，根据剩余功率的大小判断抽水蓄能机组是否满足运行条件，若抽水蓄能机组满足运行条件，进一步确定其运行工况。该方法可以有效弥补风力发电、光伏发电的随机性与不均匀性，能够克服对柴油机等传统能源方式的依赖，适用于海岛及偏远地区，可为解决海岛及偏远地区的用能、用水问题提供一种有效途径。



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1. 一种风-光-抽蓄-海水淡化复合系统能量管理方法，所述风-光-抽蓄-海水淡化复合系统包含风力发电部分、光伏发电部分、抽水蓄能电站和海水淡化系统，其中，抽水蓄能电站的抽水蓄能机组包含用于发电的水轮机机组和用于抽水的水泵机组；

其特征在于，所述管理方法包含以下具体步骤：

步骤1)，以小时平均风速为单位采集风速数据，以小时平均光照强度为单位采集光照资源数据；

步骤2)，根据风速数据、光照强度数据、风机数量N_w、光伏组件数量N_{pv}计算出风力发电部分、光伏发电部分出力；

步骤3)，确定风-光-抽蓄-海水淡化复合系统中的常规负荷$P_1(t)$，即t时刻风-光-抽蓄-海水淡化复合系统中除去海水淡化系统的机组负荷外的基本生产和生活用电负荷，以小时平均负荷为单位；

步骤4)，确定海水淡化系统中海水淡化需求及海水淡化机组运行数量，计算风-光-抽蓄-海水淡化复合系统的剩余功率，进而根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作。

2. 根据权利要求1所述的风-光-抽蓄-海水淡化复合系统能量管理方法，其特征在于，所述步骤4)中，当前淡水蓄水池蓄水量充足时的具体步骤如下：

步骤4.1)根据以下公式确定当前淡水蓄水池蓄水量充足：

$$S_d(t-1)-S_{d,min}\geq Q_h(t)$$

$$N_d(t)=0$$

其中，$S_d(t-1)$为第t-1小时末淡水蓄水池蓄水量，$S_{d,min}$为保证应急用水淡水蓄水池的最小蓄水量，$Q_h(t)$为第t小时海岛用水需求量，$N_d(t)$为第t时刻海水淡化机组运行数量；

步骤4.2)，不启动海水淡化机组，$P_d(t)=0$，其中，$P_d(t)$为t时段海水淡化系统用电负荷；

步骤4.3)，根据以下公式计算风-光-抽蓄-海水淡化复合系统的剩余功率：

$$\Delta P=P_w(t)+P_{pv}(t)\eta_{inv}-P_d(t)-P_1(t)$$

其中，ΔP为剩余功率，$P_w(t)$为t时段风力发电部分输出功率，$P_{pv}(t)$为t时段光伏发电部分输出功率，η_{inv}为光伏逆变器转换效率；

步骤4.4)，根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作：

当$\Delta P=0$时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组不运行；

当$\Delta P>0$时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水，$P_p(t)=P_w(t)+P_{pv}(t)\eta_{inv}-P_1(t)$，$P_p(t)$为t时刻水泵工况所消耗的功率；

当$\Delta P<0$时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水轮机工况，进行发电，$P_t(t)=P_1(t)-(P_w(t)+P_{pv}(t)\eta_{inv})$，$P_t(t)$为t时刻水轮机工况出力。

3. 根据权利要求1所述的风-光-抽蓄-海水淡化复合系统能量管理方法，其特征在于，所述步骤4)中，当前淡水蓄水池蓄水量不足，且在满足用户用水需求前提下，抽水蓄能电站中全部机组开启在一小时内无法超过蓄水池上限时的具体步骤如下：

步骤4.a)，根据以下公式确定当前淡水蓄水池蓄水量不足，且在满足用户用水需求前提下，抽水蓄能电站中全部机组开启在一小时内无法超过蓄水池上限：

$S_d(t-1)-S_{d,min}<Q_x(t)$

$S_d(t-1)+N_d(t)\times O_d-Q_x(t)\le S_{d,min}$

$$N_{d,min}(t)=\frac{Q_x(t)-(S_d(t-1)-S_{d,min})}{O_d}$$

$P_{d,min}(t)=N_{d,min}(t)\times P_{d0}$

$N_{d,max}(t)=N_d$

$P_{d,max}(t)=N_{d,max}(t)\times P_{d0}$

其中，$S_d(t-1)$为第t-1小时末淡水蓄水池蓄水量，$S_{d,min}$为保证应急用水淡水蓄水池的最小蓄水量，$S_{d,max}$为淡水蓄水池的蓄水上线，$Q_x(t)$为第t小时海岛用水需求量，$N_d(t)$为第t时刻海水淡化机组运行数量，O_d为单台海水淡化机组每小时产水量，$N_{d,min}(t)$为第t小时可开启的海水淡化机组数量下限，$N_{d,max}(t)$为第t小时可开启的海水淡化机组数量上限，N_d为海水淡化机组总数量，P_{d0}为单台海水淡化机组额定功率，$P_{d,min}(t)$为第t小时海水淡化负荷功率下限，$P_{d,max}(t)$为第t小时海水淡化负荷功率上限；

步骤4.b)，根据以下公式计算风-光-抽蓄-海水淡化复合系统的剩余功率：

$\Delta P=P_w(t)+P_{pv}(t)\eta_{ac}-P_d(t)-P_l(t)$

步骤4.c)，根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作：

$P_w(t)+P_{pv}(t)\eta_{ac}-P_{d,max}(t)-P_l(t)\le\Delta P\le P_w(t)+P_{pv}(t)\eta_{ac}-P_{d,min}(t)-P_l(t)$

当$\Delta P=0$时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组不运行；

当$\Delta P>0$时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水：

$P_p(t)=P_w(t)+P_{pv}(t)\eta_{ac}-(P_l(t)+P_d(t))$

$P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

其中$P_p(t)$为t时刻水泵工况所消耗的功率；

当$\Delta P<0$时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水轮机工况，进行发电：

$P_t(t)=P_l(t)+P_d(t)-(P_w(t)+P_{pv}(t)\eta_{ac})$

$P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

其中$P_t(t)$为t时刻水轮机工况出力。

4.根据权利要求1所述的风-光-抽蓄-海水淡化复合系统能量管理方法，其特征在于，所述步骤4)中，当前淡水蓄水池蓄水量较低，且在满足用户用水需求前提下，抽水蓄能电站中全部机组开启在一小时内必定超过蓄水池上限时的具体步骤如下：

步骤4.A)，根据以下公式确定当前淡水蓄水池蓄水量较低，且在满足用户用水需求前提下，抽水蓄能电站中全部机组开启在一小时内必定超过蓄水池上限。

$S_d(t-1)+N_d(t)\times O_d-Q_x(t)\ge S_{d,max}$

$$N_{d,max}(t)=\frac{Q_x(t)+S_{d,max}-S_d(t-1)}{O_d}$$

$P_{d,max}(t)=N_{d,max}(t)\times P_{d0}$

$$N_{d,min}(t)=\frac{Q_s(t)-(S_d(t-1)-S_{d,min})}{O_d}$$

$P_{d,min}(t)=N_{d,min}(t)\times P_{d0}$

其中，$S_d(t-1)$为第t-1小时末淡水蓄水池蓄水量，$S_{d,min}$为保证应急用水淡水蓄水池的最小蓄水量，$S_{d,max}$为淡水蓄水池的蓄水上线，$Q_s(t)$为第t小时海岛用水需求量，$N_d(t)$为第t时刻海水淡化机组运行数量，O_d为单台海水淡化机组每小时产水量，$N_{d,min}(t)$为第t小时可开启的海水淡化机组数量下限，$N_{d,max}(t)$为第t小时可开启的海水淡化机组数量上限；N_d为海水淡化机组总数量，P_{d0}为单台海水淡化机组额定功率，$P_{d,min}(t)$为第t小时海水淡化负荷功率下限，$P_{d,max}(t)$为第t小时海水淡化负荷功率上限；

步骤4.B)，根据以下公式计算风-光-抽蓄-海水淡化复合系统的剩余功率：

$\Delta P=P_w(t)+P_{pv}(t)\eta_{LD}-P_d(t)-P_l(t)$

步骤4.C)，根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作：

$P_w(t)+P_{pv}(t)\eta_{LD}-P_{d,max}(t)-P_l(t)\le\Delta P\le P_w(t)+P_{pv}(t)\eta_{LD}-P_{d,min}(t)-P_l(t)$

当$\Delta P=0$时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组不运行；

当$\Delta P>0$时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水：

$P_p(t)=P_w(t)+P_{pv}(t)\eta_{LD}-(P_l(t)+P_d(t))$

$P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

其中$P_p(t)$为t时刻水泵工况所消耗的功率；

当$\Delta P<0$时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能工作于水轮机工况，进行发电：

$P_t(t)=P_l(t)+P_d(t)-(P_w(t)+P_{pv}(t)\eta_{LD})$

$P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

其中$P_t(t)$为t时刻水轮机工况出力。

5.根据权利要求1所述的风-光-抽蓄-海水淡化复合系统能量管理方法，其特征在于，所述步骤4)中，所述的风力发电部分、光伏发电部分出力不能满足常规负荷及海水淡化基本负荷，抽水蓄能工作于水轮机工况进行发电，水轮机工况出力仍不能满足负荷缺口时，则水轮机工况的出力为其当时条件下的最大出力。

一种风-光-抽蓄-海水淡化复合系统能量管理方法

技术领域

[0001] 本发明涉及可再生能源综合利用系统能量管理领域，特别是涉及一种风-光-抽蓄-海水淡化复合系统能量管理方法。

背景技术

[0002] 环境污染和能源紧缺是人类生存亟待解决的两大难题。在全球变暖的碳减排压力和化石能源不可持续的危机之下，世界各国以风能、太阳能为代表的可再生能源开发利用步伐日益加快。随着可再生新能源发电占比的不断提高，稳定发电出力波动、增强可调节性、改善电网消纳能力等面临巨大挑战。

[0003] 可再生能源发电系统的核心问题是解决发电出力与负荷的平衡问题。储能技术是消除可再生能源大规模开发利用瓶颈的关键技术，可弥补风电、光伏发光电的不可预测性，提高能源利用效率，改善电网电能质量。

[0004] 抽水蓄能是目前唯一商业最成熟的大规模储能技术，能够很好的起到削峰填谷的作用。由于太阳能和风能在时间分布上具有很强的互补性，风光天然的互补性可以有效的减小峰谷差，从而可以降低对抽水蓄能的要求，使抽水蓄能机组的规模大大降低，降低投资，以更好的适应市场的要求。

[0005] 海岛的核心需求是用能、用水。可再生能源系统与海水淡化结合，可以有效解决海岛的用能、用水问题。同时，海水淡化对可再生能源系统出力具有很好的适应性，能够在系统的能量平衡方面承担重要的角色。

[0006] 基于上述分析，提出了一种针对风-光-抽蓄-海水淡化复合系统的能量管理方法，可以有效克服风力发电、光伏发电的随机性、波动性问题，可为解决海岛及偏远地区的用能、用水问题提供一种有效途径。

发明内容

[0007] 本发明所要解决的技术问题是针对背景技术中所涉及到的缺陷，提供一种风-光-抽蓄-海水淡化复合系统能量管理方法。

[0008] 本发明为解决上述技术问题采用以下技术方案：

[0009] 一种风-光-抽蓄-海水淡化复合系统能量管理方法，风-光-抽蓄-海水淡化复合系统包含风力发电部分、光伏发电部分、抽水蓄能电站和海水淡化系统，其中，抽水蓄能电站的抽水蓄能机组包含用于发电的水轮机机组和用于抽水的水泵机组；

[0010] 所述管理方法包含以下具体步骤：

[0011] 步骤1)、以小时平均风速为单位采集风速数据，以小时平均光照强度为单位采集光照资源数据；

[0012] 步骤2)、根据风速数据、光照强度数据、风机数量N_w、光伏组件数量N_{pv}计算出风力发电部分、光伏发电部分出力；

[0013] 步骤3)、确定风-光-抽蓄-海水淡化复合系统中的常规负荷$P_1(t)$，即t时刻风-光-

抽蓄-海水淡化复合系统中除去海水淡化系统的机组负荷外的基本生产和生活用电负荷，以小时平均负荷为单位；

[0014]　步骤4)，确定海水淡化系统中海水淡化需求及海水淡化机组运行数量，计算风-光-抽蓄-海水淡化复合系统的剩余功率，进而根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作。

[0015]　作为本发明一种风-光-抽蓄-海水淡化复合系统能量管理方法进一步的优化方案，所述步骤4)中，当前淡水蓄水池蓄水量充足时的具体步骤如下：

[0016]　步骤4.1)根据以下公式确定当前淡水蓄水池蓄水量充足：

[0017]　$S_d(t-1)-S_{d,min}\geq Q_w(t)$

[0018]　$N_d(t)=0$

[0019]　其中，$S_d(t-1)$为第t-1小时末淡水蓄水池蓄水量，$S_{d,min}$为保证应急用水淡水蓄水池的最小蓄水量，$Q_w(t)$为第t小时海岛用水需求量，$N_d(t)$为第t时刻海水淡化机组运行数量；

[0020]　步骤4.2)，不启动海水淡化机组，$P_d(t)=0$，其中，$P_d(t)$为t时段海水淡化系统用电负荷；

[0021]　步骤4.3)，根据以下公式计算风-光-抽蓄-海水淡化复合系统的剩余功率：

[0022]　$\Delta P=P_w(t)+P_{pv}(t)\eta_{inv}-P_d(t)-P_l(t)$

[0023]　其中，ΔP为剩余功率，$P_w(t)$为t时段风力发电部分输出功率，$P_{pv}(t)$为t时段光伏发电部分输出功率，η_{inv}为光伏逆变器转换效率；

[0024]　步骤4.4)，根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作：

[0025]　当$\Delta P=0$时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组不运行；

[0026]　当$\Delta P>0$时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水，$P_p(t)=P_w(t)+P_{pv}(t)\eta_{inv}-P_l(t)$，$P_p(t)$为t时刻水泵工况所消耗的功率；

[0027]　当$\Delta P<0$时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水轮机工况，进行发电，$P_t(t)=P_l(t)-(P_w(t)+P_{pv}(t)\eta_{inv})$，$P_t(t)$为t时刻水轮机工况出力。

[0028]　作为本发明一种风-光-抽蓄-海水淡化复合系统能量管理方法进一步的优化方案，所述步骤4)中，当前淡水蓄水池蓄水量不足，且在满足用户用水需求前提下，抽水蓄能电站中全部机组开启在一小时内无法超过蓄水池上限时的具体步骤如下：

[0029]　步骤4.a)，根据以下公式确定当前淡水蓄水池蓄水量不足，且在满足用户用水需求前提下，抽水蓄能电站中全部机组开启在一小时内无法超过蓄水池上限：

[0030]　$S_d(t-1)-S_{d,min}<Q_w(t)$

[0031]　$S_d(t-1)+N_d(t)\times Q_d-Q_w(t)\leq S_{d,max}$

[0032]　$$N_{d,min}(t)=\frac{Q_w(t)-(S_d(t-1)-S_{d,min})}{Q_d}$$

[0033]　$P_{d,min}(t)=N_{d,min}(t)\times P_{d0}$

[0034]　$N_{d,max}(t)=N_d$

[0035] $P_{d,max}(t)=N_{d,max}(t)\times P_{d0}$

[0036] 其中，$S_d(t-1)$为第t-1小时末淡水蓄水池蓄水量，$S_{d,min}$为保证应急用水淡水蓄水池的最小蓄水量，$S_{d,max}$为淡水蓄水池的蓄水上线，$Q_h(t)$为第t小时海岛用水需求量，$N_d(t)$为第t时刻海水淡化机组运行数量，O_d为单台海水淡化机组每小时产水量，$N_{d,min}(t)$为第t小时可开启的海水淡化机组数量下限，$N_{d,max}(t)$为第t小时可开启的海水淡化机组数量上限，N_d为海水淡化机组总数量，P_{d0}为单台海水淡化机组额定功率，$P_{d,min}(t)$为第t小时海水淡化负荷功率下限，$P_{d,max}(t)$为第t小时海水淡化负荷功率上限；

[0037] 步骤4.b)，根据以下公式计算风-光-抽蓄-海水淡化复合系统的剩余功率：

[0038] $\Delta P=P_w(t)+P_{pv}(t)\eta_{DC}-P_d(t)-P_l(t)$

[0039] 步骤4.c)，根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作：

[0040] $P_w(t)+P_{pv}(t)\eta_{DC}-P_{d,max}(t)-P_l(t)\le\Delta P\le P_w(t)+P_{pv}(t)\eta_{DC}-P_{d,min}(t)-P_l(t)$

[0041] 当$\Delta P=0$时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组不运行；

[0042] 当$\Delta P>0$时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水；

[0043] $P_p(t)=P_w(t)+P_{pv}(t)\eta_{DC}-(P_l(t)+P_d(t))$

[0044] $P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

[0045] 其中$P_p(t)$为t时刻水泵工况所消耗的功率；

[0046] 当$\Delta P<0$时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水轮机工况，进行发电；

[0047] $P_t(t)=P_l(t)+P_d(t)-(P_w(t)+P_{pv}(t)\eta_{DC})$

[0048] $P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

[0049] 其中$P_t(t)$为t时刻水轮机工况出力。

[0050] 作为本发明一种风-光-抽蓄-海水淡化复合系统能量管理方法进一步的优化方案，所述步骤4)中，当前淡水蓄水池蓄水量较低，且在满足用户用水需求前提下，抽水蓄能电站中全部机组开启在一小时内必定超过蓄水池上限时的具体步骤如下：

[0051] 步骤4.A)，根据以下公式确定当前淡水蓄水池蓄水量较低，且在满足用户用水需求前提下，抽水蓄能电站中全部机组开启在一小时内必定超过蓄水池上限；

[0052] $S_d(t-1)+N_d(t)\times O_d-Q_h(t)\ge S_{d,max}$

[0053] $$N_{d,max}(t)=\frac{Q_h(t)+S_{d,max}-S_d(t-1)}{O_d}$$

[0054] $P_{d,max}(t)=N_{d,max}(t)\times P_{d0}$

[0055] $$N_{d,min}(t)=\frac{Q_h(t)-(S_d(t-1)-S_{d,min})}{O_d}$$

[0056] $P_{d,min}(t)=N_{d,min}(t)\times P_{d0}$

[0057] 其中，$S_d(t-1)$为第t-1小时末淡水蓄水池蓄水量，$S_{d,min}$为保证应急用水淡水蓄水池的最小蓄水量，$S_{d,max}$为淡水蓄水池的蓄水上线，$Q_h(t)$为第t小时海岛用水需求量，$N_d(t)$为第t时刻海水淡化机组运行数量，O_d为单台海水淡化机组每小时产水量，$N_{d,min}(t)$为第t小时可开启的海水淡化机组数量下限，$N_{d,max}(t)$为第t小时可开启的海水淡化机组数量上限；

N_d为海水淡化机组总数量，P_{d0}为单台海水淡化机组额定功率，$P_{d,min}(t)$为第t小时海水淡化负荷功率下限，$P_{d,max}(t)$为第t小时海水淡化负荷功率上限；

[0058] 步骤4.B)，根据以下公式计算风-光-抽蓄-海水淡化复合系统的剩余功率：

[0059] $\Delta P=P_w(t)+P_{pv}(t)\eta_{LD}-P_d(t)-P_l(t)$

[0060] 步骤4.C)，根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作：

[0061] $P_w(t)+P_{pv}(t)\eta_{LD}-P_{d,max}(t)-P_l(t)\leq\Delta P\leq P_w(t)+P_{pv}(t)\eta_{LD}-P_{d,min}(t)-P_l(t)$

[0062] 当$\Delta P=0$时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组不运行；

[0063] 当$\Delta P>0$时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水：

[0064] $P_p(t)=P_w(t)+P_{pv}(t)\eta_{LD}-(P_l(t)+P_d(t))$

[0065] $P_{d,min}(t)\leq P_d(t)\leq P_{d,max}(t)$

[0066] 其中$P_p(t)$为t时刻水泵工况所消耗的功率；

[0067] 当$\Delta P<0$时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能电站中抽水蓄能工作于水轮机工况，进行发电：

[0068] $P_t(t)=P_l(t)+P_d(t)-(P_w(t)+P_{pv}(t)\eta_{LD})$

[0069] $P_{d,min}(t)\leq P_d(t)\leq P_{d,max}(t)$

[0070] 其中$P_t(t)$为t时刻水轮机工况出力。

[0071] 作为本发明一种风-光-抽蓄-海水淡化复合系统能量管理方法进一步的优化方案，所述步骤4)中，所述的风力发电部分、光伏发电部分出力不能满足常规负荷及海水淡化基本负荷，抽水蓄能工作于水轮机工况进行发电，水轮机工况出力仍不能满足负荷缺口时，则水轮机工况的出力为其当时条件下的最大出力。

[0072] 本发明采用以上技术方案与现有技术相比，具有以下技术效果：

[0073] 1.克服风力发电、光伏发电的随机性、波动性，目前大多数可再生能源系统采用蓄电池作为储能装置，但蓄电池寿命短，成本高，有污染，且不能大量存储，抽水蓄能电站能够大量储存电能，且启动迅速，运行灵活可靠，能够有效弥补风力发电和光伏发电的随机性与不均匀性。

[0074] 2.海水淡化系统参与调节，能够实现海水淡化负荷与可再生能源发电单元出力的匹配，根据用户用水需求、淡水蓄水池容量、海水淡化机组数量限制，当风光资源丰富时，尽可能利用海水淡化机组以最大化消耗可再生能源系统出力；当风、光资源相对匮乏时，根据用户用水需求，优先利用淡水蓄水池中储存的水量来满足用户基本用水需求，尽可能减少海水淡化机组启动数量，以实现系统出力与用户用电、用水需求相匹配。

[0075] 3.能够克服对柴油机等传统能源方式的依赖，适用于海岛及偏远地区，为海岛及偏远地区的用能、用水问题提供一种有效途径。

附图说明

[0076] 图1是本发明的风-光-抽蓄-海水淡化复合系统结构示意图。

[0077] 图2是本发明的海水淡化机组运行策略流程图。

[0078] 图3是本发明的风-光-抽蓄-海水淡化复合系统能量交换策略流程图。

具体实施方式

[0079]　下面结合附图对本发明的技术方案做进一步的详细说明：

[0080]　本发明公开了一种风-光-抽蓄-海水淡化复合系统能量管理方法。

[0081]　如图1所示，风-光-抽蓄-海水淡化复合系统包含风力发电部分、光伏发电部分、抽水蓄能电站和海水淡化系统，其中，抽水蓄能电站包含用于发电的水轮机机组和用于抽水的水泵机组。

[0082]　本发明管理方法包含以下具体步骤：

[0083]　步骤1)，以小时平均风速为单位采集风速数据，以小时平均光照强度为单位采集光照资源数据；

[0084]　步骤2)，根据风速数据、光照强度数据、风机数量N_w、光伏组件数量N_{pv}计算出风力发电部分、光伏发电部分出力；

[0085]　步骤3)，确定风-光-抽蓄-海水淡化复合系统中的常规负荷$P_1(t)$，即t时刻风-光-抽蓄-海水淡化复合系统中除去海水淡化系统的机组负荷外的基本生产和生活用电负荷，以小时平均负荷为单位；

[0086]　步骤4)，确定海水淡化系统中海水淡化需求及海水淡化机组运行数量，计算风-光-抽蓄-海水淡化复合系统的剩余功率，进而根据剩余功率控制抽水蓄能电站中抽水蓄能机组工作。

[0087]　海水淡化机组运行数量受用户淡水需求、海水淡化系统淡水蓄水池当前蓄水量、淡水蓄水池总容量等因素的影响，根据这些因素可确定海水淡化机组运行数量的可调范围，从而确定单位时间内海水淡化机组运行所需要消耗功率的上下限，然后再结合可再生能源出力大小、常规负荷大小进一步确定剩余功率，最终根据剩余功率大小判断抽水蓄能机组的运行状态及其工况。

[0088]　如图2和图3所示，步骤4)具体分以下三种情况：

[0089]　第一种情况：当前蓄水量充足时，即

[0090]　$S_d(t-1)-S_{d,min}\geq Q_h(t)$

[0091]　$N_d(t)=0$

[0092]　即无需启动海水淡化机组

[0093]　$P_d(t)=0$

[0094]　其中：$S_d(t-1)$为第t-1小时末淡水蓄水池蓄水量；$S_{d,min}$为保证应急用水淡水蓄水池的最小蓄水量；$Q_h(t)$为第t小时海岛用水需求量；$N_d(t)$为第t时刻海水淡化机组运行数量；

[0095]　$P_d(t)$为t时段海水淡化系统用电负荷。

[0096]　风-光-抽蓄-海水淡化复合系统能量平衡关系：

[0097]　$\Delta P=P_w(t)+P_{pv}(t)\eta_{inv}-P_d(t)-P_1(t)$

[0098]　其中：ΔP为剩余功率；$P_w(t)$为t时段风力发电部分输出功率；$P_{pv}(t)$为t时段光伏发电部分输出功率；η_{inv}为光伏逆变器转换效率。

[0099]　当ΔP=0时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能机组不运行；

[0100] 当 $\Delta P>0$ 时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水，有

[0101] $P_p(t)=P_w(t)+P_{pv}(t)\eta_{ID}-P_1(t)$

[0102] 其中：$P_p(t)$ 为 t 时刻水泵工况所消耗的功率。

[0103] 当 $\Delta P<0$ 时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能机组工作于水轮机工况，进行发电（假设水轮机工况出力足够大），有

[0104] $P_t(t)=P_1(t)-(P_w(t)+P_{pv}(t)\eta_{ID})$

[0105] 其中：$P_t(t)$ 为 t 时刻水轮机工况出力。

[0106] 第二种情况：当前蓄水量不足，且在满足用户用水需求前提下，全部机组开启，在一小时内无法超过蓄水池上限时，即

[0107] $S_d(t-1)-S_{d,min}<Q_n(t)$

[0108] $S_d(t-1)+N_d(t)\times Q_d-Q_n(t)\le S_{d,max}$

[0109] $$N_{d,min}(t)=\frac{Q_n(t)-(S_d(t-1)-S_{d,min})}{Q_d}$$

[0110] $P_{d,min}(t)=N_{d,min}(t)\times P_{d0}$

[0111] $N_{d,max}(t)=N_d$

[0112] $P_{d,max}(t)=N_{d,max}(t)\times P_{d0}$

[0113] 其中：$S_{d,max}$ 为海水淡化系统淡水蓄水池最大蓄水量；Q_d 为单台海水淡化机组每小时产水量；$N_{d,min}(t)$ 为第 t 小时可开启的海水淡化机组数量下限；$N_{d,max}(t)$ 为第 t 小时可开启的海水淡化机组数量上限；N_d 为海水淡化机组总数量；P_{d0} 为单台海水淡化机组额定功率；$P_{d,min}(t)$ 为第 t 小时海水淡化负荷功率下限；$P_{d,max}(t)$ 为第 t 小时海水淡化负荷功率上限。

[0114] 根据风-光-抽蓄-海水淡化复合系统能量平衡关系：

[0115] $\Delta P=P_w(t)+P_{pv}(t)\eta_{ID}-P_d(t)-P_1(t)$

[0116] 有：$P_w(t)+P_{pv}(t)\eta_{ID}-P_{d,max}(t)-P_1(t)\le\Delta P\le P_w(t)+P_{pv}(t)\eta_{ID}-P_{d,min}(t)-P_1(t)$

[0117] 当 $\Delta P=0$ 时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能机组不运行；

[0118] 当 $\Delta P>0$ 时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水，有

[0119] $P_p(t)=P_w(t)+P_{pv}(t)\eta_{ID}-(P_1(t)+P_d(t))$

[0120] $P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

[0121] 其中：$P_p(t)$ 为 t 时刻水泵工况所消耗的功率。

[0122] 当 $\Delta P<0$ 时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能机组工作于水轮机工况，进行发电（假设水轮机工况出力足够大），有

[0123] $P_t(t)=P_1(t)+P_d(t)-(P_w(t)+P_{pv}(t)\eta_{ID})$

[0124] $P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

[0125] 其中：$P_t(t)$ 为 t 时刻水轮机工况出力。

[0126] 第三种情况：当蓄水量较低，且在满足用户用水需求前提下，全部机组开启，在一小时内必定超过蓄水池上限时，即

[0127] $S_d(t-1)+N_d(t)\times Q_d-Q_n(t)\ge S_{d,max}$

[0128] $N_{d,max}(t)=\frac{Q_s(t)+S_{d,max}-S_d(t-1)}{Q_d}$

[0129] $P_{d,max}(t)=N_{d,max}(t)\times P_{d0}$

[0130] $N_{d,min}(t)=\frac{Q_s(t)-(S_d(t-1)-S_{d,min})}{Q_d}$

[0131] $P_{d,min}(t)=N_{d,min}(t)\times P_{d0}$

[0132] 根据风-光-抽蓄-海水淡化复合系统能量平衡关系：

[0133] $\Delta P=P_w(t)+P_{pv}(t)\eta_{LD}-P_d(t)-P_l(t)$

[0134] 有：$P_w(t)+P_{pv}(t)\eta_{LD}-P_{d,max}(t)-P_l(t)\le\Delta P\le P_w(t)+P_{pv}(t)\eta_{LD}-P_{d,min}(t)-P_l(t)$

[0135] 当$\Delta P=0$时，即风、光发电系统输出功率等于海水淡化负荷及常规负荷时，抽水蓄能机组不运行；

[0136] 当$\Delta P>0$时，即风、光发电系统输出功率大于海水淡化负荷及常规负荷时，抽水蓄能机组工作于水泵工况，利用剩余功率进行抽水，有

[0137] $P_p(t)=P_w(t)+P_{pv}(t)\eta_{LD}-(P_l(t)+P_d(t))$

[0138] $P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

[0139] 其中：$P_p(t)$为t时刻水泵工况所消耗的功率。

[0140] 当$\Delta P<0$时，即风、光发电系统输出功率小于海水淡化负荷及常规负荷时，抽水蓄能工作于水轮机工况，进行发电(假设水轮机工况出力足够大)，有

[0141] $P_t(t)=P_l(t)+P_d(t)-(P_w(t)+P_{pv}(t)\eta_{LD})$

[0142] $P_{d,min}(t)\le P_d(t)\le P_{d,max}(t)$

[0143] 其中：$P_t(t)$为t时刻水轮机工况出力。

[0144] 所述的海水淡化系统参与可再生能源系统能量管理作用体现在：根据用户用水需求、淡水蓄水池容量、海水淡化机组数量限制，当风、光资源丰富时，尽可能利用海水淡化机组以最大化消耗可再生能源系统出力；当风、光资源相对匮乏时，根据用户用水需求，优先利用淡水蓄水池中储存的水量来满足用户基本需求，尽可能减少海水淡化机组启动数量，以实现系统出力与用户用电、用水需求相匹配。

[0145] 所述的风、光发电系统出力不能满足常规负荷及海水淡化基本负荷，抽水蓄能工作于水轮机工况，进行发电，若水轮机工况出力仍不能满足负荷缺口时，则水轮机工况的出力为其当时条件下的最大出力。

[0146] 本技术领域技术人员可以理解的是，除非另外定义，这里使用的所有术语(包括技术术语和科学术语)具有与本发明所属领域中的普通技术人员的一般理解相同的意义。还应该理解的是，诸如通用字典中定义的那些术语应该被理解为具有与现有技术的上下文中的意义一致的意义，并且除非像这里一样定义，不会用理想化或过于正式的含义来解释。

[0147] 以上所述的具体实施方式，对本发明的目的、技术方案和有益效果进行了进一步详细说明，所应理解的是，以上所述仅为本发明的具体实施方式而已，并不用于限制本发明，凡在本发明的精神和原则之内，所做的任何修改、等同替换、改进等，均应包含在本发明的保护范围之内。

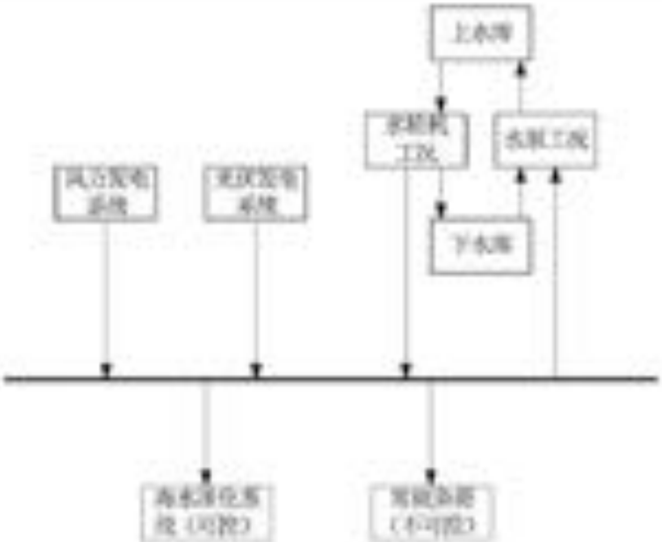
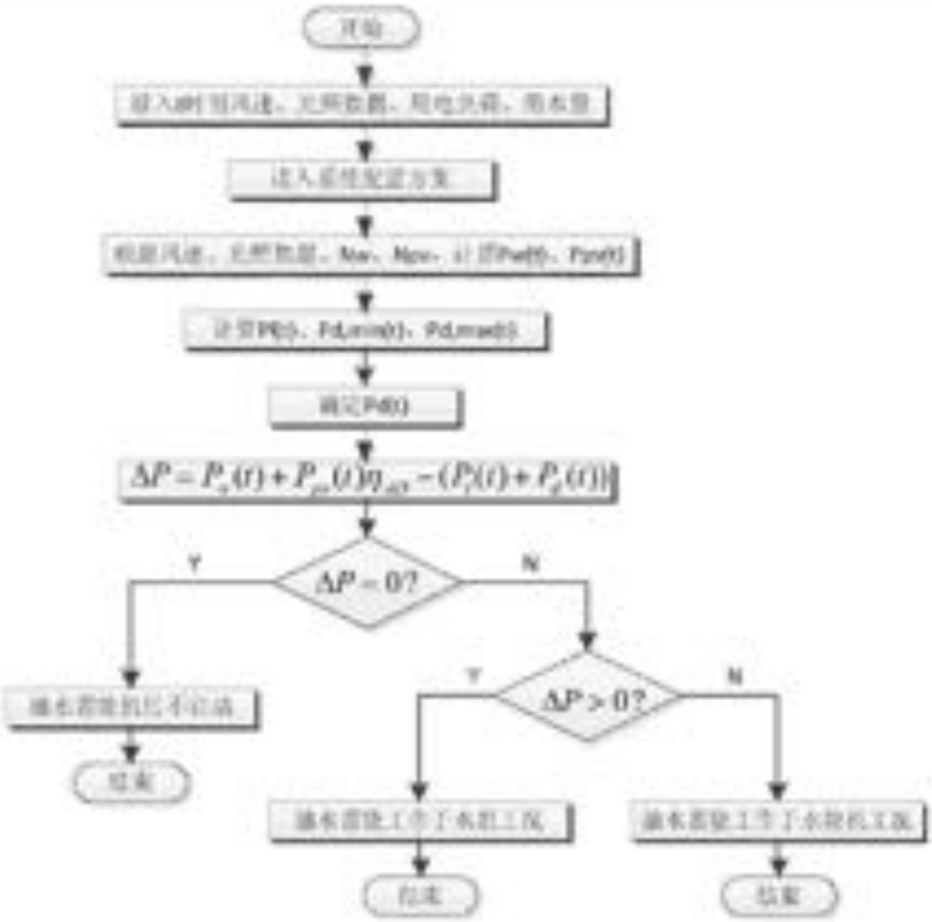


图1

图2


开始
$\Delta P = P_w(t) + P_{pv}(t)\eta_{dc} - (P_l(t) + P_d(t))$
Y
$\Delta P = 0?$
N
Y
$\Delta P > 0?$
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结束
结束
结束

图3

CN105589331A-WPI / 2017 Clarivate Analytics.

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TI - Desalting seawater involves using device, which comprises wind power generation unit, photovoltaic power delivering unit, energy storage power station and sea water desalting unit, where energy storage power station comprises turbine

AB - NOVELTY : Desalting seawater involves using device, which comprises wind power generation unit, photovoltaic power delivering unit, energy storage power station and sea water desalting unit, where energy storage power station comprises turbine used for power generation and pumping unit for water pumping. Method involves measuring average wind speed hourly to collect the wind speed data. Then measured average light intensity hourly to collect the light intensity data. The wind speed data and light intensity data is used to calculated the number of fans is Nw, number of photovoltaic module is Npv.

- DETAILED DESCRIPTION : Desalting seawater involves using device, which comprises wind power generation unit, photovoltaic power delivering unit, energy storage power station and sea water desalting unit, where energy storage power station comprises turbine used for power generation and pumping unit for water pumping. Method involves measuring average wind speed hourly to collect the wind speed data. Then measured average light intensity hourly to collect the light intensity data. The wind speed data and light intensity data is used to calculated the number of fans is Nw, number of photovoltaic module is Npvand output of photovoltaic power deliver unit. Determine the pumping and storing system conventional load P1(t), where t is time of production and domestic use power load. Determined the number of units required for desalination of sea water. Determine the remaining power of pumping and storing unit, then pumping unit worked accordingly to control the remaining power of energy storage power station.
- USE : Method for desalting seawater (claimed).
- ADVANTAGE : The method enables to overcome the dependence on diesel engine and other form of energy, and is also suitable for sea island and remote area.
- ENVIRONMENT : Preferred Process: Fresh water reservoir pondage capacity is determined if the difference of Sdx (difference of t and 1) and Sdmin≥ Qwx (t) and Ndx (t) is equal to 0, where Sd(difference of t and 1) is the amount of fresh water reservoir pondage in t minus one hour, Sdmin is the minimal emergency storage of water storage pool,

Qwx (t) is the t hour of island water demand, Ndx (t) is the t time of the number of operation of water desalting machine. Desalting machine is not started, Pdx (t) is equal to 0, where Pd x (t) is the t period for electric load of sea water desalting system. Remaining power is calculated according to the formula δ P is equal to Pwx (t) +Ppv(t) η ad-Pdx (t)-P1x (t), where δ P is remaining power, Pwx (t) for t times the wind power generation input power, Ppvx (t) is t times the photovoltaic power deliver unit output power, η AD is photovoltaic inverter switching efficiency, Depending on the remaining power control pumped storage power station is set to work, the time when δ P is equal to 0, wind, light power generation system output power is equal to the sea water desalting load and conventional load, the pumped energy storage unit is not working if δ P≯ 0, wind, light power generation system output power greater than sea water desalting load and conventional load. The pumped storage power station of pumped storage units work on the pump operating mode, using remaining power, Ppx (t)=Pwx (t)+Ppvx (t)η ad-P1x (t), where Ppx (t) is t times of power consumed by the water pump, when δ P is ≮ 0, wind, light power generation system output power is less than sea water desalting load and conventional load. The pumped storage power station turbine is set to work, and carried out power generation, Ptx (t) is equal to P1x (t)-(Pwx (t) + Ppvx (t)η ad), where Ptx (t) is the time t outlet force is in working condition. Fresh water reservoir pondage insufficiency is determined by if the deiffernce of Sdand Sdmin≮ Qwx (t), and if sum of Sdx (difference of t and 1) and Ndx (t) multiplied with difference of Odand Qwx (t) is ≤ Sdmax. Pdminx (t) is equal to Ndminx (t) multiplied with Pd0. Ndmaxx (t) is equal to Nd. Pdmaxx (t) is equal to Ndmaxx (t) multiplied with Pd0, where Sdmax is storage capacity of fresh water storage pool, Odis the production of one sea water desalting machine per hour, Ndminx (t) is the minimum number of hours when desalination unit is opened, and Ndmaxx (t) is the maximum number of hours when desalination unit is opened, Ndis the total number of desalting machine, Pd0is the rated power of the single sea water desalting machine, Pdminx (t) is sea water desalting load power minimum limit in t hours, Pdmaxx (t) is is sea water desalting load power minimum limit in t hours. Remainig power is calculated as follows: δ P is equal to difference of sum of Pwx (t) and Ppvx (t)η ad, and sum of Pdx (t) and Plx (t). Depending on the remaining power control pumped storage power station is set to work if difference of sum of Pwx (t) and Ppvx (t)η ad, and sum of Pdmaxx (t) and Plx (t) is less than or equal δ P≤ difference of sum of Pwx (t) and Ppvx (t)η ad, and sum of Pdminx (t) and Plx (t).

When δ P is equal to zero, wind, light power generation system output power is equal to the sea water desalting load and conventional load. If δ P≯ zero, pumped storage power station is not working and when δ P≯ zero, then wind, light power generation system output power greater than sea water desalting load and conventional load, energy storage power station is in working condition. Fresh water reservoir pondage capacity is determined, which meets user requirement as follows: if sum of Sdx (difference of t and 1) and Ndx (t) multiplied with difference of Odand Qwx (t) is more than or equal to Sdmax. Pdmaxx (t) is equal to Ndmaxx (t) multiplied with Pd0. Wind power photovoltaic power generation unit if not able to meet the the conventional output load and desalination base load, pumped storage power generation unit started the turbines and turbine contribute to its maximum output in that condition.

IW - DESALINATE SEA DEVICE COMPRISE WIND POWER GENERATE UNIT PHOTOVOLTAIC DELIVER ENERGY STORAGE STATION WATER TURBINE

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