TESIS DE LA UNIVERSIDAD
DE ZARAGOZA

2019

59

Raquel Langarita Tejero

Electricity sector in Spain: Challenges and approach to its modelization in Economics

Departamento
Análisis Económico

Director/es
SANCHEZ CHOLIZ, JULIO
DUARTE PAC, Mª ROSA

ISSN 2254-7606

Prensas de la Universidad
Universidad Zaragoza

ISSN 2254-7606

Tesis Doctoral

ELECTRICITY SECTOR IN SPAIN: CHALLENGES AND APPROACH TO ITS MODELIZATION IN ECONOMICS

Autor

Raquel Langarita Tejero

Director/es

SANCHEZ CHOLIZ, JULIO
DUARTE PAC, Mª ROSA

UNIVERSIDAD DE ZARAGOZA

Análisis Económico

2019

Electricity sector in Spain: Challenges and approach to its modelization in Economics

Doctor of Philosophy in Economics

Raquel Langarita Tejero

PhD Advisors: Rosa Duarte Pac and Julio Sánchez Chóliz

Department of Economic Analysis
Faculty of Economics and Business Studies
University of Zaragoza
2018

Electricity sector in Spain: Challenges and approach to its modelization in Economics

Doctorado en Economía

Raquel Langarita Tejero

Directores de tesis: Rosa Duarte Pac y Julio Sánchez Chóliz

Departmento de Análisis Económico
Facultad de Economía y Empresa
Universidad de Zaragoza

2018

“If we knew what it was we were doing, it would not be called research, would it?”

Albert Einstein

A mi familia

Agradecimientos

Parte de las investigaciones realizadas durante mi etapa de estudiante de doctorado han dado lugar a la presente Tesis Doctoral, cuya elaboración no hubiese sido posible sin la ayuda de muchas personas e instituciones, lo que me lleva a transmitir mi más sincero agradecimiento.

En primer lugar, debo transmitir mi más sincero agradecimiento y mi cariño a mis directores de tesis, Julio y Rosa, por su confianza, su paciencia y su integridad académica y personal. Su disposición y plena dedicación han permitido la elaboración de esta Tesis Doctoral. Gracias a los dos por haberme guiado en el proceso y por haber disculpado mis errores, de los que, de haberlos en este documento, no sois responsables. Gracias. Espero poder seguir contando con vuestra ayuda y colaboración en el futuro.

Me gustaría agradecer a todo el personal de los Departamentos de Análisis Económico y de Estructura e Historia Económica y Economía Pública su disponibilidad para resolver cualquier cuestión, tanto académica como burocrática, en todos estos años. En especial, gracias a todos los miembros del grupo de investigación Crecimiento, Demanda y Recursos Naturales (CREDENAT), por su acogida y por ofrecerme su ayuda desinteresada. En especial, muchas gracias a Ignacio Cazcarro y a Cristina Sarasa, por su disponibilidad y paciencia para responder a todas mis consultas, y por compartir conmigo todo el material que podía precisar para elaborar este documento.

La realización de esta Tesis me ha dado la oportunidad de realizar una estancia de investigación en la Universidad de Illinois. Quiero hacer constar mi más sincero agradecimiento a Geoffrey Hewings, por su paciencia para responder a todas mis dudas, sus más que útiles comentarios y su generosidad y apoyo tanto a nivel académico como personal. Muchas gracias también a Sandy Dall'erba y a todo el equipo del Regional Economics Application Laboratory (REAL), por su cariñosa acogida y por las facilidades aportadas para hacer mi estancia inolvidable. Muchísimas gracias a todos los *REAL movers*, compañeros y amigos. Gracias, Geoff, por permitirnos conocernos, trabajar juntos y aprender unos de otros en un ambiente inmejorable.

Este periodo de aprendizaje predoctoral también me ha brindado la posibilidad de iniciarme en la docencia, por lo que debo dar las gracias de nuevo al Departamento de Análisis Económico. En especial, gracias a aquellos con los que he compartido asignaturas, Francisco Salvador, Lorena Olmos y Ana Serrano, por su flexibilidad, amabilidad y ayuda, confiando en mí al mismo tiempo y permitiéndome hacerlo de una forma independiente.

De manera muy especial, gracias a todos mis compañeros y amigos de la Sala de Becarios 1 de la Facultad de Economía y Empresa, porque siempre hacéis que vaya a trabajar con una sonrisa.

Asimismo, muchas gracias también a mis compañeros y amigos del Máster en Investigación en Economía, por el gran apoyo y compañerismo en esta primera etapa de la investigación.

Debo agradecer también el apoyo económico recibido de la Comunidad General de Riegos del Alto Aragón a través de los proyectos 2012/0559 y 2013/0559 así como su disponibildad para la obtención de datos utilizados en esta tesis, del Gobierno de Aragón, del Ministerio de Educación, Cultura y Deporte y del Fondo Social Europeo, a través de becas predoctorales y de proyectos.

Finalmente, he tenido un gran apoyo en mi vida personal. Muchas gracias a mi familia, por apoyarme siempre y por animarme desde el principio en este proyecto. En especial, muchas gracias a mis padres, su apoyo incondicional y su confianza han sido claves en mi trayectoria. Gracias también a mis amigos, por su apoyo y por escucharme y consolarme en los momentos difíciles. De una manera muy especial, gracias a Víctor, por confiar siempre en mí. Gracias también a Claudia, su amistad y ayuda incondicional me han permitido disponer de más tiempo para investigar. Muchas gracias a todos.

Acknowledgements

Part of the research done during my time as a PhD student has resulted in the present Doctoral Thesis, whose elaboration would not have been possible without the help of several people and institutions, to whom I wish to transmit my sincerest acknowledgments.

First, I must mention my thesis supervisors, Julio and Rosa, for their trust, their patience and their academic and personal integrity. Their willingness and dedication have contributed greatly to this Doctoral Thesis. Thank you both for having guided me in the process and for having excused my mistakes, for which, if there are any in this document, you are not responsible. Thanks. I hope I can continue to count on your help and collaboration in the future.

I would like to thank all the staff of the Departments of Economic Analysis and of Structure and Economic History and Public Economy for their availability to answer my question, both academic and bureaucratic, during these years. Special thanks to all the members of the research team Growth, Demand and Natural Resources (CREDENAT in its Spanish acronym), for their reception and for offering me their selfless assistance. Especially, thank you very much to Ignacio Cazcarro and Cristina Sarasa, for their availability and patience in answering all my queries, and for sharing with me all the material I needed to complete this document.

The realization of this Thesis has given me the opportunity of a research stay at the University of Illinois. And I want to record my sincerest acknowledgements to Geoffrey Hewings, for his patience in answering all my questions, his extremely useful comments, and his generosity and support both at academic and personal levels. Many thanks also to Sandy Dall'erba and to all the team of Regional Economics Application Laboratory (REAL), for their affectionate hosting and for the facilities provided to make my stay unforgettable. Many thanks to all the *REAL movers*, colleagues and friends. Thanks, Geoff, for bringing the team together to learn from each other in an excellent atmosphere.

This pre-doctoral time has also given me the opportunity to begin teaching, for which I must again thank the Department of Economic Analysis. Especially, thanks to those with whom I have shared subjects, Francisco Salvador, Lorena Olmos, and Ana

Serrano, for their flexibility, kindness, and help, trusting me at the same time and letting me do it in an independent way.

In a very special way, I thank all my colleagues and friends in the Sala de Becarios 1 of the Faculty of Economics and Business Studies, because you always make me go to work with a smile.

Likewise, many thanks also to my colleagues and friends in the Master in Research in Economics Program, for the great support and partnership in this first research step.

I also must thank the economic support received from the Upper Aragon Irrigation Scheme, through the projects 2012/0559 and 2013/0559, as well as their availability to obtain the data used in this thesis, from the Aragonese Government, from the Ministry of Education, Culture and Sport, and from the Social European Fund, through pre-doctoral grants and projects.

Finally, I have had great support in my personal life. Many thanks to my family, for always supporting me and for encouraging me from the beginning of this project. Especially, many thanks to my parents, their selfless support and their trust have been key elements in my trajectory. Thanks also to my friends, for their support and for listening to and consoling me in the difficult moments. In a very special way, thanks to Víctor, for always trusting me. Thanks also to Claudia; her friendship and selfless help have allowed me to have more time to research. Thank you very much to all concerned.

Contents

List of Figures

Gráficos de la Introducción

Figures of Introduction

Figures of Chapter 1

Figures of Chapter 2

Figures of Chapter 3

Figures of Chapter 4

List of Tables

Tablas de la Introducción

Tables of Introduction

Tables of Chapter 1

Tables of Chapter 2

Tables of Chapter 3

Tables of Appendix of Chapter 3

Tables of Chapter 4

Introducción

I. Motivación

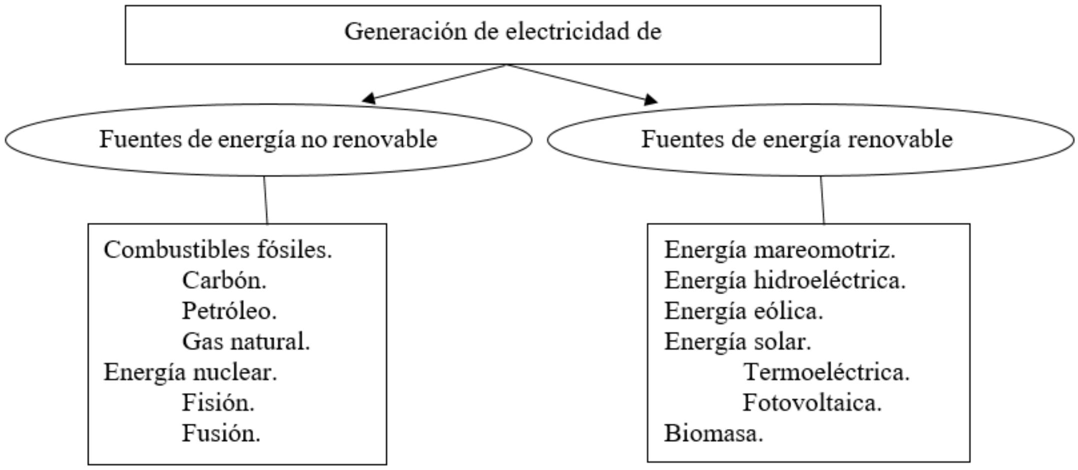
De la misma forma que los seres humanos necesitan energía para vivir, las plantas necesitan el sol para hacer la fotosíntesis y los animales y los humanos también necesitan energía para desarrollarse, la energía es un elemento esencial para el correcto funcionamiento de una economía porque todos los sectores necesitan de ella para funcionar. Así, la dependencia energética y su impacto en el crecimiento económico suponen actualmente una gran preocupación tanto para la sociedad en general como para la comunidad científica en particular, no siendo posible concebir el desarrollo sostenible sin una profunda discusión sobre el mix energético de países, dependencia energética, elecciones energéticas para futuro y cómo combinar sostenibilidad económica con sostenibilidad medio ambiental.

En Física, energía se define como la capacidad de un objeto o sustacia de generar trabajo. En nuestro caso, si nos centramos en aspectos tecnológicos o económicos, la energía podría considerarse como un recurso natural, el cual, si se manipula y transforma correctamente, es capaz de usarse en procesos industriales.

Como podemos ver en ENDESA (2016), la energía se tiene que obtener de objetos o materiales los cuales deben ser almacenados, como el sol, el viento o el carbón, es decir, diferentes fuentes de energía. La cantidad disponible de estas fuentes de energía es lo que comúnmente denominamos recursos energéticos.

Si tenemos en cuenta la forma de uso de la energía, podemos hablar de energías primarias o secundarias. Las energías primarias se obtienen directamente de la naturaleza, como el carbón, el petróleo, el gas natural, el uranio natural, la energía hidráulica, el viento, la energía solar o la biomasa. La electricidad es una fuente de energía secundaria, lo que significa que se genera convirtiendo energías primarias. Aunque a lo largo de esta presentación hablaremos de energía y de electricidad, en esta tesis nos centraremos fundamentalmente en la electricidad, la cual es el factor que entra en la mayoría de procesos productivos, y, en consecuencia, afecta a la productividad, así como también es usada por los consumidores. La electricidad se puede clasificar de acuerdo con las fuentes de energía primaria desde las que se genera, o "tecnologías de generación". Por tanto, podemos clasificar la electricidad de acuerdo con el origen de los recursos usados para su generación, como se muestra en el Gráfico I.

Gráfico I. Clasificación de la electricidad de acuerdo con la fuente usada

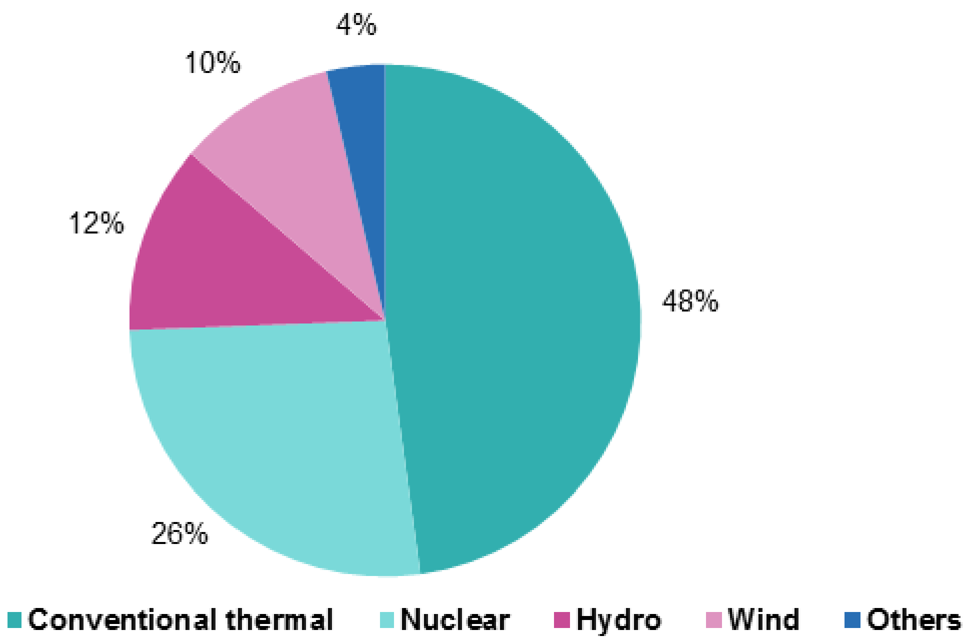


Fuente: elaboración propia.

Una de las razones por las que las energías renovables se están haciendo recientemente más populares es el calentamiento global. Una de las causas principales del calentamiento global es las emisiones de CO_2. Para evitar las emisiones a la atmósfera, se están desarrollando varios tratados internacionales y varias propuestas científicas. Éste es el caso de la conferencia de París sobre cambio climático, que tuvo lugar en París del 30 de noviembre al 13 de diciembre de 2015, donde 195 países firmaron el Acuerdo de París para reemplazar el Tratado de Kioto. El objetivo de los Acuerdos de París es limitar el calentamiento global decarbonizando la actividad humana, ver Naciones Unidas (2016). Otro ejemplo de una medida más concreta, por ejemplo, para los países de la Unión Europea, en términos de renovables, es los objetivos fijados por el Diario Oficial de Unión Europea (2009). Ya que uno de los sectors que más emiten es la electricidad, algunas de estas medidas están asociadas con la electricidad. Esta preocupación internacional más que justifica un estudio profundo del sector eléctrico, el cual es el foco de esta tesis.

El Gráfico II muestra el mix de generación eléctrica por tecnologías en 2015. Podemos ver que la térmica convencional cubre casi la mitad del total de generación, seguida de nuclear, hidroeléctrica, eólica y otras. Además, podemos destacar que la generación eléctrica de origen térmico convencional aumentó en 2015 en un 1.3% con respecto a 2014 en la UE-28. La electricidad producida por las plantas de energía nuclear disminuyó (-2.2 %) entre 2014 y 2015. En el caso de la hidroeléctrica, disminuyó en un 9.5% y la eólica aumentó en la UE-28 en un 21.8%.

Gráfico II. Mix eléctrico en Europa por tecnologías en 2015



Fuente: EUROSTAT (2016).

Centrándonos en España, la dependencia energética de España en el exterior es mayor que la de la media de la Unión Europea. El nivel de autoabastecimiento de energía primaria (relación entre la producción doméstica y el total de consumo energético) fue aproximadamente del 30% en 2013, lo que supone que en España alrededor del 70% de la energía primaria consumida se importa de otros países, de acuerdo con datos del Banco Munidal (2016).

Además de esto, el sistema eléctrico español se ha visto afectado a largo plazo por varios aspectos relacionados con su funcionamiento, como es, por ejemplo, la baja competencia entre las empresas del sector (como se puede ver en CNMC (2016), tres compañías comercializadoras abastecen electricidad al 70% del mercado), la existencia del déficito tarifario[1], y las recientes medidas establecidas con el objetivo de cubrir su financiación. Este alto número de medidas legales pueden provocar otros problemas, como la incertidumbre legal (en el sentido de que los inversores dudan sobre sus inversiones en España) o el incremento de la tarifa de acceso por potencia contratada, lo que, además, podría conllevar problemas medio ambientales a largo plazo, ya que se será menos consciente del consumo. Todo esto ha causado un fuerte incremento de los precios de la electricidad en España, los cuales han pasado en estos años de estar, tanto

[1] El déficit tarifario es una deuda que el Gobierno de España tiene con las empresas eléctricas.

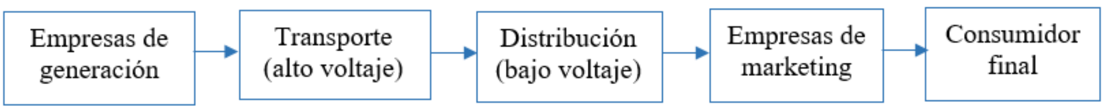
a nivel doméstico como industrial, por debajo o en la media de la Unión Europea en 2002, a ser los más altos de la UE en 2013, ver EUROSTAT (2014a, 2014b).

Con el objetivo de introducir competencia entre las empresas de este sector, en 1997, el Gobierno separó las actividades de generación, transporte, distribución y comercialización y la misma empresa no puede desarrollar más de una de estas actividades. Ver BOE (1997). Esta oficial desagragación, sin embargo, no siempre ha sido efectiva.

Otro problema al que se enfrenta el sistema eléctrico español es la persistencia de un déficit tarifario, el cual hace aumentar los precios de la electricidad, y hace que estos precios se mantengan más altos, comparados con otros en la UE. Una de las razones comúnmente aceptadas para esto ha sido las primas para las renovables, las cuales se eliminaron en 2013. De 2014 a 2016 el déficit tarifario desapareció. Sin embargo, en 2017 incluso a pesar de la eliminación del déficit tarifario, los precios eléctricos continúan siendo altos.

Independientemente de la fuente de energía usada para producir electricidad, en España, el proceso productivo de la electricidad es el siguiente: las empresas de generación vierten la electricidad a la red. Luego, las empreas de transporte, en España, principalmente la empresa pública Red Eléctrica de España (REE), transporta la electricidad a través de la red de alto voltaje a la red de bajo voltaje, donde las empresas de distribución distribuyen la electricidad a las empresas de comercialización y, finalmente, las empresas de comercialización venden la electricidad al consumidor final, el cual podría ser un hogar o una empresa, como se muestra en el Gráfico III.

Gráfico III. Proceso de la electricidad en España

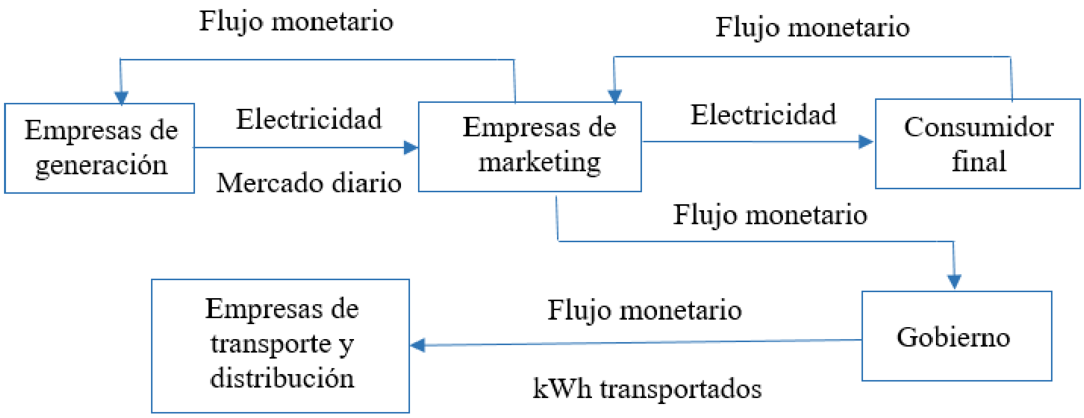


Fuente: elaboración propia.

Esta explicación sobre el proceso por el cual la electricidad llega al consumidor final, y los diferentes pasos en el proceso eléctrico, no significa que el sentido de la venta (el flujo monetario) se dé exactamente así. Como se puede ver en el Gráfico IV, las empresas de generación venden su electricidad a las empresas comercializadoras en el mercado diario. Las actividades de transporte y distribución reciben sus ingresos del

Gobierno por los kilovatios-hora (kWh) transportados. El Gobierno obtiene sus ingresos de las tarifas de acceso por potencia y energía y garantiza los costes de operar y mantener la red más un margen de beneficio asegurado.

Gráfico IV. Flujos monetarios en el sistema eléctrico español



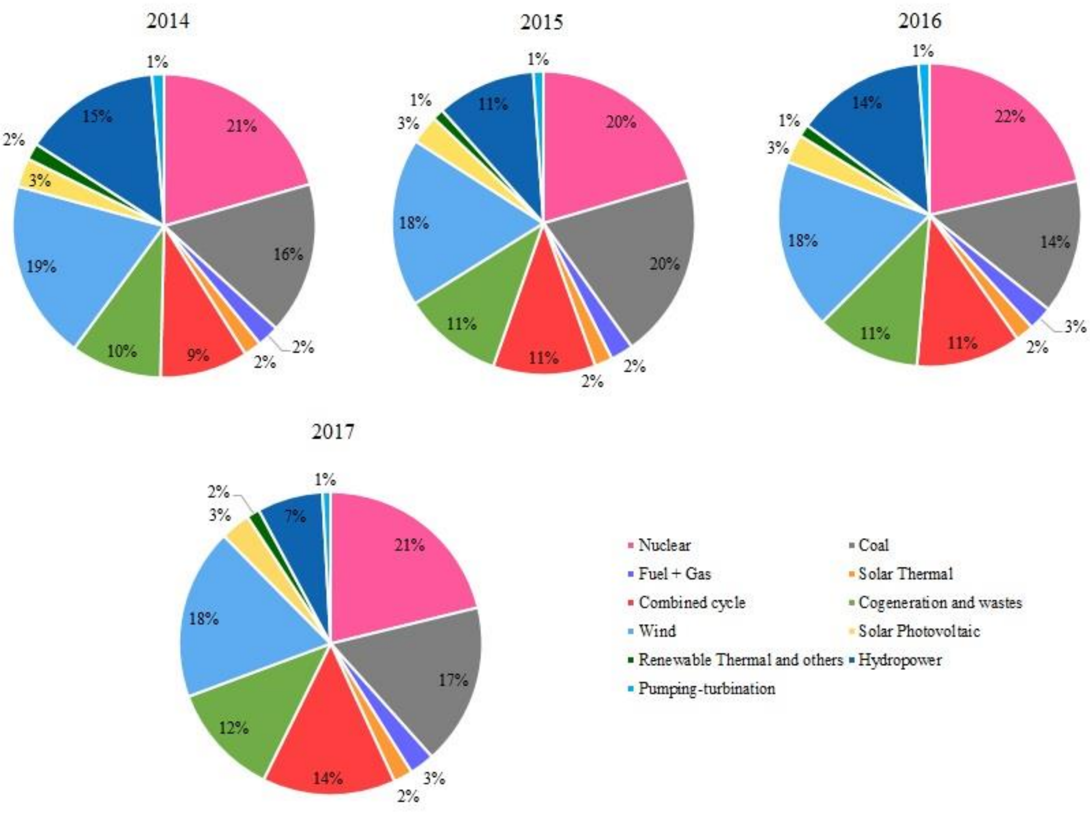
Fuente: elaboración propia.

Otra característica relevante en el sector eléctrico español es su bajo nivel de conexión con Europa. Aunque hay una conexión con el norte de África, la conexión de redes tiene una baja capacidad para abastecer electricidad a las redes europeas, lo que hace que las exportaciones y las importaciones no sean muy altas y, en práctica, es una red bastante autónoma. Además, hay algunas áreas dentro del país en las que la red debería mejorarse, como se puede ver en varios informes, como REE (2017), donde se explican algunas ampliaciones de la red.

En 2015, la demanda de electricidad en la Península Ibérica se estimó en 228.837.000 gigavatios-hora (GWh). Como vamos a ver, en 2015 280.481 GWh se produjeron en España, por tanto, es posible cubrir la demanda con la producción doméstica, ver MINETUR (2015). Así, como vamos a ver más adelante, en 2015 España fue exportadora neta de electricidad. La contribución al PIB de estos GWh es aproximadamente el 2,5%. Como vamos a comprobar a lo largo de esta tesis, el porcentaje del valor añadido de la electricidad sobre el total de valor añadido en España en 2013 fue el 2,66%.

En el Gráfico V y en la Tabla I podemos observar el mix de generación eléctrica por tecnologías en España de 2014 a 2017. La principal diferencia entre 2014 y 2015 es que de 2014 a 2015 la energía hidroeléctrica produjo un 4% menos de electricidad y, en 2015, este 4% fue generado por fuentes de carbón. En 2016, la hidroeléctrica aumentó su porcentaje de participación en la generación de electricidad total hasta el 14% y, en 2017, se redujo hasta el 7%. Las energías renovables (térmica solar, eólica, solar fotovoltaica, térmica renovable y otras e hidroeléctrica) aportaron al mix eléctrico nacional en 2015 aproximadamente el 37% de los kilovatios-hora (kWh), mientras que gas, carbón y nuclear aproximadamente 42% (petróleo y gas 2%, carbón 20% y nuclear 20%). Ciclo combinado aportó el 11% y cogeneración alrededor del 10%.

Gráfico V. Generación de electricidad de diferentes fuentes de energía (GWh)



Fuente: elaboración propia basada en datos de REE (2018).

Tabla I. Mix de generación eléctrica por tecnologías (GWh)

	2014	2015	2016	2017
Nuclear	54,870	54,755	56,099	55,609
Carbón	43,320	52,789	37,491	45,196
Petróleo + Gas	6,257	6,497	6,765	7,011
Solar Térmica	4,959	5,085	5,071	5,348
Ciclo combinado	25,075	29,291	29,260	37,296
Cogeneración y residuos	25,886	28,748	29,299	31,655
Eólica	51,031	48,115	47,697	47,897
Solar Fotovoltaica	8,208	8,243	7,978	8,385
Térmica renovable y otras	4,729	3,184	3,425	3,614
Hidroeléctrica	39,117	28,335	36,061	18,384
Bombeo-turbinación	3,416	2,895	3,134	2,249
Generación total	266,867	267,936	262,279	262,645

Fuente: REE (2018).

Debido al hecho de que los costes eléctricos para las empresas y los consumidroes tienen una gran importancia y el relativo bajo peso que representa la energía consumida en los costes unitarios, para finalizar esta breve contextualización del sistema eléctrico en España, presentamos ahora los diferentes componentes que tiene la factura del consumidor. De forma esquemática, como se muestra en el Gráfico VI, los precios pagdos por el consumidor final están compuestos principalmente por un componente de potencia y un componente de energía. El componente de potencia incluye básicamente la tarifa de acceso por potencia; ésta es una parte fija dependiendo de los kilovatios contratados; por tanto, entonces, el coste total de esta parte es independiente de la energía consumida. El componente de energía no es fijo, y depende de la energía consumida, siendo la tarifa de acceso por energía consumida una parte pequeña de este componente.

Gráfico VI. Esquema de los precios de electricidad

Precios = [Tarifa de potencia] + [tarifa de acceso por consumo de energía] + [costes] + [margen de beneficio]

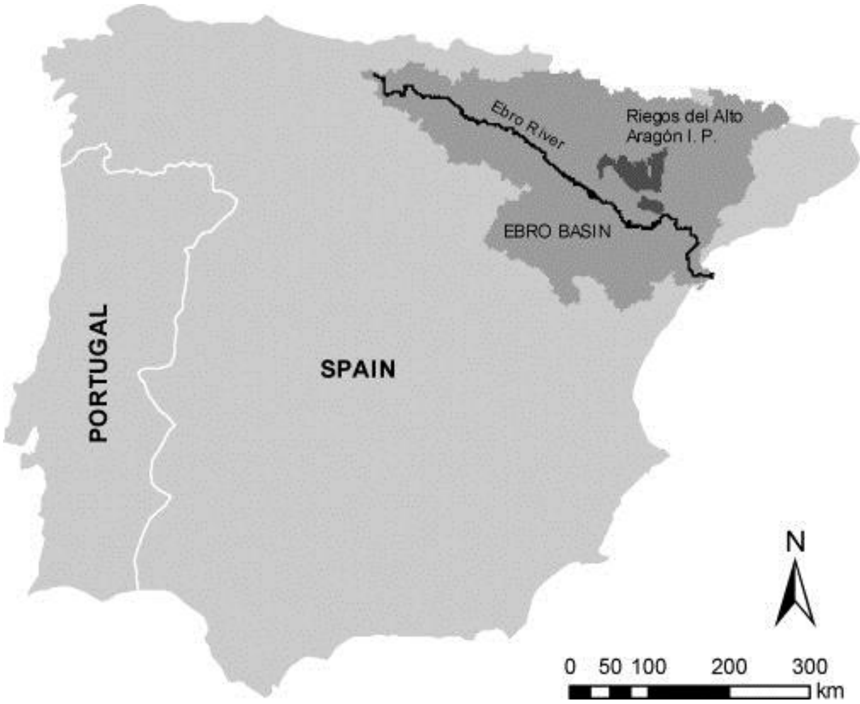
En resumen, el sistema eléctrico español es bastante adecuado para aumentar la proporción de energías renovables por las características físicas del país. También sería posible cubrir la demanda con producción propia. Sin embargo, para incentivar la sostenibilidad medio ambiental, deberíamos reducir la tarifa de acceso por potencia, ya que no tiene en cuenta la electricidad consumida, solo la potencia contratada. Es más, el sector agrícola, particularmente después de los recientes procesos de modernización en la agricultura de regadío, se ha revelado como un sector altamente dependiente de la evolución de la disponibilidad y de los precios eléctricos. Éste será el contexto general que explorará esta tesis.

La modernización de las estructuras de regadío tradicional ha implicado un porcentaje mayor de agricultura de regadío en la producción agraria, con una productividad notablemente más alta, pero también una dependencia más fuerte de la electricidad y de los precios eléctricos. Para aproximarnos mejor a esta cuestión, la primera parte de la tesis se centra en el estudio del sistema eléctrico en la actividad de la agricultura en una región de España: Aragón. Más específicamente, nos centramos en la Comunidad General de Riegos del Alto Aragón (CGRAA), que es un grupo de 58 comunidades de regantes, situado en la provincia de Huesca, en el norte de Aragón (España) y abastece a más de 130.000 hectáreas de cultivo en la cuenca del Ebro. Este sistema de riego es actualmente el más grande de la cuenca del río Ebro y de España en su conjunto, ver Sánchez Chóliz y Sarasa (2013).

La cuenca de río Ebro es la cuenca hidrográfica más importante en España y representa el 17% de su territorio. Además, España es uno de los países más importantes en el mundo en términos de territorio regable.

La producción que se genera en el regadío de Huesca alcanza más del 80% del total de la producción agrícola en la provincia. Mostramos en el Gráfico VII la cuenca del Ebro y la Comunidad General de Riegos del Alto Aragón (CGRAA). El área sombreada corresponde a la cuenca del Ebro y el color más oscuro es el territorio en el que se encuentran las comunidades de la CGRAA.

Gráfico VII. Cuenca del Ebro y el Alto Aragón



Source: Lecina et al. (2010).

En la CGRAA los costes energéticos han incrementado considerablemente en los últimos años. Otros trabajos previos han estudiado los costes energéticos en la agricultura de regadío. Por ejemplo, Rodríguez et al. (2011) dicen que, después de la modernización del regadío, los costes aumentaron un 400% en una comunidad de regantes de Andalucía. En este sentido, los incrementos de los costes energéticos en la CGRAA se deben a las crecientes necesidades de energía después de la modernización del regadío, pero se deben principalmente al incremento de ls tarifas.

La modernización del regadío ha logrado reducir el consumo de agua, y esto puede considerarse como un gran logro en la agricultura, sin embargo, para bombear y distribuir el agua de riego, el consumo de energía ha aumentado mucho. En este contexto, aparte de la necesidad de investigar en energía en términos generales, es especialmente importante la investigación en el uso de energía en la agricultura porque el consumo de energía es realmente alto en este sector.

En la siguiente sección concretamos los objetivos y estructura de la tesis doctoral y cómo tratamos de alcanzar los objetivos en los diferentes capítulos.

II. Objetivos y estructura

Como se ha visto en la sección anterior, la agricultura de regadío ha aumentado considerablemente el consumo de electricidad después de la modernización para bombear y distribuir el agua de riego. Al mismo tiempo, la agricultura, junto con el sector agroalimentario, es un sector que presenta grandes capacidades para dinamizar la economía, especialmente en áreas con alto componente rural, como podemos ver, entre otros trabajos, en Duarte et al. (2012). La importancia del binomio agua-energía puede verse en Cabrera (2011). Por estas razones, este aspecto se analizará en los capítulos 1 y 2 de esta tesis, a través del estudio del consumo eléctrico en el regadío, y el diseño y la evaluación del impacto en el coste de sistemas tarifarios alternativos.

Por tanto, un **primer objetivo** de esta tesis es estudiar e**l papel que juega el sistema eléctrico en el sector agrícola** con el objetivo de **identificar los principales problemas económicos a los que se enfrenta este sector como usuario de la electricidad y, a veces, productor,** como el bajo nivel de competencia, la evolución de los recientes incrementos en los precios y las posibles reformas de la estructura en el futuro. Analizamos **la viabilidad de diferentes medidas** como la reducción o la eliminación de las tarifas de potencia, la implementación del autoconsumo o el incremento de la conexión de red con Europa.

Dada la disponibilidad de los datos ofrecidos por la Comunidad General de Riegos del Alto Aragón (CGRAA), y su representatividad en el total de regadío de esta región, **en los capítulos 1 y 2**, centraremos el estudio en esa área, analizando la producción y el consumo eléctricos de los sistemas de riego de los miembros de la CGRAA. Los resultados del **capítulo 1**, donde ofrecemos una una visión general de todo el sistema eléctrico español, destacando los principales problemas que hemos detectado y donde proponemos posibles alternativas para reducir algunos de sus problemas en España y, particularmente, en la agricultura de regadío, nos iluminarán para el resto de la tesis, dándonos cuenta de la importancia del sector eléctrico y la necesidad de su análisis y herramientas para su estudio.

Continuando en este marco, el **capítulo 2** se centra en la **evaluación de un instrumento concreto** para reducir los costes energéticos en la agricultura de regadío, la llamada “tarifa verde” (o *tarif vert* en francés), aplicada en Francia, o alguna medida similar, como una medida transitoria, y su impacto en la agricultura de regadío.

Concretamente, el objetivo es evaluar si la aplicación de una reducción de las tarifas de acceso por potencia (hecho por esta tarifa francesa) puede favorecer la agricultura de regadío en términos de reducciones de costes energéticos.

Una vez que hemos analizado el sector eléctrico en su relación con la agricultura de regadío en los dos primeros capítulos, esta tesis expande su foco a todo el sistema eléctrico español y estudia diferentes aspectos en el contexto de una economía multisectorial.

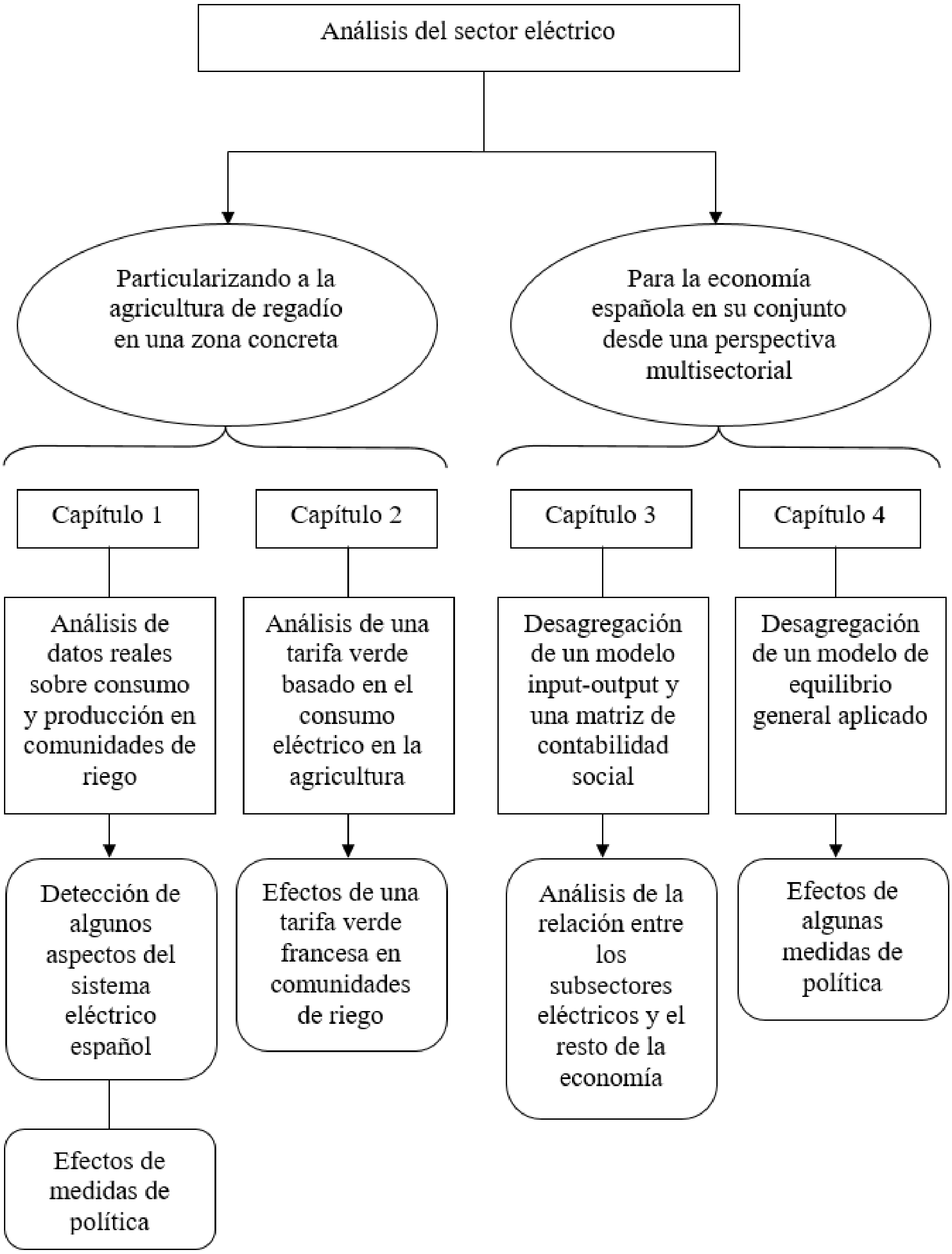
Una descripión más precisa y un análisis de los sistemas energético y eléctrico, su composición actual y su relación con el resto de sectores económicos requiere una modelización previa del sistema de energía desagregando en tecnologías productivas y actividades de negocio, y su integración en un modelo general de comportamiento de la economía, estos son otros **dos objetivos** principales de la tesis y a los que dedicamos los **capítulos 3 y 4**.

El marco analítico elegido es el uso de modelos multisectoriales: modelos input-output (IO), matrices de contabilidad social (MCSs) y modelos de equilibrio general aplicados (MEGAs), los cuales son herramientas útiles para el estudio de vínculos y dependencias de cualquier sector de la economía (en nuestro caso el sector de energía), ya que es posible desagregar en las tablas input-output (TIOs) y en las MCSs cada uno de los sectores tanto como se desee. Así, lo que proponemos es comenzar con las tablas de origen y destino, obtenidas del Instituto Nacional de Estadística (INE), para construir la TIO simétrica y la MCS para España para 2013, ya que éste fue el año más reciente para el que el INE tenía tablas origen y destino disponibles cuando comenzamos el estudio. Como se ha dicho, en 1997, el Gobierno separó las actividades de generación, transporte, distribución y comercialización y la misma empresa no puede desarrollar más de una de estas actividades. En consecuencia, para representar de una forma más detallada la actual estructura del sector, desagregamos el sector de la energía, sector de código 35 de acuerdo con la clasificación nacional de actividades económicas (CNAE), en Generación de electricidad de origen eólico, Generación de electricidad de origen nuclear, Generación de electricidad de origen térmico convencional, Generación de electricidad otros tipos y solar, Generación de hidroeléctrica, Transporte de electricidad, Distribución de electricidad, Comercialización de electricidad, Actividades relacionadas al sector eléctrico, y Gas para analizar la estructura del sector. Ésta será una de las contribuciones de la tesis, ya que, hasta donde sabemos, no existe ningún estudio previo que muestre esta total desagregación del sector energético. La construcción de estas **TIO y MCS desagregadas** para España para 2013 y el análisis de **la estructura y la relación** entre el **sector eléctrico** y el resto de la economía y el resto de la economía se mostrarán en el **capítulo 3**.

Más aún, sobre la base de la tabla construida, construiremos también un modelo de equilibrio general aplicado (MEGA). Los modelos de equilibrio general aplicados se han utilizado comúnmente en el estudio de impactos de cambios en el sector energético sobre la economía (ver, por ejemplo, Kumbaroğlu, 2003). Los efectos de las tarifas energéticas y los precios se analizan en varios estudios, ver Jensen y Tarr (2003) y Manzoor et al. (2012). Esta tesis contribuye a la literature con un **MEGA desagregado** por tipo de actividad y por tecnologías de producción con el foco en el sistema eléctrico español. Hasta donde nosotros conocemos, no hay ningún estudio previo con este nivel de detalle para la economía española, el cual es, no obstante, muy relevante en España para tratar algunos aspectos complejos en la generación y distribución de energía. Dedicaremos parte del **capítulo 4** a la construcción y explotación del MEGA. Con esta herramienta seremos capaces de simular algunas políticas de cambio, concretamente, **analizaremos** en el **capítulo 4 algunos objetivos fijados por la Unión Europea** para España en términos de electridad y observar sus efectos sobre la economía, siendo estas aplicaciones **otro de los objetivos** de la tesis.

Como se ha sugerido anteriormente, la tesis doctoral se estructura en cuatro capítulos, como se resume en el Gráfico VIII.

Gráfico VIII. Esquema general de la tesis



Fuente: Elaboración propia.

Referencias

Banco Mundial. (2016). On-line database. [View: 26 May 2016]. Available: http://datos.bancomundial.org/indicador/EG.IMP.CONS.ZS/countries?display=default

BOE. (1997). Law 54/1997, of November 27th of electric sector. Official State Bulletin, nº 285.

Cabrera, E. (2011). El binomio agua-energía. ¿Un asunto de moda o de interés real? Fundación Ciudadanía y valores.

CNMC. (2016). Informe de supervisión del mercado minorista de electricidad. Comisión nacional de los mercados y la competencia. Año 2016. 23 de noviembre de 2017.

Diario Oficial de Unión Europea. (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, 140/16.

Duarte, R.; Sánchez-Chóliz, J.; Cazcarro, I.; Rebahi, S.; Sarasa, C.; Serrano, A. (2012). La industria agroalimentaria en la economía aragonesa: capacidad dinamizadora, escenarios de crecimiento y medio ambiente. Consejo económico y social de Aragón.

ENDESA. (2016). http://www.endesaeduca.com/Endesa_educa/recursos-interactivos/conceptos-basicos/recursos-energeticos

EUROSTAT. (2014a). EUROSTAT. 2014 updating. Database. Energy statistics. Natural gas and electricity prices (from 2007 onwards).

EUROSTAT. (2014b). EUROSTAT. 2014 updating. Database. Energy statistics. Natural gas and electricity prices (until 2007 onwards).

EUROSTAT. (2016). On-line database. [View: 26 May 2016]. Available: http://ec.europa.eu/eurostat/tgm/mapToolClosed.do?tab=map&init=1&plugin=1&language=en&pcode=ten00087&toolbox=types#.

Jensen, J.; Tarr, D. (2003). Trade, exchange rate, and energy pricing reform in Iran: potentially large efficiency effects and gains to the poor. Review of development economics, 7(4), 543-562.

Kumbaroğlu, S. G. (2003). Environmental taxation and economic effects: A computable general equilibrium analysis for Turkey. Journal of Policy Modeling, 25(8), pp. 795–810.

Lecina, S.; Isidoro, D.; Playán, E.; Aragües, R. (2010). "Irrigation modernization and water conservation in Spain: The case of Riegos del Alto Aragón". Agricultural Water Manage, 97 (10): 1663-1675.

Manzoor, D.; Shahmoradi, A. and Haqiqi, I. (2012). An analysis of energy price reform: a CGE approach. OPEC Energy Review, 36: 35–54. doi: 10.1111/j.1753-0237.2011.00200.x

MINETUR. (2015). La energía en España 2015. Ministerio de industria, energía y turismo. Gobierno de España.

Naciones Unidas. (2016). United Nations Framework Convention on Climate Change (UNFCC). Conference of the parties. Report of the conference of the parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Available: http://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf

REE. (2017). El sistema eléctrico español 2017. Red Eléctrica de España.

REE. (2018). Red Eléctrica de España. On-line database. [View: 10 May 2018]. Available at http://www.ree.es/es/estadisticas-del-sistema-electrico-espanol/indicadores-nacionales/series-estadisticas.

Rodríguez-Díaz, J. A.; Pérez-Urrestarazu, L.; Camacho-Poyato, E.; Montesinos, P. (2011). "The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand". Spanish Journal of Agricultural Research, 9, 4, 1000-1008.

Sánchez Chóliz, J. and Sarasa, C. (2013). Analysis of water resources of Riegos del Alto Aragón (Huesca) in the first decade of the XXI century. Economía Agraria y Recursos Naturales, 13, 1, 97-124.

Introduction

I. Motivation

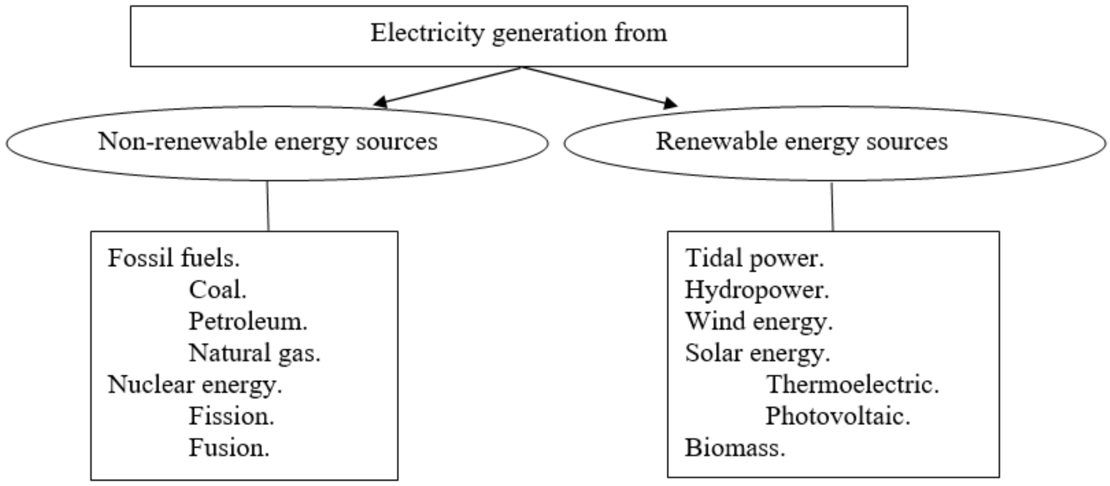
As all living beings need energy to live, plants need the sun for photosynthesis, and animals and humans both need energy in order to develop. Energy is an essential element for the good functioning of any economy because all sectors need it to work. Thus, energy dependence and its impact on economic growth are currently a major concern both for society in general, and for the scientific community in particular, since it is impossible to conceive of sustainable development without considering the energy mix of countries, energy dependence, energy choices for the future, and how to combine economic sustainability with environmental sustainability.

In Physics, energy is defined as the capacity of any object or substance to generate work. In our case, when we focus on technological or economic aspects, energy can be considered a natural resource, which, if correctly manipulated and transformed, is able to be used in industrial processes.

As we see in ENDESA (2016), energy can be obtained from any object or material which has it stored, such as the sun, wind, and coal, all of which are energy sources. The available quantity of these sources is what we commonly call energy resources.

When we take into account the form of use of energy, we also consider primary or secondary energies. Primary energies are obtained directly from nature: coal, petroleum, natural gas, natural uranium, hydraulic energy, wind, solar, and biomass. Electricity is a secondary energy source, meaning that it is generated by converting primary energy sources. Although throughout this presentation we will talk about energy and the electricity, in this thesis we will primarily focus on electricity, which is the factor entering in most production processes, and in consequence, affects productivity, as well as being used by households. Electricity can be classified according to the primary energy sources from which it is generated (or “generation technologies”). So, we can classify electricity according to the origin of the resource used for its generation, as shown in Figure I.

Figure I. Electricity classification according to the source used

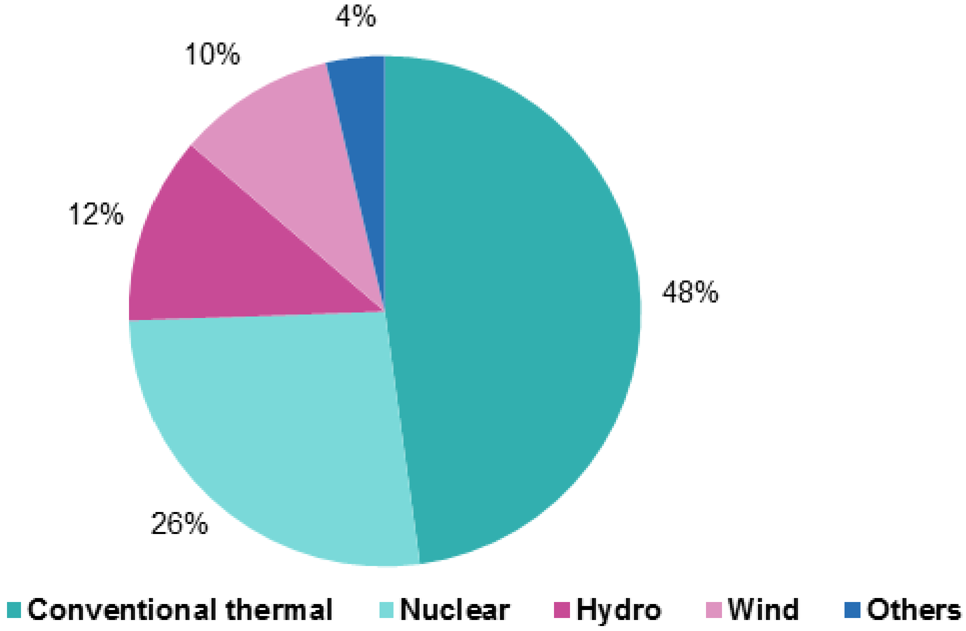


Source: Own work.

One reason why renewable energies have become more popular is the phenomenon of global warming, one of the main causes of which is the level of CO_2 emissions. For reducing or limiting emissions to the atmosphere, several international treaties, and many scientific proposals, have been and are being developed. This is the case of the Paris climate conference, held in Paris from 30 November to 13 December 2015, where 195 countries signed the Paris Agreement to replace the Kyoto Treaty. The objective of the Paris Agreement is to limit global warming by de-carbonising human activity (see United Nations, 2016). Another example, of a more concrete measure, for the countries of the European Union, in terms of renewables, are the targets set by the Official Journal of the European Union (2009). Since one of the most common emitting sectors is electricity, many of these measures are associated with electricity. This international concern more than justifies a close study of the electricity sector, which is the focus of this thesis.

Figure II shows the mix of European electricity generation, by technologies, in 2015. We can see that Conventional thermal covers almost half of the total, followed by Nuclear, Hydro, Wind, and Others. In addition, we note that electricity generation from conventional thermal origin increased in 2015 by 1.3%, with respect to 2014, in EU-28. The electricity produced by nuclear power plants decreased (-2.2 %) between 2014 and 2015. In the case of Hydro, it decreased by 9.5%, while Wind increased in EU-28 by 21.8%.

Figure II. Electricity mix in Europe by technology in 2015



Source: EUROSTAT (2016).

External energy dependence in Spain is above the average for the European Union. The level of self-supply of primary energy (the relationship between domestic production and total energy consumption) was approximately 30% in 2013, which supposes that, in Spain, around 70% of the primary energy consumed is imported from other countries, according to the data of the World Bank (2016).

In addition, the Spanish electricity system has been affected long-term by several issues related to its functioning, such as, for example, the low level of competition among the firms in this sector (as can be seen in CNMC, 2016, with only three commercialization companies supplying electricity to 70% of the market), the existence of the tariff deficit[2], and the recent measures that have the objective of covering financing. These legal measures can provoke other problems, such as legal uncertainty (in the sense that the investors doubt the wisdom of their investments in Spain) and the increase of access tariffs by capacity contracted (which, in addition, could involve long-term environmental problems, since consumers would be less conscious of their consumption). All of this has led to increased electricity prices in Spain. From being below or at the average of the European levels in 2002, electricity prices were the highest in the EU in 2013 (see EUROSTAT, 2014a, 2014b).

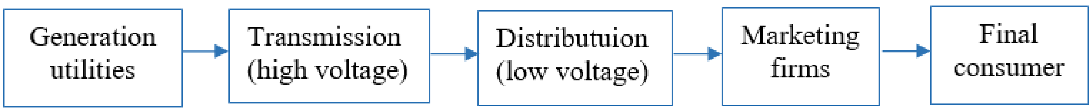
[2] The tariff déficit is a debt that the Spanish Government has with the electricity companies.

With the objective of introducing competition among the firms in this sector, in 1997, the Government separated the activities of generation, transmission, distribution and commercialization, and the same company is no longer able to engage in more than one of these businesses (see BOE, 1997). This official disaggregation, however, has not always been effective.

Another problem facing the Spanish electricity system is the persistence of a tariff deficit, which pushes electricity prices up, and keeps them higher, compared with others in the EU. One of the reasons usually offered for this has been the premiums for renewables, which were removed in 2013. From 2014 to 2016, the tariff deficit disappeared. However, in 2017, despite the removal of the tariff deficit, electricity prices continued to be high.

Independently of the source of energy used for producing electricity, in Spain, the productive process of electricity is as follows: the generation utilities feed the electricity produced into the grid. Then, the transmission companies, in Spain, mainly the public company Red Eléctrica de España (REE), transport the electricity through the high voltage network to the low voltage network, in which the distribution companies allocate the electricity to the commercialization companies and those companies sell the electricity to the final consumer, which could be a household or an industry, as shown in Figure III.

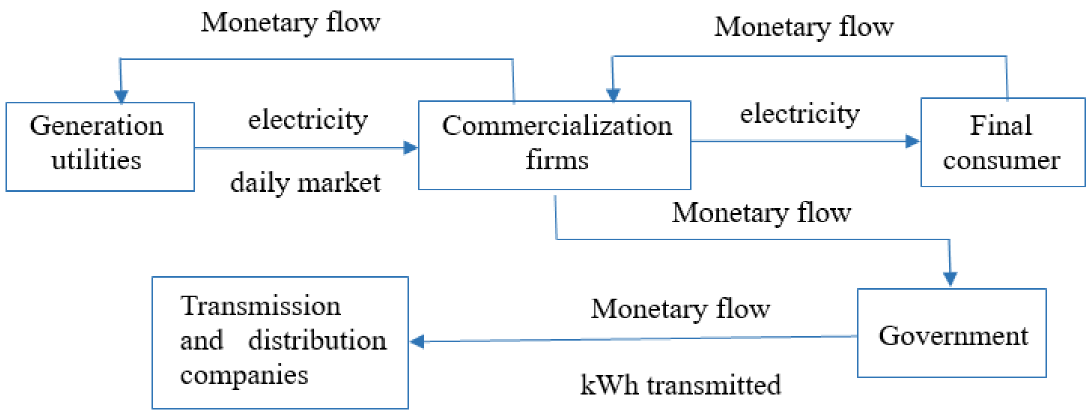
Figure III. Electricity process in Spain



Source: Own work.

This explanation of the process does not necessarily provide a precise picture of the cash flows. As can be seen in Figure IV, the generation utilities sell their electricity to the commercialization firms in the daily market. Transmission and distribution activities receive their income from the Government for the kilowatt-hours (kWh) transmitted. Government obtains the income from the capacity and power access tariffs, and guarantees the costs of operating and maintaining the networks, along with a guaranteed percentage of profit.

Figure IV. Monetary flows in the Spanish electricity system



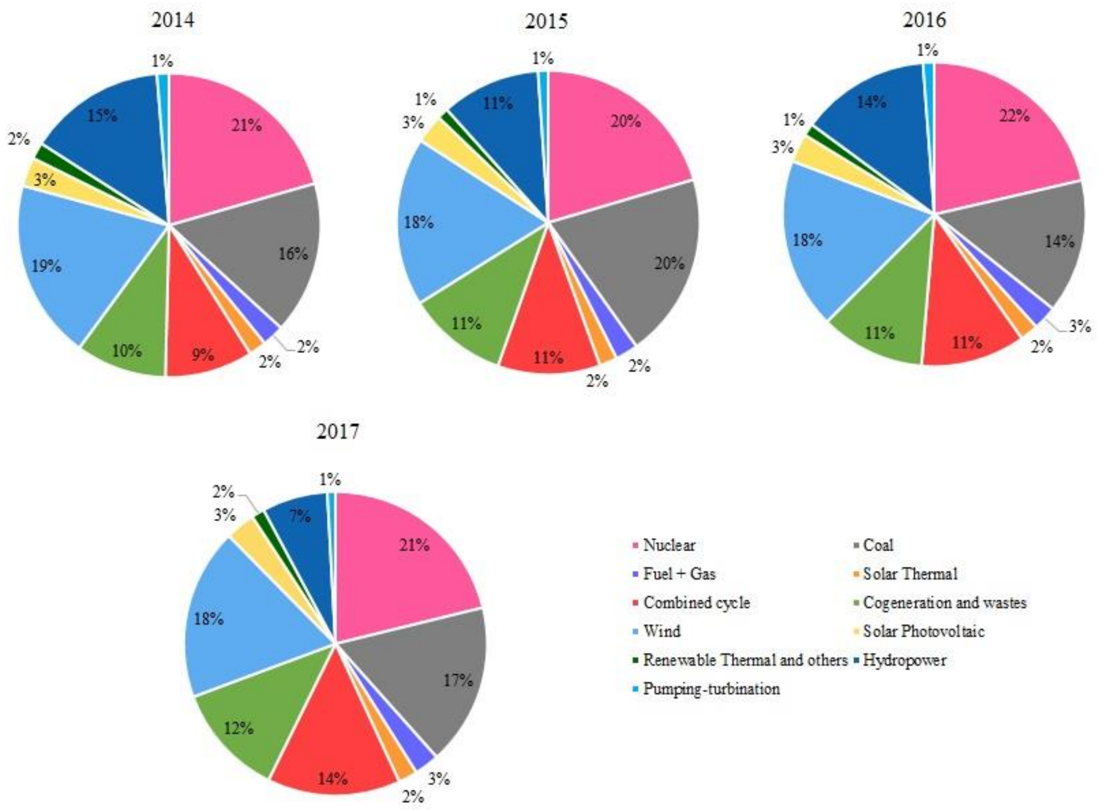
Source: Own work.

Another important characteristic of the Spanish electricity sector is its low connection level with Europe. Although there is a connection with the North of Africa, the network connection has a very low capacity to feed electricity into the European networks, which means that exports and imports are not at high levels and, in practice, the entire national network is more or less autonomous. In addition, there are certain areas within the country where the network should be improved, as can be seen in several reports, such as REE (2017), where extensions in the network are explained.

In 2015, the demand for electricity in the Iberian Peninsula was estimated at 228,837 gigawatt hours (GWh). As we will see, in 2015, 280,481 GWh were produced in Spain. Thus, domestic demand is covered by own production (see MINETUR, 2015). In 2015, Spain was a net exporter of electricity. The contribution to the GDP of these GWh is approximately 2.5%. As will be shown throughout this Thesis, the percentage of electricity value-added over the total value-added in Spain in 2013 was 2.66%.

In Figure V and in Table I, we can see the electricity generation mix by technologies in Spain, from 2014 to 2017. The main difference between 2014 and 2015 is that from 2014 to 2015 hydropower produced 4% less electricity and, in 2015, this 4% was generated by coal sources. InIn 2016, hydropower increased its percentage of participation in the total electricity generation to 14% and, in 2017, it was reduced to 7%. Renewable energies (Solar thermal, Wind, Solar photovoltaic, Renewable thermal and others, and Hydropower) supplied to the national electricity mix in 2015 approximately 37% of kilowatt hours (kWh), while gas, coal, and nuclear were responsible for approximately 42% (fuel and gas 2%, coal 20% and nuclear 20%). The combined cycle supplied 11% and cogeneration around 10%.

Figure V. Generation of electricity from different energy sources (GWh)



Source: own work based on REE (2018) data.

Table I. Electricity generation mix by technologies (GWh)

	2014	2015	2016	2017
Nuclear	54,870	54,755	56,099	55,609
Coal	43,320	52,789	37,491	45,196
Fuel + Gas	6,257	6,497	6,765	7,011
Solar Thermal	4,959	5,085	5,071	5,348
Combined cycle	25,075	29,291	29,260	37,296
Cogeneration and waste	25,886	28,748	29,299	31,655
Wind	51,031	48,115	47,697	47,897
Solar Photovoltaic	8,208	8,243	7,978	8,385
Renewable Thermal and others	4,729	3,184	3,425	3,614
Hydropower	39,117	28,335	36,061	18,384
Pumping-turbination	3,416	2,895	3,134	2,249
Total generation	266,867	267,936	262,279	262,645

Source: REE (2018).

Because electricity costs to enterprises and consumers are important, and the relatively low weight that energy represents in the unitary costs, in order to finish this brief contextualization of the electricity system in Spain, we now present the various components of the consumer bill. In a schematic way, as shown in Figure VI, the prices paid by the end-user are mainly composed of a capacity component and an energy component. The capacity component includes a capacity access tariff, which is a fixed amount depending on the kilowatts contracted, so the total cost of this part is independent of the energy consumed. The energy component is not fixed, and it depends on consumption, with the access tariff for energy consumed being a small part of this component.

Figure VI. Schema of electricity prices

Prices = capacity-based tariff + energy consumption access tariff + energy costs + profit margin

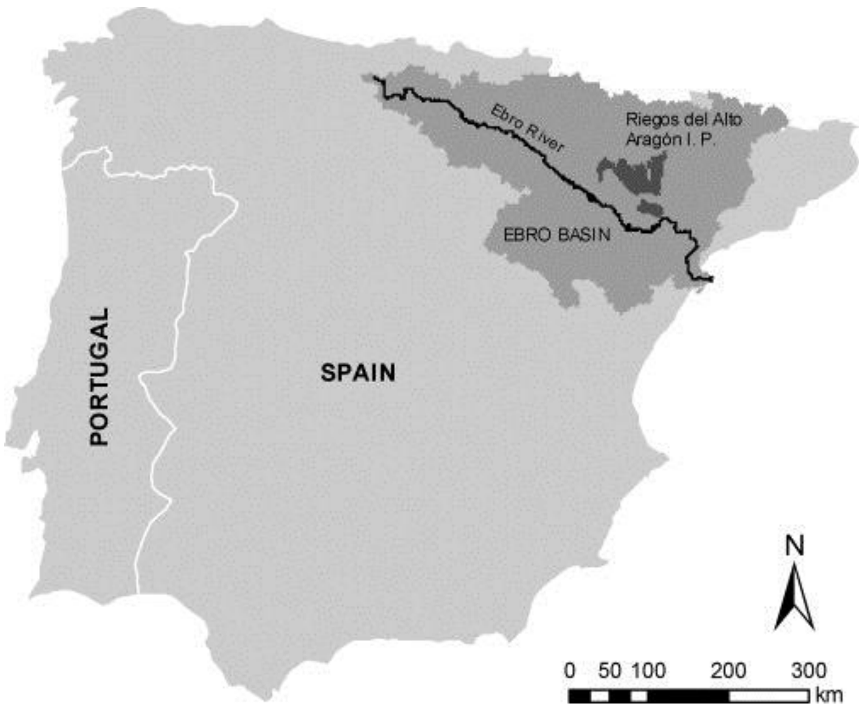
In summary, the Spanish electricity system is quite well-situated to increase the share of renewables because of the physical characteristics of the country. It would also be possible to support the demand with own production. However, in order to encourage environmental sustainability, we should reduce the access tariff for capacity, since it does not take into account the electricity consumed, only the capacity contracted. Moreover, the agricultural sector, particularly after the recent modernization in irrigated agriculture, has shown itself to be a sector highly dependent on the evolution of electricity availability and prices. This will be the general context that this PhD thesis will explore.

The modernization of traditional irrigation structures has led to a greater share of irrigated agriculture in agrarian production, with a notably higher productivity, but also a strong dependence on electricity and electricity prices. In order to better approach this question, the first part of this thesis focuses on the study of the electricity system in the agricultural activity of one region of Spain, Aragon. More specifically, we focus on the *Upper Aragon Irrigation scheme* (CGRAA in its Spanish acronym), which is a group of 58 irrigation communities, situated in the province of Huesca, in the north of Aragon (Spain) and covers more than 130,000 hectares of crops in the Ebro river basin. This irrigation scheme is currently the biggest in the Ebro River basin and in the whole Spain (see Sánchez Chóliz and Sarasa, 2013).

The Ebro river basin is the most important hydrographic river basin in Spain and represents 17% of its land area. In addition, Spain is one of the most important countries in the world in terms of its irrigated land.

Output that is produced in the irrigation of Huesca achieves more than 80% of total agricultural production in the province. We show in Figure VII the Ebro basin and the Upper Aragon Irrigation Scheme (CGRAA). The shaded area corresponds to the Ebro basin and the darker color is the territory of the CGRAA.

Figure VII. Ebro Basin and Upper Aragon



Source: Lecina et al. (2010).

In the CGRAA, energy costs have increased considerably in recent years. Other works have also studied energy costs in irrigated agriculture. For example, Rodríguez et al. (2011) find that, after irrigation modernization, costs increased by 400% in an irrigation community of Andalusia. In this line, the increases of energy costs in the CGRAA are due to the growing energy needs after irrigation modernization, but they are also largely due to increased electricity tariffs.

Irrigation modernization has reduced water consumption, and this can be considered a great achievement in agriculture. However, in terms of the pumping and distribution of irrigation water, energy consumption has increased a lot. In this context, apart from the necessity of research in energy in general terms, it is especially important to study energy use in agriculture, because of the very high levels of consumption in this sector.

In the following section, we describe the objectives and structure of the doctoral thesis and our methodology.

II. Objectives and structure

As has been shown in the previous section, modern irrigated agriculture has considerably increased electricity consumption via the pumping and distribution of irrigation water. At the same time, agriculture, together with the agrifood sector, is a sector with great potential to boost the economy, especially in rural areas, as we see in, among other works, Duarte et al. (2012). The importance of the water-energy binomial can be seen in Cabrera (2011). This issue will be analyzed in Chapters 1 and 2 of this thesis, through the study of electricity consumption in irrigation, and the design and the impact evaluation of the cost of alternative tariff systems.

So, a **first objective** of this thesis is to study **the role that the electricity system plays in the agricultural sector,** with the objective of **identifying the main economic problems this sector faces as electricity user and, sometimes, producer**, such as the low level of competition, the evolution of recent price increases and the possible structural reforms for the near future. We analyse **the feasibility of different measures,** such as the reduction or removal of capacity tariffs, the implementation of self-consumption, and the increasing network connections with Europe.

Given the availability of the data offered by the Upper Aragon Irrigation Scheme (Comunidad General de Riegos del Alto Aragón, CGRAA in its Spanish acronym), and its representativeness in the total irrigation of this region, **in Chapters 1 and 2**, we will focus on that area, analyzing the output and electricity consumption of the CGRAA's member irrigation schemes. The results of **Chapter 1**, where we offer an overview of the whole Spanish electricity system, highlighting the main problems that we see, and where we propose some possible alternatives for reducing some of the problems in Spain and, particularly, in irrigated agriculture, will illuminate the rest of the thesis.

Continuing in this framework, **Chapter 2** focuses on the **evaluation of a specific instrument** to reduce energy costs in irrigated agriculture, the so-called "green fee" (or *tarif vert* in French), applied in France, and any similar measure, as a transitory focus, and its impact on irrigated agriculture. The objective is to evaluate whether the application of a reduction in the access tariff by capacity (done by this French tariff) can favor irrigated agriculture in terms of reductions of energy costs.

Once we have analyzed the electricity sector in its relationship with irrigated agriculture in the two first chapters, the thesis expands its focus to the whole Spanish electricity system and studies various issues in the context of a multi-sectoral economy.

A more accurate description and analysis of the energy and electricity systems, their current composition, and their relationships with the rest of the economic sectors requires a previous modelization of the energy system, disaggregated into production technologies and business activities, and its integration in a general model of behavior of the economy. These are the other two main **objectives** of the thesis, and to which we will dedicate **Chapters 3 and 4**.

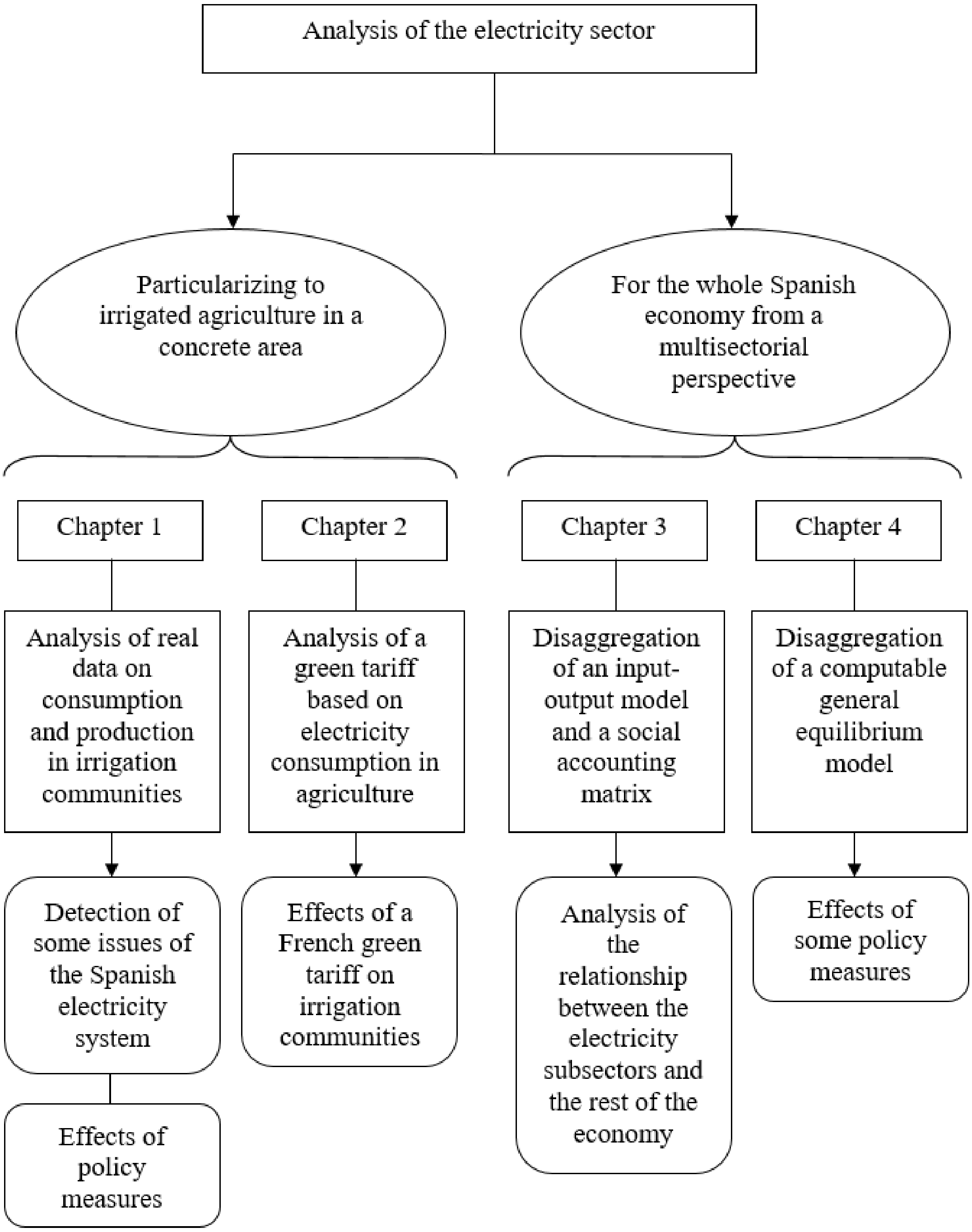
The analytical framework chosen is the use of multi-sectoral models: input-output (IO) models, social accounting matrices (SAMs), and computable general equilibrium (CGE) models, which are useful tools to study the linkages and dependencies of any sector of the economy (in our case the energy sector), since it is possible to disaggregate in the input-output tables (IOTs) and SAMs each of the sectors as much as desired. Thus, we propose to begin with the supply and use tables, obtained from the National Institute of Statistics (INE in its Spanish acronym), to build the symmetric IOT and the SAM for Spain for 2013, since it is the most recent year for which INE has supply and use tables (when we began the study. In 1997, the Government separated the activities of generation, transmission, distribution and commercialization, and the same company is not able to engage in more than one of these businesses. Consequently, to represent in detail the current structure of the sector, we disaggregate the energy sector, sector code 35 according to the national classification of economic activities (CNAE in its Spanish acronym), into Generation of electricity from wind, Generation of electricity from nuclear, Generation of electricity from conventional thermal, Generation of electricity from solar and other types, Generation of hydropower, Transmission of electricity, Distribution of electricity, Commercialization of electricity, Activities related to the electricity sector, and Gas, to analyze the structure of this sector. This will be one of the contributions of the thesis, since, to the best of our knowledge, there is no prior study that shows this current total disaggregation of the energy sector. The construction of these **disaggregated IOTs and**

SAMs for Spain for 2013, and the analysis of **the structure and the relationship** between the **electricity sector** and the rest of the economy, will be shown in **Chapter 3**.

On the basis of the constructed table, we will also build a computable general equilibrium (CGE) model. Computable general equilibrium models have been commonly used to study the impacts of changes in the energy sector on the economy (see, for example, Kumbaroğlu, 2003). The effects of energy tariffs and prices are analyzed in several studies (see Jensen and Tarr, 2003, and Manzoor et al., 2012). The thesis contributes to the literature with a **CGE model disaggregated** by type of activity and by generation technologies, with the focus on the Spanish electricity system. To the best of our knowledge, there is no prior study with this detailed level for the Spanish economy, dealing with some complex aspects in the generation and distribution of energy. We will dedicate part of **Chapter 4** to the construction and exploitation of the CGE model. With this tool we will be able to simulate certain policy changes; specifically **certain targets established by the European Union** for Spain in terms of electricity, and observe their effects on the economy, with these applications also being among **the objectives** of the thesis.

As suggested before, the doctoral thesis is structured in four chapters, as summarized in Figure VIII.

Figure VIII. General schema of the thesis



Source: Own work.

References

BOE. (1997). Law 54/1997, of November 27th of electric sector. Official State Bulletin, nº 285.

Cabrera, E. (2011). El binomio agua-energía. ¿Un asunto de moda o de interés real? Fundación Ciudadanía y valores.

CNMC. (2016). Informe de supervisión del mercado minorista de electricidad. Comisión nacional de los mercados y la competencia. Año 2016. 23 de noviembre de 2017.

Duarte, R.; Sánchez-Chóliz, J.; Cazcarro, I.; Rebahi, S.; Sarasa, C.; Serrano, A. (2012). La industria agroalimentaria en la economía aragonesa: capacidad dinamizadora, escenarios de crecimiento y medio ambiente. Consejo económico y social de Aragón.

ENDESA. (2016). http://www.endesaeduca.com/Endesa_educa/recursos-interactivos/conceptos-basicos/recursos-energeticos

EUROSTAT. (2014a). EUROSTAT. 2014 updating. Database. Energy statistics. Natural gas and electricity prices (from 2007 onwards).

EUROSTAT. (2014b). EUROSTAT. 2014 updating. Database. Energy statistics. Natural gas and electricity prices (until 2007 onwards).

EUROSTAT. (2016). On-line database. [View: 26 May 2016]. Available: http://ec.europa.eu/eurostat/tgm/mapToolClosed.do?tab=map&init=1&plugin=1&language=en&pcode=ten00087&toolbox=types#.

Jensen, J.; Tarr, D. (2003). Trade, exchange rate, and energy pricing reform in Iran: potentially large efficiency effects and gains to the poor. Review of development economics, 7(4), 543-562.

Kumbaroğlu, S. G. (2003). Environmental taxation and economic effects: A computable general equilibrium analysis for Turkey. Journal of Policy Modeling, 25(8), pp. 795–810.

Lecina, S.; Isidoro, D.; Playán, E.; Aragües, R. (2010). “Irrigation modernization and water conservation in Spain: The case of Riegos del Alto Aragón”. Agricultural Water Manage, 97 (10): 1663-1675.

Manzoor, D.; Shahmoradi, A. and Haqiqi, I. (2012). An analysis of energy price reform: a CGE approach. OPEC Energy Review, 36: 35–54. doi: 10.1111/j.1753-0237.2011.00200.x

MINETUR. (2015). La energía en España 2015. Ministerio de industria, energía y turismo. Gobierno de España.

Official Journal of the European Union. (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, 140/16.

REE. (2017). El sistema eléctrico español 2017. Red Eléctrica de España.

REE. (2018). Red Eléctrica de España. On-line database. [View: 10 May 2018]. Available at http://www.ree.es/es/estadisticas-del-sistema-electrico-espanol/indicadores-nacionales/series-estadisticas.

Rodríguez-Díaz, J. A.; Pérez-Urrestarazu, L.; Camacho-Poyato, E.; Montesinos, P. (2011). "The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand". Spanish Journal of Agricultural Research, 9, 4, 1000-1008.

Sánchez Chóliz, J. and Sarasa, C. (2013). Analysis of water resources of Riegos del Alto Aragón (Huesca) in the first decade of the XXI century. Economía Agraria y Recursos Naturales, 13, 1, 97-124.

United Nations. (2016). United Nations Framework Convention on Climate Change (UNFCC). Conference of the parties. Report of the conference of the parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Available: http://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf

World Bank. (2016). On-line database. [View: 26 May 2016]. Available: http://datos.bancomundial.org/indicador/EG.IMP.CONS.ZS/countries?display=default

Chapter 1

Analysis of the Spanish electricity system in the agricultural sector: a case study for Upper Aragon

1.1. Motivation

A first motivation of our interest in studying the electricity sector in Spain is the collaboration with the *Upper Aragon Irrigation Scheme* (CGRAA in its Spanish acronym), which is composed of 58 communities of farmers in the province of Huesca, in north-eastern Spain, and which irrigates more than 133,000 hectares of land, which is highly representative of irrigated agriculture in the Ebro Valley, and in Spain as a whole.

In the context of a research collaboration with the CGRAA, which is directly affected by rising costs associated with the extension of irrigation modernization schemes, one of the objectives of this chapter is to diagnose the Spanish electricity system, identifying the effects of the different tariff systems on irrigated farming.

We used data on electricity generation, consumption, and supply provided directly by the CGRAA, allowing for the calculation of costs and observations of growth. On this basis, we calculate electricity consumption and costs for the period 2010-2013, and estimate them for 2014.

This chapter presents an overview of the Spanish electricity system as well as a first approach to an analysis of the impact of the current electricity system and the tariff design on the Spanish agricultural sector. In this regard, it is also a first stage for the formulation of suggestions for the rest of the topics addressed in the following chapters of the thesis.

Most of the content in Section 1.2 has been published in the article “Electricity costs in irrigated agriculture: A case study for an irrigation scheme in Spain”, published in *Renewable & Sustainable energy reviews* (see Langarita et al., 2017). In what follows, we will see two differentiated parts: a general overview of the Spanish electricity system, and the application to the agrarian case, where we study the effects of different tariffs.

1.2. Electricity costs in irrigated agriculture: A case study for an irrigation scheme in Spain

1.2.1. General overview of the Spanish electricity system

Electricity is key to the functioning of the Spanish, and of course every other, economy: industries cannot function without power. This is nowhere more true than in the case of irrigated agriculture, a sector that has considerably increased its energy consumption to pump and distribute water as a result of the modernization of the last thirty years (see Jackson et al. [1], Jiménez-Bello et al. [2], and Plappally and Lienhard [3]). A nationwide process of modernization over this period has raised farm output and competitiveness to unprecedented levels, significantly improving farmers' incomes. However, the resulting structure of irrigation systems is highly sensitive to energy costs, and the continuous increases and variability of energy prices in recent years have become a significant obstacle to the sustainability of agricultural earnings.

The link between energy and water has generated a global interest in this issue, with the objective of reducing consumption, especially, of conventional energy sources (which have many environmental impacts), particularly for irrigation applications. Gopal et al. [4] carry out a literature review on this topic, and there are several studies of alternative energy sources for pumping water (see Haddad [5], Bataineh [6], Chandel et al. [7], Ali et al. [8], and Purohit and Kandpal [9]).

The electricity industry in Spain faces serious problems: the lack of competition between power utilities, the premiums on renewable energy, the high dependence on gas and imported coal, and deficiencies in the grid. These problems have been further aggravated by the issue of the *tariff deficit* (accumulated debt in favour, primarily, of the electricity firms), resulting in a sharp rise in the cost of electricity in Spain, which has adversely affected the country's competitiveness.

In this context, our study examines these rising energy costs as they affect irrigated farming. Prior studies have analysed the impact of energy costs on agriculture, including Lecina et al. [10] and Rodríguez et al. [11], who observed a 400% increase in the costs incurred by one irrigation scheme in Andalusia, after the modernization of the infrastructure and technology. Our aim goes beyond the study of energy costs in irrigated farming to propose viable options to reduce the burden, in a context of increasing costs due to modernization.

One of the objectives of this study is, therefore, to analyse the Spanish electricity system in order to determine the effects of the different tariff systems on irrigated farming. We look at the *Upper Aragon Irrigation Scheme* (CGRAA in its Spanish acronym), which brings together 58 communities of farmers in the province of Huesca, in north-eastern Spain. The CGRAA irrigates more than 133,000 hectares of land, which is very representative of irrigated agriculture in the Ebro Valley, and it is the largest irrigation scheme in Spain. Moreover, our ideas on this issue could be applied to other EU irrigation systems. The case of France is relevant, where there is a special green tariff for irrigation (see JORF [12]) that includes a capacity tariff, but this capacity tariff is very low compared to the one in Spain.

Energy costs in the CGRAA have mushroomed in recent years, the result of growing energy needs on one hand, due to the modernization of irrigation systems (see Sánchez Chóliz and Sarasa [13]), and rising energy prices on the other.

We use data on electricity generation, consumption and supply provided directly by the CGRAA. Official electricity tariffs for both energy consumed and capacity contracted are published periodically in the Official Journal of the Spanish State (BOE in its Spanish acronym), allowing for the calculation of costs and observation of its growth, in particular due to price hikes. On this basis, we have calculated energy consumption and costs for the period 2010-2013 and estimated them for 2014. This period corresponds with the establishment of major electricity reforms in Spain. Moreover, despite the economic crisis, the first cause of increasing electricity consumption in agriculture is linked to water needs for irrigation that boost the modernization processes, with Spanish irrigated agriculture being one of the sectors least affected by the crisis. This makes this case study very suitable for the objective of our work, as the CGRAA presents water constraints that are addressed through improvements in technology (see Philip et al. [14]).

Additionally, based on the results of direct estimations and simulations of different tariffs, we propose to remove or, at least, to reduce the capacity-based tariffs to respond to the observed problems and to cut energy costs, especially for farmers. We also highlight the possibility of increasing self-consumption as a complementary measure.

In Section 1.2.2, we describe the Spanish electricity system and highlight its main problems. Section 1.2.3 examines the specific case of the CGRAA in terms of output and power consumption, and Section 1.2.4 proposes some possible solutions to the issues identified. The paper ends with some brief concluding remarks.

1.2.1.1. Competition issues

The electricity market began to be liberalized in several countries in the 1980s (see Erdogdu [15], Pollitt [16], and Slabá et al. [17]). In 1997, the Spanish Electricity Industry Act of the Spanish Government (see BOE [18]) was designed to foster competition between power utilities. To this end, it decoupled generation, transportation, distribution, and marketing, and prohibited any single company from engaging in more than one of these businesses.

At the time, it was believed that this unbundling would establish the conditions in which competition could flower. Today, however, we can question whether this measure has been a success, and if so in what ways. From the standpoint of economic theory, there is no particular reason why this vertical splitting should encourage competition. Furthermore, decoupling does not always work in practice, in spite of the legal separation of generation and distribution firms, because the shareholders often overlap and they avoid competing with each other and tend to cooperate in pursuit of common goals.

Power is sold at auction in a daily market, which operates by matching supply and demand so that the marginal price is the final price. The system is seriously flawed in terms of competition, among other reasons because a minimum guaranteed output is applied to nuclear power, while renewable energies like solar and wind power enjoy preferential access to the grid. Also, generating conditions allow producers of nuclear power to offer very low prices in the market in order to boost their sales. There can be no doubt, then, that this auction system creates winners (nuclear plants and wind farms) and losers (combined-cycle plants, which use two thermodynamic cycles: gas turbine and steam turbine), as can be observed in Table 1. 1. Moreover, in this line, certain authors also suggest penalizing less/combined plants (see Cardoso and Fuinhas [20]).

Table 1. 1. Daily market power output by generating technology, January and February 2014

	Daily market – January		Daily market – February	
	GWh	%	GWh	%
Oil-Gas	0	0.0	0	0.0
Thermal (subsidized)	300	1.3	250	1.2
Coal	1,238	5.6	108	0.5
Combined cycle	251	1.1	210	1.0
Nuclear	4,559	20.5	4,703	22.6
Hydroelectric	3,891	17.5	5,259	25.2
Imports	1,324	6.0	892	4.3
Wind	6,592	29.6	5,967	28.6
Cogeneration/Waste/ Small hydro	4,982	18.4	3,462	16.6
TOTAL	22,236	100.0	20,851	100.0

Source: OMIE (2014) [19].

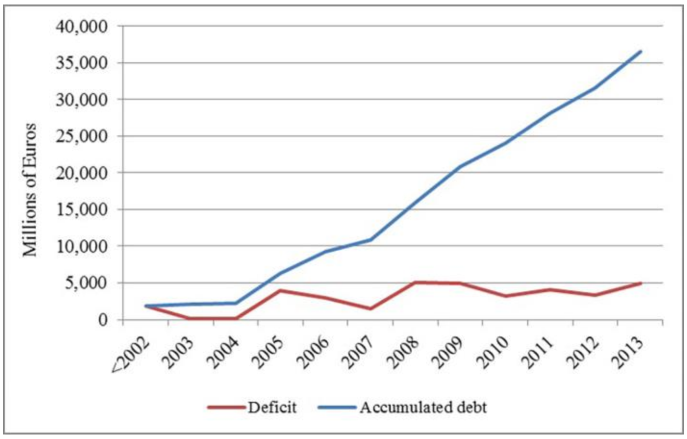
In addition, the transmission system suffers from a dearth of connections with Europe, and large areas of Spain itself are burdened by connection deficiencies, with the result that there is not enough external and internal competition. Moreover, in Spain, the distribution conditions are unquestionably optimized by the existence of a single grid, given the very large infrastructure investments required, the general use of the system, and its geographic extent, and for these reasons it would be quite justifiable for Government to take over management of the grid. By contrast, while the Spanish state could manage electricity distribution (not to be confused with marketing) and the upkeep of the grid directly, so far, it has preferred in practice to entrust responsibility to private firms, paying them the costs incurred in this activity and a guaranteed margin so that profits are assured. Under these conditions, there is little incentive to compete and firms have a clear interest in colluding to demand all they can from Government, increasing the upward pressure on electricity prices.

Finally, competitive conditions in electricity marketing are likewise questionable, in view of the market shares of the utilities involved. In reality, the market is an oligopoly in which just two firms account for most of the pie, as shown in Yusta [21].

1.2.1.2. The tariff deficit

As in the management of electricity distribution and the upkeep of the grid, so the Spanish Government has established by law a number of regulated activities for which the power utilities receive incomes as compensation for the regulated costs that they bear (see references in Table 1. 2). The tariff deficit is the difference between the regulated income received and the regulated costs. The tariff problem first arose in 1997 as a consequence of intense lobbying (then as now) by the electricity industry. Given the clearly oligopolistic nature of the electricity market in the 1990s, the power utilities were able to wield significant social, media, and political influence in Spain. The Government at the time was keen to freeze the rising energy costs paid by consumers, as any hike in electricity bills would have been deeply unpopular among the general public and electricity prices already had a major impact on the economy and growth. In this light, the Government resolved in 1997 to freeze consumers' electricity bills, and this was the origin of the tariff deficit. It was decided that the electricity price would be split into two parts, one of which would be payable directly in cash through the electricity bill, and the other part deferred as a debt owed by the electricity system (guaranteed by the Spanish Government) to the utilities. This debt was the germ of the tariff deficit, which has since grown each year to become a massive cumulative burden, more than €35 billion in 2013 (see Figure 1. 1). The immediate result of the Government's decision was to rein in Spain's current electricity bill, but the utilities' revenues (in which the Government-backed debt was included *de facto*) swelled, regardless of any economic rationale for rising prices, and ignoring the woeful lack of competition in the electricity market.

Figure 1. 1. Tariff deficit and cumulative debt



Source: Own work based on CNE data.

In order to understand the reasons for the significant growth in the tariff deficit, we need to look at the way in which regulated income and costs are settled. Table 1. 2 shows an estimate of settlements in the period 2009-2013.

Table 1. 2. Tariff deficit, 2009-2013

(thousands of euros)	2009	2010	2011	2012	2013
A. Gross regulated income	**13,824,138**	**12,716,222**	**12,905,933**	**14,120,906**	**14,364,200**
Income from customers at tariff prices	7,299,390				
Income from access tariffs	6,524,748	12,716,222	12,757,933	13,858,906	14,177,200
Income from generators' grid access tolls			148,000	142,000	127,000
Surplus on last resort tariffs (TUR)				120,000	60,000
B. Earmarked charges	**1,816,714**	**1,369,133**	**1,189,815**	**433,306**	**392,782**
Island and non-mainland weightings	1,295,213	897,240	760,654		
System operators	37,517	38,267	39,032	39,618	
Market operator	11,140				
National Energy Commission (CNE) charge	19,746	22,892	23,876	25,536	20,997
Nuclear moratorium	3,000	100,228	54,463	54,661	75,460
2^{nd} part of nuclear fuel cycle			129	138	140
Financing of Radioactive Waste Plan	71,047	127			
2005 Income deficit surcharge	379,051	310,379	311,661	313,352	296,185
C. Net regulated income (C=A-B)	**12,007,424**	**11,347,088**	**11,716,118**	**13,687,601**	**13,971,418**
D. Special regime premium	**4,808,563**	**5,888,099**	**6,019,145**	**7,013,581**	**9,050,000**
E. Cost of Electricity delivered to tariff customers	**4,291,714**				
F. Regulated activities settlement income (F=C-D-E)	**3,707,147**	**5,458,989**	**5,696,973**	**6,674,020**	**4,921,418**
G. Regulated costs	**8,632,357**	**8,649,213**	**9,802,917**	**10,059,110**	**9,925,475**
Transport	1,344,021	1,397,104	1,534,426	1,722,434	1,672,136
Distribution and marketing	5,384,477	5,201,642	5,457,149	5,692,748	5,474,444
Settlement income differences	900,369	1,252,905	1,309,324	788,776	673,610
Island and non-mainland generating differences	188,989	280,643	165,553	473,206	
Elcogas, S.A. viability plan	64,501	66,919			
Securitization fund				948,817	1,632,195
Temporary deficit for 2009			814,465		
Market interruption system		450,000	522,000	561,499	748,900
Capacity payments system deficit/surplus	750,000			-268,000	-275,810
H. Deficit/Surplus (H=F-G)	**-4,925,210**	**-3,190,224**	**-4,105,944**	**-3,385,090**	**-5,004,057**
I. Other costs for settlement					**550,500**
Financing of social rebates					292,500
Estimated 2011 island and non-mainland system (SEIE) cost overruns					58,000
Estimated final interest cost					200,000
J. External income from access tolls					**5,571,468**
Law 15/2012					2,921,468
CO_2					450,000
Extraordinary credit					2,200,000
K. Settlement deficit/surplus (H-I+J)					**16,911**

Source: CNE (2010) [22], (2011) [23], (2012) [24] and (2013) [25], and CNMC (2013) [26].

Clearly, the settlement of regulated income and costs includes certain items that should not, by their nature, be treated as regulated costs, as they are only indirectly attributable to the electricity industry and consist rather of expenses and costs originating from political decisions (so that they would be more appropriately allocated to the national budget)[3]. These items include the earmark for the “Nuclear moratorium”, the “Island and non-mainland weightings”, the “Special regime premiums” and the “Capacity payments system deficit/surplus”.

As explained in Martínez [27], the “Nuclear moratorium” consists of financial compensation paid to the promoters of nuclear plants authorized in the late 1970s and early 1980s - but never built, because of the suspension of the nuclear program by the Spanish Government in 1984. It may well be asked, why should electricity consumers be required to pay for such a clearly political decision directly. “Island and non-mainland weightings” consist of compensation paid for the extra costs ostensibly incurred by conventional generating plant situated in the Balearic and Canary Islands, and in the non-mainland enclaves of Ceuta and Melilla, on the north coast of Morocco (CNE [22]). It may also well be asked, why a cost originating from the Government’s inter-regional budget redistribution policy should be charged directly to consumers’ electricity bills. “Special regime premiums” represent incentives paid for renewables, co-generation, and waste-to-energy generation. Finally, the “Capacity payments system deficit/surplus” is designed to incentivize the construction of generating plant to ensure that there is sufficient power available at peak hours. However, the economic rationale for these payments is debatable, in view of the surplus capacity of existing plant in Spain.

In summary, and as a consequence, this situation involves an increasing debt that must be paid by final consumers; more concretely, an annual cost of more than €6.5 billion, due to industrial policy incentives, territorial quotas, and business errors, must be paid by final users in the coming years. The adding of these four items amounts to 6,857, 6,886, 6,800, and 8,850 million, from 2009 to 2013 respectively, with the 2013 figure being around 45% of the total regulated costs.

In this context, we do not necessarily consider that the described costs are unreasonable; they may indeed be perfectly justifiable in terms of economic policy. What we do question is whether they should be directly included in energy prices. For example, it is undeniably reasonable for the Government to establish incentives for the use of renewables (see Ballester and Furió [28]), but it is nonetheless open to question

[3] We are aware that there are only three options for financing these expenditures: tariffs, the treasury, or default (in this case, perhaps the result of court litigation). Our proposal is to transfer these expenditures to the national budget, and we maintain that the treasury should assume these political costs.

whether such incentives should be financed via the system of premiums applied in recent years, which were not only very high, but were also passed on directly to consumers via their electricity bills and the tariff deficit. It is clear, in the first place, that incentives for renewable energy sources should foster innovation (in generation and energy storage technologies), but not output, and still less installed capacity, as has hitherto been the case. Second, these incentives should not be financed out of the settlement of regulated costs and income. The most logical and socially responsible solution would be to fund incentives for renewables directly from the national budget.

In the case of the "Island and non-mainland weightings compensations", in addition to being an inter-regional policy that should not be included as a regulated cost to be paid by direct users, it has been suggested that this extra cost could be reduced by implementing the correct measures (see Guerrero-Lemus et al. [29]).

1.2.1.3. Recent reforms

The welter of energy legislation in recent years has caused much legal uncertainty. As a result, private companies, and especially foreign investors, have either reduced their investments in Spain or begun to consider them much more carefully. In line with other authors, such as del Río and Mir [30], we maintain that changes in energy policy should be gradual and predictable in order to avoid investors leaving Spain.

Although there is a significant trend of changing energy legislation in Spain (see del Río [31]), the legislative riot began with the Spanish Electricity Industry Act, 1997 (BOE [18]). However, we shall focus here on the key changes made in 2012 and 2013, the breadth and nature of which have heightened the industry's qualms.

A number of changes were made to the regulation of the Spanish electricity industry in 2012, including the removal of incentives for plant capacity, the definition of new criteria for the compensation of regulated activities, the creation of new taxes, and an increase in tolls and *last resort tariffs* (BOE [32, 33, 34]).

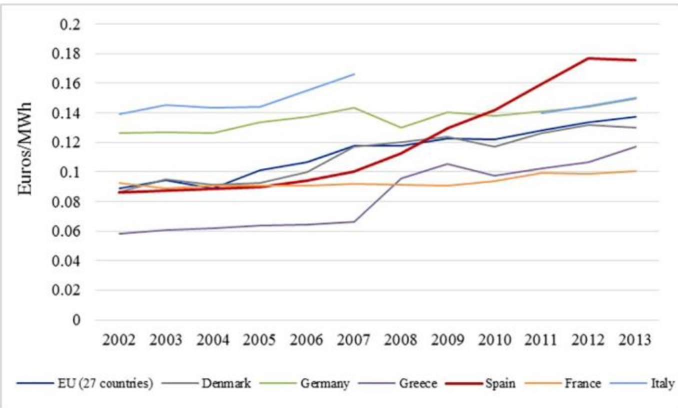
Meanwhile, incentives for renewables were first tweaked, and then removed in 2013, and a new *voluntary small-consumers' price* was created to replace the former *last resort tariff* (BOE [35, 36, 37]). Let us note here that the *last resort tariffs* modified in 2012 were removed in 2013, changing prices twice in less than 12 months.

Royal Decree 9/2013 implemented one of the most significant reforms, seeking to resolve the problem of the tariff deficit once and for all. This decree had its greatest impact on the compensation of special regime generating plant, which was slashed. Apart from eroding the profits of non-conventional generating companies, this measure also had adverse environmental outcomes, insofar as incentives for renewables helped reduce atmospheric CO_2 emissions. As a matter of particular interest to this case study, the CGRAA lost revenue from the premiums received for the operation of its six small hydroelectric plants. The value of its premiums was around €2,802 million, 49.91% of its 2013 electricity costs, which amounted to €5,615 million. In addition, the reform of August 2013 sharply raised the capacity tariff, a charge payable per kW of power contracted by electricity customers, regardless of their actual consumption. Unfortunately, this last measure will increase a more wasteful energy use in the medium term, because it will weaken users' sensitivity to the cost effects of increased consumption.

1.2.1.4. Price hike

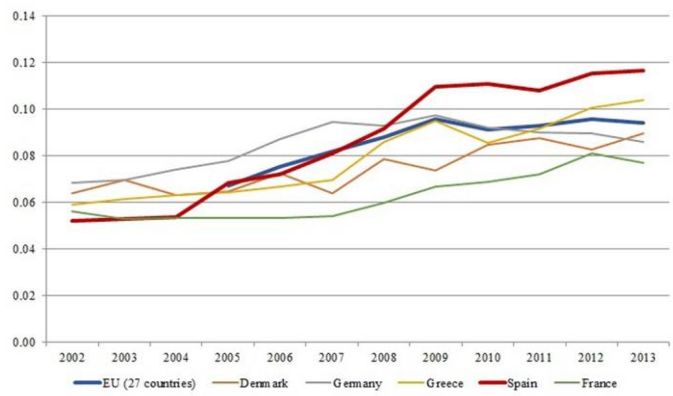
Electricity prices have risen inexorably in Spain in recent years, as a direct consequence of the matters described in sections 1.2.2.1, 1.2.2.2 and 1.2.2.3, to the point where they are now among the highest in Europe, although they were among the lowest not ten years ago. By contrast, generating costs in Spain are close to the EU average. This development is reflected in Figures 1.2 and 1.3, which show the electricity prices paid by domestic and industrial consumers, respectively.

Figure 1.2. Domestic prices (Euros/MWh)



Source: Own work based on EUROSTAT (2014a) [38] and (2014b) [39].

Figure 1.3. Industrial prices (Euros/MWh)



Source: Own work based on EUROSTAT (2014a) [38] and (2014b) [39].

This is because the price paid by the consumer is affected mainly by the general lack of competition between utilities, the deficiencies of the distribution network, the low level of international connections, and a costly grid access toll, which is decided by the Spanish Government. Moreover, the Government has successively raised this toll in an effort to cover the tariff deficit.

This hike in energy prices has had serious consequences throughout the economy, undermining its competitiveness in general, and it has hurt farmers in particular because the modernization of irrigation systems has led to a significant increase in energy use. In the specific case of the CGRAA, costs have soared because of increases both in the energy consumed per hectare and in the number of hectares irrigated, which has expanded continuously in recent years.

1.2.2. Electricity use in agriculture

1.2.2.1. Generation and energy use in the CGRAA

In this section, we use actual data to show that rising energy costs are basically attributable to the increase in grid-access tariffs. To this end, we focus on irrigated agriculture in the CGRAA, a scheme in the north of Aragon (Spain) with more than 133,000 hectares of irrigated land.

The CGRAA is both an energy producer, generating power from small hydroelectric dams situated on its canals and reservoirs, and a major consumer, using large amounts of electricity since the modernization of its irrigation systems in a process that has been particularly intense over the last decade.

This study was prepared using detailed information, for the period 2010-2013, both on the output of hydroelectric plants and on energy use at the various supply points (power contracted, consumption, and hourly and monthly consumption schedules). All of this data was supplied directly by the CGRAA. Meanwhile, we obtained energy prices from the data published on the official website of the Iberian Energy Market Operator (OMIE in the Spanish acronym), while the premiums paid are detailed in the Official Journal of the Spanish State (BOE), which also lists the tariffs applicable to the capacity contracted and energy consumed.

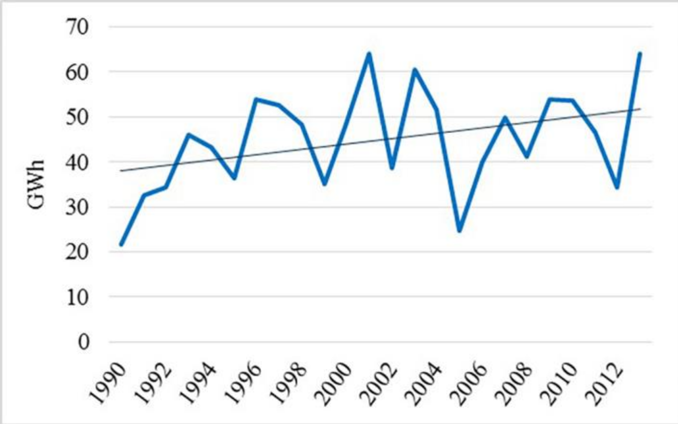
Generating activity

It is not usual for irrigation schemes to operate their own generating plant. However, the CGRAA chose in the 1980s to invest in small hydroelectric plants to generate power for sale in the wholesale market.

The Valdespartera and La Sotonera hydroelectric plants, each of which has generating capacity of 5,000 kW, were opened in 1989, and the Berbegal and Odina plants with respective capacities of 2,300 and 630 kW (which we shall hereafter treat as a single facility) came on stream in 1991. Finally, the Montanera (1,145 kW), Piracés (1,135kW) and Torrollón (893 kW) small hydro plants were inaugurated in 2000. The CGRAA thus has six small hydroelectric generating plants.

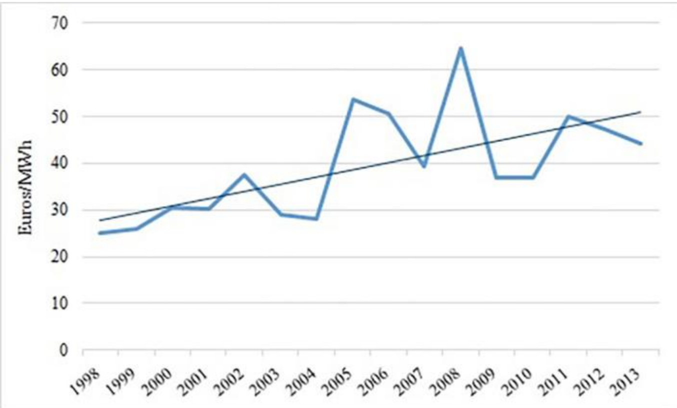
The original aim of building these small plants was to earn additional revenues as part of the CGRAA's operations, but as shown in Figure 1. 4, their overall output has grown over the years. This, and the rise in energy prices (see Figure 1. 5) have recently led the CGRAA to consider the self-consumption alternative. Such a course could be justified because the total power generated is in fact greater than the scheme's total consumption, as reflected in Tables 1. 3 and 1. 4, which show that the CGRAA could easily generate enough power to supply all of its own needs. However, this strategy is conditioned by transmission factors and serious current legal barriers to self-consumption.

Figure 1. 4. CGRAA energy output



Source: Own work based on CGRAA data, available on request.

Figure 1. 5. Mean OMIE price (€/MWh)



Source: Own work based on OMIE data, http://www.omie.es/files/flash/ResultadosMercado.swf.

Table 1. 3. Annual CGRAA power output and consumption (GWh)

	2010	2011	2012	2013
Power generated	53.67	46.41	34.33	63.96
Power consumed	36.1	46.7	41.5	46.2

Source: Own work based on CGRAA data, available on request.

Table 1. 4. Monthly data, 2013 (GWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Power generated	4.17	4.78	5.32	7.39	7.75	7.72	8.03	8.17	5.72	2.19	1.15	1.57	63.96
Power consumed	2.97	0.38	0.74	3.63	3.18	6.04	10.36	11.97	5.46	0.95	0.24	0.29	46.2

Source: Own work based on CGRAA data, available on request.

As shown in Figure 1. 5, average energy prices began to rise around 1998. Table 5 shows the CGRAA's generating revenues per year, and per hydro plant, resulting from the positive trend in daily market prices and rising output in kWh terms. The Table also reflects the incentives received by generating concerns until the recent reform, which accounted for almost half their income.

Table 1. 5. Market income and premiums (Euros)

		Sotonera	Valdespartera	Berbegal and Odina	Montanera	Piracés	Torrollón	Total
2010	Market	476,697	737,158	341,996	148,787	87,943	43,753	1,836,337
	Premiums	983,377	901,021	404,576	176,107	85,451	41,462	2,591,997
	Total	1,460,075	1,638,179	746,573	324,894	173,395	85,215	4,428,335
2011	Market	508,933	1,020,142	431,043	179,313	135,234	59,391	2,334,058
	Premiums	379,981	788,751	292,500	105,986	78,679	33,501	1,679,401
	Total	888,914	1,808,893	723,543	285,299	213,914	92,893	4,013,460
2012	Market	307,095	823,035	351,436	147,384	68,033	27,609	1,724,594
	Premiums	247,213	675,940	251,951	92,347	41,787	16,056	1,325,297
	Total	554,309	1,498,976	603,388	239,731	109,820	43,665	3,049,892
2013	Market	874,577	1,288,297	375,319	159,070	70,494	44,713	2,812,473
	Premiums	948,912	1,215,827	397,067	153,854	52,244	34,485	2,802,390
	Total	1,823,489	2,504,125	772,387	312,925	122,738	79,198	5,614,863

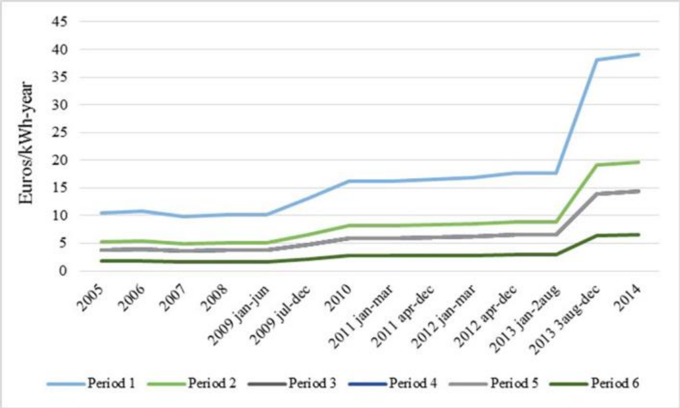
Source: Own work based on CGRAA data, available on request.

Tariffs and energy consumption

The energy price comprises two parts, namely the capacity contracted and the energy consumed. The capacity component is fixed by Government in the form of access tariffs per kW contracted. This charge does not depend on the amount of electricity actually consumed, and although it is paid by the consumer to the supplier, the utilities in fact act merely as intermediaries, passing on to the State the amounts collected, which are used to cover the regulated costs. The energy component consists of a charge per kWh consumed. It is agreed with the electricity utilities and it consists of various items, including the energy consumption access tariff. The problem with tariffs in the Spanish system resides in the very significant increase in the capacity charge in recent years. In the following discussion, we refer to the tariff types usually contracted by farmers, although the arguments made apply equally to others.

Since the electricity market was liberalized, and the special electricity tariffs applied to agriculture were removed in July 2008 (BOE [40, 41]), the CGRAA has normally contracted tariffs named 3.1 A and 6.1. Over the years, however, tariff 6.1 has been the most widely contracted and it is the one most commonly used at the supply points with the highest energy consumption. This tariff divides the day into six four-hour scheduling periods and it is applicable to installations with a voltage of between 0 and 36 kV, provided the capacity contracted is greater than or equal to 450 kW. Figures 1. 6 and 1. 7 show the evolution of the capacity component and the energy access tariff of tariff 6.1.

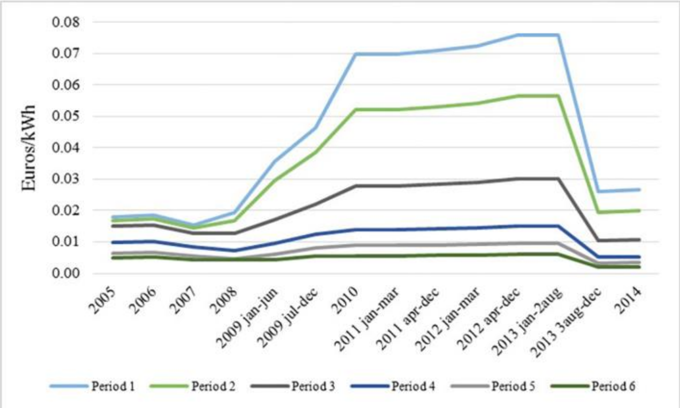
Figure 1. 6. Capacity component (Capacity access tariff) (€/kW-year)



The capacity contracted in periods 3, 4 and 5 is the same.

Source: Own work based on data published in the Official Journal of the Spanish State (BOE).

Figure 1. 7. Energy access tariff (€/kWh)



Source: Own work based on data published in the Official Journal of the Spanish State (BOE).

The capacity component of tariff 6.1 has increased continuously since 2005, resulting in a medium-term loss of energy efficiency because of the relative increment in the fixed cost inherent in the electricity bill, compared to the variable cost. Moreover, the energy access tariff of the electricity bill has actually fallen since August 2013, further accentuating this effect. Tariffs 3.1 A and 6.2 contracted for irrigation have also followed this path.

Access tariffs generate income for the state and provide a means of covering the cost of regulated activities. However, Government should consider all aspects of economic, environmental, and growth policy, and not just revenue and opportunities to cut the tariff deficit. This does not appear to be the case. As explained above, the trend has been to increase capacity and cut energy tariffs, thereby benefitting the largest consumers at a given level of power (as consumption per kWh is cheaper). This provides a negative incentive for efficient energy use and has regressive environmental effects. This is just one of the several arguments we make below for removing, or at least seriously reducing, capacity tariffs.

In addition to access tariffs, we have also obtained data on the energy prices. Aggregating the two components, we can obtain the total energy cost incurred by the CGRAA, as explained in Section 1.2.3.3 below.

According to the data reflected in Table 1. 3, the CGRAA consumes the most energy between May and October. However, the scheme is obliged to contract capacity all year round, which increases its costs. This irregular consumption pattern has led farmers to propose *seasonal contracts*, which would make summer consumption cheaper, arguing that the need to contract power at the same level on a year-round basis is an unwarranted expense, and that this penalty should be compensated for by cuts in the energy price in summer. The proposal we make below would also solve this problem.

Energy costs

Having analysed both energy consumption and prices, let us move on to consider the CGRAA's energy costs in 2010-2013. This analysis was performed individually at each of the scheme's supply points, but we shall here describe only the overall energy costs incurred.

Table 1. 6 shows the capacity contracted (mean for all supply points), the energy consumed by CGRAA, and the total cost under tariff 3.1 A. As may be observed, energy consumption in scheduling period 1 (the most expensive) fell sharply over the time horizon of the study and increased gradually in period 2, remaining practically constant in period 3. Despite the diminution in the power contracted and the limited (5.63%) growth in energy consumption, however, the total cost increased from

€229,054 in 2010 to €390,425 in 2013, mostly because of the rise in capacity access tariffs.

Table 1. 6. Power, energy and cost, 2010-2013, Tariff 3.1 A

	Mean capacity contracted (kW)			Energy consumed (kWh)*				Cost (euros)
	P1	P2	P3	P1	P2	P3	Total	Total
2010	60	175	175	96,249	603,553	1,042,910	1,742,712	229,054
2011	60	170	170	114,856	675,163	1,280,758	2,070,777	228,671
2012	60	150	160	92,741	605,833	1,151,808	1,850,382	229,669
2013	55	160	160	55,605	699,079	1,086,250	1,840,934	390,425

*Tariff 3.1A only has three daily periods. Source: Own work based on CGRAA data, available on request.

Table 1. 7 reflects the capacity contracted, the energy consumed, and the cost incurred at the supply points under contracting tariff 6.1 in the period 2010-2013. As may be observed, the capacity contracted in the cheapest scheduling period (period 6) increased over the time horizon from 855 to 1,035 kW, but in period 1, which is the most expensive, it dropped from 380 to 340 kW. The increase in the capacity contracted in certain periods is mainly due to rising demand from modernized irrigation facilities. Meanwhile, consumption trended downwards in periods 1 and 5, and rose in periods 2, 3 and 6, so that the total energy consumed in all scheduling periods increased overall, though only by 26.75%. The main reason for this overall increment is, once again, increased demand from upgraded and recently-modernized irrigation facilities. Despite the diminution in the capacity contracted in the most expensive scheduling periods, however, and the fact that consumption increased by only 26.75% over the time horizon, costs climbed every year, rising by 68.21%, from €3,433,277 in 2010 to €5,775,541 in 2014. Hence, it is clear that the growth in costs is due principally to soaring energy prices driven, above all, by the increase in capacity tariffs.

Table 1. 7. Capacity, energy and cost, 2010-2013, Tariff 6.1

	Mean capacity contracted (kW)						Energy consumed (kWh)							Cost (euros)
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6	Total	Total
2010	380	670	680	680	700	855	1,397,621	2,423,264	449,776	1,401,409	2,172,704	26,512,749	34,357,523	3,433,277
2011	375	715	720	720	720	930	1,588,367	3,192,995	470,313	1,636,054	2,781,834	35,437,538	45,107,101	4,035,201
2012	315	650	655	655	700	940	900,812	2,195,129	533,830	1,668,506	1,505,481	32,604,768	39,408,526	4,401,254
2013	340	765	770	770	810	1035	1,179,937	3,329,836	492,293	1,888,034	1,863,571	34,795,021	43,548,692	5,775,541

Source: Own work based on CGRAA data, available on request.

The above tables reflect the trends found in the CGRAA, revealing that the capacity contracted in the early scheduling periods is significantly lower than in periods

5 and 6, whose capacity tariffs are also much lower. Meanwhile, over 70% of consumption occurs in period 6, when the cost per kWh is lowest, although these are not daytime hours. Where any of the supply points do not follow this pattern, this is due to structural and infrastructure problems, which may make it necessary to consume more energy than may initially be desired in other periods (mainly periods 2, 4 and 5).

The energy costs for 2014 were estimated based on the CGRAA's energy consumption and the capacity contracted in 2013, as the 2014 figures were not yet available when the study was carried out. However, we were able to obtain the necessary information on the prices agreed with electricity utilities. On this basis, the estimated total cost to all of the irrigation schemes included in the CGRAA in 2014 was €6,986,074, showing that the upward trend continues (the total cost was €3,662,331 in 2010, €4,263,331 in 2011, €4,630,923 in 2012, and €6,269,858 in 2013). Furthermore, the cost of contracted capacity in 2014 was €3,521,172 compared to a cost of €2,252,443 in respect of energy consumed, revealing the inexorable rise in the share of the electricity bill represented by capacity.

Simulation based on different tariffs

In order to confirm that the increase in costs is indeed due mainly to hikes in access tariffs, we perform a simulation of the energy cost at different tariffs, assuming actual levels of contracted capacity and energy consumed. Six simulations were addressed based on the applicable tariffs per BOE [42, 43, 44, 45, 46, 47]. In all cases, the cost per month and scheduling period at each one of the irrigation scheme supply points were taken into consideration, as well as the power and energy figures for 2013. These data were obtained directly from the CGRAA.

As can be observed in Table 1.8, the general cost trend is increasing[4]. We show the costs for the communities that contract tariff 6.1 because it is the most representative. When we compare the tariffs applicable in January 2010 [42] and February 2014 [47], for example, we find that the total cost rises from €4,380,281 to €6,092,780, an increase of 40.88%, most of which was generated by the tariff changes introduced by the August 2013 reform [46]. It results in an increase of 14.79% in costs,

[4] Note that the costs in Table 7 are not the same as those in Table 8 (even when we talk about the same year), because Table 7 takes into account the tariff changes throughout the year, and in the simulation of Table 8 we used annual fixed tariffs.

from €5,307,704 to €6,092,780 (mainly due to the rise in the capacity tariff). To make matters worse, this increase is even more acute in the most expensive periods. Specifically, the total cost in scheduling period 1 would have been €679,352 in 2013, 73.31% of which (€498,031) consists of capacity charges, up from 49.99% with the tariffs of 2010. Moreover, the upward trend in capacity costs does not appear likely to change, as this component makes up 73.71% of the estimated cost for 2014. The results simulated for scheduling period 2, again one of the most expensive periods, are similar. Based on the BOE [42] tariff, the capacity cost would have represented around 24.92% of the total cost, much smaller than the 41.96% with the August 2013 reform.

Table 1.8. Simulation of CGRAA costs in Tariff 6.1 for different electricity tariffs (Euros)

	P1	P2	P3	P4	P5	P6	Total
BOE [42]							
Capacity cost	212,647	237,693	174,710	174,710	184,637	107,177	1,091,573
Power cost	212,731	511,696	58,376	187,331	171,374	2,147,201	3,288,708
Total cost	425,378	749,389	233,086	362,040	356,011	2,254,378	4,380,281
% of capacity by total	49.99%	31.72%	74.96%	48.26%	51.86%	4.75%	24.92%
BOE [43]							
Capacity cost	216,900	242,447	178,204	178,204	188,329	109,321	1,113,404
Power cost	214,821	516,100	58,723	187,993	171,796	2,152,157	3,301,591
Total cost	431,721	758,547	236,927	366,197	360,125	2,261,478	4,414,996
% of capacity by total	50.24%	31.96%	75.21%	48.66%	52.30%	4.83%	25.22%
BOE [44]							
Capacity cost	221,238	247,296	181,768	181,768	192,096	111,507	1,135,672
Power cost	243,418	564,538	69,452	222,272	189,844	2,531,171	3,820,695
Total cost	464,656	811,833	251,220	404,040	381,940	2,642,678	4,956,367
% of capacity by total	47.61%	30.46%	72.35%	44.99%	50.29%	4.22%	22.91%
BOE [32]							
Capacity cost	231,135	258,358	189,899	189,899	200,689	116,495	1,186,475
Power cost	256,990	592,278	70,885	226,168	196,178	2,778,730	4,121,230
Total cost	488,125	850,636	260,784	416,066	396,867	2,895,226	5,307,704
% of capacity by total	47.35%	30.37%	72.82%	45.64%	50.57%	4.02%	22.35%
BOE [46]							
Capacity cost	498,031	556,689	409,179	409,179	432,429	251,014	2,556,521
Power cost	181,321	431,114	58,376	201,038	180,394	2,484,017	3,536,259
Total cost	679,352	987,803	467,555	610,217	612,822	2,735,031	6,092,780
% of capacity by total	73.31%	56.36%	87.51%	67.05%	70.56%	9.18%	41.96%
BOE [47]							
Capacity cost	511,589	571,845	420,318	420,318	444,201	257,848	2,626,120
Power cost	182,442	433,517	58,576	201,468	180,700	2,488,255	3,544,959
Total cost	694,032	1,005,362	478,895	621,787	624,901	2,746,103	6,171,079
% of capacity by total	73.71%	56.88%	87.77%	67.60%	71.08%	9.39%	42.56%

Source: Own work.

1.2.2.2. Possible alternatives

In this section, we set out two possible alternatives, which could help cut the energy costs paid by consumers in general and farmers in particular, and would foster competitiveness and efficiency in the electricity industry. The first of these alternatives consists of removing, or at least sharply reducing, capacity tariffs to link the cost to the energy actually consumed. In most countries, connection charges are used to recover the cost of investments in the distribution grid, although other financing sources do exist.

Moreover, governments usually fund the lion's share of the capital expenditures required. This is the way that our proposal would take place in Spain. The other alternative would be to encourage energy self-consumption that is partially a complementary measure to the previous one. Therefore, though they are technically separate, the ideal would be to move forward with both measures at the same time.

Reduction of capacity tariffs

Our first proposal to reduce the impact of capacity tariffs on electricity costs would change the current system applied to the compensation of the electricity industry, by removing or cutting the payments made by users for the capacity contracted. This would involve, at the same time, moving towards charges linked to the energy consumed and the true transmission cost, which would depend on distances, and the distribution systems used. Let us look at this option in more detail.

In order to analyse the effects of the removal of the capacity-based tariff, we present the following four scenarios for 2013 in the CGRAA (results are shown in Table 1. 9). The energy (kWh) and capacity (kW) contracted are the same in the four scenarios, i.e. the 2013 figures.

We simulate the four scenarios based on the fact that, in 2013, the unjustified expenditures are supposed to be around 45% of total capacity cost (see Section 1.2.2.2). Thus, this 45% is assumed by the Government in the four scenarios. We propose alternative payments of the remaining 55%.

The first scenario consists of removing the capacity-based tariffs and keeping the energy tariffs that we had previously. In this case, the consumer's cost would only include the energy cost, as the transport and distribution costs are assumed by the Government and paid from the State budget (in other words, the remaining 55% is also assumed by the Government). In this case, the total cost would be around €3,536,259, approximately 58% of the 2013 costs.

The second scenario is based on transferring one third of the 55% of the capacity cost to the energy cost. For that, we must increase the energy tariff by 13.25%. The other two thirds of the capacity cost would be assumed by the Government. When we compare this measure with the current situation, we observe that the CGRAA saving would be more than €2 million, with respect to the current situation. Note that the total electricity cost using the tariffs of August of 2013 for the CGRAA was €6,092,780.

In the third scenario, the capacity-based tariff is reduced by 100%. In this case, 2/3 of the remaining 55% are applied to the energy tariff and 1/3 is assumed by the Government. The CGRAA would save more than €1.5 million, taking into account the 2013 costs.

Finally, the fourth scenario transfers the remaining 55% of the capacity cost to the energy cost. In this case, we would increase the power tariff by 39.76%. The saving for CGRAA would be in excess of €1 million (the costs would be €4,942,346).

Table 1. 9. Simulation of CGRAA costs in Tariff 6.1 with our proposal (Euros)

Periods	P1	P2	P3	P4	P5	P6	Total
Current situation							
Capacity cost	498,031	556,689	409,179	409,179	432,429	251,014	2,556,521
Power cost	181,321	431,114	58,376	201,038	180,394	2,484,017	3,536,259
Total cost	679,352	987,803	467,555	610,217	612,822	2,735,031	6,092,780
% of capacity by total	73.31%	56.36%	87.51%	67.05%	70.56%	9.18%	41.96%
Scenario 1: Capacity 0							
Power cost = total cost	181,321	431,114	58,376	201,038	180,394	2,484,017	3,536,259
Scenario 2: Capacity 0, power increases in 13.25%							
Power cost = total cost	205,353	488,254	66,113	227,683	204,303	2,813,248	4,004,955
Scenario 3: Capacity 0, power increases in 26.51%							
Power cost = total cost	229,385	545,393	73,850	254,329	228,212	3,142,479	4,473,650
Scenario 4: Capacity 0, power increases in 39.76%							
Power cost = total cost	253,418	602,533	81,588	280,974	252,122	3,471,711	4,942,346

Source: Own work.

Covered and lower costs and environmental gains

The proposals in these four scenarios would cause no additional tariff deficit and could address the different types of payments established. The differences are the role played by Government, which covers the regulated cost in total in the first alternative and a significant part in the others, and the energy price paid by consumers. So, this option cannot be rejected on the grounds that it would be financially insufficient to cover costs.

The hikes in capacity tariffs in recent years have considerably increased energy costs. As we can see in Table 1. 9, as expected, if we apply our four proposals, the user's energy costs would be lower than they are now because a part is paid by Government. And, in any case, the user payments are proportional to the energy used.

On the other hand, recently the cost of energy presents an ever-diminishing share of the total cost, so that Spain is heading towards something like a flat-rate charge, a situation in which energy use is increasingly irrelevant compared to the capacity contracted. This has clearly negative environmental consequences in the long run. Our four proposals would disentangle consumer reactions, as users would be able to associate cost and consumption more directly, providing a clear signal that would foster savings because rising energy use would bring with it a concomitant increase in costs, and this increase would offer a first incentive for all consumers to rein in their energy use. At the same time, energy savings would translate into lower costs for the consumer and in the long run would mitigate adverse environmental outcomes.

Capacity outcomes

In a system such as currently exists in Spain, especially since the recent hike in access tariffs, the fact that consumers pay for the capacity contracted means they seek to adjust this component, with the result that they tend to contract the lowest possible amount of power in order to avoid costs. In our proposal, as users would not have to pay a capacity charge, each consumer would be more free to contract adequate capacity and install plant based on their actual energy needs. This would, to a great extent, remove the influence of cost concerns in contracting capacity and would prevent bad choices, because decisions would be taken in view of technological and safety factors, rather than being dictated by cost. We believe that the availability of capacity up to 4,500 kW in households reduces the risk of fire and ensures more rational use. In general, linking cost to consumption would ensure the installation of adequate, safe levels of capacity, which would in turn provide gains for the transport and distribution grid, and for consumers. Additionally, it could help foster technological development.

Seasonal consumption

Importantly, our proposal would de-penalize seasonal patterns of energy use, because users would pay for consumption rather than the capacity of their installations. In light of the data provided by the CGRAA (see Table 1. 4), irrigation schemes use energy most intensively between May and October. Under the current billing system, such seasonal consumption is penalized over the year as a whole, because farmers must pay tariffs for the capacity they contract year round, although they use very little energy in the winter months. The alternative we propose would remove this problem, because billings would be closely tied to the energy consumed. In the case of irrigation, farmers would thus pay most of their total energy costs in summer, which is when they use the most electricity. The effect would be similar to the so-called *seasonal contract* or to *the French green tariff* (although the approach is different). This is very important to irrigation, but also in other industries, such as tourism and, indeed, in the case of second homes, and the implementation of consumption-based billings would encourage efficient energy use in all cases.

Implementation

One simple way to implement this alternative could be based on the current cost structure: it would be sufficient merely to increase the charge for energy actually consumed, to replace the part of the capacity tariff paid by users. This tariff could then be gradually cut and the charges for regulated activities, which should not be included in the electricity bill, could be removed.

As commented at the beginning of Section 1.2.4.1, different tariffs are possible, depending on the distribution grid or system used. It is a technical reality that not all transmission and distribution facilities entail the same costs per kWh. Low voltage and urban grids usually suffer higher levels of wastage and their structure is generally larger in spatial terms, which creates other specific costs. In this light, we propose that, if the Government does not cover the total capacity cost, each different type of user pay depending on the type (or types) of distribution infrastructure used based on the energy consumed. For example, exporters and importers who only use the high-voltage grid and transformers should pay for the cost of this infrastructure per kWh exported. Likewise, if households purchase their power from nearby utilities, they should not be asked to pay for long-distance transmission grids. This is, of course, a complex matter, but it would not be impossible to analyse infrastructure construction and maintenance costs and allocate them to consumers in such a way that each would pay for their own use.

Public grid

A keystone of this proposal is the existence of a truly public distribution grid, so that energy producers, industrial users, and domestic consumers would simply be users of the necessary infrastructure to transmit or receive electricity. This grid should be operated as a non-profit and treated rather as a national infrastructure, like the road and rail networks. Government should fund the construction and maintenance of new electricity transmission and distribution infrastructure in total (Scenario 1) or partially

(Scenarios 2, 3 and 4). In this last case, the Government could fix a charge based on three basic parameters, namely kWh consumed, distance between the source and the point of consumption of the energy, and the type of distribution infrastructure utilized. In any event, the criteria established should be completely transparent and conditions should be the same for all regions in order to facilitate economic and social integration and foster competition.

Moreover, any entity paying the fixed toll would have full and unrestricted access to the grid. This would mean that the Government would no longer be a passive player, becoming a true regulator and a facilitator, at the same time guaranteeing the minimum or basic electricity supply.

This public grid could also solve two other serious current problems, to wit, international interconnections, and access to the grid from any geographical point in Spain. The first issue is fundamental to raising competitiveness by broadening the market and opening it up to foreign utilities and providers. This would improve matters for many other industries, thereby fostering growth, and it would also make the alternative of self-consumption much easier, again providing a spur to growth. Moreover, such a national grid would weaken the separation between generation and marketing, which has not proved an effective driver of competition in Spain.

Self-consumption

In light of the CGRAA's annual and monthly electricity generation and consumption figures (Tables 1. 3 and 1. 4), it would be possible to cover much of the scheme's energy use out of its own energy output, if generating schedules could be properly aligned and measures were taken to facilitate transmission. Beyond the CGRAA, numerous other generating facilities are in a similar position. The main problem is the need for an institutional and legal framework that would foster and facilitate generation of this kind.

In general terms, the self-consumption option consists of generating the energy consumed, or at least a significant part of it. This could prove to be a very interesting option for irrigation schemes because they have the water needed for hydroelectric generation in their canals and reservoirs, and the land needed to site solar plants, which would allow them to consume their own power in their operations and sell any surplus.

There can be little doubt that self-consumption provides efficiency gains due to proximity and encourages competition by increasing the number of suppliers.

At present, two drafts exist for a Royal Decree to regulate self-consumption. In both cases, only consumers contracting capacity of 100 kW or less per supply point would qualify for authorization to consume their own energy, and even then, only if they had an internal electricity generating facility earmarked for self-consumption.

The first is the *Draft Royal Decree on the regulation of photovoltaic self-consumption or the net energy balance in Spain* (see MINETUR [48]). The fundamental feature of this net balance is that producers can feed a given quantity of kWh into the grid and can acquire the amount of energy they require when they wish. At the end of the year, a settlement would be prepared, in which producers would pay if the kWh consumed were higher than the kWh generated, and would receive a price for their surplus energy otherwise. Meanwhile, an "access toll" would be charged for use of the network, but no tariff would be applied for the capacity contracted.

It is no easy task to evaluate draft legislation before it is actually published, but we see at least three weaknesses in the current text. To begin with, constraints are placed on the size of the generating plant, which makes little sense from the standpoint of an open market, as industries should not be shut out by legislation prohibiting their operations, but by the efficiency with which they are able to generate electricity. Furthermore, the draft Royal Decree (surprisingly) fails to address the geographic reach of the distribution grid, which forms the basis for any system of self-generation because it is to be expected that a producer-consumer will be systematically exposed to energy shortfalls and surpluses. Finally, the draft is unforthcoming about the concept of the "access toll" and other associated payments, leaving the door open to the inclusion of all of the currently-existing regulated costs.

The other and most recent legislative blueprint is the one shown in MINETUR [49], which establishes the access tolls.

Surprisingly, this draft is prey to almost exactly the same weaknesses as the previous one. It maintains size constraints via the regulation of installed capacity, and it fails to move towards a public grid that would be largely autonomous of energy utilities.

Table 1. 10 shows the data on the simulation of self-consumption. We estimate what the savings would be for the CGRAA if self-consumption was implemented. First,

as is shown in Tables 1. 3 and 1. 4, we can see that the difference between the kWh produced, around 64 million kWh, and consumed, around 47 million kWh, is positive, so, it is possible to cover the CGRAA consumption with its own production. Moreover, more than 17 million kWh could be sold to the market. We are assuming that the savings would be the difference between the expenditure for the electricity consumption and the income from selling the production of this 47 million kWh to the market. In Table 1. 10, we can observe that the expenditure for electricity consumption in 2013 was €6.3 million; and, if we only take into account the expenditure for power consumption (and not for capacity contracted), the expenditure was a little more than €4 million. For our simulation, we could only consider (discounting from the savings) the income from selling the 47 million kWh. As we can also see in Table 1. 10, the CGRAA income from selling the 47 million kWh in 2013 was a little more than €4 million in total, including premiums, which are recently removed; then, the expected income from production is around €2 million (coming from the market, without premiums). The difference between the power consumed and the income from selling without premiums (taking into account only the 47 million kWh consumed) is €1,950,991, which is a first estimation of the savings. Now, taking into account the access costs for paying the tolls, which would be[5] €472,705, the costs for transporting the kWh to the consumption points. When we take these costs into account, the total savings would be €1,478,286. This is without considering the capacity costs, which in 2013 were €2,353,713. In a real situation, only the 50% of this capacity cost should be paid by a self-consumption supplier; in that case, the actual savings would approach €2.5 million.

[5] We calculate the transport costs taking into account the access tolls established in MINETUR (2013).

Table 1. 10. Self-consumption simulation for 2013

	Total
kWh produced	63,957,170
kWh consumed	46,845,638
Difference between kWh produced and consumed	17,111,532
Expenditure for 2013 consumption (Euros)	6,364,709
Expenditure for 2013 power consumption (Euros)	4,010,996
2013 income for the 46,2 GWh (Euros)	5,614,863
2013 income without premiums (Euros)	2,812,473
Access toll cost (Euros)	472,705
2013 expenditure for consumption - 2013 income without premiums (Euros)	1,198,523
Saving taking into account access toll costs	725,818

Source: Own work.

Finally, we should not ignore the fact that self-consumption could actually improve the supply of energy and facilitate management of the system, because it would decentralize generating. However, the main challenge, which the draft legislation discussed above should address, is to raise competition between firms and ensure that all of them, whether large or small, can provide capacity to cover Spain’s energy needs.

1.2.3. Conclusions

As we have seen, the energy industry in Spain is prey to major problems, including a lack of competition between firms, the tariff deficit, and the latest round of legislative reform, the sheer volume of which has significantly increased legal uncertainty, while its content will produce adverse environmental effects over the long run. All of this has driven up Spanish electricity prices, which represents a serious challenge to the country’s growth and modernization, increasing energy costs for industry of all kinds and for irrigated farming in particular. These price hikes are largely a result of the sharp increase in capacity tariffs in an effort to reduce the tariff deficit. While we would not wish to deny that these reforms have certain positive aspects, none of them addresses energy-saving incentives as a principal goal, or the use renewables, at least in the short to medium term.

This paper presents some alternatives, specifically with regard to tariff criteria, which we believe would help Spain progress in the right direction. We have based our study on the experience of the CGRAA because of the availability of data on both energy consumption and generation in this major irrigation scheme.

Observing the CGRAA's own electricity use, we may note that rising energy consumption has been accompanied by tariff hikes, which has significantly increased the scheme's energy costs, particularly since August 2013. As is well known, energy consumption is closely associated with the modernization of irrigation systems. The increase in prices and costs described in this paper is not confined to irrigated agriculture but has also affected all sectors of the Spanish economy and their competitiveness. The prices paid by both industry and households have shot up from relatively low or medium levels compared to Spain's EU partner countries, to become among the most expensive in Europe.

In the period 2010-2013, the capacity contracted by the CGRAA stayed practically unchanged, and even fell in the most expensive scheduling periods, while energy consumption rose, but not as fast as costs. Energy consumed under tariff 6.1 (the most commonly used by the CGRAA, accounting for much of its energy use) increased by 26.75% between 2010 and 2013, but costs soared from €3,433,277 to €5,775,541, or 68.21%, clearly revealing that the phenomenon is largely attributable to price effects.

To demonstrate this, we perform a simulation of the CGRAA's energy costs under different electricity tariffs, based on the actual levels of consumption and power contracted. We develop this simulation for tariff 6.1, which is the most common in irrigation. Where costs totalled €4,380,281 with the tariff of January 2010, they had risen to €6,171,079 by February 2014, an increase of 40.88%. This increase was caused mainly by the reform of August 2013, which alone resulted in a 14.79% increase, from €5,307,704 to €6,092,780. This once again demonstrates that the growth in costs is due to the tariff increase.

In this light, we propose possible measures to reduce energy costs. Our first proposal, to reduce the impact of capacity tariffs on electricity costs, would change the current system applied to compensation of the electricity industry, by removing or cutting the payments made by users for the capacity contracted and moving towards charges linked more closely to the energy consumed and the true transmission cost, which would depend on distances and the distribution systems used. In order to analyse this measure, we propose four scenarios, which differ in the part of the capacity cost paid by users through proportional increases in the power access tariff.

For the reasons explained in Section 1.2.2.2, we assume that around 45% of the capacity cost is not justified, and that expenditures would be paid by the State budget.

Thus, our first assumption is reducing the capacity cost by 45%. The difference in the four scenarios will be the financing of the remaining 55% of the capacity cost. In the first, the 55% is also assumed by the Government. Scenario 2 proposes that the consumers would pay one third of this 55% through the power tariff. In scenario 3, consumers would pay two thirds of this 55% of the capacity cost through the power tariff. And, finally, in scenario 4, consumers would pay the whole 55% through the power tariff.

Our proposal could, in any case, cover the costs of the distribution grid, but crucially it would incentivize energy savings, because cost would be linked to electricity consumption rather than capacity contracted. Furthermore, it would encourage a more rational approach to the choice of the capacity to contract for a given installation, thereby reducing the risk of power overloads and short circuits, and it would increase competition between energy firms, because the final electricity bill would be less conditioned by distribution costs. Meanwhile, the penalty incurred for irregular or seasonal consumption would be removed, which would clearly be fairer, because the consumers would pay according to their consumption. Quite probably, this would also indirectly encourage self-consumption, a measure mooted by both farmers and many other industries for some time now, especially if there existed a public, inexpensive grid that would allow more economical, or even free, access to the distribution grids.

An alternative (and complementary) measure proposed is the implementation of self-consumption. As shown in Table 1. 10, the savings for the CGRAA would be positive if self-consumption was implemented. In addition, the CGRAA could sell the difference between its energy produced and consumed (positive difference) in the daily market.

Unfortunately, the two draft Royal Decrees in the pipeline to regulate self-consumption in Spain are restricted to small generating facilities and neither addresses the need to develop the grid or to cut access costs, which in practice would hobble growth in energy availability and favour competition between energy firms.

To conclude, returning to the convenience of expanding the electricity grid, which should be considered as a public service: competition within the industry could be enhanced by improving and upgrading the grid, which would increase alternative supply options and broaden the market by allowing energy to be bought and sold in times of surplus or deficit. This measure would also solve the serious current problems of international interconnection (which again increases competition and fosters the entry of foreign firms and providers) and easier access to the grid from anywhere in the country.

1.2.4. References

[1] Jackson, T. M.; Khanc, S.; Hafeez, M. (2010). A comparative analysis of water application and energy consumption at the irrigated field level. Agricultural Water Management, 97, 1477–1485.

[2] Jiménez-Bello, M. A.; Martínez, F.; Bou, V.; Bartolí, H. J. (2010). Methodology for grouping intakes of pressurised irrigation networks into sectors to minimise energy consumption. Biosystems engineering, 105, 429–438.

[3] Plappally, A. K.; Lienhard, J. H. (2012). Energy requirements for water production, treatment, end use, reclamation, and disposal. Renewable and Sustainable Energy Reviews, 16, 4818–4848.

[4] Gopal, C.; Mohanraj, M.; Chandramohan, P.; Chandrasekar, P. (2013). Renewable energy source water pumping systems-A literature review. Renewable and Sustainable Energy Reviews, 25, 351–370.

[5] Haddad, S.; Benghanem, M.; Mellit, A.; Daffallah, K. O. (2015). ANNs-based modeling and prediction of hourly flow rate of a photovoltaic water pumping system: Experimental validation. Renewable and Sustainable Energy Reviews, 43, 635–643.

[6] Bataineh, K. M. (2016). Optimization analysis of solar thermal water pump. Renewable and Sustainable Energy Reviews, 55, 603–613.

[7] Chandel, S. S.; Nagaraju-Naik, M.; Chandel, R. (2015). Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. Renewable and Sustainable Energy Reviews, 49, 1084–1099.

[8] Ali, A.; Bahadur Rahut, D.; Behera, B. (2016). Factors influencing farmers′ adoption of energy-based water pumps and impacts on crop productivity and household income in Pakistan. Renewable and Sustainable Energy Reviews, 54, 48–57.

[9] Purohit, P.; Kandpal, T. C. (2005). Renewable energy technologies for irrigation water pumping in India: projected levels of dissemination, energy delivery and investment requirements using available diffusion models. Renewable and Sustainable Energy Reviews, 9, 6, 592–607.

[10] Lecina, S.; Isidoro, D.; Playán, E.; Aragües, R. (2010). “Irrigation modernization and water conservation in Spain: The case of Riegos del Alto Aragón”. Agricultural Water Manage, 97 (10): 1663-1675.

[11] Rodríguez-Díaz, J. A.; Pérez-Urrestarazu, L.; Camacho-Poyato, E.; Montesinos, P. (2011). “The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand”. Spanish Journal of Agricultural Research, 9, 4, 1000-1008.

[12] JORF. (2013). JORF n° 0063 de 15 marzo de 2013, página 4537, texto n° 21. Journal officiel de la République française. http://www.legifrance.gouv.fr/affichTexte.do?dateTexte=&categorieLien=id&cidTexte=JORFTEXT000027172789

[13] Sánchez Chóliz, J. and Sarasa, C. (2013) Analysis of water resources of Riegos del Alto Aragón (Huesca) in the first decade of the XXI century. Economía Agraria y Recursos Naturales, 13, 1, 97-124.

[14] Philip, J. M.; Sánchez-Chóliz, J.; Sarasa, C. (2014) Technological change in irrigated agriculture in a semiarid area in Spain. Water Resources Research, 50, 12, 9221-9235.

[15] Erdogdu, E. (2013). Implications of liberalization policies on government support to R&D: Lessons from electricity markets. Renewable and Sustainable Energy Reviews, 17, 110–118.

[16] Pollitt, M. G. (2012). The role of policy in energy transitions: Lessons from the energy liberalisation era. Energy Policy, 50, 128–137.

[17] Slabá, M.; Gapko, P.; Klimešová, A. (2013). Main drivers of natural gas prices in the Czech Republic after the market liberalization. Energy Policy, 52, 199–212.

[18] BOE. (1997). Law 54/1997, of November 27th of electric sector. Official State Bulletin, nº 285.

[19] OMIE. (2014). “Evolution of the electricity market”. February 2014.

[20] Cardoso, A.; Fuinhas, J. A. (2015). The role of Portuguese electricity generation regimes and industrial production. Renewable and Sustainable Energy Reviews, 43, 321–330.

[21] Yusta Loyo, J. M. (2013). Contracting of electricity supply. Opportunities and strategies to reduce the cost of electricity bills.

[22] CNE. (2010). Report about the provisional liquidation number 14 of 2009 and conducted verifications electricity sector. Energy National Commission.

[23] CNE. (2011). Report about the provisional liquidation number 14 of 2010 and conducted verifications electricity sector. Energy National Commission.

[24] CNE. (2012). Report about the provisional liquidation number 14 of 2011 and conducted verifications electricity sector. Energy National Commission.

[25] CNE. (2013). Report about the provisional liquidation number 12 of 2012 and conducted verifications electricity sector. Energy National Commission.

[26] CNMC. (2013). Report about the results of the provisional liquidation number 8 of 2013 electricity sector. National Commission of markets and competition.

[27] Martínez, L. (2013). Electricity demand and tariff deficit. Critical economy journal nº 15, first semester 2013, ISNN 2013-5254.

[28] Ballester, C.; Furió, D. (2015). Effects of renewables on the stylized facts of electricity prices. Renewable and Sustainable Energy Reviews, 52, 1596–1609.

[29] Guerrero-Lemus, R. González-Díaz, B.; Ríos; G.; Dib, R. N. (2015). Study of the new Spanish legislation applied to an insular system that has achieved grid parity on PV and wind energy. Renewable and Sustainable Energy Reviews, 49, 426–436.

[30] Del Río, P.; Mir, P. (2012). Support for solar PV deployment in Spain: Some policy lessons. Renewable and Sustainable Energy Reviews, Volume 16, Issue 8, Pages 5557–5566.

[31] del Río-González, P. (2008). Ten years of renewable electricity policies in Spain: An analysis of successive feed-in tariff reforms. Energy Policy 36, 2917–2929.

[32] BOE. (2012b). Royal Decree-Law 1/2012, of January 27th. Official State Bulletin, nº 24. General arrangement.

[33] BOE. (2012c). Royal Decree-Law 13/2012, of March 30th. Official State Bulletin, nº 78. General arrangement.

[34] BOE. (2012d). Royal Decree-Law 20/2012, of July 13th. Official State Bulletin, nº 168. General arrangement.

[35] BOE. (2013b). Royal Decree-Law 2/2013, of February 1st. Official State Bulletin, nº 29. General arrangement.

[36] BOE. (2013c). Royal Decree-Law 9/2013, of July 12th. Official State Bulletin, nº 167. General arrangement.

[37] BOE. (2013d). Royal Decree-Law 17/2013, of December 27th. Official State Bulletin, nº 311. General arrangement.

[38] EUROSTAT. (2014a). EUROSTAT. 2014 updating. Database. Energy statistics. Natural gas and electricity prices (from 2007 onwards).

[39] EUROSTAT. (2014b). EUROSTAT. 2014 updating. Database. Energy statistics. Natural gas and electricity prices (until 2007 onwards).

[40] BOE. (2007). Law 17/2007, of July 4th. Official State Bulletin, nº 160.

[41] BOE. (2008). Order ITC/1857/2008, of June 26th. Official State Bulletin, nº 156.

[42] BOE. (2009). Order ITC/3519/2009, of December 28th. Official State Bulletin, nº 315. General arrangement.

[43] BOE. (2011b). Order ITC/688/2011, of March 30th. Official State Bulletin, nº 77. General arrangement.

[44] BOE. (2011a). Order IET/3586/2011, of December 30th. Official State Bulletin, nº 315. General arrangement.

[45] BOE. (2012a). Order IET/843/2012, of April 25th. Official State Bulletin, nº 100. General arrangement.

[46] BOE. (2013a). Order IET/1491/2013, of August 1st. Official State Bulletin, nº 185. General arrangement.

[47] BOE. (2014). Order IET/107/2014, of January 31st. Official State Bulletin, nº 28. General arrangement.

[48] MINETUR. (2011). Draft Royal Decree by which the regulation of the administrative, technical and economical conditions on the net balance electricity supply mode are established. Ministry of industry, turism and commerce. Spanish Government.

[49] MINETUR. (2013). Draft Royal Decree by which the regulation of the administrative, technical and economical conditions on the self-consumption and generation with self-consumption electricity supply mode are established. Ministry of industry, turism and commerce. Spanish Government.

Chapter 2

Some alternatives to reduce energy costs in irrigated agriculture: effects of the implementation of a green tariff in Spain

2.1. Motivation

In Chapter 1, certain characteristics of the electricity sector in Spain were described, and instruments proposed aimed at reducing electricity costs in irrigated agriculture (concretely, one of them was the idea of reducing the payment by capacity contracted). In Chapter 2, we study the effects of a specific tariff whose payment by capacity is lower for farmers. We present in Section 2.2. an alternative measure: a green fee, which could be understood as a transition measure, starting from the current situation and seeking to achieve some of the objectives of Chapter 1. The analysis of this alternative tariff constitutes the main content of this chapter. The most important parts of the chapter were published in Langarita et al. (2016): “Los costes energéticos en la agricultura de regadío. Alternativas para su reducción y efectos de la implantación de una tarifa verde en España”, *Regional and Sectoral econmic studies*, 16,1, 123-140.

2.2. Energy costs in irrigated agriculture. Options for their reduction and effects of the implementation of a green tariff in Spain

2.2.1. Introduction

Energy is an essential element for the functioning of the economy, since all sectors need it to work, but particularly for irrigated agriculture, which has considerably increased energy consumption for pumping and distributing irrigation water, after modernization.

Recently, due to the importance of both energy and irrigated agriculture sectors, several authors have paid special attention to the water-energy binomial, as we can see in Cabrera et al. (2010), Cabrera (2011), Uche (2013), Corominas (2010), and Carrillo-Cobo et al. (2010). In addition, in recent years, energy prices have considerably increased.

In this context, a review of energy consumption in irrigation and the design and rate of the electricity tariffs in Spain becomes of great importance and can facilitate the design of measures that aim to reduce energy costs in irrigation, as well as to obviate some of the problems that the electricity sector presents.

This work carries out, first, a review of the evolution of electricity tariffs and energy consumption in irrigation; second, it analyses the effects of the implementation in Spain of a green French tariff ("*Tarif Vert*" from now; see JORF, 2013), on irrigated agriculture.

We begin with a real case study, the Upper Aragon Irrigation Scheme (CGRAA in its Spanish acronym), a group of 58 irrigation communities. The CGRAA is situated in the province of Huesca, in the North of Aragon (Spain) and it comprises more than 127,000 hectares of crops in the Ebro Basin.

The Ebro basin is the most important river basin in Spain and it represents 17% of its land, with Spain being one of the most important countries in the world in terms of its irrigated land. Within the Ebro river basin, irrigation in the province of Huesca covers more than 200,000 hectares, which represents almost 40% of the utilized agricultural area in Huesca and 6% of the utilized agricultural area of Spain. Output that is produced in the irrigation of Huesca achieves more than 80% of total agricultural production in the province. CGRAA is the largest irrigation system in the Ebro Basin and in Spain (Sánchez-Chóliz and Sarasa, 2013).

In the CGRAA, energy costs have increased considerably in recent years. In line with prior papers, such as Rodríguez et al. (2011), who say that, after irrigation modernization, costs increased by 400% in an irrigation community of Andalusia, the increases of energy costs in the CGRAA are mainly due to the increase of consumption after irrigation modernization; but they are also due to increased electricity tariffs. More specifically, this work observes that the part of the increase in costs which is provoked by the increase in tariffs is due to the increase in the access tariffs by capacity.

These results point to a possible alternative to reduce costs: the introduction of a French tariff named *Tarif Vert*, with which it is possible to reduce costs in irrigated agriculture, and also dissipate other problems this sector presents.

In section 2.2.3. we analyze the available information, which allows us to evaluate energy costs. In section 2.2.4, the main characteristics of the Tarif Vert are shown and we also show the results of its introduction in Spain. Finally, the work ends with some brief reflections.

2.2.2. The importance of irrigated agriculture in Spain and its relationship with the electricity sector

The agricultural sector, together with the agrifood sector, are industries with a great capacity to boost the economy (see Duarte et al., 2012). Following Rasmussen's (1956) classification, backward sectors (also called boosters or drivers) of the economy are those that, if their production increases, provoke an effect on other industries greater than their own increase. Forward sectors (also named receptors) are those in which, when demand increases, an increase in their production greater than the increase in the demand is generated. Key sectors of the economy are those which are, at the same time, backward and forward. Finally, non-significant sectors are also considered (those which are neither backward nor forward).

Several papers mark agricultural and/or agrifood sectors as key, backward, or forward sectors, in the different communities of the Spanish economy; that is to say, these sectors always appear significant in one sense or another in the Spanish economy (see, for example, Cardenete and López, 2012, and Cardenete et al., 2015), indicating that agrifood is a key sector and the agricultural sector is backward for the Andalusian economy. Duarte et al. (2015b) observe that the agricultural sector is a forward sector for the Aragonese economy and the agrifood industry is a key sector. Iráizoz (2006) observe that in Navarra both agriculture and agrifood industry are key sectors for the economy. In the same line, Polo and Valle (2002) see agriculture as a forward sector for the Balearic Islands, while Cardenete (2011) finds that, for the whole Spanish economy, agriculture is a backward sector.

Therefore, we can say that, according to the above works, the good functioning of the agriculture sector favors the good functioning of the general economy, since all reviewed works find that production in agriculture has a multiplier effect on the rest of the sectors that make up the economy (it does not appear in any of the reviewed works as non-significant). Within agriculture, irrigation covers 20% of the cropped land in Spain, which comprises almost 60% of agrarian final production (see Corominas, 2010). That is to say, irrigation productivity is much higher than the productivity of dry-land agriculture. After irrigation modernization, as we said, energy consumption considerably increased, so there is a strong relationship between these two sectors.

However, as noted above, recently, energy prices have sharply increased in Spain, due to the fact that in the Spanish electricity system there are serious problems. First, there is little or no competition among the firms in this sector (see Fabra and Fraba Utray, 2010). Second, the temporary irregularity of energy consumption is penalized (see Duarte et al., 2015b). This affects especially agriculture, because most electricity consumption is done in the summer months. The main problem is that with the current design of the tariffs, power is contracted throughout the year. And, third, the tariff deficit is high and has a growing trend (see CNE, 2010, 2011, 2012, 2013, CNMC, 2013, and Yusta, 2013). Additionally, this deficit has promoted some legislation that is causing other problems, as for example, the legal uncertainty due to the changes in the financing system because of changes in the legislation (see BOE, 2012b, 2012c, 2012d, 2013b, 2013c, 2013d).

Given the increase in energy prices and the problems that the Spanish electricity sector faces, we should consider solutions. However, our aim here is not to discover measures of a general character that require more time for their implementation. This work, given the importance of agriculture in the Spanish economy and the necessity of encouraging its good functioning in the short term, we focus on trying to reduce energy costs in this sector, taking into account an alternative tariff which is established in France, the *Tarif Vert*.

2.2.3. Energy costs in the CGRAA

This section shows that the increase in energy costs in agriculture is caused mainly by the increase in the access tariffs by capacity, with the consequent increase in the final price that this entails. We make use of real data on energy consumption provided directly by the CGRAA.

The CGRAA, in addition to being a set of 58 irrigation communities combined to maintain its modernized irrigation activities, is also an energy producer, via the hydroelectric pumps situated in its canals and reservoirs. The community receives water from forty supply points, although four of them are encouraged to supply energy to the hydroelectric plants for their maintenance.

We have detailed information for the period 2010-2013 on energy consumption, contracted capacity, and the period and the month in which each of these consumptions are produced at the various supply points, with all data provided directly by the

CGRAA. In the Official State Bulletin (BOE in its Spanish acronym), we can see the access tariffs by capacity contracted and by energy consumed. In addition, we have the prices agreed with the electric companies, also provided by the CGRAA. Although the CGRAA is also an energy producer, having recently installed six mini-hydropower plants, and whose energy production is quite significant, following the objective of this work we focus on the analysis of costs, on the level of consumption. In the first subsection of this section, we explain the tariffs applicable in Spain and the energy consumption in the CGRAA, and in the second, we present how these tariffs affect the energy cost in the specific case of the CGRAA.

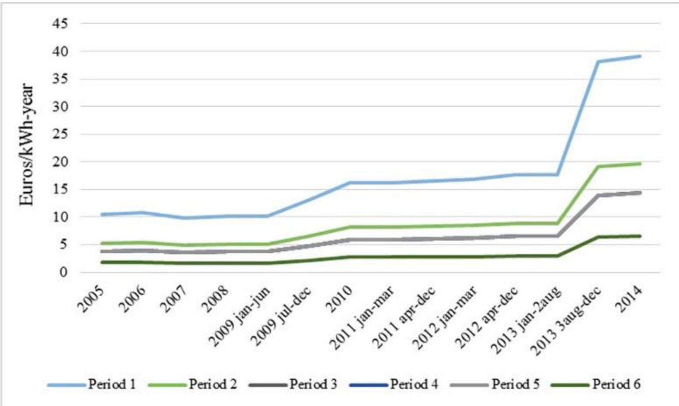
2.2.3.1 Electricity tariffs and energy consumption in the CGRAA

In the calculation of the energy price, two parts are distinguished: the capacity term and the power term. The capacity component is entirely fixed by Government, and is the access tariffs per kilowatt (kW) of capacity contracted. The energy component is agreed with the electricity utilities and several items are included in it, among them being the access tariff per kilowatt-hour (kWh) of energy consumed. The problem that the access tariffs present, in the Spanish case, is that the capacity component has increased considerably in recent years. We comment here on the characteristics and the evolution of the tariffs which have usually been contracted in agriculture, while not forgetting that the rest of the tariffs present similar characteristics.

After the liberalization of the electricity market, which began in 1977 in an attempt to introduce competition among the firms in this sector, following the trend of other countries of the European Union (see BOE, 1997), and the removal of the special electricity tariffs that could be applied in agriculture till July 2008, (see BOE, 2007, 2008), the CGRAA has traditionally contracted tariffs 3.1 A and 6.1, according to the capacity contracted in each of the supply points, except for the year 2013, in which tariff 6.2 is contracted for a new supply point. Nevertheless, throughout the years, the tariff contracted in the supply points with the highest energy consumption is tariff 6.1, so we now focus on this tariff.

Tariff 6.1 applies to installations with a voltage between 0 and 36 kilovolts (kV) and whose contracted capacity is higher or equal to 450 kW. It is divided into six scheduling periods, whose complete calendar of the timetable distribution can be seen in INDESO (2014). These periods, as can be seen in Figures 2. 1 and 2. 2, both for the power term and the capacity term, follow a decreasing order in prices, that is to say period 1 is the most expensive and period 6 is the cheapest. Figure 2. 1 shows the evolution of the capacity term of tariff 6.1, which presents an increasing tendency since year 2005. This increasing tendency induces a loss of energy efficiency, since, apart from the increase in total costs, the cost that the fixed part represents with respect to the total expenditure of the electric bill increases, so it is relatively much cheaper energy consumption. Figure 2. 2 shows the evolution of the energy term of tariff 6.1, producing a reduction of the energy term from August 2013, further accentuating the effect, because the variable part of the bill is even more reduced and the fixed part supposes a larger percentage.

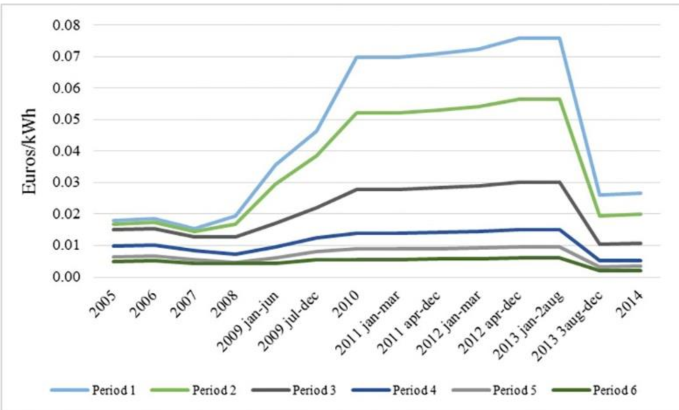
Figure 2. 1. Capacity term (€/kW-year)



The capacity contracted in periods 3, 4 and 5 is the same.

Source: Duarte et al. (2015b).

Figure 2. 2. Energy term (€/kWh)



Source: Duarte et al. (2015b).

Access tariffs generate income for the state and they are fixed by the state, so they should be established in the fairest way possible. One argument to support the reduction of the access tariffs by capacity comes from economic theory. Remember that a lump sum tax is the source of tax revenue that involves the least redistribution of income. An access tariff by capacity is a fixed fee, that is to say, we do not pay proportional to consumption. This tendency to increase the tariffs by capacity and decrease the tariffs by power means that, increasingly, state tariffs for the use of the energy seem more like a *regressive tax*.

One other concern is that this procedure supposes a disincentive to saving energy, since the part of the total paid for consumption is relatively cheaper. By paying an important part for capacity, that is, a fixed cost, the cost of energy consumed is reduced.

Given the importance of the agriculture sector in the Spanish economy, the measure proposed aims to reduce costs in this sector through the reduction of the capacity tariff, which can reduce costs and enhance the sensitivity of the consumer to energy saving. As the total cost would be lower due to the reduction of the cost by capacity, consumption would be relatively more expensive, which would lead to more cautious consumption. Another negative effect of high tariffs by capacity is the tendency to contract a very low capacity, which can lead to undesirable interruptions in the supply and even to reductions of the security of their own installations.

In Table 2. 1 we show the monthly consumption of the CGRAA in 2013. In that year, the bulk of the consumption was between April and September, although in other years it could vary, and be between May and October. This irregular consumption over time has led farmers to propose *seasonal contracts*, which would make summer consumption cheaper.

Table 2. 1. Monthly energy consumption in the CGRAA in 2013 (GWh)

Mes	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Consumption (GWh)	2,97	0,38	0,74	3,63	3,18	6,04	10,36	11,97	5,46	0,95	0,24	0,29	46,2

Source: Own work from CGRAA.

This proposition is based on the penalty imposed for having the same capacity contracted for all the year and aims to introduce reductions in the energy tariffs in the summer. For that, one possible solution would be the possibility of having annual contracts in which we could distinguish two seasons of the year: one of intensive consumption, and the other of residual consumption.

Focusing on agriculture, in an irrigation community the intensive consumption season would be April or May to September or October, including any restriction as, in the season of residual consumption, could be contracted, as a maximum, at 20% of the total capacity. This would allow the irrigators to have some electricity supply during the slow season. With our proposal we will see that this problem would be largely solved[6].

Table 2. 2 shows the energy consumption at each of the forty supply points in the CGRAA in period 2010-2013. We can see that, in 2013, Alconadre, Almudévar-Artical-Violada, and Lalueza are the supply points that consume the most energy. Thus, we will use these three points to simulate the effects of the implementation in Spain of the *Tarif Vert*.

[6] Another measure that farmers have often proposed is self-consumption, which should be broadly addressed. In the CGRAA we observe that it would be possible to cover the energy consumption with its own production. This is the case not only in this community, but it happens in many other productive installations. The main problem is that an institutional and legal framework to favor and facilitate this type of production is needed.

Table 2. 2. Total energy consumption by supply point (kWh)

Nº	Irrigation community	2010	2011	2012	2013
1	A-19-20 Estación Saso sector 34	813,307	1,069,112	977,682	1,031,240
2	A-19-20 (Rebombeo Salillas) sector 34	39,271	65,064	56,890	55,477
3	A-19-20 Estación Huerto sector 35	2,502,544	3,001,803	2,616,020	2,541,768
4	A-19-20 Estación Salillas sector 33	1,058,994	1,326,326	1,056,393	1,123,252
5	Alconadre	3,675,012	4,002,023	3,250,710	3,812,277
6	Almudévar Abaries	939,911	2,092,065	1,991,373	2,069,049
7	Almudévar-Artical-Violada	1,252,814	2,697,321	2,524,724	2,857,633
8	Almudévar Colladas	334,917	632,323	635,815	772,343
9	Almudévar Matilero	255,161	644,325	532,818	682,219
10	Canal del Cinca-Barbastro	167,879	179,385	196,935	183,645
11	Collarada 2ª Sección	1,500,667	2,082,119	2,026,527	2,058,784
12	La Campaña	208,020	244,317	229,303	285,328
13	La Corona (bombeo 1) Valdabra	779,092	1,144,362	1,046,157	1,708,146
14	La Corona (bombeo 2) Albero	1,080,899	1,293,044	1,179,331	1,130,936
15	La Corona (bombeo 3) Piracés	681,105	909,973	845,292	824,867
16	Lalueza	2,040,945	3,055,018	2,716,143	2,894,789
17	Lasesa (bombeo 3)	1,535,432	1,704,472	1,227,039	1,548,063
18	Lasesa (bombeo 4)	1,773,524	2,280,231	1,402,606	1,905,571
19	Lasesa (bombeo 5)	491,802	532,682	419,459	431,028
20	Lasesa (bombeo 6)	686,986	754,461	601,004	662,387
21	Montesnegros	3,424,694	3,580,224	2,670,233	2,427,603
22	Piracés Flumen	182,410	307,812	284,044	327,747
23	Sangarrén	63,598	143,828	207,114	233,754
24	San Pedro	832,528	863,206	889,373	920,830
25	San Pedro	1,295,102	1,521,072	1,399,418	280,205
26	San Juan - Laluenga	731,084	824,233	828,533	785,013
27	San Miguel	2,668,946	2,727,504	2,205,652	2,407,051
28	Sector VII	696,291	749,420	1,065,724	1,362,060
29	Sector VIII	266,543	749,420	1,154,925	1,613,812
30	Sector XI	1,561,187	2,029,252	1,794,511	1,862,055
31	Sector XI	1,493,517	1,988,784	1,896,505	2,613,002
32	Tramaced	346,250	512,892	421,812	375,819
33	Val de Alferche bombeo Berbegal	314,248	378,345	384,456	328,345
34	Val de Alferche bombeo Fornillos	229,971	296,635	287,655	283,766
35	Sodeto	77,198	296,635	387,777	918,353
36	Central H. Valdespartera	19,399	14,230	20,498	8,135
37	Central H. Montanera	24,224	19,749	12,062	18,414
38	Central H. Piracés	22,311	11,182	25,669	25,151
39	Central H. Torrollón	19,232	16,923	20,029	19,709
40	Lasesa Lastanosa				808,937
	Total	36,087,015	46,741,772	41,488,211	46,198,563

Source: own work base on CGRAA.

2.2.3.2 Increase in costs provoked by the increase in the access tariffs

In Table 2. 3, we show the capacity contracted, the energy consumed, and the total energy cost for the supply points, which contract with tariff 3.1 A in the period 2010-2013. The capacities we show are the average capacity for each of the supply points that contract with this tariff. In this table we observe, first, that the capacity contracted decreases in the three periods. In addition, there is a tendency to decrease energy consumption significantly in period 1, which is the most expensive, and to increase it gradually in period 2, remaining practically constant in period 3. However, despite the diminution in the power contracted and the limited (5.63%) growth in energy consumption, the total cost increased from €229,054 in 2010 to €390,425 in 2013, an increase of more than 70%, which indicates that this is mainly due to the increase in the tariffs, specifically the access tariffs by capacity.

Table 2. 3. Power, energy and cost, 2010-2013, Tariff 3.1 A

	Mean capacity contracted (kW)			Energy consumed (kWh)*				Cost (euros)
	P1	P2	P3	P1	P2	P3	Total	Total
2010	60	175	175	96,249	603,553	1,042,910	1,742,712	229,054
2011	60	170	170	114,856	675,163	1,280,758	2,070,777	228,671
2012	60	150	160	92,741	605,833	1,151,808	1,850,382	229,669
2013	55	160	160	55,605	699,079	1,086,250	1,840,934	390,425

*Tariff 3.1A only has three daily periods. Source: Duarte et al. (2015b).

In the period 2010-2013 the capacity contracted with tariff 6.1. in all of the communities of the CGRAA, observed in Table 2. 4, increases in the cheapest scheduling periods, such as period 6, and decreases in expensive periods, such as period 1. We observe a tendency to decrease consumption in periods 1 and 5, and increase in periods 2, 3 and 6, so that the total energy consumed in all scheduling periods increased overall more than 25%, from 2010 to 2013. The main reason for this overall increment is, once again, greater demand from modernized irrigation, or in those communities that are adapting to the modernization process. In the last column of Table 2. 4, we present the evolution of the total cost, which grew in all years, rising from €3,433,277 in 2010 to €5,775,541 in 2013. The increase in costs is very much higher than the increase in consumption, due principally to the increase in access tariffs by capacity term.

Table 2. 4. Capacity, energy and cost, 2010-2013, Tariff 6.1

	Mean capacity contracted (kW)						Energy consumed (kWh)							Cost (euros)
	P1	P2	P3	P4	P5	P6	P1	P2	P3	P4	P5	P6	Total	Total
2010	380	670	680	680	700	855	1,397,621	2,423,264	449,776	1,401,409	2,172,704	26,512,749	34,357,523	3,433,277
2011	375	715	720	720	720	930	1,588,367	3,192,995	470,313	1,636,054	2,781,834	35,437,538	45,107,101	4,035,201
2012	315	650	655	655	700	940	900,812	2,195,129	533,830	1,668,506	1,505,481	32,604,768	39,408,526	4,401,254
2013	340	765	770	770	810	1035	1,179,937	3,329,836	492,293	1,888,034	1,863,571	34,795,021	43,548,692	5,775,541

Source: Duarte et al. (2015b).

In summary, at the supply points that contract with tariff 3.1A, in spite of having decreased contracted capacity in the three tariff periods, throughout the period 2010-2013 and having increased the energy consumed, also by 5.63%, the costs increased by 70.45%. On the other hand, at the points that contract with tariff 6.1, the capacity in period 6 (the cheapest period) decreases. Thus, energy consumed increased by 26.75% and costs increased by 68.21% in the period 2010-2013. In addition, the total cost was €3,662,331 in 2010, €4,263,331 in 2011, €4,630,923 in 2012, and €6,269,858 in 2013. Taking into account the capacity contracted in 2013 and the access tariffs published in BOE, which change throughout the year, the prevision of the cost by capacity for the CGRAA communities for 2014 is €2,184,415, while the prevision for electricity consumption for 2014 is €3,092,345. This makes that projected cost in 2014 is around €6,986,074, with which it seems the trend continues to grow.

Viewing the results and with the objective of confirming that the increase in the energy costs in the CGRAA is mainly due to hikes in access tariffs, we present the results of some simulations made with the objective of observing the changes in the energy costs with different electricity tariffs, for the same data of contracted capacity and energy consumed data of the CGRAA for 2013. We perform six estimations, taking into account for each of them the applicable tariffs according to BOE (2009, 2011b, 2011a, 2012a, 2013a, 2014).

Table 2. 5 presents the results obtained and shows that, taking into account the tariffs applicable in January 2010 (BOE 2009) and February 2014 (BOE 2014), costs would change from €3,984,760 to €5,276,760, an increase of 32.42%. This increase is provoked mainly by the August 2013 reform (BOE 2013a), with which costs would change from €4,588,789 to €5,178,301, that is to say, they would increase by 12,84%.

Table 2. 5. Simulation of energy cost according to different electricity tariffs (Euros)

BOE	Capacity cost	% Capacity	Energy cost	% Energy	Total cost
2009	910,990.04	22.86%	3,073,770.68	77.14%	3,984,760.71
2011b	929,209.86	25.03%	2,782,477.36	74.97%	3,711,687.71
2011a	947,794.04	22.06%	3,348,074.02	77.94%	4,295,686.08
2012b	990,192.28	21.58%	3,598,597.60	78.42%	4,588,789.88
2013a	2,124,403.69	41.03%	3,053,897.23	58.97%	5,178,301.03
2014	2,184,415.43	41.40%	3,092,345.23	58.60%	5,276,760.65

Source: Own work.

In addition, we can observe that the percentage that the capacity cost represents over the total cost is increasing with the different regulations applied, with the largest increase being with the August 2013 reform[7]. Moreover, it does not only increase in relative terms, but also in absolute terms. On the other hand, the cost, both in absolute and percentage terms, of the energy term, decreases. These results clearly discourage the wise use of energy, since, as mentioned, in relative terms, consumption is much cheaper.

2.2.4. Green fee introduction in Spain

2.2.4.1. *Tarif Vert* characters

Given the importance of agriculture as a driver of any economy and the backward effect on the rest of the sectors that it presents in the Spanish economy, particularly, as has been noted in Section 2.2.2, the proposal we perform is the implementation in Spain of the *Tarif Vert* (or any adaptation of that), a special French tariff for agriculture, with which we could reduce costs in irrigation, along with alleviating some of the problems that currently exist in the electricity sector, as for example the penalty of temporary irregularity, or the inequality of income redistribution.

In this section we present the main characteristics of this French tariff with the objective of understanding its structure, and in the next section we simulate the energy costs as if it were the tariff for the three supply points that consume the most energy in the CGRAA.

Tarif Vert is a tariff for high voltage plants (higher than 1 kV), in which three different types of tariff are distinguished, according to the capacity contracted. These tariff types are: A (less than 10 MW), B (from 10 to 40 MW), and C (more than 40 MW). In our case study, we select the A type, because in the CGRAA none of the supply points achieve 10,000 kW of power contracted.

Three options are distinguished according to the size of the plants: "Option Base", "Option EJP" and "Option modulable". In the *Tarif Vert A5 Option Base* two

[7] Nevertheless, the August 2013 reform is not the most recent available, but it is the most significant, especially with respect to the irrigation, due to the increase in access tariffs and the removal of the premiums for renewables. See BOE (2013a).

seasons are also distinguished: winter and summer. “Winter” season starts in November and finishes in March and “summer” season runs from April to October.

In addition, as we can see in JORF (2013), the scheme distinguishes five time periods: *peak hours* (Pte), from 9 to 11 hours and from 18 to 20 hours in December, January and February; *full winter hours* (HPH), 6-9, 11-18 and 20-22 hours in December, January and February; *valley winter hours* (HCH), 0-6 and 22-24 hours from November to March and Sundays in summer; *full summer hours* (HPE), 6-22 from April to October; and *valley summer hours* (HCE), 0-6 and 22-24 from April to October and Sundays in summer. We can see this in the full calendar of Table 2. 6.

Table 2. 6. Calendar of time periods *Tarif Vert A5 Option Base*

	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sept	Oct	Nov	Dic	Domingos (nov-mar)	Domingos (abr-oct)
0-1	HCH	HCH	HCH	HCE	HCE	HCE	HCE	HCE	HCE	HCE	HCH	HCH	HCH	HCE
1-2	HCH	HCH	HCH	HCE	HCE	HCE	HCE	HCE	HCE	HCE	HCH	HCH	HCH	HCE
2-3	HCH	HCH	HCH	HCE	HCE	HCE	HCE	HCE	HCE	HCE	HCH	HCH	HCH	HCE
3-4	HCH	HCH	HCH	HCE	HCE	HCE	HCE	HCE	HCE	HCE	HCH	HCH	HCH	HCE
4-5	HCH	HCH	HCH	HCE	HCE	HCE	HCE	HCE	HCE	HCE	HCH	HCH	HCH	HCE
5-6	HCH	HCH	HCH	HCE	HCE	HCE	HCE	HCE	HCE	HCE	HCH	HCH	HCH	HCE
6-7	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
7-8	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
8-9	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
9-10	Pte	Pte	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	Pte	HCH	HCE
10-11	Pte	Pte	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	Pte	HCH	HCE
11-12	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
12-13	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
13-14	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
14-15	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
15-16	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
16-17	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
17-18	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
18-19	Pte	Pte	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	Pte	HCH	HCE
19-20	Pte	Pte	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	Pte	HCH	HCE
20-21	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
21-22	HPH	HPH	HPH	HPE	HPE	HPE	HPE	HPE	HPE	HPE	HPH	HPH	HCH	HCE
22-23	HCH	HCH	HCH	HCE	HCE	HCE	HCE	HCE	HCE	HCE	HCH	HCH	HCH	HCE
23-24	HCH	HCH	HCH	HCE	HCE	HCE	HCE	HCE	HCE	HCE	HCH	HCH	HCH	HCE

Source: own work based on JORF (2013).

When we compare the tariff periods of the *Tarif Vert* with the tariff 6.1 periods (see the complete calendar of tariff 6.1 periods in INDESO, 2014), we observe that the cheapest period, the HCE, is similar to period 6 of the tariff 6.1. The main difference is that, in the French case, it does not include the winter months. The next cheapest period, the full winter hours (HPE), could be compared with period 5 of tariff 6.1, but, in the Spanish case, only in April, May and October. The most expensive French hours, the peak hours (Pte), are similar to period 1 of tariff 6.1, which applies in January, February and December. In the case of tariff 6.1, period 1 comprises January, February and December, but includes the last fifteen days of June and the entire month of July.

There exist several versions of this tariff, which can be chosen by the customers, depending on the quantity of energy that they consume: CU (short use), MU (medium use), LU (large use), TLU (very large use).

In summer season, in which the energy demand is much higher than in winter in agriculture (the same as in Spain, see Table 2. 1), access tariffs are considerably more reduced than in the winter season, as we can observe in Table 2. 7, in which the tariffs applicable in each of the periods appear. These tariffs are composed, as in the Spanish case, of a capacity term and an energy term. The capacity term is a fixed annual term, that is to say, it does not vary during the year, although it is different for each of the versions of which this tariff is composed (observe the first column of the table, "Fixed annual premium"). This fixed term is calculated based on the annual contracted capacity. A different tariff for kWh of energy consumed is fixed like the seasons (winter and summer) and periods (Pte, HPH, HCH, HPE and HCE).

Table 2. 7. Tariffs of the *Tarif Vert A5-Option Base* (€/kW-year and €/kWh)

Version	Fixed annual premium (Euros/kW-year)	Winter (€/kWh)			Summer (€/kWh)	
		Peak	HPH	HCH	HPE	HCE
TLU	74.16	0.07154	0.0582	0.04452	0.04458	0.0282
LU	54.6	0.10421	0.06667	0.04606	0.04525	0.02881
MU	43.2	0.1421	0.07772	0.04934	0.046	0.02887
CU	30.24	0.21387	0.09782	0.05305	0.046	0.02727

Source: own work based on JORF (2013).

To calculate the capacity "billed", we must take into account the reduction coefficients of capacity. In the case of the *Tarif Vert A5 Option Base*, the capacity for which we will finally pay (whose prices are those that appear in the column "Fixed annual premium" of Table 2. 7) are calculated by subtracting in each period the capacity contracted in the previous period and applying the reduction coefficients that appear in Table 2. 8.

Table 2. 8. Reduction coefficients of power in *Tarif Vert*

Versions	Peak	HPH	HCH	HPE	HCE
TLU	1	0.67	0.27	0.23	0.23
LU	1	0.76	0.4	0.37	0.34
MU	1	0.75	0.36	0.33	0.28
CU	1	0.78	0.52	0.46	0.42

Source: own work base on JORF (2013).

There are also some additional costs for excess capacity, as in the Spanish case, but they are not significant, and are not taken into account in our simulations. In addition, they do not influence the comparison between tariffs, due to the fact that these costs are not taken into account in the French case nor in the Spanish case. In addition, we have not taken taxes into account, in either France or Spain[8].

This tariff would reduce the problem of irregular consumption during the year, because the main payment is done by kWh, both in summer and in winter (the energy payment has a much greater weight in the total cost). Although the result would be similar, the measures would be different from the case of the *seasonal contract*, because the reduction of the cost of capacity does not occur through the removal or reduction of the capacity tariff. What the *Tarif Vert* does is increase the total capacity for which we finally must pay.

On the other hand, as we can deduce from Tables 2.6 and 2.7, this type of tariff maintains the payment for capacity, but it strongly modifies the method of its payment. Capacity is divided into an initial period, and incremental increases in the rest of the periods. For the initial period, we always pay the same, and another price is applied to each of the increases, in addition to the reduction coefficient. One of the things that this tariff allows is to reduce the price of the additional contracted capacities for summer use, along with the lower payment for energy in summer. In other words, this tariff has lower prices for the summer use.

From the design of this tariff, given the lower capacity for which we finally must pay, and viewing the previous reasons, it seems to favor an increase in income redistribution, a decrease in energy costs, and a promotion of energy savings.

[8] One of the most significant taxes in Spain is the Value Added Tax (IVA in its Spanish acronym). We have not included it in the analysis, nor can we compare the Spanish and French tariffs without taxes, because qualitatively it has no effect. In any case, if the IVA increases, the increases in costs would be greater.

2.2.4.2. Cost simulation with *Tarif Vert*

In 2013, the supply points that consume the most energy in the CGRAA are Alconadre, Almudévar-Artical-Violada, and Lalueza. We now carry out a simulation in order to study the costs at these supply points with the French tariff.

In Table 2. 9 we observe the equivalences that have been assumed for the simulation both for capacity and energy in the *Tarif Vert* and tariff 6.1, contracted at the studied supply points. We assume the same capacity contracted in the period Pte (the most expensive of the *Tarif Vert*) as in period 1 (the most expensive of the tariffs 6.1); in the periods HPH, HCH and HPE (intermediate periods in terms of the contracted power price by kW), we will assume the medium contracted capacity between periods 2, 3, 4, and 5 of the tariff 6.1; and, finally, in the period HCE (the cheapest of the *Tarif Vert*) we will assume the contracted power in period 6 of the tariff 6.1, given the similarities in the hours and, especially, in the prices of contracting power in those periods. On the other hand, for the energy consumption, taking into account the comparison of the hour periods between the tariff 6.1 and the *Tarif Vert*, and the periods in which the consumption is done, we assume the energy consumption that is shown in Table 2. 9.

Table 2. 9. Equivalences between periods in Tarif Vert and in tariff 6.1

Capacity		Energy	
Periods Tarif Vert	Periods Tariff 6.1	Periods Tarif Vert	Periods Tariff 6.1
Pte	P_1	*HCH*	$\frac{P_6}{2}$
HPH	$\frac{P_2+P_3+P_4+P_5}{4}$	*HCE*	$\frac{P_6}{2}$
HCH	$\frac{P_2+P_3+P_4+P_5}{4}$	*HPH*	P_2+P_4
HPE	$\frac{P_2+P_3+P_4+P_5}{4}$	*HPE*	$P_5+P_3+\frac{P_1}{2}$
HCE	P_6	*Pte*	$\frac{P_1}{2}$

Source: own work.

In Table 2. 10 we show the capacity and energy with the current Spanish tariffs and in Table 2. 11 with the French tariff in each of the three studied supply points.

Table 2. 10. Capacity contracted and energy consumed by periods, tariff 6.1, 2013

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Total
				Point 5			
Capacity (kW)	930	1,400	1,400	1,400	1,400	1,400	-
Energy (kWh)	154,639	189,640	67,921	209,833	190,764	1,728,971	2,541,768
				Point 7			
Capacity (kW)	20	1,907	1,907	1,907	1907	2,212	-
Energy (kWh)	7,410	159,601	25,059	111,116	103,951	2,450,496	2,857,633
				Point 16			
Capacity (kW)	50	1,200	1,200	1,200	1,200	1,200	-
Energy (kWh)	133,796	217,958	51,809	133,529	96,236	2,261,461	2,894,789

Source: own work.

Table 2. 11. Capacity contracted and energy consumed by periods, adaptation to *Tarif Vert*

	Pte	HPH	HCH	HPE	HCE	Total
			Point 5			
Capacity (kW)	930	1,400	1,400	1,400	1,400	-
Energy (kWh)	77,320	399,473	864,486	336,005	864,486	2,541,768
			Point 7			
Capacity (kW)	20	1,907	1,907	1,907	2,212	-
Energy (kWh)	3,705	270,717	1,225,248	132,715	1,225,248	2,857,633
			Point 16			
Capacity (kW)	50	1,200	1,200	1,200	1,200	-
Energy (kWh)	66,898	351,487	1,130,731	214,943	1,130,731	2,894,789

Source: own work.

Remember that the capacity for which we finally must pay, or capacity "billed", is calculated by subtracting from one period the power contracted in the previous period and applying the reduction coefficients shown in Table 2. 8. Thus, for each of the supply points, capacity "billed" would be what is shown in Table 2. 12.

Table 2. 12. Capacity "billed", *Tarif Vert*

Version	Peak	HPH	HCH	HPE	HCE	Total
			Point 5			
TLU	930	315	0	0	0	1,245
LU	930	357	0	0	0	1,287
MU	930	353	0	0	0	1,283
CU	930	367	0	0	0	1,297
			Point 7			
TLU	20	1,264	0	0	70	1,354
LU	20	1,434	0	0	104	1,558
MU	20	1,415	0	0	85	1,521
CU	20	1,472	0	0	128	1,620
			Point 16			
TLU	50	771	0	0	0	821
LU	50	874	0	0	0	924
MU	50	863	0	0	0	913
CU	50	897	0	0	0	947

Source: own work.

In Table 2. 13 we show an estimation of what would be the cost with the same energy consumption and capacity contracted with *Tarif Vert*.

Table 2. 13. Cost with *Tarif Vert* (Euros)

Version	Fixed	Peak	HPH	HCH	HPE	HCE	Total
				Point 5			
TLU	92,321.78	5,531.44	23,249.33	38,486.89	14,979.08	24,378.49	198,947.02
LU	70,281.12	8,057.47	26,632.86	39,818.20	15,204.20	24,905.83	184,899.68
MU	55,404.00	10,987.10	31,047.04	42,653.71	15,456.21	24,957.70	180,505.76
CU	39,209.18	16,536.32	39,076.45	45,860.96	15,456.21	23,574.52	179,713.64
				Point 7			
TLU	100,445.27	265.06	15,755.73	54,548.04	5,916.43	34,551.99	211,482.52
LU	85,056.97	386.10	18,048.70	56,434.92	6,005.35	35,299.39	201,231.44
MU	65,692.08	526.48	21,040.13	60,453.74	6,104.89	35,372.91	189,190.22
CU	48,987.59	792.39	26,481.54	64,999.41	6,104.89	33,412.51	180,778.33
				Point 16			
TLU	60,848.28	4,785.88	20,456.54	50,340.12	9,582.16	31,886.60	177,899.59
LU	50,450.40	6,971.44	23,433.64	52,081.45	9,726.17	32,576.35	175,239.44
MU	39,420.00	9,506.21	27,317.57	55,790.24	9,887.38	32,644.19	174,565.59
CU	28,637.28	14,307.48	34,382.46	59,985.25	9,887.38	30,835.02	178,034.87

Source: own work.

The capacity and energy costs, without including taxes, for 2013 for the supply point of Alconadre (point 5) were, respectively, €96,498.93 and €309,622.42, which total €406,121.35. We observe that, depending on the tariff type chosen, the total cost would vary, with the cheapest version being the "CU". Although there would be no legal restrictions for choosing one or another of the versions, the total cost is much less with the tariff *Vert* than with the current Spanish tariffs; even when we apply the most expensive French tariff, it would be possible to save more than one half of the costs.

In the case of point 7, the version "CU" would also be the cheapest. In this case, with the most expensive version, it would save around 36%; and, with the cheapest one, around 58%, because the capacity and energy costs without including taxes in 2013 for this supply point were, with the Spanish tariff of, respectively, €86,398.71 and €199,685.50, for a total of €286,084.21. In the case of point 16, the same as in the case of the supply point of Alconadre, even with the most expensive version of the *Tarif Vert*, it would be possible to save almost half of the cost, taking into account that capacity and energy costs (without including taxes) in 2013 were, for this supply point, respectively, €78,159.50 and €223,974.35, for a total of €302,133.85.

2.2.5. Final comments

This work proposes a measure with which to try to reduce energy costs in irrigated agriculture, in addition to trying to alleviate some of the issues of the Spanish electricity system - such as, for example, the penalization of temporary irregularity. For that, we propose the implementation in Spain of the *Tarif Vert*, a tariff in France applicable to agriculture. This work suggests that the energy costs in irrigated agriculture would be reduced if we exchange the current tariffs in Spain for the French tariff *Tarif Vert*, whose main advantage is the payment by "billed capacity", which is a significant difference from the Spanish tariffs.

This work plans, first, to analyse the energy costs in irrigated agriculture to try to reduce them. For that, we have limited the analysis to the CGRAA, given its significant size and the availability of data in terms of its consumption and electricity production.

Through the analysis of energy costs in the CGRAA, we observe that in period 2010-2013 the capacity contracted at the supply points which contract with tariff 3.1A decreases, and the energy consumed increases by a little more than 5%, while the costs increase more than 70%. At the supply points that contract with tariff 6.1, something similar happens. The average capacity contracted increases in period 6, which is the cheapest; however, it decreases in period 1, which is the most expensive. The energy consumed increases, by a little more than 25%, and the costs increase by almost 70%, From this, we can deduce that the increase in costs is due mainly to the increase in tariffs.

We analyse what the costs would be under different tariffs with the same data on capacity and consumption. We observe a clear increase in costs when we apply new regulations. In addition, the percentage that the cost represents by capacity over total cost increases. Taking into account the tariffs applicable in January 2010, and those applicable in February 2014, costs would increase by 32.42%, which is mainly from the increases made by the August 2013 reform, under which costs increased by 12.84%.

A second objective of this work leads us to plan an alternative to reduce energy costs as soon as possible, analysing the effects of implementing in Spain the *Tarif Vert*.

After several simulations for the three most important supply points of the CGRAA in terms of energy consumption, we observe that, depending on the chosen version (there are four alternatives), the total cost would vary, with the cheapest version of all analysed cases being the one of "short use" (CU). But the most important finding is that, in all the cases, even with the most expensive version of the French green tariff, this implementation would lead to a saving of more than 30% in energy costs. However, with the adequate choice of the contracted version it would be possible to save in all cases more than 50% of the costs. So, this study demonstrates that, with the implementation in Spain of the *Tarif Vert*, it would be possible to considerably reduce energy costs in irrigated agriculture, with positive effects for rest of the economy.

This topic is important in Spain due to the recent increase in energy consumption after irrigation modernization. In addition, viewing the importance of the agriculture and, particularly, irrigation, in the Spanish economy, and the great energy consumption necessary to pump and distribute irrigation water, we should consider a first measure for the Spanish electricity sector, to reduce energy costs in this sector to favour its production, which would have spill-over effects in the economy as a whole. In addition, from an environmental perspective, the decrease in the capacity payment makes consumption costs more visible and this could be an incentive for energy saving.

2.2.6. References

BOE. (1997). Ley 54/1997, de 27 de noviembre del sector eléctrico. Boletín Oficial del Estado, nº 285.

BOE. (2007). Ley 17/2007, de 4 de julio. Boletín Oficial del Estado, nº 160.

BOE. (2008). Orden ITC/1857/2008, de 26 de junio. Boletín Oficial del Estado, nº 156.

BOE. (2009). Orden ITC/3519/2009, de 28 de diciembre. Boletín Oficial del Estado, nº 315. Disposición general.

BOE. (2011a). Orden IET/3586/2011, de 31 de diciembre. Boletín Oficial del Estado, nº 315. Disposición general.

BOE. (2011b). Orden ITC/688/2011, de 30 de marzo. Boletín Oficial del Estado, nº 77. Disposición general.

BOE. (2012a). Orden IET/843/2012, de 25 de abril. Boletín Oficial del Estado, nº 100. Disposición general.

BOE. (2012b). Real Decreto-ley 1/2012, de 27 de enero. Boletín Oficial del Estado, nº 24. Disposición general.

BOE. (2012c). Real Decreto-ley 13/2012, de 30 de marzo. Boletín Oficial del Estado, nº 78. Disposición general.

BOE. (2012d). Real Decreto-ley 20/2012, de 13 de julio. Boletín Oficial del Estado, nº 168. Disposición general.

BOE. (2013a). Orden IET/1491/2013, de 1 de agosto. Boletín Oficial del Estado, nº 185. Disposición general.

BOE. (2013b). Real Decreto-ley 2/2013, de 1 de febrero. Boletín Oficial del Estado, nº 29. Disposición general.

BOE. (2013c). Real Decreto-ley 9/2013, de 12 de julio. Boletín Oficial del Estado, nº 167. Disposición general.

BOE. (2013d). Real Decreto-ley 17/2013, de 27 de diciembre. Boletín Oficial del Estado, nº 311. Disposición general.

BOE. (2014). Orden IET/107/2014, de 31 de enero. Boletín Oficial del Estado, nº 28. Disposición general.

Cabrera Marcet, Enrique; Pardo Reguero, Miguel Ángel; Cabrera Rochera, Enrique; Cobacho Jordán, Ricardo. (2010). Agua y energía en España: un reto complejo y fascinante. Ingeniería del Agua, volumen 17, nº 3, p. 337-363. ISSN 1134-2196.

Cabrera, E. (2011). El binomio agua-energía. ¿Un asunto de moda o de interés real? Fundación Ciudadanía y valores.

Cardenete, Manuel Alejandro. (2011). Análisis comparativo de sectores clave desde una perspectiva regional a través de matrices de contabilidad social: enfoques alternativos. Revista de métodos cuantitativos para la economía y la empresa (12). Páginas 39-64. ISSN: 1886-516X. D.L: SE-2927-06.

Cardenete, M. Alejandro; Fuentes, Patricia D.; Mainar, Alfredo J.; Rodríguez-Morilla, M. Carmen. (2015). Análisis y explotación mediante modelos económicos multisectoriales de la matriz de contabilidad social de Andalucía para 2008. Regional and Sectoral Economic Studies, Vol. 15-1.

Cardenete Flores, M. Alejandro y López Álvarez, Jorge M. (2012). Estructura y evolución de los sectores económicos estratégicos y del empleo de la economía andaluza a partir del marco Input-Output 1995-2000-2005. Revista de estudios regionales, nº 95, I.S.S.N.: 0213-7585 (2012), pp. 39-72.

Carrillo-Cobo, M. T.; Rodríguez-Díaz, J. A.; Camacho-Poyato, E. (2010). The role of energy audits in irrigated areas. The case of 'Fuente Palmera' irrigation district (Spain). Spanish Journal of Agricultural Research, 8(S2), S152-S161. ISSN: 1695- 971-X.

CNE. (2010), (2011), (2012). Informe sobre la liquidación provisional nº 14 de 2009, 2010, 2011 y 2012 y verificaciones practicadas sector eléctrico. Comisión Nacional de la Energía.

CNE. (2013). Informe sobre la liquidación provisional nº 12 de 2012 y verificaciones practicadas sector eléctrico. Comisión Nacional de la Energía.

CNMC. (2013). Informe sobre los resultados de la liquidación provisional nº 8 de 2013 sector eléctrico. Comisión Nacional de los mercados y la competencia.

Corominas, Joan. (2010). Agua y energía en el riego, en la época de la sostenibilidad. Ingeniería del agua, vol. 17, Núm. 3.

Duarte, Rosa, Jiménez, Sofía; Langarita, Raquel; Sánchez, Julio. (2015a). Evaluating the structural effects of a big cultural event: the case of the International Expo Zaragoza 2008. Regional and Sectoral Economic Studies, vol 15-1.

Duarte, R.; Jiménez, S.; Langarita, R.; Sánchez-Chóliz, J.; Sarasa, C. (2015b). Energy efficiency management in irrigated agriculture: A case study in Spain. Working paper presented in the 10th Conference on Sustainable Development of Energy, Water and Environment Systems, Dubrovnik, Croacia. Departamento de Análisis Económico de la Universidad de Zaragoza.

Duarte, R.; Sánchez-Chóliz, J.; Cazcarro, I.; Rebahi, S.; Sarasa, C.; Serrano, A. (2012). La industria agroalimentaria en la economía aragonesa: capacidad dinamizadora, escenarios de crecimiento y medio ambiente. Consejo económico y social de Aragón.

Fabra, Natalia y Fabra Utray, Jorge. (2010). Competencia y poder de mercado en los mercados eléctricos. Cuadernos económicos del ICE, nº 79.

INDESO. (2014). INDESO. Actualización 2014. Calendario energético. http://www.indeso.es/Calendario%206.1A%202015%20Peninsular.pdf

Iráizoz Apezteguía, Belén. (2006) ¿Es determinante el método en la identificación de los sectores clave de una economía? Una aplicación al caso de las tablas Input-Output de Navarra. Estadística Española. Vol. 48, Núm. 163, págs. 551 a 585.

JORF. (2013). JORF n° 0063 de 15 marzo de 2013, página 4537, texto n° 21. Journal officiel de la République française. http://www.legifrance.gouv.fr/affichTexte.do?dateTexte=&categorieLien=id&cidTexte=JORFTEXT000027172789

Polo, Clemente y Valle, Elisabeth. (2002). Un análisis input-output de la economía balear. Estadística Española, vol. 44, Núm.151, 2002, págs. 393 a 444.

Rasmussen, P. N. (1956). Studies in Intersectoral Relations. Einar Harcks Forlag & North-Holland. Copenhagen and Amsterdam.

Rodríguez-Díaz, J. A.; Pérez-Urrestarazu, L.; Camacho-Poyato, E.; Montesinos, P. (2011). The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand. Spanish Journal of Agricultural Research, 9, 4, 1000-1008.

Sánchez Chóliz, J. y Sarasa, C. (2013). Análisis de los recursos hídricos de Riegos del Alto Aragón (Huesca) en la primera década del siglo XXI. Economía Agraria y Recursos Naturales, 13, 1, 97-124.

Uche, Javier. (2013). La energía en el agua. Prensas de la Universidad de Zaragoza. Textos Docentes, 218.

Yusta Loyo, José María. (2013). Contratación del suministro eléctrico: oportunidades y estrategias para reducir el coste de las facturas eléctricas. Ed. Paraninfo.

Chapter 3

Structure of the electricity sector in Spain: an analysis using a disaggregated input-output model

3.1. Motivation

We have explored certain characteristics of the electricity system applied to irrigated agriculture in the previous chapters: the new design of the tariffs suggested in Chapter 1 and the application of a French green fee, with which it would be possible to reduce electricity costs in irrigated agriculture, as a transitory measure. Our next step is to go deeper into the analysis of the whole electricity sector in Spain and its links with the rest of the economic activities. In this analysis, we pay attention to the structural characteristics of the sector, the different sub-sectors forming the electricity system, and its role within a multi-sectoral economy.

In order to take the linkages across the economy into account, which will serve us in assessing the degree of dependence that the Spanish economy has on this sector, and its role as driver of production and income, input-output models and computable general equilibrium (CGE) models are excellent tools (see Castillo and Bravo, 2010). In addition, the most common database used in the literature for calibrating a CGE model is a social accounting matrix (SAM), although it requires an adequate level of disaggregation of the sectors of interest, the energy sector in our case. Disaggregated input-output models and SAMs for analyzing specific sectors in Spain, either in a CGE model or in a linear model, can be seen, for instance, in Cazcarro et al. (2010), Barrera-Lozano et al. (2015), and Cámara et al. (2013).

One of the primary characteristics detected in the Spanish electricity system is the unbundling of the various activities of the electricity sector, something which is not properly reflected in the National Accounts. So, in order to correctly depict the current electricity system structure, we develop an input-output model and a social accounting matrix for the Spanish economy, with the electricity sector disaggregated into its component activities: generation, transmission, distribution, commercialization, and another sector called related activities to the electricity sector. At the same time, we want to disaggregate the generation activity into its several production technologies. This process is developed in this chapter as well as the structural analysis of this sector. Moreover, in Chapter 4, we develop a CGE model calibrated on this input-output table.

To the best of our knowledge, these are the first input-output model and social accounting matrix in which the electricity sector is disaggregated into its main activities (Generation, Transmission, Distribution, Commercialization and Activities related to the electricity sector). This splitting is very important in correctly depicting the current structure of the electricity system in Spain. This kind of unbundling has held in other European countries, so, although we particularize our analysis for the Spanish economy, it is possible to assume this productive structure for other European countries.

A great part of this work has been published in the article “Electricity industry in Spain: a structural analysis using a disaggregated input-output model” in *Energy* (see Duarte et al., 2017).

3.2. Electricity industry in Spain: a structural analysis using a disaggregated input-output model

3.2.1. Introduction

Energy dependence and its impact on economic growth is a major current concern both for society in general and for the scientific community in particular. Meanwhile, the price of electricity directly affects consumption and production decisions, given that power is indispensable both in the home and in industry. It is a commonplace that energy takes different forms, and it can therefore be classified in at least two categories. The first refers to the availability of energy sources (non-renewable such as fossil fuels and nuclear energy, or renewable such as hydropower, wind, solar and biomass). The second category is based on the energy source used, allowing us to distinguish between primary energy (found in nature, such as oil or hydraulic energy) and secondary energy, defined as the final energy obtainable from a primary source by means of some kind of transformation. It is this category with which the present study is concerned.

This paper focuses on the Spanish electricity industry and its relationships with the rest of the country's activities in a multi-sectoral context. Spain's economic growth in recent decades cannot be understood without considering the significant development and changes that have occurred in the energy industry. Economic growth in the 1980s and 90s was to a considerable extent based on energy-intensive industries, resulting in rising demand for energy in the expansive phase of the economic cycle (until the international crisis of 2007) even while the EU trend was already on a downward path ([1]). Strong national demand for energy coupled with very limited primary energy production (given Spain's scarcity of conventional energy resources) created a panorama informed by a strong potential energy deficit and country vulnerability, threatening further economic expansion. According to [2], Spanish energy dependence in 1997 was as high as 71%. This drove the search for alternatives in the form of energy diversification, progressive deregulation and the decoupling of the electricity system in 1997. Specifically, the Spanish Electricity Industry Act (Law 54/1997) laid the foundations for the current electricity model for the sector, seeking to deregulate the sector and guarantee the power supply at the lowest possible cost. As a crucial step in this deregulation process, articles 11 and 14 of the Act provided for the unbundling of the power utilities' generating, distribution, transport and marketing businesses. Major issues nevertheless persist, including scant competition, the rising tariff deficit, regulatory uncertainty (affecting self-consumption initiatives and the development of renewables), limited connexion with foreign grids, high capacity tariffs, and occasional sharp price hikes (see [3] and [4]).

In this tangled context, any evaluation of the electricity industry's current role, its importance as a driver of economic growth, and existing economic dependences and bottlenecks will require a new description of interrelationships both within the sector and between it and the rest of the economy. Our work is a first step in this direction, providing a structural analysis of the electricity industry in Spain, of its operational subsectors and of the associated production technologies. To this end, we focus on building and analysing an input-output table (IOT) of the Spanish economy in 2013 (the most recent year for which the basic input-output table data are available for Spain), and on a specific disaggregation of the electricity industry by activities and technologies. The IOT is further extended to social accounts in order to include income relationships between sectors and institutions and to arrive at a disaggregated Social Accounting Matrix (SAM).

The disaggregated IOT and SAM produced are significant results in themselves, because this is the first time, to the best of our knowledge, that the Spanish electricity industry has been broken down into a multi-sectoral schema despite its importance for the economy as a whole. This disaggregation into 10 subsectors is defined by generating technologies and by transmission, distribution, marketing and related activities, opening the way to different methodological options for policy design.

These disaggregated matrices provide the empirical basis for a structural analysis of the links and dependences currently existing between the Spanish economy as a whole and the electricity industry and its different subsectors. There is a wide literature on the analysis of the relevance of energy sector in the economies, and its relationship with the rest of economic sectors from different methodological perspectives (see for instance [5]; [6]; [7] or [8]). Our analysis will be based on the analysis of inter-sector linkages and the study of the structure of the dependence chains in an input-output framework.

While the structural analysis is the central focus of this paper, the disaggregated IOT and associated SAM have additional value *per se*, as a basis for the future calibration of computable general equilibrium models (CGEM). Despite the interest of CGEM in the field of energy issues, the design and evaluation of specific policies is beyond the scope of this paper. In any case, the IOT and SAM structures allow us to undertake an in-depth analysis of the electricity industry and its role in the Spanish economy using forward and backward linkages, graph analysis, and dependence chains, with significant results.

Multi-sector IO models provide a powerful tool for economic analysis because they can account not only for direct dependences between sectors but also for all direct and indirect relationships along the whole length of the supply chain [9-14]. These models have been used to analyse the links between the energy and other sectors of the economy like tourism [15] and agriculture [16]. Moreover, the extension of input-output databases to social accounting matrices (SAMs), including both IOT production accounts and institutional and social accounts (such as Taxes, Government Expenditure, Savings/Investment, Households, Trade, and Margins and Taxes on products), allows the evaluation of relationships between energy use ([17]), GHG emissions ([18,19]) and the generation and distribution of income in the economy, as well as providing a basis for the calibration of CGEMs ([20,21]) as mentioned above.

To sum up, our work could be considered a first step towards the design and assessment of a raft of future energy policies covering, for instance, self-consumption, energy tariffs, and alternative technologies. Meanwhile, other European countries have also pressed ahead with decoupling of the businesses involved in the electricity industry following similar processes to that seen in Spain. In this regard, our methodology and findings may also help advance understanding of the energy production nexus and structure in other European countries, even though the present analysis focuses more narrowly on the Spanish economy.

The rest of the paper is organized as follows. In section 3.2.2, we present the steps followed to obtain the disaggregated IOT for the Spanish economy in 2013 from the original supply and use tables. In section 3.2.3, we extend the IOT to obtain a SAM with a similar disaggregation. Section 3.2.4 presents the results from the structural analysis. The paper closes with some final remarks and comments on future lines of research.

3.2.2. A symmetric 2013 IOT and SAM for Spain with disaggregated electricity industry

As explained in the introduction, our objective is to obtain a disaggregated industry-by-industry 2013 symmetric IOT for the Spanish economy with a special focus on the structure of the electricity sector, and then to extend it to a SAM. Our starting point is the most recent edition of the Spanish supply and use tables for 2013 published by INE [22]. Our initial IOT obtained from [22] covers 63 industries and has only one sector referring to energy: "Electricity, gas, steam and air conditioning" (sector code 35 in NACE rev. 2). We proceeded in three steps. First, we disaggregated the sector into Electricity, Gas and other subsectors. Next, the new Electricity industry was again disaggregated into its main activities, *viz.* Electricity Generating (further broken down into Wind generating, Nuclear generating, Conventional Thermal generating, Hydrogenerating, and Solar and other generating), Transmission, Distribution, Marketing and Related Activities. The result is an IOT with 72 industries, 10 of which are energy related. Finally, having obtained the IOT, we took the income flows in the economy to construct a SAM with the same energy industry disaggregation.

A symmetric IOT is usually obtained from the information offered by supply and use tables. The supply matrix shows which sector or industry is producing each kind of good and the levels of output. It is a matrix of products (goods) by industries, and the number of products may differ from the number of industries. A use matrix shows which sector or industry consumes what kind of goods in its own production processes. Our starting point is the 2013 supply and use tables for Spain published by [22]. Obtaining a symmetric IOT means reorganizing the information included in the supply and use tables without changing the value of the macro-economic aggregates. Symmetric IOTs can be either industry-by-industry or product-by-product matrices, showing the sales of each industry (product) in the ranks and the purchases of each industry (product) to meet production needs in the columns. IOTs also include sector information about both final demand and value added (VA). When reorganizing the supply and use tables, it is necessary to decide if the symmetric IOT required is an industry-by-industry or product-by-product table. This choice will depend on the specific objective of the economic analysis concerned. We use the former option because industry-by-industry IOTs are closer to statistical sources in Spain. In addition, they are more commonly applied to the Spanish economy (see [23-26]).

INE publishes supply and use tables annually. The most recent INE supply and use tables refer to 2013 [22], which we used to obtain the symmetric IOT following the criteria suggested by [27]. More specifically, the IOT was built using the fixed product sales structure assumption. The result is a first IOT, which we may call 2013IOT. By way of illustration, Table 3. 1 presents an aggregation of 2013IOT with 5 productive sectors.

Table 3. 1. 2013IOT with five sectors (Millions of Euros)

	Primary sector	Manufacturing	Energy	Construction	Services	**Total**	Consumption	Gross capital formation	Exports	Transport and commercial margins and taxes on products	**Total uses at purchaser prices**
Primary sector	3,214	32,836	66	94	4,138	40,348	19,456	1,280	14,410	-15,533	59,961
Manufacturing	17,433	286,682	23,964	28,524	106,015	462,618	227,346	63,979	221,778	-202,595	772,783
Energy	587	19,716	28,645	3,326	17,212	69,486	21,328	395	809	-4,540	87,479
Construction	144	3,506	937	25,001	14,345	43,933	10,236	81,691	2,351	-5,086	133,126
Services	2,431	60,632	7,644	20,315	262,627	353,649	540,697	44,387	52,552	139,451	1,130,735
Total	23,809	403,372	61,256	77,260	404,337	970,034	819,063	191,732	291,900	-88,303	2,184,084
Wages	4,320	76,195	4,595	27,159	373,046	485,315					
Operating surplus	26,796	62,301	20,186	25,057	306,053	440,393					
Taxes	-5,367	114	553	1,732	12,915	9,947					
Output at basic prices	49,559	554,844	86,969	132,271	1,099,592	1,923,235					
Imports	10,402	245,520	510	855	31,143	288,430					
Total resources	59,961	800,364	87,479	133,126	1,130,735	2,211,665					

Source: Own calculations.

A first reading of this table confirms the relevance of the energy complex in Spain and some of its characteristics. The industry represented 4.52% of total Spanish output at basic prices in 2013, but only 2.71% of value added, compared to 28.85% of total output and 14.81% of VA in the case of manufacturing. Meanwhile, construction accounted for 6.88% of total output and 5.77% of VA. The energy operating surplus represents 23.21% of total energy output, slightly lower than the operating surplus in the service sector (27.83%) but higher than in industry (11.23%). Finally, the VA/wages ratios are 5.51 in Energy, 1.82 in Industry, 1.99 in Construction and 1.86 in Services, demonstrating high levels of productivity per worker in the energy industry.

The table also reflects the energy industry's low levels of imports and exports. Thus, just 0.18% of total Spanish imports in 2013 were made by the energy sector and 0.28% of total Spanish exports. By contrast, primary sector imports and exports were around 3.61% and 4.94% respectively, and the figures for manufacturing were 85.12% and 75.98% respectively. Moreover, energy exports make up hardly 0.92% of total energy output. Finally, the share of intermediate demand in total energy use is 79.43%, while household consumption accounts for more than 24.38% of total production.

3.2.2.1. Disaggregation of the energy sector in 2013IOT

Having calculated the 2013IOT from the supply and use tables, our next objective was to disaggregate the energy sector into 10 different sectors to obtain a final IOT, which we may call 2013IOTDE. This was done in two steps. First, we disaggregated Energy into two sectors, Electricity and Gas. Next, we disaggregated the new Electricity sector into nine subsectors based on external information. The final phase involved matching the figures so obtained applying the methods described in [28] and [29] to avoid possible contradictions.

The starting points for this first disaggregation were the Spanish IOT for 2005, [30], which included both electricity and gas sectors and their output at basic prices, and the production of electricity GWh and gas in tonnes of oil equivalent ('toe') in 2005 and 2013, obtained from the Spanish Industry Ministry [31,32]. Assuming constant rates of monetary output/physical output, we can split final energy output per 2013IOT to obtain estimates at basic prices, as shown in Table 3. 2.

Table 3. 2. Estimation of energy and gas production

		Output at basic prices (Millions of Euros)	Physical units (GWh)	Rate
2005	Electricity (GWh)	31,682	294,066	0.10773772
	Gas (GWh)	7,752	1,817.16*	4.26616258
	Total output at basic prices	39,434		
2013	Electricity (GWh)	**79,490**	271,028	
	Gas (GWh)	**7,479**	644	
	Total output at basic prices	86,969		

*The Spanish Ministry used tons of oil equivalent (toe) as its standard measure of gas production until 2011, when it switched to gigawatt-hours (GWh). Based on [33,34], we assume 1 GWh = 53,144.8 toe / 664 GWh = 80.0403 toe.

Source: MINETUR [31,32,30].

We then estimated the intermediate inputs, value added and imports of the new Electricity and Gas sectors for 2013 using the technical coefficients and the coefficients of value added and imports related to the output of both sectors for 2005, and the figures from the Energy column of 2013IOT. We proceeded in the same way to estimate intermediate and final demand based on the Energy row of 2013IOT[9].

The next step was to break down the Electricity sector obtained into 9 new sectors by generating technology used (5 sectors) and by type of business (4 sectors). The resulting technological sectors were Wind, Nuclear, Conventional Thermal, Hydropower and Solar and other Generating, and the business sectors were Generating, Transmission, Distribution, Marketing, and Related activities. The main databases for this higher disaggregation are the Iberian Balances Analysis System (SABI in its Spanish acronym), [35], and the Annual Electricity reports and activities review of the Spanish Electric Industry Association (UNESA), especially [36][10].

The "Related Activities" account contains estimates of activities carried on by generating companies but which are not a part of electricity generating as such, including civil engineering, rental of electricity meters, and maintenance work at wind farms and hydropower plants. This separation means that the generating sectors' output includes only electricity generating *per se*. The relevance of these activities is directly recognized in [38], where it is estimated that the Related Activities and International Activities of Spanish electricity companies represented around 55% of their overall output in 2013.

To estimate the share of these related activities in the total output of the electricity industry (€79.49 billion per Table 3. 2), we began with the value of electricity production in 2013, which we identified with the production of other eight sectors. More specifically, considering that the electricity price in 2013 (excl. VAT and other taxes) was around 0.1752 €/kWh for domestic uses and 0.1165 €/kWh for industrial uses according to [39], we have an average price[11] close to 0.13 €/kWh. Using [40,38,41], we split this price into three components, namely generating cost

---

[9] Certain minor changes were necessary because the Spanish National Classification of Economic Activities (CNAE in the Spanish acronym) changed in 2009 from CNAE-93 to CNAE-09, obliging us to aggregate in some cases and to disaggregate in others.

[10] The SABI database contains information on around 2,000,000 Spanish companies, representing more than the 90% of the national total. SABI data is a key tool for our purposes because it is the only source in which the different activities of the Spanish electricity system are significantly disaggregated. The database is used, for example, to disaggregate a SAM in [33].

[11] We obtained this average of domestic and industrial prices taking into account the respective shares of industries and consumer uses obtained from Table 3. 1.

(€0.05/kWh), regulated cost of Transmission, Distribution and premiums (€0.042/kWh), and marketing cost (€0.038). As shown in Table 3. 3, we then estimated total income from generating at some €27,378 million, and income from electricity activities (excluding related activities) at €49,359 million. Finally, we can assume, given the ratio 49,359/79,490=62.09%, that 37.91% of the Electricity sector is made up of Related activities, which produce total output worth €30,135 million.

Table 3. 3. Electricity production data for 2013

	Electricity sold (GWh)	Price (€/kWh)	Income (millions of euros)	Taxes	Total (millions of euros)	Tariff deficit*	Total including tariff deficit
Electricity generating	235,986	0.05	11,799	20%	14,159	2,359	27,378
Special regime premiums			9,050	20%	10,860		
Transmission		*	1,672	20%	2,006	560	2,566
Distribution		*	5,474	20%	6,568	2,084	8,653
Marketing	235,986	0.038	8,967	20%	10,760		10,760
Total		**0.13**	**36,962**		**44,355**	**5,004**	**49,359**

Source: Own calculations.

Consequently, we may assume that all Related Activities figures in 2013IOTDE (columns and rows) are equal to 37.91% of the Electricity figures previously obtained, while the total output of the eight remaining sectors is 79,490-30,135= 49,355 million euros, which we split into the eight total productions using the SABI data proportions.

After making the above adjustments, we proceeded to disaggregate the rest of the electricity industry into eight different sectors in three steps. We began the process by estimating the supply variables, then the demand variables, and finally the intermediate inputs. Taking these total values and the industry percentages obtained from SABI data on wages, social security taxes, value added and imports, we were then able to obtain industry estimates of the supply variables for the eight sectors. The exact criteria are shown in Table 3. 6 of the Appendix.

The SABI data and industry percentages also provide the basis for the estimation of the final demand variables in the sectors concerned (Consumption, Government expenditures, Exports, etc.). The criteria used are shown in Table 3. 7 of the Appendix.

In order to complete 2013IOTDE, we now needed only to reckon intermediate inputs. We used the percentages from [32] to estimate the self-consumption of the different generating technologies. The remaining intermediate inputs of the new sectors were obtained following [42]. Finally, estimates of intermediate inputs from the new sectors demanded by non-energy sectors were obtained by splitting the amounts concerned proportionally among total uses.

The process explained above allows estimation of each of the different elements of 2013IOTDE. However, the estimated figures do not satisfy the three basic IOT equations: (i) the sum of column *j* is equal to total resources *j*; the sum of row *i* is equal to total uses *i*; and (iii) total resources *j* are equal to total uses *i*. An iterative GRAS method (see [28] and [29]) was then used to match the estimated information in the table with the sums of rows and columns.

This procedure was applied in two steps. First, we updated the value-added block, and then we applied the GRAS method to the intermediate and final demand matrix. We fix the figures from 2013IOT, which do not change in the disaggregation process, thus, these values do not enter in the GRAS process. The fixed rows and columns used for the matching procedure contain the same figures as 2013IOT for the non-energy sectors. For the energy sectors, however, we were obliged to use the estimates obtained. The table produced in this way is 2013IOTDE.

3.2.3. Extending 2013IOTDE to create a social accounting matrix

The extension of 2013IOTDE to a SAM means estimating the relationships between productive sectors and institutional accounts, in our extension comprising L (labour), K (capital), H (Households), SI (Savings/Investment), five tax accounts (Net taxes on products, Social Security contributions paid by employers, Social Security contributions paid by workers, Other net taxes on production, and Personal Income Tax (PIT), Government, Foreign trade (Imports/Exports) and MT (Margins and taxes on products).

The figures in a SAM represent monetary transfers from one account to another, which we can classify in four types: (i) Transfers from productive sectors to other productive sectors, in our case representing the intermediate inputs from 2013IOTDE; (ii) Transfers from productive sectors to institutional accounts, which extend the information given by the demand variables in 2013IOTDE; (iii) Transfers from institutional accounts to productive sectors, which are also an extension of the

2013IOTDE supply variables; and (iv) Transfers from institutional accounts to other institutional accounts, which are specific to the SAM.

The data used to extend 2013IOTDE were obtained from the Spanish Revenue Service (AEAT in its official acronym), [43] and [44], following the criteria described in published papers such as [23]. The SAM obtained has 84 accounts, 12 of them institutional. An aggregated SAM with only 14 productive and 8 institutional accounts is shown in Table 3. 4.

Table 3. 4. Summary of the SAM 2013 (2013SAMDE)

	Primary sector	Industry	Generation of electricity from wind	Generation of electricity from nuclear	Generation of electricity from conventional thermal	Generation of electricity from solar and other sources	Generation of hydropower	Transmission of electricity	Distribution of electricity	Commercialization of electricity	Related activities to the electricity sector	Gas	Construction	Services	L	K	H	SI	Taxes	G	FT	MT	**SUM**
Primary sector	3,214	32,836	0	0	30	0	0	0	0	9	24	3	94	4,138	0	0	19,245	1,280	0	211	14,410	-15,533	**59,961**
Industry	17,433	299,544	28	20	995	2,611	610	19	0	7,761	8,448	3,851	29,586	109,257	0	0	221,473	64,168	0	15,443	223,388	-204,271	**800,364**
Generation of electricity from wind	11	358	3	0	0	0	0	1	0	174	119	0	63	322	0	0	392	558	0	1	23	-100	**1,927**
Generation of electricity from nuclear	6	205	0	0	0	0	0	1	0	88	68	0	36	185	0	0	225	-48	0	1	0	-38	**729**
Generation of electricity from conventional thermal	46	1,516	0	0	190	0	0	4	0	602	503	2	269	1,364	0	0	1,659	701	0	5	1	-338	**6,522**
Generation of electricity from solar and other sources	58	1,917	0	0	0	108	0	6	0	854	635	2	339	1,723	0	0	2,097	783	0	6	253	-433	**8,351**
Generation of hydropower	77	2,527	0	0	0	0	231	9	0	1,227	838	3	448	2,272	0	0	2,765	-1,437	0	8	22	-443	**8,544**
Transmission of electricity	17	556	0	0	0	0	0	1	0	126	81	0	99	500	0	0	609	-302	0	2	0	-83	**1,605**
Distribution of electricity	29	972	0	0	0	0	0	2	0	220	141	1	172	874	0	0	1,064	-92	0	3	1	-167	**3,220**
Commercialization of electricity	168	5,551	0	0	0	0	0	9	0	1,257	805	3	983	4,992	0	0	6,074	-138	0	17	25	-974	**18,773**
Related activities to the electricity sector	153	5,033	84	2	1,077	1,041	3,895	27	0	3,753	5,061	12	891	4,526	0	0	5,507	359	0	16	464	-1,574	**30,328**
Gas	22	1,081	38	1	486	469	1,756	13	0	1,869	743	0	26	454	0	0	878	10	0	3	19	-388	**7,480**
Construction	144	3,506	3	2	278	9	71	2	0	28	395	148	25,001	14,345	0	0	8,184	81,691	0	2,052	2,351	-5,086	**133,126**
Services	2,431	60,632	31	21	1,748	90	675	27	0	126	3,401	1,524	20,315	262,627	0	0	356,623	44,387	0	184,073	52,552	139,451	**1,130,735**
Labor	3,827	60,860	5	51	64	2,717	58	34	160	51	487	73	21,418	294,787	0	0	0	0	0	0	0	0	**384,591**
Capital	26,796	62,301	1,692	615	1,704	3	1,167	1,418	2,977	598	8,180	1,832	25,057	306,053	0	0	0	0	0	0	0	0	**440,393**
Household	0	0	0	0	0	0	0	0	0	0	0	0	0	0	384,591	440,393	0	0	0	154,415	0	0	**979,399**
Savings/Investment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63,508	0	0	5,247	123,166	0	**191,921**
Taxes	-4,874	15,449	5	12	-60	1,106	29	26	82	20	206	24	7,473	91,174	0	0	65,438	0	0	0	0	0	**176,109**
Government expenditure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	176,109	46,279	71,836	126,585	**420,809**
Foreign trade	10,402	245,520	38	4	9	196	53	6	1	10	193	0	855	31,143	0	0	223,661	0	0	13,028	0	0	**525,119**
Margins and taxes on products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36,606	0	**36,606**
SUM	**59,961**	**800,364**	**1,927**	**729**	**6,522**	**8,351**	**8,544**	**1,605**	**3,220**	**18,773**	**30,328**	**7,480**	**133,126**	**1,130,735**	**384,591**	**440,393**	**979,399**	**191,921**	**176,109**	**420,809**	**525,118**	**36,606**	

Source: Own work.

This table confirms some of the features of the energy complex mentioned above. One of them is the nugatory share of all electricity subsectors in imports and exports, the highest being 2.35% in the case of Solar and other generating.

We may also observe that the labour compensation is lower than in the rest of the sector blocks (4.23% of total resources in the energy sector, versus 6.38%, 7.60%, 16.09% and 26.07% in the Primary sector, Industry, Construction and Services), a sign of the electricity industry's characteristically high ratio of capital to labour. The sector with the highest percentage labour compensation is Solar and other generating. By contrast, the capital compensation is higher than in other sectors, representing 23.08% of resources compared to 44.69% in the Primary Sector, 7.60% in Manufacturing, 18.82% in Construction, and 27.07% in Services. In this case, Wind and Nuclear generating exhibit the highest capital compensation (87.76% of resources and 84.32% respectively), although the percentages in Transmission and Distribution are also very significant.

Finally, household energy demand is around 24.31% of total energy demand, as mentioned, 79.43% of which is intermediate demand. Meanwhile, household energy costs account for around the 2.17% of their total expenditure, compared to more than 36.41% in services.

3.2.4. Results

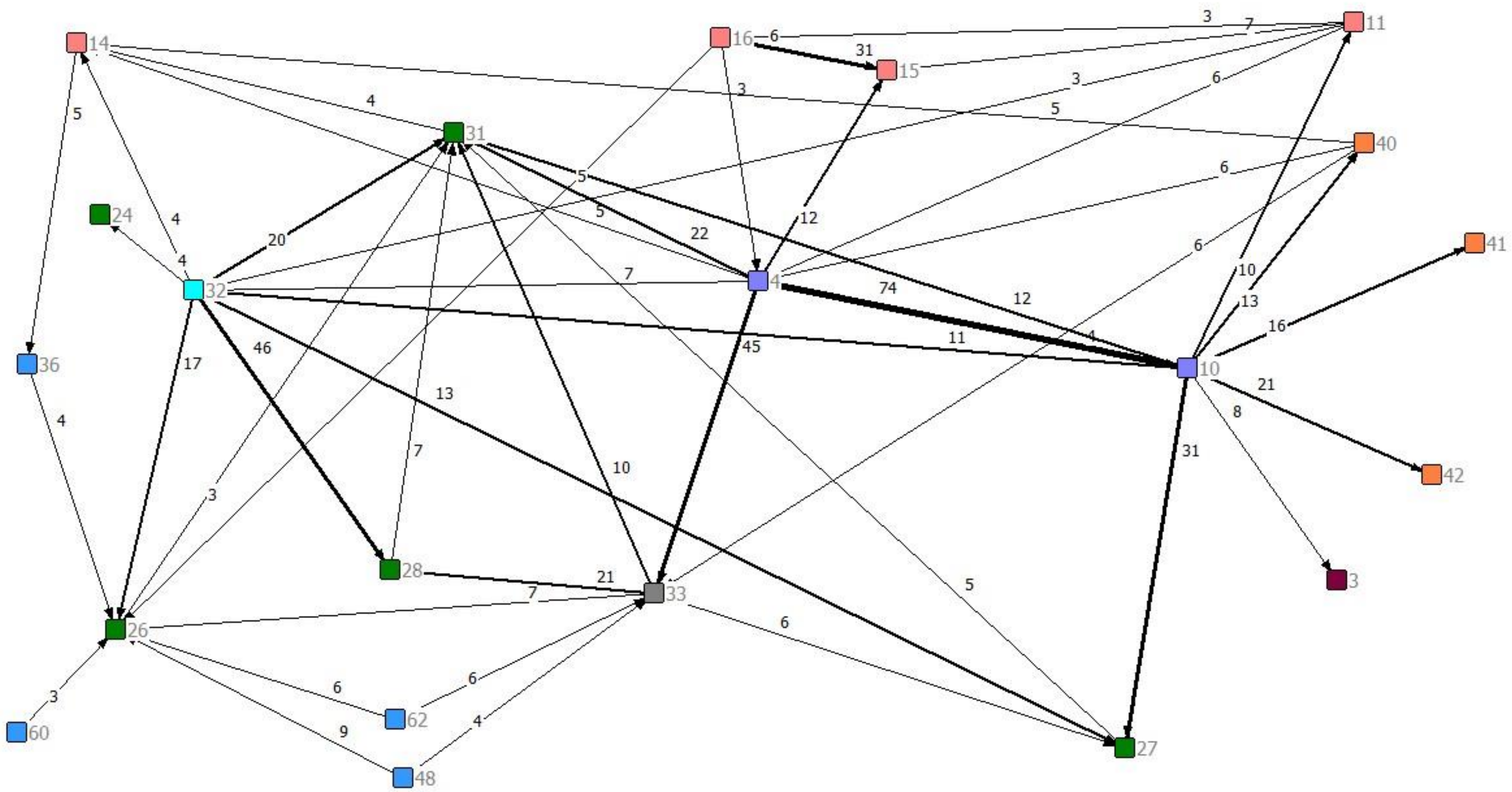
Having presented the main features of the disaggregated IOT and SAM, let us now turn to analyse the productive structure of the Spanish economy focusing in particular on the electricity industry. This will allow us to evaluate the centrality of the sector and its dependence chain. We proceed by examining first the inter-sector linkages, which are illustrated by means of a graph, and then the dependence chains found in 2013IOTDE using the Leontief model ([45]) commonly applied in the literature (see [26]).

3.2.4.1. Sectoral linkages

To begin our analysis of the electricity industry's role and the importance of its various subsectors in the Spanish economy as a whole, let us first represent the main relationships with other sectors by means of a graph, focusing initially on direct relationships. We will then complete the analysis taking into account the indirect relationships between sectors through the information provided by the backward and forward linkage indicators.

Figure 3. 1 shows energy and other strongly linked sectors (for the sake of clarity, we omit other sectors that are less tightly connected with energy). Each node represents a production sector, which is indicated by a sector number (the grey number next to the node). The arrow indicates the direction of the production flow, which is the inverse of the direction of the monetary flow. The second figure placed on the arrow represents purchases made by each sector as a percentage of its total output (only cases above 3% are represented).

Figure 3. 1. Main electricity sector relationships (purchases as a percentage of total sector output)



Source: own work. 3: Fisheries and aquaculture. 4: Extractive industries. 10: Manufacture of coke and refined petroleum. 11: Chemicals. 14: Manufacture of other non-metallic mineral products. 15: Manufacture of iron, steel and ferroalloy products. 16: Manufacture of metal products, except for machinery and equipment. 24: Wind generating. 26: Conventional thermal generating. 27: Solar and other generating. 28: Hydrogenerating. 31: Electricity marketing. 32: Related electricity sector activities. 33: Gas. 36: Construction. 40: Overland transport and pipelines. 41: Maritime transport and interior waterways. 42: Air transport. 48: Telecommunications. 60: Activities related to employment. 62: Safety, investigation and ancillary activities.

A first look at the graph shows that one of the strongest inter-sector relationships is that between Manufacture of coke and refined petroleum (10) and Extractive industries (4), in which the latter's sales are equal to 74% of the former's total output. Furthermore, Extractive industries also sell inputs to Related electricity sector activities (32), Electricity marketing (31), Gas (33), Manufacture of other non-metallic mineral products (14) and Manufacture of products of iron, steel and ferroalloys (15), and it buys inputs mainly from Manufacture of metallic products (16), Overland transport and pipelines (40) and Chemicals (11). Meanwhile, Manufacture of coke and refined petroleum (10) also sells inputs to Fisheries and aquaculture (3), Chemicals (11), Solar and other generating (27), Electricity marketing (31), Related electricity sector activities (32), Maritime transport (41), Air transport (42) and Overland transport and pipelines (40).

Wind generating (24) purchases a significant 4% of its output value from Related electricity sector activities (32), while Conventional thermal generating (26) buys inputs from Manufacture of metallic products (16), Related electricity sector activities (32), Gas (33), Construction (36), Telecommunications (48) and Safety and investigation activities (62). It sells its output to Electricity marketing (31). Solar and other generating (27) buys inputs from Manufacture of coke and refined petroleum (10), Related electricity sector activities (32) and Gas (33), and it sells to Electricity marketing (31). Hydrogenerating (28) buys inputs from Related electricity sector activities (32) and Gas (33), and it sells most of its production to Electricity marketing (31).

Electricity marketing (31) purchases inputs from Extractive industry (4), Manufacture of coke and refined petroleum (10), and, given the sales of the different generating technologies, from Conventional thermal generating (26), Solar and other generating (27), Hydrogenerating (28), and Related electricity sector activities (32), as well as Gas (33). The sector sells its output to Manufacture of other non-metallic mineral products (14).

Related electricity sector activities (32) buys inputs from (4), (10), (11), (28), (31) and (33) and sells part of its production to Manufacture of other non-metallic mineral products (14), Wind generating (24), Conventional thermal generating (26), Solar and other generating (27), Hydrogenerating (28), and Electricity marketing (31).

To sum up, the electricity subsectors are closely related with basic industries, and with a significant part of the transport and service sectors. Moreover, Nuclear generating (25), Electricity transmission (29) and Electricity distribution (30) do not appear on the graph, indicating a low level of direct relationships with each sector in particular, because they have small but significant links with all sectors. Extractive industries (4), Manufacture of coke and refined petroleum (10), Electricity marketing (31), Related electricity sector activities (32) and Gas (33) also play a key role. Three generating sectors—thermal (26), solar (27) and hydropower (28)—are also structurally significant, but less so than marketing (31) or related activities (32).

The graph above is a simple representation of the direct links between the electricity subsectors and the wider economy. However, the multi-sectoral framework allows us a more complete analysis of these economic linkages, revealing not only direct relationships but also indirect links. This means we can analyse the capacity of the sectors to produce the inputs needed by the different electricity sectors in each of the production steps along the whole of the supply chain.

If **x** denotes the production vector in an economy, **y** denotes net final demand, **A** = (a_{ij}) is the matrix of total technical coefficients representing the technology, and $(\mathbf{I}-\mathbf{A})^{-1} = (\alpha_{ij})$ is the Leontief inverse matrix, then the equilibrium equation for this economy can be written:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y};\ \mathbf{x} = (\mathbf{I}-\mathbf{A})^{-1}\,\mathbf{y} \qquad (1)$$

In our case, $\mathbf{A} = (a_{ij})$ is obtained from 2013IOTDE by dividing intermediate inputs by total sectoral outputs (excluding imports). The Leontief inverse, $(\mathbf{I}-\mathbf{A})^{-1} = (\alpha_{ij})$ shows the inputs generated in sector *i* that are directly or indirectly incorporated per unit of final demand of sector *j*.

The unitary backward coefficients B_j are calculated as the sum of the $(\mathbf{I}-\mathbf{A})^{-1}$ columns (see [2]) and show the production generated in the whole economy per unit of final demand. In other words, the backward coefficients reflect the capacity of a sector to drive economic activity when its final demand increases (household consumption, investment, exports,..). The global backward coefficients $\overline{B}_j$ are the sums of the $(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{y}}$ columns and estimate the vertically-integrated production associated with the final demand of sector *j*.

$$B_j = \sum_i \alpha_{ij} \ , \quad \bar{B}_j = y_j \sum_i \alpha_{ij} \tag{2}$$

The unitary forward coefficients F_i are calculated as the sum of the $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ rows (see [3]). These coefficients compute the sectoral output incorporated per an additional unit of final demand in all sectors of the economy. Hence, these coefficients tell us how different sectors facilitate the activity of others by supplying the inputs they need to fulfil their final demand. The global forward coefficients are calculated as the sum of the $(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{y}}$ rows and are equal to sectoral production.

$$F_i = \sum_j \alpha_{ij} \ , \quad \overline{F}_i = \sum_j \alpha_{ij} y_j \tag{3}$$

According to [46], economic sectors can be classified according to their capacity to boost the economy through direct and indirect purchases from all other sectors (backward linkages), their capacity to facilitate the activity of other sectors (forward linkages), or both. Thus, an industry may be regarded as a key sector when both linkages are above the average values for the economy, as a backward sector if only its backward linkage is above average, and as a forward sector if the forward linkage is higher than the average. Finally it will be a non-significant sector if both linkages are below the average values. Although this classification is made on the basis of unitary indicators in the literature, a complementary picture of the sectors' importance in the economy can also be obtained from the global backward and forward linkages.

A key sector depends on other industries, which is to say it uses inputs from other sectors in order to incorporate them in its production process and, in turn, its output is sold to other industries to be modified in their production processes. Hence, such a sector will be highly integrated in the economic structure, both pulling and pushing the activity of other sectors. In a backward or forward sector, however, only one of these two perspectives will predominate. Table 3. 5 shows the values for the energy sectors and for certain sectors strongly linked to them (see Figure 3. 1), as well as the average values for the Spanish economy as a whole.

Table 3. 5. Backward and forward linkages of sectors associated with energy activities

		Unitary backward	Unitary forward	Classifi cation	Global backward	Global forward
3	Fisheries and aquaculture	2.5312	1.0818	Backward	3,518	2,972
4	Extractive industries	2.5871	8.5290	Key	-118,281	6,244
10	Manufacture of coke and refined petroleum	3.6408	6.0231	Key	33,459	45,470
11	Chemicals	3.5265	7.6420	Key	-10,287	48,352
14	Manufacture of other non-metallic mineral products	2.8940	2.0476	Backward	4,045	15,452
15	Manufacture of iron, steel and ferroalloy products	3.5034	5.4969	Key	9,085	40,587
16	Manufacture of metallic products, except for machinery and equipment	3.0354	3.7093	Key	12,650	27,426
24	Wind generating	1.2763	1.1262	N. S.	1,068	1,889
25	Nuclear generating	1.1631	1.0701	N. S.	158	725
26	Conventional thermal generating	2.8665	1.5525	Backward	5,783	6,513
27	Other generating	2.7731	1.6765	Backward	6,962	8,154
28	Hydrogenerating	3.4733	1.9292	Backward	2,990	8,492
29	Electricity transmission	1.2103	1.1557	N. S.	266	1,599
30	Electricity distribution	1.0002	1.2721	N. S.	808	3,219
31	Electricity marketing	3.8850	2.5538	key	19,403	18,764
32	Related activities	3.0381	4.8932	Key	13,910	30,135
33	Production, distribution and commercialization of gas and steam, and air conditioning	2.8476	2.2138	Backward	1,484	7,479
36	Construction	2.5121	3.1256	Key	221,913	132,271
40	Overland transport and pipelines	2.4474	3.9010	Key	49,790	47,156
41	Maritime transport and interior waterways	2.7458	1.0641	Backward	6,003	2,840
42	Air transport	2.9906	1.4515	Backward	17,710	9,806
48	Telecommunications	2.0813	2.8464	Forward	32,149	34,910
60	Activities related to employment	1.2116	1.4406	N. S.	-2	3,265
62	Safety, investigation and ancillary activities	1.6924	3.4888	Forward	-174	27,074
	Average	2.3370	2.3370		26,712	26,712

Source: Own work.

Two out of the nine new electricity sectors obtained from our disaggregation—Electricity marketing (31) and Related electricity sector activities (32)—are key sectors. Marketing has a backward linkage of 3.88 compared to an average value of 2.34, while the backward linkage of Related activities is 3.04. Three sectors—Conventional thermal generating (26), Solar and other generating (27) and Hydrogenerating (28)—are backward sectors. These five sectors all boost growth in the Spanish economy when their demand increases, but only the first two facility it significantly, especially Related activities, which has a forward linkage equal to 4.89. Surprisingly, the remaining sectors (wind and nuclear generating, and electricity transmission and distribution) belong to the non-significant category. In other words, they have only a very limited role as drivers of growth.

Extractive industry (4) is a key sector, and it has the highest forward coefficient, so that when production expands it generates a large increase in the output of the remaining sectors in terms of both sales and purchases. This is important for us because it produces inputs for energy sectors, although it is not itself an energy industry. This is also the case with the Manufacture of coke and refined petroleum (10), another key sector with a high forward linkage of 6.02 compared to an average value 2.34.

Table 3. 5 shows a further five key sectors, three of them industrial—(11), (15) and (16)—, Construction (36) and a transport sector (40). These sectors are important drivers of the Spanish economy, and electricity and/or energy is an essential input for them. Energy is in fact crucial for the Spanish economy because of its links with the industrial, construction and service sectors rather than in itself.

3.2.4.2. Analysis of the dependence chain of electricity sectors in the Spanish economy

The foregoing analysis confirms the importance of the electricity industry to the Spanish economy. To explore this matter further, let us classify the different sectors of the Spanish economy based on their greater or lesser supply- and demand-side capacity, evaluating both of them in a global way, in direct and indirect terms. This classification will provide an overview of the global dependence chains between the different productive sectors in the economy.

We use the methodology described in [47], which consists of organizing the hierarchy of sectors according to their nature as supply- or demand-side industries. The criterion followed involves placing the more independent sectors (stronger supply-side characteristics) at the beginning of the table and the more dependent sectors (dominant demand-side) at the end. Thus, the sector which directly or indirectly demands inputs from the most sectors will be placed at the end of the chain. An iterative method was used to obtain the classification, starting with the inverse Leontief matrix obtained from 2013IOTDE. In each step of the iteration, we eliminated all scores below a given value for the step concerned, focusing only on the purchases and sales described by the remaining coefficients.

If no coefficients are removed from our matrix, we find that it can be broken down into two indecomposable[12] blocks, the first comprising sectors (1) to (71) and the second formed only by Activities of households as employers (72). In our hierarchy, then, sector (72) appears in the last position, because it has zero intermediate sales to other sectors.

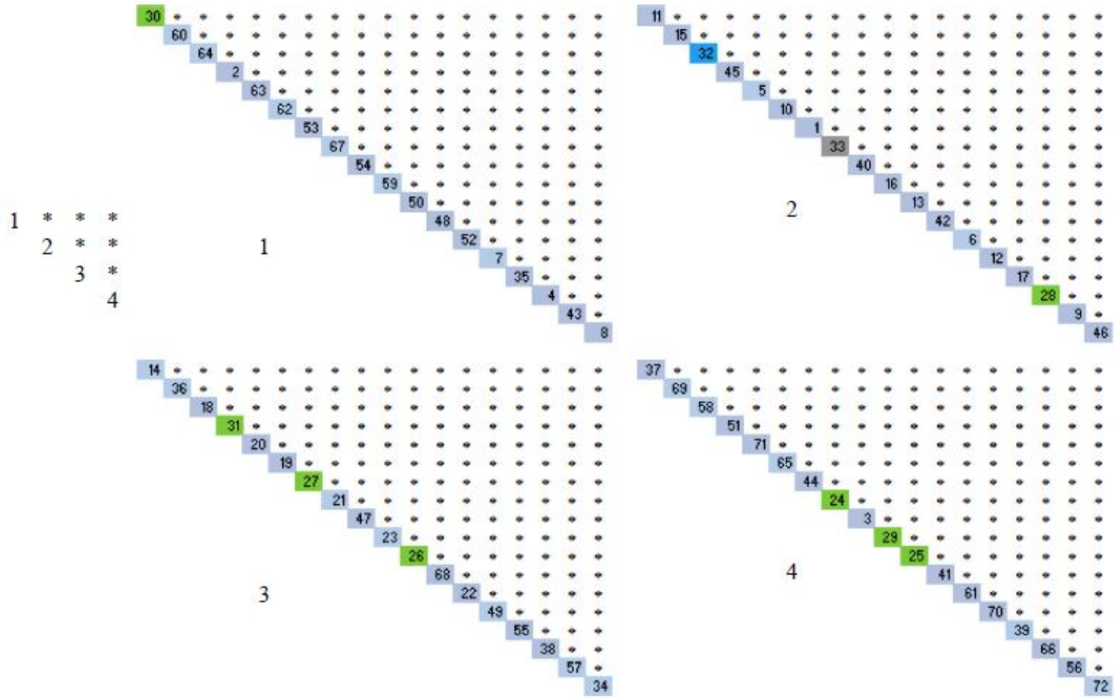
Then, removing the coefficients smaller than a value *b* small enough, we can break the previous block with 71 sectors into two new indecomposable blocks. One with 70 sectors and another composed by only one sector, Scientific research and development (56), which has no significant sales to any sector. For this reason, this sector (56) appears in the new hierarchy in post 71, before sector (72). We can repeat iteratively this process, putting the unisectoral block in front position or behind depending on if the block has null purchases or null sales. The process finishes when all sectors are ordered. We can see the hierarchy obtained in Figure 3. 2.

As may be observed, five key sectors of the Spanish economy—Chemicals (11), Construction (36), Metals (15), Transport (40) and Metal manufactures (16)—are placed in the central part of the classification with Chemicals (11) at the top (position 19 of 72) and Construction (36) at the bottom in position 38. The size and key nature of these industries drive the role of electricity activities, as mentioned above. A further two sectors, Extractive industries (4) and Coal and oil (10) also occupy central positions, respectively placed the 16th and 24th, as major suppliers of the electricity industry.

The result of all this is that certain electricity sectors also occupy relatively central positions. For example, Solar and other generating (27) is placed 43rd, while Hydrogenerating (28) ranks 34th. However, the technical nature or dominant backward roles of other sectors push them towards the extremes of the classification, as explained above. For example, Distribution (30) is placed first in the list as a supplier of all of the other sectors, while Transmission (29) and Nuclear (25) are in the 64th and 65th place, revealing that they sell their output either directly to consumers or to intermediate sectors which make very significant sales to end consumers.

[12] A block is indecomposable if any sector of this block sells inputs directly or indirectly to all sectors of the block.

Figure 3. 2. Hierarchy of seller and buyer sectors



Source: own work. The names of each sector are provided in Table 3. 8 of the Appendix.

3.2.5. Final remarks and future research

The Spanish energy system faces major challenges, which will have crucial implications both for the future development of the electricity sector and for the economy as a whole. Key issues include scant competition, the tariff deficit, faulty tariff design, a raft of uncertainties, potential market integration and the introduction of new technologies. In this context, the need for tools that provide detailed information on the complexities of the sector and its relationships with the rest of the economy is a matter of some urgency. This paper takes a first step in this direction, contributing to an accurate depiction of the sector’s structure. To that end, we have constructed and disaggregated an IOT for the Spanish economy in 2013, disaggregating the electricity sector by activity (generating, transmission, distribution, marketing, and related activities). Generating was then further disaggregated into the different production technologies. The resulting table reveals the interrelationships between electricity sector activities and the rest of the economy. To the best of our knowledge, this is the first time that energy activities in the Spanish IOT have been disaggregated into ten sectors (nine electricity sectors and gas activities) to throw light on the technological structure of the industry and inter-sectoral links. We have also extended the IOT to a SAM with 11 additional accounts, including five tax accounts and one trade account.

We began by representing sectoral relationships in a graph and calculating forward and backward linkages to obtain an initial picture of the structural role played by electricity activities. This analysis was further fleshed out by an examination of dependence chains through the hierarchical classification of sectors based on their supply- or demand-side nature.

One of the salient structural features of the Spanish electricity system is its scant connection with foreign power distribution grids. Connections with France, Portugal and Morocco are far what might be considered a desirable level, which means that domestic output must meet Spanish demand practically in its entirety, while exports and imports of electricity are absolutely nugatory. This has serious consequences for competitiveness and has fostered the emergence of oligopolistic structures. There can be no doubt that increasing the level of connections with France and other countries would encourage competition in the electricity market and help secure the power supply.

Another significant finding is that both generating and the transport and distribution sectors are highly capital intensive but create relatively few jobs. This is doubtless largely a consequence of the technical characteristics of these activities, but it also points to the highly relevant fact that these industries are not *a priori* drivers of employment. As we revealed by the linkages analysed, however, the sector is strongly linked to extractive industries (notably coal), which do create jobs, and this is something that should not be lightly passed over.

Our findings with regard to the "key" nature of the electricity sector were something of a surprise. It is common sense to suppose electricity to be essential to economy, and it might therefore be imaged that these are "Rasmussen" key sectors. As we have seen, however, this is true only of Electricity marketing, while all of the others except Related activities are backward sectors (i.e. demand predominates over supply), or they are not significant. Hence, none of the electricity generating sectors is key. The explanation is fortunately simple and may be observed in Table 3. 5. All of these sectors have strong linkages to metals industries, construction and transport, and their significance to the wider economy lies in their role in aiding the development of these sectors.

The disaggregation of the electricity sectors also revealed how varied they actually are, which should put us on our guard about making overly general analyses. The power generated by conventional thermal systems and hydroelectric plants accounts for more than 50% of the value of electricity output, yet it is nuclear and wind power that exercise public opinion. Nuclear power produces only around 7% of total output, while wind generating suffers from the problem of variability and the technical difficulty of accumulation. This may be why neither these two sectors are relevant under the Rasmussen classification, as shown in Table 3. 5.

The electricity sectors are also very different in terms of the business models involved: while the generating sectors' revenues are determined basically by daily electricity auctions, transport and distribution revenues are tariff-based, and the marketing sector operates under fundamentally competitive conditions. This is a further indication of the highly varied nature of the industry as a whole, and therefore of the need to ensure that analyses take account of inter-sector differences.

These differences and the limitations of the structural analysis based on input-output tables described in this paper provide the starting point for our main line of future research, the extension of the SAM obtained to a computable general equilibrium model at the same level of disaggregation. This would provide a sound basis for the analysis of differentiated policies targeting the various sectors involved in the electricity industry and it would allow quantification of the likely effects of upgrading connections with Europe, as well as evaluation of the possible outcomes of changes in consumption patterns or the mix of generating technologies.

Finally, electricity sector activities have also been decoupled in other European countries, and in this light our methodology and conclusions about the structure of electricity production may well be applicable to other countries or regions. This is a further line of research which we hope to address at some point in the future.

3.2.6. Appendix

Table 3. 6. Criteria estimation for Supply variables

Sectoral variables in SABI data for electricity sector *j*	Variable name of electricity sectors *j* from 2013IOTDE	Criteria for estimation
Aggregated value (**a**=(a_j))	Value added at basic prices (**b**=(b_j))	$b_j = \frac{a_j}{\sum_j a_j}$ *0.6209*Value added in Electricity sector
Personnel expenditure (**c**=(c_j))	Gross wages and salaries (**e**=(e_j))	$e_j = \frac{c_j}{\sum_j c_j}$ *0.6209*Wages and salaries in Electricity sector
	Social contributions (**f**=(f_j))	$f_j = e_j t_f$, with $t_f = \frac{\text{Social contributionsin Electricity sector}}{\text{Wages and salaries in Electricity sector}}$
	Remuneration of employees (**d**=(d_j))	$d_j = e_j + f_j$
Corporate tax (**g**=(g_j))	Other net taxes on production (**h**=(h_j))	$h_j = \frac{cg}{\sum_j g_j}$ *0.6209*Other net taxes on production in Electricity sector
Out-turn for the financial year (**k**=(k_j))	Gross operating surplus / Mixed income (**n**=(n_j))	We obtain $\tilde{n}_j = k_j + l_j + m_j$, then n_j is estimated as: $n_j = \frac{\tilde{n}_j}{\sum_j \tilde{n}_j}$ *0.6209*Gross operating surplus/Mixed income in Electricity sector
Allowances for depreciation (**l**=(l_j))		
Financial expenses (**m**=(m_j))		
Operating Income (**u**=(u_j))	Total resources (**v**=(v_j))	$v_j = \frac{u_j}{\sum_j u_j}$ *0.6209*Total resources in Electricity sector
Corporate tax (**g**=(g_j))	Net taxes on products (**p**=(p_j))	$p_j = \frac{g_j}{\sum_j g_j}$ *0.6209*Net taxes on products in Electricity sector
Imports (**q**=(q_j))	Total imports (**r**=(r_j))	$r_j = \frac{q_j}{\sum_j q_j}$ *0.6209*Total imports in Electricity sector
	Imports EU (**s**=(s_j))	$s_j = r_j t_s$, with $t_s = \frac{\text{EU imports in Electricity sector}}{\text{Total imports in Electricity sector}}$
	Imports RoW (**t**=(t_j))	$t_j = r_j t_t$, with $t_t = \frac{\text{RoW imports in Electricity sector}}{\text{Total imports in Electricity sector}}$
	Production at basic prices (**x**=(x_j))	$x_j = v_j - r_j$

	Production at purchaser prices (**w**=(w_j))	$w_j = x_j - b_j$
	Total intermediate inputs (**z**=(z_j))	$z_j = w_j - p_j$

* Income received by the firms as a guaranteed debt

Source: Own work with data from [36,34,37].

Table 3. 7. Criteria estimation for Final demand variables

Sectoral variables in SABI data for electricity sector	Variable name of electricity sectors *i* from 2013SIOTDE	Criteria for estimation
	Total use (**C**=(C_i))	$C_i = v_j$, Total uses are equal to Total resources
	Consumption of households (**E**=(E_i))	$H_i = \frac{C_i}{\sum_i C_i}$*0.6209*Consumption by households in Electricity sector
	Consumption of the non-profit institutions (**F**=(F_i))	$H_i = \frac{C_i}{\sum_i C_i}$*0.6209*Consumption by non-profit institutions in Electricity sector
	Consumption of Government (**G**=(G_i))	$H_i = \frac{C_i}{\sum_i C_i}$*0.6209*Consumption by Government in Electricity sector
	Total final consumption expenditure (**H**=(H_i))	$H_i = E_i + F_i + G_i$
Fixed assets 2010 (**J**=(J_i))	Gross fixed capital formation (**K**=(K_i))	$K_i = \frac{J_i - L_i}{\sum_i (J_i - L_i)}$*0.6209*Gross fixed capital formation in Electricity sector
Fixed assets 2009 (**L**=(L_i))		
Inventories 2010 (**M**=(M_i))	Variation of inventories (**N**=(N_i))	We estimate N_i as $N_i = (M_i - O_i) - \rho C_i$, with ρ being $\rho = \left[\frac{\sum_i (M_i - O_i) - 0.6209\text{*Variation of inventories and .... in Electricity sector}}{\sum_i C_i} \right]$
Inventories 2009 (**O**=(O_i))		
	Gross capital formation (**P**=(P_i))	$P_i = K_i + N_i$
Exports (**Q**=(Q_i))	Total exports (**R**=(R_i))	$R_i = \frac{Q_i}{\sum_i Q_i}$*0.6209*Total exports in Electricity sector
	Exports EU (**S**=(S_i))	$S_i = R_i t_S$, with $t_S = \frac{\text{EU exports in Electricity sector}}{\text{Total exports in Electricity sector}}$
	Exports RoW (**T**=(T_i))	$T_i = R_i t_T$, with $t_R = \frac{\text{RoW exports in Electricity sector}}{\text{Total exports in Electricity sector}}$
	Total final demand	$U_i = H_i + P_i + R_i$

	(**U**=(U_i))	
	Total intermediate demand (**V**=(V_i))	$V_i = C_i - U_i$

Source; Own work.

Table 3. 8. Accounts of the SAM

	Accounts
1	Agriculture, livestock, hunting and related services
2	Forestry and logging
3	Fisheries and aquaculture
4	Extractive industries
5	Agrifood industry
6	Textile industry
7	Industry of wood and cork
8	Paper industry
9	Graphical arts and reproduction of recorded media
10	Manufacture of coke and refined petroleum
11	Chemicals
12	Manufacture of pharmaceutical basics and prepared pharmaceutical products
13	Manufacture of products of rubber and plastic
14	Manufacture of other non-metallic mineral products
15	Manufacture of products of iron, steel and ferroalloys
16	Manufacture of metallic products, except for machinery and equipment
17	Manufacture of computer products, electronic and optical products
18	Manufacture of material and electrical equipment
19	Manufacture of machinery and equipment n.c.o.p.
20	Manufacture of motor vehicles, trailers and semi-trailers
21	Manufacture of other transport equipment
22	Manufacture of furniture; other manufacturing
23	Repair and installation of machinery and equipment
24	Generation of electricity from wind
25	Generation of electricity from nuclear
26	Generation of electricity from conventional thermal
27	Generation of electricity from other sources
28	Generation of hydropower
29	Transmission of electricity
30	Distribution of electricity
31	Commercialization of electricity
32	Related activities to the electricity sector
33	Gas, steam and air conditioning
34	Collection, purification and distribution of water
35	Withdrawal and treatment of waste water and residues
36	Construction
37	Sale and repair of motor vehicles and motorcycles
38	Wholesale trade
39	Retail trade, except for motor vehicles and motorcycles
40	Overland transport and pipelines
41	Maritime transport and interior waterways
42	Air transport
43	Storage and attached activities to transport
44	Post and courier activities
45	Hosting, service of meals and drinks
46	Publishing
47	Activities of cinema, television and music
48	Telecommunications
49	Information, transmission and computer services
50	Financial services, except insurance and pension funding
51	Insurance, reinsurance and pension funding, except compulsory social security

52	Auxiliary activities to financial services and to insurances
53	Real estate activities
54	Juridical and consultation activities
55	Technical services of architecture and engineering; tests and technical analyses
56	Scientific research and development
57	Advertising and market research
58	Other professional, scientific and technical activities; veterinary activities
59	Rental activities
60	Activities related to employment
61	Activities related to tourism
62	Safety activities and investigation and auxiliary activities to companies
63	Public administration and defence
64	Education
65	Sanitary activities
66	Activities of social services
67	Activities of arts, entertainment and recreation
68	Sports activities and amusement and recreation activities
69	Activities of membership organizations
70	Computer repair, personal items and housewares
71	Other personal services
72	Activities of households as employers
L	Labor
K	Capital
H	Household
SI	Savings/Investment
Cotizem	Social contributions by employers
tn	Net taxes on products
Ty	Other net taxes on production
Cotizt	Social contributions by employees
IRPF	Income tax from individuals
G	Government expenditure
FT	Foreign trade
MT	Margins and taxes on products
sum	Total (equal to total resources)

Source: own work.

3.2.7. References

[1] MAGRAMA (Spanish Ministry of Agriculture and Environment). (2007). Spanish Sustainable Development Strategy. http://www.mapama.gob.es/es/ministerio/planes-estrategias/estrategia-espanola-desarrollo-sostenible/09047122800cfd5b_tcm7-14860.pdf

[2] Pardo Abad, C.J. (2001). Situación actual del sector energético en España. Espacio, Tiempo y Forma, Serie VI, Geografía, 13, 59-83.

[3] Langarita, R.; Sánchez-Chóliz, J.; Sarasa, C.; Duarte, R.; Jiménez, S. (2017). Electricity costs in irrigated agriculture: A case study for an irrigation scheme in Spain. Renewable & Sustainable energy reviews, 68, 1008-1019.

[4] BOE. (1997). Law 54/1997, of November 27th of electric sector. Official State Bulletin, nº 285.

[5] Ang, B.W. (2004). Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy, 32, 1131-1139.

[6] Wang, W.W.; Liu, X.; Zhang, M.; Song, X.F. (2014). Using a new generalized LMDI method to analyze China's energy consumption. Energy, 67, 617-622.

[7] Su, B.; Ang, B.W. (2012). Structural decomposition analysis applied to energy and emissions: Some methodological developments. Energy Economics, 34, 177-188.

[8] Zhang, M.; Song, Y. (2015). Exploring influence factors governing the changes in China's final energy consumption under a new framework. Natural Hazards, 78: 653-668.

[9] Zhang, H.; Lahr, M.L.; Bi, J. (2016). Challenges of green consumption in China: a household energy use perspective. Economic Systems Research, 28, 183-201.

[10] Lopes de Carvalho, A.; Henggeler Antunes, C.; Freire, F.; Olivera Henriques, C. (2015). A hybrid input–output multi-objective model to assess economic–energy–environment trade-offs in Brazil. Energy, 82, 769-785.

[11] Cui, L. B.; Peng, P.; Zhu, L. (2015). Embodied energy, export policy adjustment and China's sustainable development: A multi-regional input-output analysis. Energy, 82, 457-467.

[12] Meng, F. Y.; Zhou, D. Q.; Zhou, P.; Bai, Y. (2014). Sectoral comparison of electricity-saving potentials in China: An analysis based on provincial input-output tables. Energy, 72, 772-782.

[13] Pahlavan, R.; Omid, M.; Akram, A. (2012). Energy input-output analysis and application of artificial neural networks for predicting greenhouse basil production. Energy, 37, 171-176.

[14] Kuhtz, S.; Zhou, C.; Vito Albino, V.; Yazan, D. M. (2010). Energy use in two Italian and Chinese tile manufacturers: A comparison using an enterprise input–output model. Energy, 35, 364–374.

[15] Logar, I.; Van den Bergh, J. C. J. M. (2013). The impact of peak oil on tourism in Spain: An input-output analysis of price, demand and economy-wide effects. Energy, 54, 155-166.

[16] Ozkan, B.; Akcaoz, H.; Fert, C. (2004). Energy input–output analysis in Turkish agriculture. Renewable Energy, 29, 39–51.

[17] Hartono, D.; Resosudarmo, B. P. (2008). The economy-wide impact of controlling energy consumption in Indonesia: An analysis using a Social Accounting Matrix framework. Energy Policy, 36, 1404–1419.

[18] Baiocchi, G., Minx, J. and Hubacek, K. (2010), The Impact of Social Factors and Consumer Behavior on Carbon Dioxide Emissions in the United Kingdom. Journal of Industrial Ecology, 14: 50–72.

[19] Parikh, J.; Panda; M.; Ganesh-Kumar, A.; Singh, v. (2009). CO2 emissions structure of Indian economy. Energy, 34, 1024–1031.

[20] Cansino, J. M.; Cardenete; M. A.; González-Limón, J. M.; Román, R. (2014). The economic influence of photovoltaic technology on electricity generation: A CGE (computable general equilibrium) approach for the Andalusian case. Energy, 73, 70-79.

[21] Fujimori, S.; Dai, H.; Masui; T.; Matsuoka, Y. (2016). Global energy model hindcasting. Energy, 114, 293-301.

[22] INE. (2016). Cuentas económicas. Contabilidad Nacional Anual de España. Base 2010. Marco input-output. http://www.ine.es/jaxi/menu.do?type=pcaxis&path=/t35/p008/&file=inebase

[23] Cazcarro, I.; Duarte, R.; Sánchez-Chóliz, J. (2010). Water Consumption Based on a Disaggregated Social Accounting Matrix of Huesca (Spain). Journal of Industrial Ecology, Volume 14, Issue 3, pages 496–511.

[24] Velázquez, E. (2006). An input–output model of water consumption: Analysing intersectoral water relationships in Andalusia. Ecological Economics, 56, 226-240.

[25] Alcántara, V.; Padilla, E. (2003). "Key" sectors in final energy consumption: an input-output application to the Spanish case. Energy Policy, 31, 1673–1678.

[26] Polo, Clemente; Valle, Elisabeth. (2002). Un análisis input-output de la economía balear. *Estadística Española*, vol. 44, Núm.151, 2002, págs. 393 a 444.

[27] EUROSTAT. (2008). Eurostat Manual of Supply, Use and Input-Output Tables. Eurostat methodologies and working papers. ISSN 1977-0375.

[28] Junius, T.; Oosterhaven, J. (2003). The solution of Updating or Regionalizing a Matrix with both Positive and Negative Entries. Economic Systems Research, nº 15: 1, pp 87-96.

[29] Lenzen, M.; Wood, R.; Gallego, B. (2007). Some comments on the GRAS Method. Economic Systems Research, nº 19: 4, pp 461-465.

[30] INE. (2010). (Instituto Nacional de Estadística). Cuentas económicas. Contabilidad Nacional de España. Base 2000. Marco input-output. Resultados 2000-2007. Published on December 20, 2010. http://www.ine.es/daco/daco42/cne00/cneio2000.htm

[31] MINETUR (2005). La energía en España 2005. Ministerio de industria, comercio y turismo. Gobierno de España.

[32] MINETUR. (2013). La energía en España 2013. Ministerio de industria, comercio y turismo. Gobierno de España.

[33] MINETUR (2010). La energía en España 2010. Ministerio de industria, comercio y turismo. Gobierno de España.

[34] MINETUR (2011). La energía en España 2011. Ministerio de industria, comercio y turismo. Gobierno de España.

[35] SABI. (2017). Sistema de Análisis de Balances Ibéricos. On-line database. [View: 5 April 2017]. Available under license: https://sabi.bvdinfo.com/version-20151210/Search.QuickSearch.serv?_CID=0&context=3VTIBVFGGIWNW7U

[36] UNESA. (2013). Asociación española de la industria eléctrica. Informe eléctrico. Memoria de actividades. Memoria estadística. 2013.

[37] Barrera-Lozano, M.; Mainar, A. J.; Vallés, J. (2015). Disaggregation of sectors in social accounting matrices using a customized Wolsky method. Applied Economics Letters, Volume 22, Issue 13.

[38] UNESA. (2014). Asociación española de la industria eléctrica. Informe eléctrico. Memoria de actividades. Memoria estadística. 2014.

[39] EUROSTAT. (2014). EUROSTAT. 2014 updating. Database. Energy statistics. Natural gas and electricity prices. http://ec.europa.eu/eurostat/web/energy/data/database?p_p_id=NavTreeportletprod_WAR_NavTreeportletprod_INSTANCE_QAMy7Pe6HwI1&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-2&p_p_col_count=1

[40] CNMC. Report about the results of the provisional liquidation number 8 of 2013 electricity sector. National Commission of Markets and Competition; 2013.

[41] OMIE. (2014). Electricity market. April 2017. http://www.omie.es/files/flash/ResultadosMercado.swf

[42] Peters, J. C. (2015). The GTAP-Power Database: Disaggregating the Electricity Sector in the GTAP Database, working paper, Center for Global Trade Analysis, Purdue University, West Lafayette, IN, USA.

[43] AEAT. (2013). Informe anual de recaudación tributaria año 2013. Servicio de Estudios Tributarios y Estadísticas. Agencia Tributaria.

[44] MEYSS (2014). Presupuestos de la Seguridad Social. Ejercicio 2014 Seguridad Social. Informe económico-financiero. Secretaría de Estado de la Seguridad Social. Ministerio de empleo y seguridad social. Gobierno de España.

[45] Leontief, W. (1941). The structure of American economy 1919-1929: An empirical application of equilibrium analysis. Cambridge, Massachusetts. Harvard University Press.

[46] Rasmussen, P. N. (1956). Studies in Intersectoral Relations. Einar Harcks Forlag & North-Holland. Copenhagen and Amsterdam.

[47] Sánchez, J.; Royo, M.; Moraga, B.; Soto, S.; Del Amo, J. A. (1994). Technological blocks in 1972, 1978 and 1985 Input-Output Tables of Aragon. 3rd Conference on Aragonese Economy. Regional Government of Aragon: Zaragoza (Spain).

3.3. Final comments of Chapter 3

Taking into account the several issues of the Spanish electricity system (low level of competition, tariff deficit, design of the tariffs, legal uncertainty, and splitting of its activities), we want to correctly depict the structure of this sector in Spain. For that, a social accounting matrix is a very useful tool.

We have constructed and disaggregated the input-output table for the Spanish economy for 2013 into the different activities of the electricity sector: generation, transmission, distribution, commercialization, and related activities. At the same time, the generation activity is disaggregated into the different production technologies. With this, we can see the interrelationships between the electricity sector activities and the rest of the economy.

In addition, we are providing other researchers with a very useful database, which depicts in great detail the productive structure of the Spanish economy, especially of the electricity sector.

One of the main results of this chapter is the disaggregation of the input-output table and the social accounting matrix, because they both take into account the details of the interrelationship between the electricity sector and the rest of the economy, between the electricity sector and the external sector, and between the various activities within the energy sector.

Another important issue of this chapter is that, on the basis of these tables, in Chapter 4, we will develop a CGE model for simulating some economic policies related to the electricity sector.

3.4. Appendix A 3: Methodology background

3.4.1. Marco input-output

A symmetric input-output table (IOT) is usually obtained from the supply and use tables.

3.4.1.1. Supply and use tables

The structure of the supply matrix, following INE (2016), is represented in Table A3. 1. The supply matrix depicts the "origin" of the goods, that is to say, which sector or industry is producing each kind of good.

Table A3. 1. Structure of a supply table

	Industries *j*	Total production	Imports	Total supply at basic prices
Products *i*	$\mathbf{V^t}$	**q-Im**	**Im**	**q**
Total	$\mathbf{g^T}$			

Source: own work following EUROSTAT (2008) nomenclature and INE (2016) structure.

$\mathbf{V^t}$ = Supply matrix (product by industry), industry *j* has produced the good *i*.

V = Make matrix - transpose of supply matrix (industry by product)

q = Column vector of product output

$\mathbf{q^T}$ = Row vector of product output

$\mathbf{g^T}$ = Row vector of industry output

g = Column vector of industry output

Im = Imports matrix

Use matrix is represented in Table A3. 2. The use matrix shows the "use" of the goods, that is to say, which sector or industry is consuming each kind of good for including it in their productive process.

Table A3. 2. Structure of the use matrix

	Industries *j*	Total intermediate demand	Final demand	Total uses
Products *i*	**U**		**Y**	**q**
Value added	**W**			
Total output at purchasing prices	$\mathbf{g}^T$			

Source: own work based on EUROSTAT (2008) nomenclature and INE (2016) structure.

U = Use matrix for intermediates (product by industry), industry *j* has consumed the good *i*.

Y = Final demand matrix (product by category), demand of good *i*.

W = Value added matrix (components by industry), value added of industry *j*.

3.4.1.2. Symmetric table

A symmetric input-output table is a reorganization of the supply and use tables, but without changing the value of the macro-economic aggregates, and in which the same classification is used (products or industries). It is very similar to the use table but adding imports. Finally, we have the total resources of each sector in the economy, at basic prices (or purchase prices, depending on the previous supply and use tables used).

When reorganizing the supply and use tables, we must decide if we want to construct a product-by-product or industry-by-industry symmetric input-output table. The answer will depend on the purpose of the study. For analytical purposes, assumptions about the relations between inputs and outputs are required. In addition, for the transformation of supply and use tables into symmetric input-output tables, various assumptions must be made and sometimes adjustments are required.

We now explain the four basic assumptions involved in each of the options to transform supply and use tables into symmetric input-output tables:

- Product-by-product input-output tables
    - Product technology assumption (Model A): each product is produced in its own specific way, irrespective of the industry where it is produced.
    - Industry technology assumption (Model B): each industry has its own specific mode of production, irrespective of its product mix.

    - A mixture of both assumptions can also be applied by implementing a hybrid technology assumption.

- Industry-by-industry input-output tables

    - Fixed industry sales structure assumption (Model C): each industry has its own specific sales structure, irrespective of its product mix.

    - Fixed product sales structure assumption (Model D): each product has its own specific sales structure, irrespective of the industry where it is produced.

As noted, the selection of the appropriate type of input-output tables (product-by-product vs. industry-by-industry) depends on the specific objective of economic analysis. The latter are closer to statistical sources, at least in Spain, than the former. In addition, in the case of the Spanish input-output analysis, the use of industry-by-industry tables is more common. (See, for example, Duarte et al., 2015, Polo and Valle, 2002, Duarte et al., 2002, Alcántara and Padilla, 2003, Velázquez, 2006, and Cazcarro et al., 2010).

The symmetric input-output table can be obtained following EUROSTAT (2008) (see Table A3. 3), except for the imports matrix (**Im**). We need a matrix which is able to transform products to industries. Although EUROSTAT says nothing about the import matrix, we assume that we must use the **D** matrix for transforming products into industries (see Table A3. 3). We obtain the imports matrix of the symmetric table (**m**) as:

$$\mathbf{m} = \mathbf{D} * \mathbf{Im}$$

Where the **Im** matrix represents the imports of the supply matrix.

Table A3. 3. Structure of an industry-by-industry symmetric input-output table (Model D)

	Industries *j*	Total	Final demand	Total use at purchaser prices
Industry *i*	**B**		**F**	**g + m**
Value added at basic prices	**W**			
Total output at basic prices	$\mathbf{g}^{\mathbf{T}}$			
Imports	**m**			
Total resources	$\mathbf{g}^{\mathbf{T}} + \mathbf{m}$			

Source: own work based on EUROSTAT (2008) nomenclature.

B = Matrix for intermediates (industry by industry); **B** = **A** * diag(**g**).

A = **D** * **Z**: Technical coefficients matrix.

D = **V** * inv(diag(**q-Im**)): Market shares matrix (contribution of each industry to the output of a product)

diag(**q-Im**) = Diagonal matrix of product output

Z = **U** * inv(diag(**g**)): Input requirements for products per unit of output of an industry (intermediates)

diag(**g**) = Diagonal matrix of industry output

F = Final demand matrix (industry by category); **F** = **D** * **Y**.

W = Value added matrix (components by industry); **W** = **W**.

m = **D** * **Im**: imports matrix of the symmetric table.

On the basis of the symmetric table, we can construct the input-output model. Broadly speaking, input-output models describe the production flows between all sectors of an economy, establishing the relationship between domestic and external industrial activities, as well as the economic flows between productive sectors, institutions, and final consumers. It shows a simplified, but real, description of the entire production process and of the inter-relationships between factors, productive activities, and agents. Clearly, one very useful characteristic of this kind of model is the breakdown by branches of productive activity, allowing us to describe in detail the productive structure of an economy and the products and income transfers between different sectors.

More specifically, when **x** is the production vector, **y** denotes the net final demand, **A** is the matrix of total technical coefficients, representing the technology, and $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ represents Leontief's inverse matrix, the equilibrium equation for this economy can be written as:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y}$$

or, in terms of the Leontief inverse:

$$\mathbf{x} = (\mathbf{I}\text{-}\mathbf{A})^{-1}\,\mathbf{y}$$

This is the equilibrium equation for the demand-driven model, showing the relationship between total output and final demand, and the effects that changes in final demand may induce in the output of the economy. Matrix **A**, and the associated Leontief inverse are representations of the production technology to the extent that their representative elements show, respectively, the sectoral inputs of sector i necessary per unit of production of sector j (a_{ij}), and the total inputs generated in sector i that are directly or indirectly incorporated per unit of final demand of sector j (α_{ij}).

On the basis of these equations, the effects of final demand changes over the main economic variables can be analyzed. Thus, if we denote by $\mathbf{\Delta y}$ an exogenous change in final demand (due, for example, to an increase in investment, an increase in household expenditures, or an improvement in the trade balance), the additional output generated in the economy as a consequence of this shock can be computed as:

$$\mathbf{\Delta} x = (\mathbf{I}\text{-}\mathbf{A})^{-1}\,\mathbf{\Delta y}$$

Moreover, when we denote by **l** a vector of sectoral labor coefficients $\mathbf{l} = \{l_j\}$, j = 1, … n; $l_j = (L_j/x_j)$, the additional labor associated with the demand shock can be obtained as:

$$\mathbf{\Delta} L = \mathbf{l'}\,(\mathbf{I}\text{-}\mathbf{A})^{-1}\,\mathbf{\Delta y}$$

So, the input-output model, through these equations, is a good tool to analyse the impact on production of some measures of economic policy, or, in general terms, for an analysis of the increase in production and in other economic variables, such as employment or productivity, if there are any exogenous changes in demand.

There are examples of impact analyses like these in the work of Duarte et al. (2015), Lee and Taylor (2004), and Ramírez et al. (2007).

3.4.2. Social accounting matrix

A natural extension of the input-output model is the social accounting matrix (SAM), first developed by Meade and Stone in 1941 (Meade and Stone, 1941) for the economy section of the British Cabinet Office. A SAM contains, in addition to the production flows of goods, the monetary flows between sectors and institutions; that is to say, it describes all income flows in the economy.

Social accounting matrices close all the economic flows of the economy, taking into account the transfers between agents, estimating the relationships between productive sectors and institutional accounts, such as labour, capital, Households, Savings/investment, different types of taxes, and the Government and External sectors. Thus, in this matrix, we can find transfers from productive sectors to other productive sectors, transfers from productive sectors to institutional accounts, transfers from institutional accounts to productive sectors, and transfers from institutional accounts to other institutional accounts.

For the case of Spain, useful information can be found in the Spanish Revenue Service (AEAT in its official acronym).

3.5. Additional references to Chapter 3

Alcántara, V.; Padilla, E. (2003). “Key” sectors in final energy consumption: an input-output application to the Spanish case. Energy Policy, 31, 1673–1678.

Barrera-Lozano, M.; Mainar, A. J.; Vallés, J. (2015). Disaggregation of sectors in social accounting matrices using a customized Wolsky method. Applied Economics Letters, Volume 22, Issue 13.

Cámara, Á.; Flores, M.; Fuentes, P. (2013). Una Matriz de Contabilidad Social de España para el análisis del sector de las energías renovables. Estadística Española, vol. 55 Núm. 181.

Castillo, Y.; Bravo, H. M. (2010). Incidencia económica de un impuesto a las emisiones de CO2 en el sector energía en un modelo de equilibrio general computable para México. Trabajo de investigación. Departamento de economía aplicada de la Universidad Autónoma de Barcelona.

Cazcarro, I.; Duarte, R.; Sánchez-Chóliz, J. (2010). Water Consumption Based on a Disaggregated Social Accounting Matrix of Huesca (Spain). Journal of Industrial Ecology, Volume 14, Issue 3, pages 496–511.

Duarte, R.; Jiménez, S.; Langarita, R.; Sánchez-Chóliz, J. (2015). Evaluating the structural effects of a big cultural event: the case of the International Expo Zaragoza 2008. Regional and Sectoral Economic Studies, vol. 15-1, pp. 65-80.

Duarte, R.; Sánchez-Chóliz, J.; Bielsa, J. (2002). Water use in the Spanish economy: an input-output approach. Ecological Economics, 43, 71-85.

EUROSTAT. (2008). Eurostat Manual of Supply, Use and Input-Output Tables. Eurostat methodologies and working papers. ISSN 1977-0375.

INE. (2016). Economía. Cuentas económicas. Contabilidad Nacional Anual de España. Base 2010. Marco input-output. Tablas de origen y destino 2013. http://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736165950&menu=resultados&secc=1254736195578&idp=1254735576581

Lee, C.-K.; Taylor, T. (2004). *Critical reflections on the economic impact assessment of a mega-event: the case of 2002 FIFA World Cup*. Tourism management 26, 595-603.

Meade, J.E.; Stone, R. (1941). The construction of tables of national income, expenditure, savings and investment. Economic Journal, 51, pp. 216-233.

Polo, C.; Valle, E. (2002). Un análisis input-output de la economía balear. Estadística Española, vol. 44, Núm.151, 2002, págs. 393 a 444.

Ramírez, J. M.; Ordaz, J. A.; Rueda-Cantuche, J. M. (2007). *Evaluating the economic and social impact of the great sport events at local level: the case of the Female tennis championship of the ITF in Seville in 2006*. Review of quantitative methods for economics and business. Pages 20-39.

Velázquez, E. (2006). An input–output model of water consumption: Analysing intersectoral water relationships in Andalusia. Ecological Economics, 56, 226-240.

Chapter 4

Testing European energy goals: A disaggregated computable general equilibrium model for Spain

4.1. Motivation

In this chapter, we address some of the issues identified for the sector previously (low level of competition, low inter-connection with Europe, isolation, ….) and we simulate some scenarios of change on the basis of a computable general equilibrium (CGE) model, a methodology more than justified for these studies, since the capacity of these models to analyze a range of issues regarding the energy sector has been widely demonstrated in the literature. For instance, Devarajan (1988) used computable general equilibrium models to study natural resources in developing countries. Devarajan & Hossain (1998) found that the fiscal structure in the Philippines is progressive. Gooroochurn & Milner (2005) investigated, through a computable general equilibrium model, the effects of changing taxes on tourism in Mauritius, finding that the tourism sectors were then undertaxed. Kumbaroğlu (2003) analyzed the economic effects of environmental taxation, making use of an energy–economy–environment computable general equilibrium model for Turkey. Yilmaz (1999) studied export taxes for the global cocoa market.

In this chapter, we present a preliminary CGE model applied to the Spanish economy, in which the production function is a nesting function, taking into account the current splitting of the electricity activities. We then calibrate the parameters of the model using the IOT obtained in Chapter 3, for the Spanish economy for 2013, in which the electricity sector is disaggregated into its component activities. The nesting structure of the CGE model, taking into account all the activities of the electricity sector, is an important result by itself because, to the best of our knowledge, this is the first study with CGE models in which the electricity sector is disaggregated into Generation, Transmission, Distribution, Commercialization and Related activities for the Spanish economy.

In what follows, we show our analysis, whose main content has been presented at the XIII Congress of the Spanish association for the energy economy and in the 26th International Input-Output Conference. In section 4.2, we show our current background and the scenarios proposed for analysis. In section 4.3, we show the CGE model developed in this chapter in the context of the current literature in terms of energy in CGE models. In section 4.4, we comment on the data used for the calibration. In section 4.5, we analyze three alternative scenarios: a higher level of connection to international electricity grids, a greater use of renewable electricity, and an increase in energy efficiency. In section 4.6, we discuss our final conclusions.

4.2. Background and scenarios

4.2.1. Background

A current concern in society is the design of a sustainable development strategy, in which different energy sources play an important role. There also exists a general interest in balancing economic and environmental sustainability. In terms of environmental sustainability, renewable energy sources are becoming critical as society attempts to address the problem of global warming/climate change. Nevertheless, global energy demand continues to grow. In Europe, electricity consumption has increased since 1980, except for the period of the economic crisis (from 2008 to 2011), with the industrial sector consuming approximately 40% of the electricity produced in Europe.

External energy dependence in Spain is greater than the average for the European Union. The level of self-supply of primary energy (relationship between domestic production and total energy consumption) was approximately 30% in 2013, which implies that, in Spain, around 70% of the primary energy consumed is imported from other countries, according to the data of World Bank (World Bank, 2016). Although Spanish external energy dependence is high, in terms of electricity, Spain is not so dependent. According to (MINETUR, 2015), electricity demand in Spain was 228,837 GWh in 2015, compared with electricity production of 280,481 GWh; in this year, Spain was a net exporter of electricity.

However, the Spanish electricity system presents certain problematic characteristics, such as limited competition among firms in the sector, the existence of the tariff deficit[13], and recent legal reforms and associated price increases that have led

[13] The tariff deficit is a debt that the Spanish Government has with the electricity companies, and which first arose in 1997 as a consequence of intense lobbying by the electricity industry. The Spanish Government established by law a number of regulated activities for which the power utilities receive income (which suppose a cost for the Spanish Government) as compensation for the regulated costs that the companies are supposed to have. The tariff deficit is the difference between the regulated income received by the Government (which comes, mainly, from the access tariffs paid by consumers) and the regulated costs (which are paid to the companies). In 1997, the income received by the electricity companies increased and the Government at the time was keen to freeze the rising energy costs paid by consumers, thus giving rise to the tariff deficit.

to legal and production uncertainties (Langarita *et al.*, 2017). With the objective of introducing competition among electricity utilities, in 1997, the generation, transmission, distribution and marketing activities of the electricity sector were decoupled in Spain; the same company is not able to engage in more than one of these businesses (see BOE, 1997)[14].

Electricity, as well as the different character of the trade in this market, presents other differentiating characteristics, in comparison with other commodities and industries. Currently, there are only limited possibilities to store the stock, so, in order to cover the demand, electricity needs to be generated at the very same time as demand appears. Demand and prices have a cyclic nature, in terms of diurnal, seasonal, and annual cycles, which increases the generation challenge. The transmission network also has several limitations; for example, the possibility of network congestion; and its public good characteristics must be taken into account. Attention needs to be paid to system stability, reliability, and the security of supply.

In the case of the EU, it is important to consider the challenge of market coupling and coordination among countries, as well as the influence of support schemes for renewable energy sources for electricity (RES-E).

In terms of these challenges, the European Commission has stated several future objectives, as part of its strategy of sustainable growth in countries, in line with other international commitments (for instance, the Paris Agreements, 2015, see United Nations, 2016). These objectives represent important challenges for the Spanish electricity system and will potentially affect directly- and indirectly-related sectors of the Spanish economy. The aim of this chapter is to approximate to the potential economy-wide and environmental effects of following the line suggested by the EU strategies. More specifically, we evaluate the effects of three (following) scenarios of change.

One of the weaknesses of the Spanish electricity sector is its limited connection with Europe, mainly due to its geographical position, which helps perpetuate the low

[14] A similar measure is also considered in the European Third Energy Package, which came into law on 3rd March 2011, and whose main objective was to harmonize the European internal energy market. With this, transmission activity is supposed be separated from the rest. The first legislative package for electricity was enacted in 1996 and the second in 2003, see de Hauteclocque and Rious (2011).

level of internal competition among firms. Thus, our first scenario of analysis, as we will explain in more detail in section 4.2.2, deals with increasing the integration with the European network by increasing electricity exports. Taking into account environmental sustainability, our second scenario aims to evaluate the effects of increasing the use of renewable energy sources, while decreasing the use of brown energy sources. Our third scenario aims to evaluate the effects of a general increase in energy efficiency, through a reduction in costs as a first approach.

This work makes use of a computable general equilibrium model to formulate and evaluate the macro- and micro-economic effects of the three different scenarios proposed. The model developed has 72 productive sectors, eleven of which are energy sectors, with nine of them being electricity sectors, two consumer factors, and two productive factors. According to the current structure of the sector, Electricity is divided into generation (from wind, nuclear, conventional thermal, other types and solar, and hydropower sources), transmission, distribution, commercialization, and related activities[15], with this disaggregation being one of the main contributions of the chapter. The model is calibrated on a previously- developed input-output table with this detailed disaggregation for Spain for 2013 (see Duarte et al., 2017).

Because of the heterogeneity of the electricity subsectors, in our preliminary results we can see quite different economic effects in these subsectors. We observe increases in final production with especially high increases in final production of electricity, in the three scenarios evaluated. Moreover, we also find environmental improvements in the second scenario. The results also suggest potential increases in consumption in the first and third scenarios.

4.2.2. Current situation and scenarios

In what follows, we describe in detail the current situation of the Spanish electricity sector and the scenarios proposed to be analyzed. In order to better isolate the pure effects of the proposed measures, we assume in all scenarios that these measures do not have additional costs for consumers or companies.

Scenario 1: Increasing Integration with the European Electricity Network

[15] "Related activities" covers those activities that are accounted for by the electricity firms but which are not actually part of the production process of electricity, such as rent of windmills or hydropower plants.

In Table 4. 1 the Spanish international trade in electricity is presented over the period from 2010 to 2016. Between 2010 and 2015, Spain was a net exporter of electric energy, thanks to transactions with Portugal and Morocco. However, in 2016, Spain was a net importer of electricity, especially because of the decrease in exports to Portugal. The main international imports come from France and Portugal; there is a tendency of imports from these two countries to increase until 2015. In the case of France, imports grew from 1,983 GWh in 2010 to 9,131 GWh in 2015. However, in 2016 the imports from France were 3,115 GWh.

Table 4. 1. International interchanges of physical electricity (GWh)

		2010	2011	2012	2013	2014	2015	2016
Imports	Andorra	0	0	0	0	0	0	0
	France	1,983	3,987	4,911	4,879	5,963	9,131	3,115
	Portugal	3,189	3,930	2,871	5,323	6,345	5,811	4,192
	Morocco	34	16	5	1	3	14	1
	Total	5,206	7,932	7,786	10,204	12,310	14,956	7,309
Exports	Andorra	264	306	286	287	235	264	97
	France	3,514	2,463	3,028	3,171	2,395	1,807	2,431
	Portugal	5,823	6,744	10,768	8,100	7,247	8,077	1,162
	Morocco	3,937	4,510	4,904	5,377	5,839	4,941	1,744
	Total	13,539	14,023	18,986	16,936	15,716	15,089	5,434
Net exports	Andorra	264	306	286	287	235	264	97
	France	1531	-1524	-1883	-1708	-3568	-7324	-684
	Portugal	2634	2814	7897	2777	902	2266	-3030
	Morocco	3903	4494	4899	5376	5836	4927	1743
	Total	8333	6091	11200	6732	3406	133	-1875
Total electricity generation in Spain		288,483	279,934	283,381	273,767	258,131	263,283	265,009
(Imports+Exports)/ Generation		6.50%	7.84%	9.45%	9.91%	10.86%	11.41%	4.81%
Imports/Generation		1.80%	2.83%	2.75%	3.73%	4.77%	5.68%	2.76%
Exports/Generation		4.69%	5.01%	6.70%	6.19%	6.09%	5.73%	2.05%

* Own work based on REE (2017).

In contrast, the main exports go to Portugal and Morocco, although there are some exports to France and to Andorra, although the latter are very low in all years (less than 300 GWh). Exports to Portugal in 2010 were 5,823 GWh and, in 2015, 8,077 GWh, although they decreased again in 2016.

Calculating the degree of trade openness as the sum of imports and exports of electricity, divided by the total electricity generated in Spain, we observe an increasing trend in this ratio until 2015, with a ratio of 11.41%, decreasing strongly in 2016 to 4.81%.

The energy authorities in the European Union stated a minimum interconnection target of 10% by 2020 and 15% by 2030 (*Energy Union Framework Strategy*, European Commission, 25 February 2015, see COM, 2015), so in the first scenario, we evaluate what would be the effects on the Spanish economy of a greater electricity integration between Spain and the European electricity grids. Trieb *et al.* (2012) note that, under certain conditions, from a technical point of view, it would be possible to import some electricity into Europe from the Middle East and North Africa. One indicator of this is the UK-France exchange that has been in existence for many decades thanks to a connection under the English Channel, the High Voltage Direct Current (HVDC) Interconnector[16]. In addition, in Spain, there is an excess of installed capacity of electricity, so there exists potential capacity to export.

We model the change (increase) in total electricity exports and evaluate the effects of this change across economic sectors. In line with the targets proposed by European Commission (see COM, 2015) for 2020, we assume that exports move from the current share (4.81%) to 10%, which is an increase of almost 100%.

Scenario 2: Increasing Use of Renewable Energy Sources for electricity

According to REE (2016), renewable energy sources for electricity (Solar thermal, Wind, Solar photovoltaic, Renewable thermal and others, and Hydropower) supplied to the national electricity mix in 2015 approximately 37% of kilowatt hours (kWh), while gas, coal, and nuclear supplied approximately 42% (fuel and gas 2%, coal 20% and nuclear 20%), while combined cycle supplied 11% and cogeneration around 10%.

According to EEA (2013), although the share of renewables for electricity in 2011 was 31.5%, the share of renewables over the total energy consumption (taking into account the total energy, not just electricity) was 14.3% in 2012 (see EEA, 2018). The share of renewables over total energy in the input-output table for 2013 used is around 12%.

[16] According to its official webpage, http://www.channelcable.co.uk/, the HVDC Interconnector is 130 kilometers long and is situated 90 meters beneath the English Channel. Its purpose is to improve the security of supply on both sides of the water, and to improve the use of existing generation resources.

According to the Official Journal of the European Union (2009), the target set by the European Commission for the share of renewables in Spain's final energy consumption (taking into account the total energy, not just electricity) by 2020 is set to be 20% (20.8% is the objective set at the national level) and 27% by 2030 (see Martínez et al., 2017, and González Ruiz and Descalzo Benito, 2017). This is stated in the Directive 2009/28/EC in the Official Journal of the European Union (see Official Journal of the European Union, 2009).

In the second scenario, we test the impact of changes on electricity production from traditional or non-renewable sources to green or renewables. Sáenz de Miera *et al.* (2008), in a study of wind energy in Spain, suggest that the three objectives of the EU (renewable energy sources for electricity (RES-E) deployment, CO_2 emissions reductions, and moderate consumer prices) can be achieved simultaneously through an ambitious RES-E promotion policy. They also find that RES-E support is not as burdensome for the final electricity consumer as is usually assumed. Del Río and Unruh (2007) evaluate the causal factors behind the deployment of renewable energy technologies in the Spanish context, concluding that economic and institutional factors play decisive roles in fostering or inhibiting diffusion. Taking into account the potential viability of these options, we plan here to increase the use of renewable energy sources, specifically, wind and hydropower. In this scenario, it is especially interesting to evaluate the environmental effects of this measure.

More specifically, we simulate a reduction in brown electricity demand (here represented by Generation of electricity from conventional thermal) and increasing green electricity demand (with the disaggregation of the input-output table used in this chapter, it would be possible with wind and hydropower).

We assume an increase up to 20% of the demand for generation of electricity from wind (24)[17] and generation of hydropower (28) and a balanced reduction of the demand for electricity from conventional sources.

Scenario 3: Increasing the Competitiveness of the Electricity Sector

The objective in this scenario is to evaluate a general strategy to increase the competitiveness of the sector. Specifically, this scenario simulates an increase in the

[17] From here, the numbers in brackets represent the position of the sector in Table 4. 2.

energy efficiency and productivity of electricity sectors, which could be implemented by reducing inputs and costs in the production function. This could be achieved even if the size of the firms does not increase, since Marins Machado et al. (2016) find that small firms could be even more efficient that the large ones.

The 2012 Energy Efficiency Directive (Official Journal of the European Union, 2012) establishes a set of measures to help the EU reach its 20% energy efficiency target by 2020. Under the Directive, all EU countries are required to use energy more efficiently at all stages of the supply chain, from production to final consumption. This Directive was later modified on 30 November, 2012, to include a new 30% energy efficiency target for 2030. (For more information about the targets and projections for 2020, see EEA 2013, and for the targets by 2030 see EEA 2017).

The scenario proposed primarily affects the production side. More specifically, we simulate this change by reducing the a_{ij} coefficients in the **A** matrix for the sectors we want to improve in efficiency. In our case, these sectors are electricity generation subsectors.

We approximate to the objective of the European Commission for increasing the competitiveness of the electricity sector by improving energy efficiency by 20% by 2020 (see European Commission, 2017) and by 27-30% by 2030, simulating a reduction in electricity costs by 20%.

4.3. Model Development

4.3.1. Energy in CGE Models

The role of energy in CGE models has been addressed from many different perspectives. Jensen and Tarr (2003) explore the effects of energy tariffs in Iran; Manzoor *et al.* (2012) explore energy prices; the impacts of energy price liberalization in Turkey have been analyzed by Akkemik and Oğuz (2011). Devarajan, 1988; Devarajan & Hossain, 1998; Gooroochurn & Milner, 2005; Kumbaroğlu, 2003, and Yilmaz, 1999 are other applications of CGE models to the analysis of the energy sector.

One critical concern is the way the energy sector is embedded in the CGE model. Most analysts opt for a nested energy production function. Babiker *et al.* (1997) develop an energy composite that is produced from different energy sources, distinguishing between electric and coal, and between oil and gas. This approach is very similar to the one used in Bourne *et al*. (2015). Rutherford and Paltsev (2000) develop a model in which the energy composite is a combination of electricity and non-electric energy, and the latter is a combination of coal and a composite oil-gas.

In terms of the concerns of this paper, Wing (2006, 2008) develops a hybrid CGE model in which the electricity sector is a composite of three activities: generation of energy, transmission and distribution (together as only one activity), and overhead (certain administrative costs). It is modeled by production functions that combine inputs of primary factors and non-energy intermediate materials. Generation encompasses a number of discrete generation technologies, each of which can be modeled as a production function that combines inputs of labor, capital, and fuel to produce electricity (see Wing, 2006, 2008).

Another concern is the choice between a bottom-up or top-down approach. “Bottom-up” energy models show the technology in an explicit way, based on microeconomic theory and, in some cases, specifying the energy requirements for determining energy consumption. In contrast, “top-down” economic models present a view of the whole economy, but with simplified technological options; they reflect a more macroeconomic perspective. Of course, there are hybrid models that combine these two approaches, such as Rutherford and Montgomery (1997), Böhringer (1998), and Böhringer and Rutherford (2008). Since we will distinguish in our model several technologies and activities of the electricity sector, and we will also plan a view of the whole economy, we could classify our model as hybrid. Wing (2006, 2008) also makes use of a disaggregated framework, with an important effort to reflect the heterogeneity of the activities, and making explicit the “administration costs”.

Since the different activities of the electricity sector are currently decoupled, one of the contributions of this paper is the separation in a CGE model of all electricity activities: generation, transmission, distribution and commercialization, and related activities while, at the same time, a distinction is made between various generation technologies.

Energy-related policies have also been explored within a CGE framework. Dai *et al.*, (2011) analyze the effects and impacts of policies designed to achieve China’s Copenhagen commitments. Their hybrid static CGE model features the electricity sector disaggregated into 12 generation technologies. However, they do not distinguish among the different activities of the production process of electricity (generation, transmission, distribution and commercialization, and the activities that we have named "Related activities")**,** a characteristic of most energy-related CGE applications.

4.3.2. Features of the model

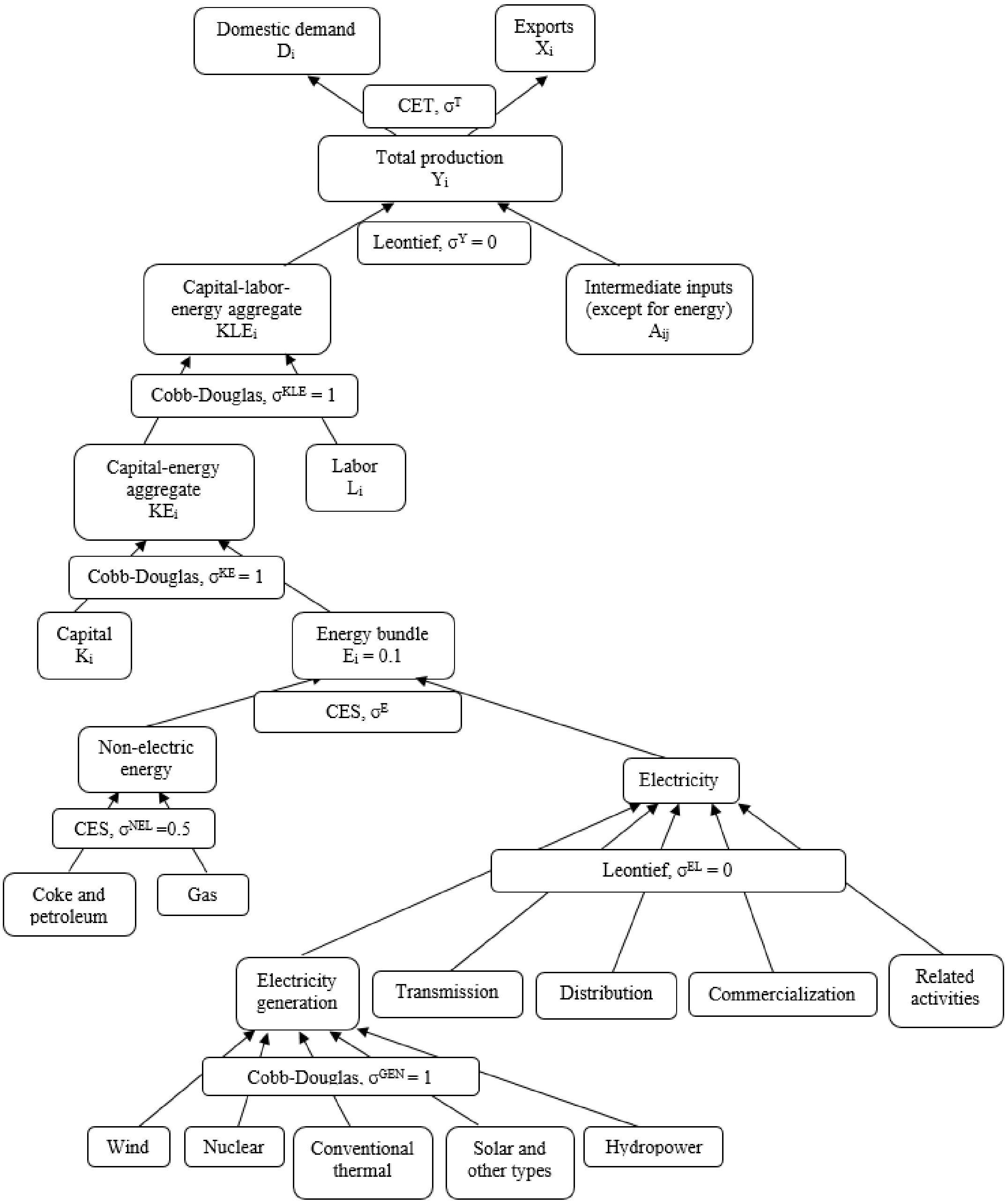
The proposed model adopts the following classical features of CGE models. Final output of each sector i (Y_i) is produced through a combination of capital (K_i), labor (L_i), energy (E_i) and intermediate inputs (A_{ji}). Following Armington (1969), these intermediate inputs (A_{ji}), or intermediate demands, are represented as a composite of domestic goods (D_i) and imports (M_i) used in the production process of sector i. The final output (Y_i) is allocated for domestic goods (D_i) and exports (X_i).

In this model, there are two agents that consume the goods produced in the productive process: the household or representative agent, and the government. We also present the external sector and investment. Spain's economy is considered too small to influence world prices, which are fixed. So, we consider that Spain is a price taker. The exchange rate is also fixed, assuming the role of *numeraire.*

4.3.2.1. Production

In this model there are 72 sectors, 11 of which are energy sectors: Manufacture of coke and refined petroleum, Gas, and nine electricity sectors. There are two productive factors, labor and capital that, following Dai *et al*. (2011), are both fully employed. The productive process is carried out through the adoption of a nested production function, as shown in Figure 4. 1.

Figure 4. 1. Static model structure of the current situation in Spain



Source: own work.

Following Sancho (2010) and Cansino *et al*. (2014), the final output Y (shown on the top of the nested production function shown in figure 1), is produced by a combination of intermediate inputs (except for energy) and the aggregate capital-labor-energy (*KLE*), using a Leontief production function, implying that the elasticity of substitution between these aggregate inputs is 0.

This production is intended for domestic consumption goods and exports through a constant elasticity of transformation (CET) function and, for the sectors that do not export, production is only used for domestic use.

One issue raised in the literature is how to combine capital, labor, and energy to produce the capital-labor-energy composite. In this model, following the literature, the capital-labor-energy (*KLE*) aggregate is a combination of the capital-energy (*KE*) aggregate and the labor (*L*) factor, through a Cobb-Douglas production function (elasticity of substitution between inputs is equal to 1, following the literature). The capital-energy aggregate is accomplished through the combination of the capital factor (*K*) and an energy bundle (*E*).

In the energy bundle, electricity production is identified and then the production of non-electric energy. At the same time, within the electricity production, the various activities of the electricity sector are separated: generation, transmission, distribution, commercialization, and related activities. These activities produce the electricity bundle through a Leontief production function[18]. In addition, the generation activities among different production technologies are distinguished: electricity from wind, electricity from nuclear, electricity from conventional thermal, electricity from other types, and hydropower. These types of generation combine through a Cobb-Douglas function to obtain the generation bundle. The non-electric energy is produced by the combination of coke and refined petroleum and gas through a CES function. The selection of one function or another is based on results in the literature.

4.3.2.2. Consumers

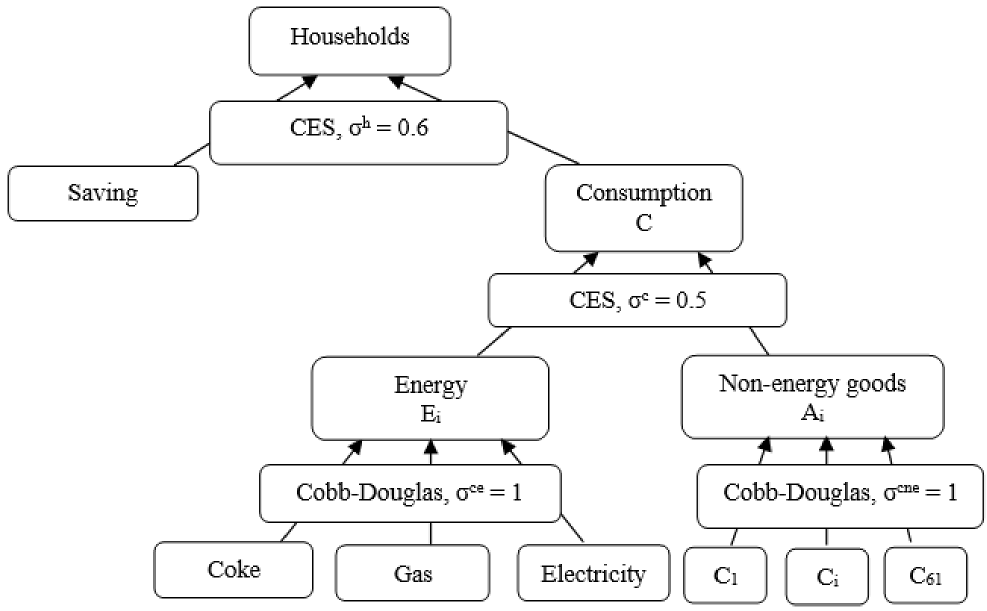
Representative agent

In this model, there is a representative agent, who assumes a collective decision on consumption (*C*). This representative agent obtains income from the selling of the initial endowments of labor (*L*) and capital (*K*). In this context, the representative agent maximizes the total utility, subject to the budgetary constraint, and he also saves and pays taxes. The representative agent also receives transfers from the Government and from the external sector.

[18] As this structure is new, there is no information about this elasticity of substitution in the literature. Being conservative, we assume elasticity among the several activities of the electricity sector is 0.

Thus, households must decide, as can be seen in Figure 4. 2, on consumption and saving. The elasticity of substitution between saving and consumption is 0.6 (σ^h = 0.6) (see Sarasa and Sánchez, 2014).

Figure 4. 2. Consumption nesting structure



Source: Adaptation from Sarasa and Sánchez (2014) and Rutherford and Paltsev (2000).

C is an aggregate of a combination of energy and non-energy goods through using a CES utility function. Based on Rutherford and Paltsev (2000), it is assumed that the substitution elasticity between energy and non-energy goods is 0.5. The 61 non-energy sectors combine through a Cobb-Douglas function. In the energy sector, we distinguish between Manufacture of coke and refined petroleum (*Coke* in Figure 4. 2), Production, distribution and commercialization of gas (*Gas* in Figure 4. 2), and electricity. In so doing, a distinction is made between energy for transportation (coke and refined petroleum), energy for home (gas) and electricity (electric energy for home). Note that, at present, in the electricity aggregate there is no distinction in the consumption function between different production technologies, because, although consumers are increasingly concerned about the environment, and the preference for renewable energies is becoming more important, consumers cannot distinguish the origin of electricity when consumed in their homes.

<u>*Government*</u>

The second agent to consume goods is the government. In this model, the government is responsible for collecting taxes, *T*, and consuming goods. Total public expenditure is modelled through a fixed coefficients structure. Government transfers revenue to the representative agent, and also saves. Government income comes from several taxes: social contributions by employers, net taxes on products, other net taxes on production, social contributions by employees, and income tax from individuals (IRPF in its Spanish acronym).

4.3.2.3. Foreign sector

The external sector demands exports and is endowed with imports. As described in the features of the model, Spain's economy is considered too small to influence world prices, so they are fixed. Thus, we consider that Spain is a price taker, assuming that the exchange rate is fixed, becoming the *numeraire* of the model.

4.3.2.4. Savings and investment

Investment, *I*, is an aggregate coming from the investment function, which combines, through a Leontief function, the investment of the 72 sectors of this economy. The savings-investment account closes the model with the allocation of savings to sectoral investment. In an open economy, the difference between savings and investment must be equal to the difference in payments to the foreign sector. Since the exchange rate is fixed, the trade balance is determined by it. Therefore, savings and investment are determined.

4.4. Data and calibration

For the benchmark equilibrium, the input-output table (IOT) for the Spanish economy for 2013, developed in Chapter 3, is used because the energy sector is properly disaggregated. The full list of sectors can be seen inTable 4. 2. This IOT has information for 72 industries (with special attention to sectors from 24 to 33, in which the disaggregation of the "Supply of electricity, gas, steam and air conditioning" sector is carried out and which, together with Manufacture of coke and refined petroleum (sector number 10 in the list), are all the energy subsectors), two productive factors (labor and capital), households, the savings/investment account, five types of taxes noted in section 4.3.2.2, government expenditure, and foreign trade.

Table 4. 2. List of sectors in the 2013 Spanish input-output table

	Accounts	CNAE code
1	Agriculture, livestock, hunting and related services	01
2	Forestry and logging	02
3	Fisheries and aquaculture	03
4	Extractive industries	05–09
5	Agrifood industry	10-12
6	Textile industry	13-15
7	Industry of wood and cork	16
8	Paper industry	17
9	Graphical arts and reproduction of recorded media	18
10	Manufacture of coke and refined petroleum	19
11	Chemicals	20
12	Manufacture of pharmaceutical basics and prepared pharmaceutical products	21
13	Manufacture of products of rubber and plastic	22
14	Manufacture of other non-metallic mineral products	23
15	Manufacture of products of iron, steel and ferroalloys	24
16	Manufacture of metallic products, except for machinery and equipment	25
17	Manufacture of computer products, electronic and optical products	26
18	Manufacture of material and electrical equipment	27
19	Manufacture of machinery and equipment n.c.o.p.	28
20	Manufacture of motor vehicles, trailers and semi-trailers	29
21	Manufacture of other transport equipment	30
22	Manufacture of furniture; other manufacturing	31-32
23	Repair and installation of machinery and equipment	33
24	Generation of electricity from wind	3518
25	Generation of electricity from nuclear	3517
26	Generation of electricity from conventional thermal	3516
27	Generation of electricity from solar and other sources	3519
28	Generation of hydropower	3515
29	Transmission of electricity	3512
30	Distribution of electricity	3513
31	Commercialization of electricity	3514
32	Related activities to the electricity sector	352
33	Gas, steam and air conditioning	3530
34	Collection, purification and distribution of water	36
35	Withdrawal and treatment of waste water and residues	37-39
36	Construction	41-43
37	Sale and repair of motor vehicles and motorcycles	45
38	Wholesale trade	46
39	Retail trade, except for motor vehicles and motorcycles	47
40	Overland transport and pipelines	49
41	Maritime transport and interior waterways	50
42	Air transport	51
43	Storage and attached activities to transport	52
44	Post and *courier* activities	53
45	Hosting, service of meals and drinks	55-56
46	Publishing	58
47	Activities of cinema, television and music	59-60
48	Telecommunications	61
49	Information, transmission and computer services	62-63
50	Financial services, except insurance and pension *funding*	64

51	Insurance, reinsurance and pension funding, except compulsory social security	65
52	Auxiliary activities to financial services and to insurances	66
53	Real estate activities	68
54	Juridical and consultation activities	69-70
55	Technical services of architecture and engineering; tests and technical analyses	71
56	Scientific research and development	72
57	Advertising and market research	73
58	Other professional, scientific and technical activities; veterinary activities	74-75
59	Rental activities	77
60	Activities related to employment	78
61	Activities related to tourism	79
62	Safety activities and investigation and auxiliary activities to companies	80-82
63	Public administration and defence	84
64	Education	85
65	Sanitary activities	86
66	Activities of social services	87-88
67	Activities of arts, entertainment and recreation	90-92
68	Sports activities and amusement and recreation activities	93
69	Activities of membership organizations	94
70	Computer repair, personal items and housewares	95
71	Other personal services	96
72	Activities of households as employers	97-98

Source: own work.

Another fundamental set of data for the calibration of the general equilibrium are the elasticities of substitution. First, the parameters of the elasticities of substitution, *constant elasticity of substitution* (CES), between the inputs of the functions for each of the nesting levels of the productive structure and for each sector, need to be estimated. The same is true for the parameters of the elasticity of transformation, *constant elasticity of transformation* (CET), between outputs, which are, in this case, domestic consumption goods and exports. Armington (elasticities of substitution between imports and domestic goods), transformation and demand elasticities are taken from Sarasa and Sánchez (2014) and Rutherford and Paltsev (2000).

In addition, the substitution elasticities between inputs for the production function in each nested level and for each sector are needed. We pay special attention to the electricity bundle, assuming that elasticity of substitution between generation, transmission, distribution, commercialization, and related activities is equal to 0 (Leontief function). We can see all the elasticities of substitution inTable 4. 3.

Table 4. 3. Elasticities of substitution

	Accounts	σ^A	σ^T
1	Agriculture, livestock, hunting and related services	2.3	3.9
2	Forestry and logging	2.3	3.9
3	Fisheries and aquaculture	2.3	3.9
4	Extractive industries	1.22	2.9
5-6	Agrifood industry - Textile industry	2.2	2.9
7-8	Industry of wood and cork - Paper industry	3.13	2.9
9	Graphical arts and reproduction of recorded media	2.2	2.9
10	Manufacture of coke and refined petroleum	5	2.9
11-12	Chemicals - Manufacture of pharmaceutical basics and prepared pharmaceutical products	1.31	2.9
13-15	Manufacture of products of rubber and plastic - Manufacture of products of iron, steel and ferroalloys	2.2	2.9
16	Manufacture of metallic products, except for machinery and equipment	1.01	2.9
17-18	Manufacture of computer products, electronic and optical products - Manufacture of material and electrical equipment	2.2	2.9
19-21	Manufacture of machinery and equipment n.c.o.p. - Manufacture of other transport equipment	2.8	2.9
22-23	Manufacture of furniture; other manufacturing - Repair and installation of machinery and equipment	2.2	2.9
24-33	Generation of electricity from wind - Gas, steam and air conditioning	2.8	2.9
34	*Collection, purification and distribution of water*	2.8	2.9
35	Withdrawal and treatment of waste water and residues	2.8	2.9
36	Construction	1.9	0.7
37	Sale and repair of motor vehicles and motorcycles	1.9	0.7
38	Wholesale trade	1.9	0.7
39	Retail trade, except for motor vehicles and motorcycles	1.9	0.7
40-72	Overland transport and pipelines - Activities of households as employers	1.9	0.7

Elasticities in the production function nesting levels	
Generation bundle	$\sigma^{GEN} = 1$
Non-electric energy	$\sigma^{NEL} = 0.5$
Electricity	$\sigma^{EL} = 0$
Energy bundle	$\sigma^{E} = 0.1$
Capital-energy aggregate	$\sigma^{KE} = 1$
Capital-labor-energy aggregate	$\sigma^{KLE} = 1$
Total production	$\sigma^{Y} = 0$
Elasticities at the consumption nesting levels	
Consumption	$\sigma^{s} = 0.5$
Energy	$\sigma^{e} = 1$
Non-energy sectors	$\sigma^{c} = 1$

σ^A: elasticity of substitution between imports and domestic production (Armington).

σ^T: elasticity of transformation between exports and domestic goods.

Source: adaptation from Sarasa and Sánchez (2014) and Rutherford and Paltsev (2000) except for σ^{EL}.

The model and its calibration are programmed in GAMS (see Brooke *et al.*, 1988). The programming language used is the *Mathematical Programming System for General Equilibrium Analysis* (MPSGE), developed in Rutherford (1999). The model is programmed as a *mixed complementarity problem* (MCP) and the algorithm used for its resolution is PATH, which solves MCP problems and was developed in the University of Wisconsin in Madison (see Dirkse and Ferris, 1995).

In order to see the effects on the emissions produced by each of the sectors, we use the emission vector obtained from INE (2017) and we disaggregate the emissions of sector “Supply of electricity, gas, steam and air conditioning”, sector of code 35 according to the national classification of economic activities (NACE Rev. 2), following the disaggregation needed in our paper, making use of EXIOBASE (2015).

According to the literature, the effect on environmental emissions in each of the scenarios proposed are calculated to include the six greenhouse gases listed in the Kyoto protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF_6). We transform all the gases to CO_2 equivalent to include this disaggregation in the vector of total emissions.

4.5. Simulations and results

According to the background and hypothesis in Section 4.2.2, we show in the following subsections the main results of the three scenarios, in terms of economic and environmental effects.

4.5.1. Increasing Integration with the European Network

Scenario 1 represents a greater integration of the Spanish electricity system with the European network. More specifically, we simulate the effects of an increase in the exports of the total electricity block. Although we only show the final results, the transmission mechanisms throughout the economy would be the following: in an aggregated way, the increase in exports, as part of the final demand, would lead to an increase in total production since the firms would have to increase their production to cover the goods demand excess. This increase in production would provoke an increase in the level of employment, which would increase the costs, and, thus, the prices. Indirectly, these exports would also provoke an increase in imports because of the rebound effect. In the case in which there are several sectors, the effect could change from one sector to another.

When we focus on the main results, shown in Table 4. 4, we can highlight the following results, focusing on the energy sector in general and on the electricity sector in particular.

Table 4. 4. Results of scenario 1 (percentage of change)

		Domestic price	Total production	Exports	Imports	CO_2 equivalent
3	Fisheries and aquaculture	0.12%	0.00%	-0.40%	0.32%	0.00%
4	Extractive industries	-0.02%	0.59%	0.62%	0.55%	0.59%
10	Manufacture of coke and refined petroleum	0.00%	0.43%	0.43%	0.42%	0.43%
11	Chemicals	-0.02%	0.18%	0.21%	0.14%	0.18%
14	Manufacture of other non-metallic mineral products	-0.19%	0.37%	0.77%	-0.22%	0.37%
15	Manufacture of iron, steel and ferroalloy products	-0.10%	0.16%	0.35%	-0.15%	0.16%
16	Manufacture of metallic products, except for machinery and equipment	0.01%	0.04%	0.03%	0.05%	0.04%
24	Generation of electricity from wind	-1.09%	1.06%	4.25%	-2.08%	2.25%
25	Generation of electricity from nuclear	0.18%	0.00%	0.00%	0.51%	0.00%
26	Generation of electricity from conventional thermal	-0.23%	0.40%	1.06%	-0.23%	0.41%
27	Generation of electricity from other sources	-3.31%	4.08%	14.07%	-5.85%	7.14%
28	Generation of hydropower	-1.07%	1.53%	4.73%	-1.50%	1.77%
29	Transmission of electricity	0.13%	1.27%	0.00%	1.64%	1.27%
30	Distribution of electricity	0.17%	1.10%	0.61%	1.57%	1.13%
31	Commercialization of electricity	-0.77%	1.37%	3.66%	-0.80%	1.50%
32	Related activities to the electricity sector	-1.86%	2.36%	7.89%	-3.03%	3.85%
33	Gas, steam and air conditioning	0.07%	0.60%	0.40%	0.80%	0.60%
36	Construction	0.07%	0.03%	-0.02%	0.16%	0.03%
40	Overland transport and pipelines	0.12%	0.06%	-0.01%	0.30%	0.06%
41	Maritime transport and interior waterways	0.19%	-0.04%	-0.12%	0.39%	-0.04%
42	Air transport	0.13%	0.00%	-0.06%	0.28%	0.00%
48	Telecommunications	0.12%	0.09%	0.01%	0.32%	0.09%
60	Activities related to employment	0.16%	0.20%	0.08%	0.50%	0.20%
62	Safety, investigation and ancillary activities	0.15%	0.03%	-0.06%	0.32%	0.03%
Global variables						
	Total of 72 sectors		0.15%	0.24%	0.24%	0.38%
	Total of electricity sectors		2.90%	119.06%	-3.71%	1.35%
	Consumption	0.2%				
	Labor remuneration	0.2%				
	Capital remuneration	0.2%				

Source: Own work.

When we focus on the price paid by the final consumer, we can see that the price of Manufacture of coke and refined petroleum (10) would remain almost constant. The prices paid for[19] Generation of electricity from wind (24), Generation of electricity from conventional thermal (26), Generation of electricity from other sources (27), Generation of hydropower (28), Commercialization of electricity (31), and the price of Related activities to the electricity sector (32) would all decrease.

However, the price paid by the final consumer for Generation of electricity from nuclear (25), Transmission of electricity (29), the price of Distribution of electricity (30), and the price of Gas, steam and air conditioning (33) would increase.

The final production of all of the energy and electricity sectors and subsectors would increase. The final production for all the electricity subsectors would increase by 2.90% and the final production for the whole economy would increase by 0.15%.

As expected, exports would increase for all the energy and electricity subsectors, leading to exports for the whole electricity sector increasing a little more than the initial shock: with an initial shock of 100%, total electricity exports would increase by 119.06%.

Imports, mainly due to the rebound effect, which is more intense in some of the sectors, would increase for Manufacture of coke and refined petroleum (10), Generation of electricity from nuclear (25), Transmission of electricity (29), Distribution of electricity (30) and Gas (33), and the total imports for the electricity sector would decrease by 3.71%.

Household consumption, the remuneration of labor and remuneration of capital would increase by 0.2%.

In Table 4. 4, we can also see specific results for industries notably affected by the changes. These industries are important because of their high capacity as providers of inputs or consumers of the electricity subsectors.

Final production would increase for all sectors, except for Maritime transport and interior waterways (41). Exports and imports would increase and decrease, respectively, for some of the sectors highly related to electricity.

---

[19] Numbers in brackets represents the position of the sector in the list, seeTable 4. 2.

We can see the effects on CO_2 emissions in Table 4. 4. As expected, since production is increasing, CO_2 emissions for the energy and electricity subsectors would increase somewhat, and the same applies to the sectors highly related to electricity, except for Maritime transport and interior waterways (41).

Since the initial shock on exports provokes a change on imports, we show in Table 4. 5 the final net gains/losses in terms of imports and exports of electricity (we only show the energy sectors).

Table 4. 5. Results of scenario 1: Balance between imports and exports after increasing the trade (Millions of Euros)

		Exports	Imports	Balance (Exports – Imports)
10	Manufacture of coke and refined petroleum	21,869	14,361	7,508
24	Generation of electricity from wind	49	37	12
25	Generation of electricity from nuclear	0	4	-4
26	Generation of electricity from conventional thermal	2	9	-7
27	Generation of electricity from other sources	578	185	394
28	Generation of hydropower	45	52	-7
29	Transmission of electricity	0	6	-6
30	Distribution of electricity	2	1	1
31	Commercialization of electricity	52	10	43
32	Related activities to the electricity sector	1,002	187	814
33	Gas, steam and air conditioning	19	0	19
	Total electricity (24 to 32)	1,730	490	1,240

Source: Own work.

We note that generation of electricity from nuclear (25), generation of electricity from conventional thermal (26), generation of hydropower (28), and transmission of electricity (29) would have a negative trade balance; that is, their imports are higher than their exports. However, even taking into account only the electricity subsectors, the positive balance of generation of electricity from wind (24), generation of electricity from other sources (27), distribution of electricity (30), commercialization of electricity (31) and, especially, Related activities to the electricity sector (32), makes the total balance for electricity positive.

4.5.2. Increasing Use of Renewable Energy Sources

The second scenario, the increase of the use of renewable energy sources is designed as a change from brown to green technologies, as explained in Section 4.2.

In Table 4. 6, we can see the results of the changes of 66% (the necessary percentage to obtain a share of renewables of 20% in the mix) from brown to green technologies on the prices and variables by sector (we only show the energy industries and the industries highly related to them).

Table 4. 6. Results of scenario 2: Effects of increasing green energy sources (percentage of change)

		Pd	y	x	im	CO_2 emissions
3	Fisheries and aquaculture	0.02%	-0.01%	-0.07%	0.03%	-0.01%
4	Extractive industries	0.01%	0.01%	-0.01%	0.04%	0.01%
10	Manufacture of coke and refined petroleum	0.00%	0.01%	0.01%	0.03%	-0.02%
11	Chemicals	0.01%	-0.02%	-0.03%	0.00%	-0.04%
14	Manufacture of other non-metallic mineral products	-0.01%	0.00%	0.01%	-0.01%	-0.02%
15	Manufacture of iron, steel and ferroalloy products	0.00%	-0.04%	-0.04%	-0.03%	-0.02%
16	Manufacture of metallic products, except for machinery and equipment	0.01%	-0.03%	-0.04%	-0.02%	-0.01%
24	Generation of electricity from wind	-40.52%	5.32%	359.22%	-76.23%	0.01%
25	Generation of electricity from nuclear	-78.97%	0.44%	0.00%	-98.72%	-0.02%
26	Generation of electricity from conventional thermal	55.10%	-0.42%	-72.11%	240.37%	-0.04%
27	Generation of electricity from other sources	0.00%	-0.05%	-0.06%	-0.05%	-0.05%
28	Generation of hydropower	-40.20%	1.29%	346.88%	-76.16%	0.00%
29	Transmission of electricity	0.03%	0.06%	0.00%	0.14%	-0.04%
30	Distribution of electricity	0.03%	0.05%	-0.05%	0.15%	-0.03%
31	Commercialization of electricity	-0.03%	0.07%	0.15%	-0.01%	-0.04%
32	Related activities to the electricity sector	0.00%	0.24%	0.25%	0.24%	-0.05%
33	Gas, steam and air conditioning	0.01%	0.30%	0.27%	0.34%	-0.04%
36	Construction	0.01%	0.00%	-0.01%	0.02%	-0.09%
40	Overland transport and pipelines	0.02%	0.00%	-0.01%	0.03%	-0.06%
41	Maritime transport and interior waterways	0.03%	-0.02%	-0.03%	0.04%	-0.02%
42	Air transport	0.01%	-0.01%	-0.02%	0.02%	0.00%
48	Telecommunications	0.02%	-0.01%	-0.02%	0.03%	73.42%
60	Activities related to employment	0.00%	-0.02%	-0.02%	-0.01%	377.82%
62	Safety, investigation and ancillary activities	0.01%	-0.01%	-0.01%	0.00%	-35.79%
Global variables						
	Total of 72 sectors		0.3890%	-0.0005%	-0.0005%	-7.03%
	Total of electricity sectors		9.70%	20.18%	1063.15%	-30.71%
	Consumption	0%				
	Labor remuneration	0%				
	Capital remuneration	0%				

Source: Own work.

In the case of the prices paid by the final consumer, the results are mixed. As can be seen, the price paid by the final consumer for Manufacture of coke and refined petroleum (10), Conventional thermal (26), Other types (27), Transmission (29), Distribution (30), and Gas (33) would increase. The price paid for Generation of electricity from wind (24), Generation from nuclear (25), Hydropower (28), and Commercialization of electricity (31) would decrease. The price of Related activities (32) would remain constant.

The final production would increase for Manufacture of coke and refined petroleum (10), Generation of electricity from wind (24), Generation from nuclear (25), Generation of hydropower (28), Transmission (29), Distribution (30), Commercialization of electricity (31), Related activities (32), and Gas (33). Final production of Conventional thermal (26) and Other types (27) would decrease.

Exports and imports would also offer mixed results, depending on the affected sectors. In the aggregate, the final production for the whole economy would increase by 0.38%, and, for the total electricity sector, final production would increase by 9.70%.

For the case of CO_2 emissions, some technologies would increase and some others would decrease their CO_2 emissions, making the total emitted by the electricity sector decrease by 30.71% and the total emissions of the whole Spanish economy decrease by 7.03%.

4.5.3. Increasing the Competitiveness and Energy Efficiency in Electricity Sectors

Assuming that a combination of incentives, changing regulations, and proactive policies is carried out, in the end, competitiveness could be increased. Taking this into account, the results could be as shown in Table 4. 7.

Table 4. 7. Results of scenario 3: Variation by sectors after a reduction of the inputs consumed by electricity generation subsectors (percentage of change)

		Domestic price	Total production	Exports	Imports	CO_2 emissions
3	Fisheries and aquaculture	0.37%	0.15%	-1.12%	1.19%	0.15%
4	Extractive industries	-0.40%	2.03%	2.65%	0.98%	2.03%
10	Manufacture of coke and refined petroleum	-0.07%	0.46%	0.60%	0.07%	0.46%
11	Chemicals	-0.30%	1.29%	1.88%	0.59%	1.29%
14	Manufacture of other non-metallic mineral products	-1.17%	2.27%	4.72%	-1.37%	2.26%
15	Manufacture of iron, steel and ferroalloy products	-0.68%	1.95%	3.32%	-0.24%	1.95%
16	Manufacture of metallic products, except for machinery and equipment	-0.20%	0.67%	1.10%	0.31%	0.67%
24	Generation of electricity from wind	-1.34%	-3.03%	0.80%	-6.68%	-3.03%
25	Generation of electricity from nuclear	-0.60%	-5.30%	0.00%	-6.90%	-5.30%
26	Generation of electricity from conventional thermal	-14.79%	9.18%	73.63%	-30.25%	9.18%
27	Generation of electricity from other sources	-12.76%	9.47%	60.17%	-26.44%	9.35%
28	Generation of hydropower	-17.75%	17.06%	105.88%	-32.41%	17.03%
29	Transmission of electricity	0.49%	5.92%	0.00%	7.37%	5.92%
30	Distribution of electricity	0.76%	5.08%	2.79%	7.33%	5.08%
31	Commercialization of electricity	-2.60%	6.06%	14.46%	-1.49%	6.06%
32	Related activities to the electricity sector	-1.03%	3.43%	6.53%	0.44%	3.43%
33	Gas, steam and air conditioning	0.24%	-2.54%	-3.20%	-1.88%	-2.54%
36	Construction	0.16%	0.06%	-0.05%	0.38%	0.06%
40	Overland transport and pipelines	0.38%	0.30%	0.07%	1.06%	0.30%
41	Maritime transport and interior waterways	0.65%	0.01%	-0.23%	1.47%	0.01%
42	Air transport	0.40%	0.11%	-0.07%	0.98%	0.11%
48	Telecommunications	0.40%	0.06%	-0.20%	0.83%	0.06%
60	Activities related to employment	0.62%	-0.31%	-0.74%	0.86%	-0.31%
62	Safety, investigation and ancillary activities	0.53%	-0.06%	-0.40%	0.98%	-0.06%
Global variables						
	Total of 72 sectors		0.56%	0.66%	0.67%	2.58%
	Total of electricity sectors		6.47%	26.62%	-14.40%	9.20%
	Consumption	0.7%				
	Labor remuneration	0.7%				
	Capital remuneration	0.8%				

Source: Own work.

We see increases in the prices paid for Transmission (29), Distribution (30), and Gas (33), while the rest of the energy subsectors decrease their prices. Moreover, as a result of the proposed changes, increases in final production for Manufacture of coke and refined petroleum (10), Generation of electricity from conventional thermal (26), Generation of electricity from other types (27), Generation of hydropower (28), Transmission of electricity (29), Distribution of electricity (30), Commercialization of electricity (31), and Related activities to the electricity sector (32) can be observed. Only the final production of Generation of electricity from wind (24), Generation of electricity from nuclear (25), and Gas (33) would decrease their final production. When we take into account the whole economy, total production would increase by 0.56% and the final production for the whole electricity sector would increase by 6.47%.

Exports, by sector, would increase for all the electricity subsectors and for coke and petroleum and would decrease for gas; for all Spanish electricity sectors, exports would increase by 26.62% and for the whole Spanish economy by 0.66%. Imports would decrease for the electricity subsectors, except for transmission, distribution and related activities; for the electricity sector in total they would decrease by 14.40% and for the whole Spanish economy they would increase by 0.67%.

The electricity subsectors would somewhat increase their emissions to the atmosphere, except for wind and nuclear, so that, in total, emissions from all electricity sectors would increase by 9.20% and by the total economy by 2.58%. In consequence, the scenario shows that general improvements in the economic efficiency of these sectors, should be accomplished with other technological and environmental policies aiming at the progressive reduction of CO_2 emissions. In this context, the environmental rebound effects should be seriously considered.

4.6. Remarks

The redesign of the European electricity market has come to the forefront of national and international concerns, in the context of a progressive transformation to a decarbonized system. The European electricity market faces several challenges, such as market coupling, and the implementation of common EU policies. In this context, the European Union has formulated several targets.

Taking into account this general framework and the specific characteristics of the Spanish electricity system, the objective of this paper is to analyze some scenarios of change, policies which would make it possible to improve some of the issues of the electricity sector in Spain: (1) Increasing Integration with the European Network, because of the current low level of external competition; (2) Increasing Use of Renewable Energy Sources; and, (3) Increasing the Competitiveness of the Spanish Electricity Sector; for which the EU has also given several targets.

To see the economic and environmental effects of these scenarios, we make use of a computable general equilibrium model, developing a preliminary CGE model applied to the Spanish economy for 2013, in which the production function is a nested function taking into account the current splitting of electricity activities. In our CGE model, the generation, transmission, distribution, commercialization and related activities of the electricity sector are separately represented (since we are interested in correctly depicting the current structure of this sector after the splitting of its activities) and several production technologies are represented. On the demand side, we also take into account the characteristics of the energy sector for its representation.

For the calibration of the model, we use an input-output table for the Spanish economy for 2013 in which the electricity sector is disaggregated into its activities and production technologies (see Chapter 3), as required for the detailed structure of the CGE model.

One important result of this chapter is the construction of the CGE model in itself, because it takes into account the details of the current structure and the interrelationships between the electricity sector and the rest of the economy, between the electricity sector and the external sector, and between the various activities within the energy sector. In addition, we have taken into account the substitutability between inputs in the production function, mainly focusing on the electricity and energy nesting levels. We have also taken into account the elasticities of substitution among goods on the demand side.

Our results suggest the existence of potentially positive effects for the Spanish economy as a whole of moving in the strategic directions proposed by the EU (namely increasing electricity trade with the rest of Europe, stated by COM (2015); increasing the use of renewables, established in Official Journal of the European Union (2009); and increasing electricity efficiency, specified by Official Journal of the European Union (2012)). More specifically, in the three scenarios analysed, we can observe increases in the final production of the economy with especially high increases in electricity production, along with important reductions in CO_2 emissions in the second scenario.

According to the targets of the European Union, and viewing the potentially positive effects of these measures, we should also encourage electricity trade with the rest of Europe, increasing of the share of renewables in the electricity mix, and increasing energy efficiency.

This approximation has certain limitations and is subject to several uncertainties which should be explored further. First, in this paper, elasticities of substitution have been taken from the literature, so the specific estimations of some of them for Spain, making use of econometric techniques, may improve the accuracy of the results obtained. Second, a natural extension of this paper is an analysis of the trade-offs between policies in the context of the long-run costs associated with the implementation of these measures, which could modify some of the estimated effects. Third, other options to simulate scenarios as changes in the relevant function parameters, could be compared, to evaluate the alternative scenarios, as well as the generation of paths to the future where several of the scenarios analyzed here are combined.

All in all, this approach shows the validity of the multisectorial and computable general equilibrium models to evaluate broad effects of policies and challenges, key for the future of the electricity sector in a European country like Spain, on all economic sectors. Given that some of the problems mentioned are shared by other European countries, and since it is possible to reproduce and adapt the methodology of analysis to other territorial contexts (regions of Spain, European countries, etc.), this work can be extended to evaluate regional and national policies. Specifically, one ambitious extension is the construction of a multiregional computable general equilibrium model with high disaggregation of electricity activities for Europe as a whole, in order to be able to simulate these and other targets stated by the EU for all European countries, and particularly the relationships and trade-offs among them.

4.7. References

Akkemik, K. A.; Oğuz, F. (2011). Regulation, efficiency and equilibrium: A general equilibrium analysis of liberalization in the Turkish electricity market. Energy, 36(5), 3282-3292.

Armington, P.S. (1969): A Theory of Products Distinguished by Place of Production. IMF Staff Papers, nº16, pp. 159-178.

Babiker, M.H.; Maskus, K.E.; Rutherford, T.F. (1997). Carbon Taxes and the Global Trading System. Seminar Paper 97-08. Centre for International Economic Studies, University of Adelaide.

BOE. (1997). Law 54/1997, of November 27th of electric sector. Official State Bulletin, nº 285.

Böhringer, C. (1998). The Synthesis of Bottom-up and Top-down in Energy Policy Modeling. Energy Economics, 20 (3): 233–48.

Böhringer, C.; Rutherford, T.F. (2008). Combining Bottom-up and Top-Down Energy Economics, 30 (2): 574–96.

Bourne, M.; Philippidis, G.; Feijoo-Bello, M. L. (2015). A computable general equilibrium assessment of Spanish greenhouse gas emission reduction targets, including the incorporation of marginal abatement cost curves. Doctoral thesis. Department of Economic Analysis, University of Zaragoza, Zaragoza, Spain.

Brooke, A., Kendrick, D., & Meeraus, A. (1988). GAMS: A user's guide. San Francisco: Scientific Press.

Cansino, J. M.; Cardenete, M. A.; González-Limón, J. M.; Román, R. (2014). The economic influence of photovoltaic technology on electricity generation: A CGE (computable general equilibrium) approach for the Andalusian case. Energy, 73, 70-79.

COM. (2015). Paquete sobre la unión de la energía. Comunicación de la Comisión al Parlamento Europeo y al Consejo. Alcanzar el objetivo de interconexión de electricidad del 10%. Preparación de la red eléctrica europea de 2020. Comisión europea. Bruselas, 25 de febrero de 2015.

Dai, H.; Masui, T.; Matsuoka, Y.; Fujimori, S. (2011). Assessment of China's climate commitment and non-fossil energy plan towards 2020 using hybrid AIM/CGE model. Energy Policy, 39, 2875–2887.

Devarajan, S. (1988). Natural resources and taxation in computable general equilibrium models of developing countries. Journal of Policy Modeling, 10(4), pp. 505–528.

Devarajan, S.; & Hossain, S. I. (1998). The combined incidence of taxes and public expenditures in the Philippines. World Development, 26(6), pp. 963–977.

de Hauteclocque, A.; Rious, V. (2011). Reconsidering the European regulation of merchant transmission investment in light of the third energy package: The role of dominant generators. Energy Policy, 39, 7068–7077.

del Río, P.; Unruh, G. (2007). Overcoming the lock-out of renewable energy technologies in Spain: The cases of wind and solar electricity. Renewable and Sustainable Energy Reviews, 11, 1498–1513.

Dirkse, S.P.; Ferris, M. 1995. The Path solver: A non-monotone stabilization scheme for mixed complementarity problems. Optimization Methods and Software 5, 123-156.

Duarte, R.; Langarita, R.; Sánchez-Chóliz, J. (2017). The electricity industry in Spain: a structural analysis using a disaggregated input-output model. Energy, 141, Pages 2640-2651. https://doi.org/10.1016/j.energy.2017.08.088

EEA. (2013). Trends and projections in Europe 2013. Tracking progress towards Europe's climate and energy targets until 2020. European Environment Agency, EEA Report Number 10/2013.

EEA. (2017). Trends and projections in Europe 2017. Tracking progress towards Europe's climate and energy targets. European Environment Agency, EEA Report Number 17/2013.

EEA. (2018). Share of renewable energy in gross final energy consumption. European Environment Agency. On-line database. [View: 5 February 2018]. Available at https://www.eea.europa.eu/data-and-maps/indicators/renewable-gross-final-energy-consumption-4/assessment-2.

European Commission. (2017). European Commission - Fact Sheet. Towards reaching the 20% energy efficiency target for 2020, and beyond. Brussels, 1 February 2017. http://europa.eu/rapid/press-release_MEMO-17-162_en.htm

EXIOBASE. (2015). EXIOBASE2 Data Download. Last data published on February 24 2015. https://www.exiobase.eu/index.php/data-download/exiobase2-year-2007-full-data-set/80-mrsut-version2-2-2

González Ruiz, J. I.; Descalzo Benito, M. J. (2017). Electricity regulation in Spain: overview. Global guide 2017, Energy and natural resources.

Gooroochurn, N., & Milner, C. (2005). Assessing indirect tax reform in a tourism-dependent developing country. World Development, 33(7), pp. 1183–1200.

INE. (2017). Agricultura y medio ambiente. Cuentas ambientales. Cuenta de emisiones a la atmósfera. Resultados nacionales. Serie 2008-2015. Last data published on November 28, 2017. http://www.ine.es/jaxi/Tabla.htm?path=/t26/p084/base_2010/serie/l0/&file=01001.px&L=0

Jensen, J. and Tarr, D. (2003). Trade, exchange rate, and energy pricing reform in Iran: potentially large efficiency effects and gains to the poor. Review of development economics, 7(4), 543-562.

Kumbaroğlu, S. G. (2003). Environmental taxation and economic effects: A computable general equilibrium analysis for Turkey. Journal of Policy Modeling, 25(8), pp. 795–810.

Langarita, R.; Sánchez-Chóliz, J.; Sarasa, C.; Duarte, R.; Jiménez, S. (2017). Electricity costs in irrigated agriculture: A case study for an irrigation scheme in Spain. Renewable & Sustainable energy reviews, 68, 1008-1019.

Manzoor, D.; Shahmoradi, A. and Haqiqi, I. (2012). An analysis of energy price reform: a CGE approach. OPEC Energy Review, 36: 35–54. doi: 10.1111/j.1753-0237.2011.00200.x

Marins Machado, M.; Conceição Sampaio de Sousa, M.; Hewings, G. (2016). Economies of scale and technological progress in electric power production: The case of Brazilian utilities. Energy Economics, 59, 290–299.

Martínez, A.; Valero, S.; Senabre, C.; Velasco, E. (2017). International Conference on Renewable Energies and Power Quality. Malaga (Spain). April 2017.

MINETUR. (2015). La energía en España 2015. Ministerio de industria, energía y turismo. Gobierno de España.

Official Journal of the European Union. (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, 140/16.

Official Journal of the European Union. (2012). Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, Official Journal of the European Union, 315/1.

REE. (2016). Red Eléctrica de España. On-line database. [View: 19 May 2016]. Available at http://www.ree.es/es/estadisticas-del-sistema-electrico-espanol/indicadores-nacionales/series-estadisticas.

REE. (2017). Red Eléctrica de España. On-line database. [View: 28 September 2017]. Available at http://www.ree.es/es/estadisticas-del-sistema-electrico-espanol/indicadores-nacionales/series-estadisticas.

Rutherford, T. F. (1999): Applied General Equilibrium Modeling with MPSGE as a GAMS Subsystem: An Overview of the Modeling Framework and Syntax. Computational Economics, nº 14, pp. 1-46.

Rutherford, T. F.; Montgomery, W.D. (1997). CETM: A Dynamic General Equilibrium Model of Global Energy Markets, Carbon Dioxide Emissions and International Trade. 97-3. Discussion Papers in Economics. University of Colorado at Boulder.

Rutherford, T. F.; Paltsev, S. V. (2000). GTAP-Energy in GAMS: The Dataset and Static Model. Working Paper No. 00-02. Center for Economic Analysis. Department of Economics. University of Colorado. http://debreu.colorado.edu/download/gtap-eg.html

Sáenz de Miera, G.; del Río González, P.; Vizcaíno, I. (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. Energy Policy, 36, 3345– 3359.

Sancho, F. (2010). Double dividend effectiveness of energy tax policies and the elasticity of substitution: A CGE appraisal, Energy Policy, 38, 2927–2933.

Sarasa, S.; Sánchez, J. (2014). Irrigation water management: an analysis using computable general equilibrium models. Doctoral thesis. Department of Economic Analysis, Universidad de Zaragoza, Zaragoza, Spain.

Trieb, F.; Schillings, C.; Pregger, T.; O'Sullivan, M. (2012). Solar electricity imports from the Middle East and North Africa to Europe. Energy Policy, 42, 341–353.

United Nations. (2016). United Nations Framework Convention on Climate Change (UNFCC). Conference of the parties. Report of the conference of the parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Available: http://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf

Wing, I. S. (2006). The synthesis of bottom-up and top-down approaches to climate policy modeling: Electric power technologies and the cost of limiting US CO2 emissions. Energy Policy, 34, 3847–3869.

Wing, I. S. (2008). The synthesis of bottom-up and top-down approaches to climate policy modeling: Electric power technology detail in a social accounting framework. Energy Economics, 30, 547–573.

World Bank. (2016). On-line database. [View: 26 May 2016]. Available: http://datos.bancomundial.org/indicador/EG.IMP.CONS.ZS/countries?display=default

Yilmaz, K. (1999). Optimal export taxes in a multicountry framework. Journal of Development Economics, 60(2), pp.439–465.

Conclusiones e investigación futura

Observaciones finales

Teniendo en cuenta el carácter esencial de la energía en general y de la electricidad e particular, centramos la atención de esta tesis en la electricidad.

Viendo el actual incremento de la demanda de energía, lo que implica usar energías que no se agoten, y la necesidad de mantener el medio ambiente para generaciones futuras, lo que implica la necesidad de parar la contaminación, se necesita de varias acciones y esfuerzos. Particularmente, el rediseño del mercado de la electricidad es realmente necesario en nuestros días ya que la transformación a un sistema decarbonizado es precisa para mantener el medio ambiente.

Existen varios tratados internacionales que buscan tratar de reducir las emisiones a la atmósfera y que para ello tratan de mejorar nuestro sistema de energía y electricidad. En Europa también hay una preocupación general sobre la integración del mercado y la aplicación de políticas de cohesión, en el sentido de tener objetivos comunes para todos los países de la UE.

En este contexto, en comparación con los países de la UE, España tiene una dependencia de energía alta y ha incrementado mucho los precios de la electricidad en los últimos años.

Esta tesis se ha centrado en el sistema eléctrico español porque, en España, a pesar de su gran potencial en tecnologías verdes, el sistema eléctrico presenta algunas características bastante negativas, como el bajo nivel de competencia entre las empreas de este sector, la existencia del déficit tarifario, las recientes reformas que están causando incertidumbre legal e incrementos en precios, aspectos que estamos interesados en mejorar.

Dada la relación entre electricidad y agricultura de regadío, la primera parte de la tesis se centra en analizar los costes eléctricos en la agricultura de regadío, proponiendo algunas medidas con las que sería posible mejorar algunas de las debilidades de la electricidad en general y, particularmente, reducir los costes eléctricos en la agricultura de regadío en una zona concreta de España. Luego, en la segunda parte, va más allá analizando todos los sectores de la economía y para todo el país. Para eso, se han utilizado modelos input-output (IO), matrices de contabilidad social (MCS) y modelos de equilibrio general aplicados (MEGAs).

Tras haber analizado algunas políticas de cambio aplicadas a datos de regadío en el capítulo 1, una lectura del análisis de los resultados sugiere la posibilidad de obtener mejoras en el sistema y en la economía a través de cambios en el sistema de tarifas, reduciendo o eliminando el pago por potencia y compensando con un aumento en el pago por consumo de energía. Igualmente, los primeros resultados obtenidos apuntan la importancia del desarrollo del autoconsumo, teniendo en cuenta el importante papel que juega la red eléctrica tanto para la implementación del autoconsumo en sí mismo como para aumentar la competencia si esta red se extiende a Europa, aumentando así importaciones y exportaciones de energía. Con alguna de estas medidas sería posible reducir costes eléctricos en la agricutlura de regadío y, también, sería posible mejorar algunos de los otros problemas que el sistema eléctrico español presenta. Más aún, los resultados obtenidos en este capítulo 1, definen el tema y el hilo conductor de esta tesis.

Viendo la importancia de la agricultura de regadío como conductor de la economía, y teniendo en cuenta la eliminación de las tarifas de acceso por potencia propuesta en el capítulo 1, particularizamos a una medida más concreta en el capítulo 2, el cual pretendía analizar una medida con la que tratar de reducir costes energéticos en la agricutlura de regadío, además de tratar de debilitar algunos de los aspectos críticos del sistema eléctrico español, como, por ejemplo, la penalización de la irregularidad temporal. Para eso, proponemos la implementación en España de una tarifa francesa aplicable a la agricultura. Los resultados de este capítulo sugieren que los costes energéticos en la agricultura de regadío se reducirían si cambiásemos las actuales tarifas en España por la tarifa francesa *Tarif Vert*, cuya principal ventaja es el pago por "potencia facturada", la cual es una gran diferencia con las tarifas españolas, ya que la cuantía final pagada con la tarifa francesa es mucho más baja que la pagada en España.

Otro objetivo de este trabajo ha sido profundizar en las características del sector de la energía en España, en sus relaciones con el resto de sectores económicos. Esto proporciona una aproximación a la centrailidad del sector en la economía y las cadenas de dependencia relacionando el sector.

En este contexto, en el capítulo 3 estudiamos la estructura del sector eléctrico en España haciendo uso de una tabla input-output y una matriz de contabilidad social, las cuales se construyen y desagregan en este capítulo. Nuestros hallazgos del capítulo 3 con respecto al sector eléctrico fueron sorprendentes. Se podría pensar, debido a su carácter esencial para una economía, que la electricidad podría ser un sector clave

"Rasmussen". Sin embargo, esto es cierto sólo para Comercialización de electricidad, mientras todos los demás excepto Actividades relacionadas son sectores arrastre, o no significativos. Por lo tanto, ninguno de los sectores de generación de electricidad es clave. Sin embargo, sus fuertes ligaduras con industrias del metal, construcción y transporte muestran su relevancia por incentivar el desarrollo de otros sectores, los cuales sí son claves.

La desagregación de sectores eléctricos también revela cómo de diferenres son realmente, lo cual indica que tenemos que tener cuidado al hacer análisis generales. El análisis de la tabla input-output construida también muestra que la energía generada por sistemas de térmica convencional y plantas hidroeléctricas cuenta con más del 50% del valor del output de electricidad, sin embargo, la energía nuclear y eólica presionan sobre la opinión pública. La energía nucelar produce alrededor del 7% del output total, mientras la generación de eólica sufre el problema de la variabilidad y la dificultad técnica de la acumulación. Ésta puede ser la razón por la cual ninguno de estos dos sectores sea relevante bajo la clasificación de Rasmussen.

Los sectores eléctricos son también muy diferentes en términos de los modelos de actividades que involucran: mientras los ingresos de los sectores de generación se determinan básicamente por las subastas diarias de electricidad, los ingresos de transporte y distribución están basados en tarifas, y el sector de comercialización opera bajo condiciones fundamentalmente competitivas, aunque en la práctica sean pocas empresas las que se queden con la mayor cuota de mercado. Ésta es una indicación adicional de la naturaleza altamente variada de la industria en su conjunto.

Viendo la necesidad de transformar el proceso productivo hacia un sistema decarbonizado para mantener el medio ambiente, necesitamos rediseñar el Mercado eléctrico europeo, ya que es uno de los sectores que afecta a las emisiones de CO_2. En este sentido, el mercado eléctrico europeo se enfrenta a varios retos, como el acoplamiento del mercado o la implementación de políticas comunes. En este contexto, la Unión Europea ha establecido varios objetivos con el objetivo de aumentar el comercio de electricidad entre los países dela UE o con el objetivo de mantener el medio ambiente. Con el objetivo de estudiar los efectos de algunas medidas de política en términos de mejorar el sistema eléctrico, analizamos en el capítulo 4 algunos de los objetivos establecidos por la UE para España: (1) aumento de la integración con la red eléctrica europea, porque actualmente la competencia externa es muy baja y se necesita un aumento en el comercio; (2) aumento del uso de fuentes de energía renovable para mantener el medio ambiente; y, (3) aumento de la competitividad del sector eléctrico español para aumentar la eficiencia.

Para ver los efectos económicos y medio ambientales de estos escenarios, hemos hecho uso de un modelo de equilibrio general aplicado. Sobre la base de las tablas construidas en el capítulo 3, hemos construido en el capítulo 4 un modelo de equilibrio general aplicado a la economía española para 2013, en el que la función de producción es una función anidada teniendo en cuenta la actual separación de las actividades eléctricas. En nuestro MEGA, generación, transporte, distribución, comercialización y actividades relacionadas al sector eléctrico están representadas de forma separada y se representan también diferentes tecnologías productivas. En la parte de la demanda, también tenemos en cuenta las características del sector para su representación.

Un importante resultado del capítulo 4 es la construcción del MEGA en sí mismo porque tiene en cuenta los detalles de la actual estructura e interrelaciones entre los sectores eléctricos y el resto de la economía, entre el sector eléctrico y el sector exterior, y entre las diferentes actividades dentro del sector de la energía. Además, hemos tenido en cuenta la sustituibilidad entre inputs en la función de producción, principalmente centrándonos en los niveles de anidamiento de electricidad y energía. En los tres escenarios analizados podemos observar incrementos en la producción final de la economía con incrementos especialmente grandes en la producción de electricidad, encontrando también en el segundo escenario importantes reducciones en las emisiones de CO_2.

Esta tesis ha mostrado las particularidades del sistema eléctrico y su relación con el resto de sectores en España, sin embargo, las herramientas y el análisis desarrollados aquí podrían usarse para otros países en la UE.

Nos gustaría subrayar la necesidad de políticas públicas en términos de reducir las emisiones a la atmósfera de una manera global para incentivar la sostenibilidad.

En el caso de Europa, tenemos que estimular el acoplamiento del mercado y las políticas comunes para los países en la UE para incentivar la transformación del sector de una forma conjunta.

Como implicaciones de política más concretas teniendo en cuenta los resultados de esta tesis, primero, pensando en la importancia del sector de la agricultura en España como impulsor de la economía, y teniendo en cuenta la necesidad del uso de electricidad para bombear y distribuir el agua de riego, sería necesario promover la reducción de los costes eléctricos en la agricultura de regadío al igual que los agricultores han conseguido la reducción de los usos de agua después de la modernización. Ahora, es necesario pensar en reducir los costes eléctricos. Para este fin, se necesitan tarifas especiales para los agricultores.

Considerando esto, una medida concreta de reducción de los costes eléctricos en la agricultura de regadío es la eliminación o la reducción de las tarifas de acceso por potencia contratada. Deberíamos pensar en cómo podríamos reducirla, especialmente para agricultores por el bajo uso que hacen en invierno y la actula necesidad de tener la potencia contratada todo el año.

Yendo más allá en proponer medidas de política para toda la economía española, la relevancia del sector eléctrico, y su relación con otros sectores importantes de la economía, nos hacen ser cuidadosos con las medidas a establecer. Viendo el diferente carácter de los subsectores eléctricos, deberíamos pensar en medidas de política específicas para cada uno de ellos. Concretamente, el carácter clave de Comercialización de electricidad y Actividades relacionadas al sector eléctrico implica regular estos dos sectores tratando de hacerlos lo más útiles para el resto de la economía.

De acuerdo con los objetivos fijados por la Unión Europea, y viendo los potenciales efectos positivos de estas medidas, deberíamos también incentivar el comercio de electricidad con el resto de Europa, el incremento de la proporción de renovables en el mix eléctrico, y el incremento de la eficiencia energética.

Líneas de investigación futuras

Esta tesis doctoral, como parte de mi formación de doctorado, es un primer paso en el estudio del sector eléctrico y me ha dado la oportunidad de pensar en medidas sobre cómo mejorarlo. Sin embargo, la sensación más satisfactoria al hacer esta investigación es la aparición de otros varios aspectos los cuales estoy interesada en analizar en el futuro; algunos de ellos relacionados con el sector de la electricidad en general, otros relacionados con la sostenibilidad medioambiental; otros teniendo en cuenta algunos estudios analizados aquí pero para otras zonas, como, para el caso de la UE; otras ideas relacionadas con mejorar la metodología; otras sólo en términos de metodología pero aplicada a otros estudios de casos, etc.

Hemos centrado nuestro análisis en el sector eléctrico de la economía española, pero la separación de sus actividades ha tenido lugar también en otros países europeos, por lo tanto, la estructura productiva representada en la tabla input-output, la matriz de contabilidad social y el modelo de equilibrio general desarrollados en esta tesis se podría tener en cuenta para otras regiones europeas. En esta línea, además, sería realmente interesante construir un modelo multirregional input-output (MRIO) para Eurpa con el sector eléctrico desagregado.

Siguiendo la línea de esta tesis, una extensión ambiciosa es la construcción de un modelo de equilibrio general aplicado sobre la base del modelo multirregional con alta desagregación para las actividades eléctricas para Europa para ser capaces de simular objetivos fijados por la UE para todos los países europeos, y particularmente la relación y las compensaciones y contrapartidas entre ellos.

Teniendo en cuenta el desarrollo de modelos de equilibrio general, en esta tesis, las elasticidades de sustitución se han tomado de la literatura. Por tanto, une posible línea futura de investigación podría ser estimar las elasticidades de sustitución asociadas con la energía (por ejemplo, Armington o elasticidad de la demanda) para España.

En el capítulo 1 hemos analizado el autoconsumo en el contexto de la agricultura de regadío para una zona concreta del noreste de España. Estamos ahora realmente interesados en analizar el autoconsumo eléctrico para la economía españolar en su conjunto y para todos los sectores. Para esto, las tablas de origen y destino (explicadas en el apéndice del capítulo 3) parecen ser una buena herramienta porque ahí podemos ver los productos consumidos como inputs por cada uno de los sectores y también la producción de cada uno de los bienes que realiza cada actividad productiva. En este sentido, proponemos estudiar los efectos sobre toda la economía de la implementación del autoconsumo usando las tablas de origen y destino.

Dada la relación entre energía y agua, también me gustaría construir un modelo de equilibrio general para analizar cómo los cambios la disponibilidad de agua afectan al sector eléctrico y cómo los cambios en el sector eléctrico afectan a la producción de cultivos en la agricultura de regadío.

En términos de la metodología, los modelos input-output son útiles para analizar aspectos económicos muy diferentes. En este sentido, a lo largo de mi formación de doctorado, he usado el modelo input-output para analizar los efectos de la Expo Zaragoza 2008 sobre la economía aragonesa. También he utilizado el modelo input-output para estudiar lso efectos de algunos eventos de turismo de deporte en la provincia de Huesca, en el norte de Aragón. Estos dos estudios están relacionados con los efectos de un cambio en la demanda, a través de un modelo lineal, sobre la economía. Así, en este sentido, estoy interesada en analizar en el futuro cómo podemos estudiar los efectos, con la metodología input-output, en un municipio.

La tabla input-output usada para estos estudios era una tabla input-output para la Comunidad de Aragón, la cual construimos ya que las tablas input-output regionales son más útiles al analizar shocks con efectos en zonas reducidas. Todo esto está indicando que las tablas input-output regionales son cada vez más importantes, por lo tanto, estoy interesada en desarrollar tablas input-output para otras regiones españolas para analizar estudios de caso similares a los estudiados para Aragón.

Conclusions and future research

Final remarks

Taking into account the essential character of energy in general, and electricity in particular, the focus of this thesis is on electricity.

Viewing the current increase in energy demand, which involves the use of renewable energies, and the necessity to maintain the environment for future generations and restrict or reduce pollution, several actions and efforts are needed. In particular, the redesign of the electricity market is an absolute necessity today, since the transformation to a de-carbonized system is needed in order to maintain the environment.

There are a range of international approaches attempting to reduce emissions to the atmosphere and, ultimately, to improve our energy and electricity system. In Europe, there is also a broad-based concern about market coupling and applying cohesive policies, in the sense of having common objectives for all of the countries in the EU.

Within the countries of the EU, Spain has a high level of energy dependence and has also greatly increased its electricity prices in recent years.

This thesis has focused on the Spanish electricity system because, in Spain, despite its great potential in green technologies, the electricity system presents certain negative characteristics, such as the low level of competition among the firms in the sector, the existence of the tariff deficit, the recent reforms that are causing legal uncertainty, and price hikes – with all of these issues being of interest to us.

Due to the relationship between electricity and irrigated agriculture, the first part of the thesis focuses on analysing electricity costs in irrigated agriculture, proposing some measures with which it would be possible to improve some of the weaknesses of the electricity sector in general and, particularly, to reduce electricity costs in irrigated agriculture in a specific area of Spain. Then, in the second part, this Thesis analyses all sectors of the economy and for the whole country. For that, use was made of input-output (IO) models, social accounting matrices (SAMs), and computable general equilibrium (CGE) models.

Having analysed certain policies of change applied to the data on irrigation in Chapter 1, an analysis of the results suggests the possibility of obtaining improvements in the system and in the economy through changes in the tariff system, reducing or removing the payments by capacity, and compensating with an increase in payments by energy consumption. The first results obtained point to the importance of the development of self-consumption, taking into account the important role that the electricity grid plays both in the implementation of self-consumption itself, and increasing the competition if this grid is extended to Europe, thus increasing both imports and exports of energy. With any of these measures, it would be possible to reduce electricity costs in irrigated agriculture, and it would also be possible to alleviate some of the other problems inherent in the Spanish electricity system. The review of the energy consumption in irrigation and the analysis of the design and amount of the electricity tariffs in Spain, also carried out in Chapter 1, comprise the theme and the common thread of this thesis.

Viewing the importance of irrigated agriculture as a driver of the economy, and taking into account the removal of the access tariff by capacity proposed in Chapter 1, we particularize it to a more specific measure in Chapter 2, which sets out to analyse a measure with which to try to reduce energy costs in irrigated agriculture, in addition to alleviating some of the critical issues of the Spanish electricity system, such as, for example, the penalization of temporary irregularity. For that, we propose the implementation in Spain of a French tariff applicable to agriculture. The results of this chapter suggest that the energy costs in irrigated agriculture would be reduced if we exchanged the current tariffs in Spain for the French tariff *Tarif Vert*, whose main advantage is the payment by “billed capacity”, which is significantly different from the Spanish tariffs, since the final amount paid with the French tariff is much lower than that paid in Spain.

Another objective of this work has been to examine the characteristics of the energy sector in Spain in its relationships with the rest of the economic sectors. This provides an approximation to the centrality of the sector in the economy and the chains of dependence linking the sector with, and to, the others.

In this context, in Chapter 3 we study the structure of the electricity sector in Spain, making use of an input-output table and a social accounting matrix, which were also constructed and disaggregated in this chapter. Our findings in Chapter 3 with regard to the electricity sector were surprising. It could be thought, because of its essential character for an economy, that electricity is a “Rasmussen” key sector.

However, this is true only for Electricity marketing, while all of the others, except for Related activities, are either backward sectors, or they are not significant. Hence, none of the electricity generating sectors is key. However, its strong linkages to metals industries, construction, and transport show their significance by encouraging the development of other sectors, which are, in fact, key.

The disaggregation of the electricity sectors also reveals how varied they actually are, which indicates that we must be careful when doing a general analysis. The analysis of the input-output table constructed shows that the power generated by conventional thermal systems and hydroelectric plants account for more than 50% of the value of the electricity output of nuclear and wind power. Nuclear power produces only around 7% of total output, while wind generation suffers from the problem of variability and the technical difficulties of accumulation. This may be why neither of these two sectors are important under the Rasmussen classification.

The electricity sectors are also very different in terms of the business models involved: while the generating sectors' revenues are determined basically by daily electricity auctions, transmission and distribution revenues are tariff-based, and the marketing sector operates under fundamentally competitive conditions, although in practice there are very few companies that are left with the largest market share. This is a further indication of the highly varied nature of the industry as a whole.

Viewing the necessity of transforming the production processes to a decarbonized system, in order to maintain the environment, we need to redesign the European electricity market, since it is one of the sectors affecting CO_2 emissions. In this sense, the European electricity market faces several challenges, such as market coupling and the implementation of common policies. In this context, the European Union has set several targets with the objective of increasing the electricity trade among EU countries, with the objective of maintaining environmental quality. With the objective of studying the effects of certain policy measures in terms of improving the electricity system, we analyse in Chapter 4 some of the targets set by the EU for Spain: (1) Increasing the integration with the European electricity network, because currently the level of external competition is very low and an increase in trade is needed; (2) Increasing the use of renewable energy sources in order to maintain the environment; and, (3) Increasing the competitiveness of the Spanish electricity sector to increase its efficiency.

To see the economic and environmental effects of these scenarios, we make use of a computable general equilibrium model. On the basis of the tables developed in Chapter 3, we develop in Chapter 4 a computable general equilibrium model applied to the Spanish economy for 2013, in which the production function is a nested function, taking into account the current separation of electricity activities. In our CGE model, generation, transmission, distribution, commercialization and activities related to the electricity sector are separately represented and several production technologies are represented, too. On the demand side, we also take into account the characteristics of the energy sector for its representation.

One important result of Chapter 4 is the construction of the CGE model itself, because it takes into account the details of the current structure and inter-relationships between the electricity sector and the rest of the economy, between the electricity sector and the external sector, and among the different activities within the energy sector. In addition, we have taken into account the substitutability among inputs in the production function, mainly focusing on the electricity and energy nesting levels. In the three scenarios analysed, we can observe increases in the final production of the economy, with especially high increases in electricity production, also finding in the second scenario significant reductions in CO_2 emissions.

This thesis shows the particularities of the electricity system and its relationships with the rest of the sectors in Spain, although the tools and analysis developed here could be applied to other countries in the EU.

We would like to highlight the necessity of public policies in terms of reducing emissions to the atmosphere globally, while encouraging sustainability.

In the case of Europe, we must encourage market coupling and common policies for the countries of the EU, in order to promote the beneficial and cooperative transformation of the sector.

More concrete policy implications, taking into account the results of this thesis are, first, to consider the importance of the agricultural sector in Spain as a driver of the economy, and to remember the necessity of using electricity to pump and distribute irrigation water. It is necessary to encourage reductions in electricity costs in irrigated agriculture, in the the same way as farmers have achieved reductions in water uses after modernization. One concrete measure to reduce electricity costs in irrigated agriculture is the removal or reduction of the access tariff by capacity. This is especially crucial for farmers because of the low level of use that they experience in winter, and the current necessity of having the capacity contracted annually.

In terms of policy recommendations for the Spanish economy as a whole, the importance of the electricity sector, and its links to other important sectors, requires us to exercise caution with the established measures. Viewing the varied characteristics of the electricity subsectors, we should consider specific policy measures for each of them. Specifically, the key characteristics of Commercialization of electricity and Activities related to the electricity sector involve the regulation of these two important sectors, to make them the most useful for the rest of the economy.

According to the targets set by the European Union, and viewing the potential positive effects of these measures, we should also encourage electricity trade with the rest of Europe, an increase in the share of renewables in the electricity mix, and an increase in energy efficiency

Future research lines

This PhD dissertation, as part of my PhD training, is a first step in a study of the electricity sector and has given me the opportunity to think about measures to improve it. However, the most satisfactory aspect of pursuing this research is the emergence of other issues I am interested in analyzing in the future; some of these are related to the electricity sector in general, and others to environmental sustainability; yet others lead to considering factors related to the EU in its entirety, while ideas related to improving and expanding the methodologies employed are pointing to other case studies.

We have focused our analysis on the electricity sector of the Spanish economy, but the separation of electricity activities has taken place in other European countries too, so the productive structures depicted in the input-output table, the social accounting matrix, and the computable general equilibrium model developed in this thesis could well be applied to other European regions. In this line, in addition, it would be very interesting to develop a multiregional input-output (MRIO) model for Europe as a whole, with the electricity sector disaggregated.

Following the line of this thesis, one ambitious extension is the construction of a computable general equilibrium on the basis of the multiregional input-output model with high disaggregation for electricity activities in Europe, in order to be able to simulate the targets set by the EU for all the European countries, and particularly the relationships and trade-offs among them.

Taking into account the development of computable general equilibrium models, in this thesis, the elasticities of substitution are taken from the literature. So, one possible future line of research could be to estimate the elasticities of substitution associated with energy (i.e. Armington or demand elasticities) for Spain.

In Chapter 1, we have analyzed self-consumption in the context of irrigated agriculture for a specific area of North-eastern Spain. We are now very interested in analyzing electricity self-consumption for the entire Spanish economy and for all of its sectors. For this, supply and use tables (explained in the appendix of Chapter 3) appear to be a useful tool, because there we can see the commodities consumed as inputs by each of the sectors, along with the production of the various commodities that each activity produces. In this sense, we propose to study the effects on the whole economy of the implementation of self-consumption, using supply and use tables.

Because of the crucial relationship between energy and water, we would also like to construct a computable general equilibrium model to analyze how changes in water availability affect the electricity sector and how changes in the electricity sector affect the production of crops in irrigated agriculture.

In terms of the methodology, input-output models are useful for analyzing quite different economic issues. During my PhD training, I have used the input-output model to analyze the effects of Expo Zaragoza 2008 on the Aragonese economy. I have also used the input-output model to study the effects of certain sports tourism events in the province of Huesca, in the North of Aragon. These two studies are related to the effects of a demand shock, through a linear model, on the economy. Thus, I am interested in analyzing, in the future, how we can study the effects, with the input-output methodology, in a municipality.

The input-output table used for these studies was established for the region of Aragon, constructed because regional input-output tables are more useful when analyzing shocks with effects in reduced areas. All of this indicates that regional input-output tables are becoming more important. Consequently, I am also interested in developing input-output tables for other Spanish regions, in order to analyze similar case studies to those examined for Aragon.

Annex

Disaggregated input-output table for Spain for 2013

(Millions of Euros)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2,887	12	25	1	29,824	765	3	53	4	2	155	26	200	3	4
2	26	95	0	1	87	2	277	484	0	27	8	15	53	1	4
3	80	0	89	0	780	5	0	2	0	0	6	3	0	0	0
4	5	0	11	96	60	3	1	76	1	33,874	962	12	24	832	4,741
5	11,628	0	256	23	46,904	748	18	271	52	13	1,045	341	86	55	83
6	80	1	84	13	397	8,569	40	178	79	5	407	78	354	54	169
7	89	0	18	78	629	33	1,600	96	21	2	156	24	65	87	121
8	46	0	3	10	1,723	101	55	3,231	688	6	244	57	303	89	53
9	14	0	1	5	289	38	12	228	771	9	313	273	77	40	51
10	844	9	242	267	360	62	46	109	30	6,169	4,735	235	272	90	420
11	1,438	6	45	382	1,709	644	150	838	293	698	16,790	2,853	2,469	368	2,731
12	735	0	11	11	475	27	8	84	27	13	582	1,376	66	15	61
13	231	1	35	56	1,512	279	97	218	147	8	1,471	267	3,712	123	189
14	77	1	4	47	816	46	40	23	15	15	450	91	80	2,950	255
15	60	0	4	75	158	26	24	31	92	27	533	98	266	195	8,797
16	449	3	31	209	1,070	87	85	98	79	78	349	84	307	263	2,502
17	17	0	8	9	276	23	62	57	78	9	213	56	75	79	55
18	34	1	10	25	402	23	43	27	27	28	140	41	118	65	199
19	233	3	27	171	656	53	138	100	74	151	321	105	195	161	604
20	47	1	5	26	182	19	20	24	20	19	99	27	120	56	137
21	17	1	99	26	106	10	17	25	12	18	62	13	27	27	114
22	34	0	7	16	193	111	168	29	31	7	118	35	100	56	128
23	23	3	53	46	281	22	63	88	25	54	191	30	57	88	352
24	10	0	1	11	55	8	4	17	4	8	46	7	16	40	61
25	6	0	1	6	31	5	2	10	2	5	26	4	9	23	35
26	42	0	4	46	232	35	18	73	18	34	195	28	68	169	257
27	53	0	5	58	293	44	23	93	22	43	246	35	86	213	324
28	69	0	7	76	387	58	31	122	29	57	325	47	114	281	428
29	15	0	2	17	85	13	7	27	6	13	72	10	25	62	94
30	27	0	3	29	149	22	12	47	11	22	125	18	44	108	164
31	152	0	16	168	849	128	67	269	65	125	714	103	250	618	939
32	138	0	14	152	770	116	61	244	59	113	647	93	227	560	852
33	0	0	22	15	158	28	2	79	4	5	245	35	30	198	204
34	295	0	13	37	224	23	5	13	12	35	93	16	28	18	137
35	33	0	3	8	249	77	43	25	130	164	471	37	184	129	5,189
36	124	3	17	69	668	117	19	86	90	178	306	85	184	251	253
37	61	25	2	8	43	9	6	9	4	17	14	15	11	13	50
38	80	1	10	13	719	157	37	137	66	11	525	380	120	189	211
39	2	0	0	1	19	7	1	3	6	2	8	6	4	3	5
40	108	2	13	403	2,167	247	142	327	75	210	920	118	338	712	657
41	1	0	0	1	21	6	9	3	1	2	10	15	6	4	9
42	2	0	8	7	27	5	4	8	4	15	58	15	15	7	24
43	97	1	154	144	794	38	77	179	72	116	911	184	172	12	649
44	5	0	1	2	119	10	5	13	13	5	48	31	25	16	17
45	61	0	2	11	241	20	9	14	13	13	225	27	49	15	58
46	3	0	1	2	106	13	2	46	169	7	91	156	14	17	13
47	2	0	1	1	133	11	2	7	176	7	52	24	5	15	2
48	38	1	36	89	733	85	33	46	62	56	335	147	76	99	136
49	10	0	3	5	169	15	12	18	26	24	84	29	9	32	38
50	365	11	29	63	1,133	186	54	111	68	332	401	125	162	156	343

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
51	389	13	25	13	135	25	13	26	9	33	58	25	34	37	47
52	6	0	0	2	41	6	1	4	3	0	18	5	13	5	14
53	5	0	2	12	242	215	27	69	74	35	114	105	106	36	105
54	35	4	18	70	1,067	255	60	92	76	594	356	345	154	267	202
55	13	3	1	72	335	16	21	68	13	128	261	111	81	91	123
56	0	0	0	0	3	0	0	0	1	1	1	1	0	1	1
57	10	0	5	5	445	35	6	26	55	30	169	86	19	54	10
58	234	1	3	31	163	41	10	38	28	1	22	18	48	29	27
59	8	0	6	131	210	48	10	31	62	92	60	33	51	98	50
60	14	1	4	43	269	21	13	39	17	1	74	41	74	32	30
61	3	0	1	2	20	5	1	2	1	3	31	11	4	3	5
62	201	1	37	117	2,181	174	116	191	474	68	513	164	215	195	202
63	53	10	32	48	345	32	51	101	46	111	257	76	67	40	205
64	41	1	11	8	374	28	5	16	135	39	63	64	44	12	137
65	31	3	9	9	250	17	2	5	17	7	73	26	12	5	14
66	0	0	0	0	2	0	1	0	1	0	1	1	0	0	1
67	0	0	3	2	62	1	0	4	23	5	25	1	1	2	3
68	0	0	0	0	149	9	0	11	15	26	29	13	13	0	26
69	25	0	23	1	167	5	10	11	6	14	140	32	8	28	47
70	0	0	0	0	11	1	3	4	2	4	7	1	3	2	3
71	0	0	0	1	30	16	4	6	5	11	21	3	6	5	15
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	3,100	194	533	1,048	10,364	2,821	1,002	1,404	1,583	562	3,701	1,917	2,535	2,539	3,175
K	25,160	872	764	1,421	14,379	2,228	468	1,242	1,315	631	5,001	3,385	2,072	1,445	2,628
CONS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	7,360	267	3,032	1,281	50,538	25,212	3,410	2,770	1,611	27,451	15,342	17,978	3,763	4,615	3,803
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE	8,980	203	1,219	48,431	20,622	18,421	1,306	3,927	1,229	14,301	21,848	15,165	7,021	2,403	10,052
SUMA	**66,564**	**1,761**	**7,170**	**55,787**	**201,862**	**62,812**	**10,197**	**18,484**	**10,576**	**86,998**	**84,726**	**47,538**	**27,643**	**21,602**	**53,841**

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	3	3	2	3	8	6	7	2	0	0	1	0	0	0	0
2	0	0	0	0	0	0	5	0	0	0	29	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
4	23	1	14	2	10	2	8	1	0	0	0	0	0	0	0
5	50	32	45	51	79	49	27	21	3	2	22	10	72	2	0
6	87	23	54	83	930	85	298	10	0	0	17	1	5	0	0
7	101	18	78	55	101	72	1,141	24	0	0	0	0	0	0	0
8	68	24	60	39	118	38	78	21	0	0	63	1	6	0	0
9	62	89	54	32	103	44	28	37	1	1	7	2	16	1	0
10	87	17	57	69	157	60	39	27	0	0	10	2,530	0	0	0
11	915	160	524	418	1,587	465	239	127	12	8	12	34	253	8	0
12	23	10	20	18	42	21	37	5	0	0	27	0	2	0	0
13	273	141	666	255	2,896	752	346	122	0	0	16	0	2	0	0
14	256	34	86	104	455	64	40	18	0	0	19	1	9	0	0
15	8,614	261	3,192	4,811	4,198	1,259	377	332	0	0	0	0	0	0	0
16	2,343	129	868	2,421	2,573	674	542	344	1	0	357	2	12	0	0
17	81	826	440	117	590	342	111	189	0	0	98	1	6	0	0
18	154	359	1,801	587	1,248	271	163	371	1	1	139	3	20	1	0
19	411	87	261	1,563	1,182	405	135	482	5	4	31	15	112	4	0
20	123	39	144	254	17,808	447	65	97	0	0	43	1	8	0	0
21	72	13	74	48	103	1,598	23	504	1	1	0	3	21	1	0
22	152	108	107	121	391	120	1,142	49	0	0	52	0	2	0	0
23	172	58	112	30	212	434	29	734	3	2	25	9	64	2	0
24	17	2	4	12	23	4	4	5	3	0	0	0	0	1	0
25	10	1	3	7	13	2	2	3	0	0	0	0	0	1	0
26	73	8	19	51	97	16	18	22	0	0	190	0	0	4	0
27	92	11	23	64	123	20	22	28	0	0	0	108	0	6	0
28	121	14	31	85	162	27	29	37	0	0	0	0	231	9	0
29	27	3	7	19	36	6	6	8	0	0	0	0	0	1	0
30	47	5	12	33	62	10	11	14	0	0	0	0	0	2	0
31	266	31	68	186	356	59	65	82	0	0	0	0	0	9	0
32	241	28	62	169	322	54	59	75	84	2	1,077	1,041	3,895	27	0
33	15	1	1	8	32	4	2	5	38	1	486	469	1,756	13	0
34	39	10	8	13	28	13	9	6	0	0	39	0	0	0	0
35	204	8	25	24	60	20	47	31	0	0	19	0	0	0	0
36	161	70	58	180	77	143	101	81	3	2	278	9	71	2	0
37	12	2	10	11	668	14	8	9	0	0	1	1	7	0	0
38	114	29	124	290	35	182	217	16	0	0	34	0	1	0	0
39	8	3	8	10	10	4	7	3	0	0	0	0	2	0	0
40	339	33	143	371	348	156	261	62	4	3	19	13	95	2	0
41	12	0	3	17	12	1	2	9	0	0	0	0	0	0	0
42	23	4	15	8	11	72	7	49	0	0	7	0	0	0	0
43	210	65	191	192	352	167	99	36	0	0	44	0	0	0	0
44	35	1	9	29	26	2	13	2	1	1	35	2	16	1	0
45	55	12	20	52	57	74	30	11	1	1	5	2	17	1	0
46	13	12	10	14	38	11	13	7	0	0	51	0	2	0	0
47	10	9	9	16	50	10	17	3	0	0	8	0	2	0	0
48	92	55	80	162	112	52	84	27	0	0	570	1	10	0	0
49	44	93	44	126	90	39	18	77	2	1	6	5	36	2	0
50	272	76	178	265	372	187	120	95	5	4	17	16	117	5	0

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
51	50	9	33	34	37	26	21	11	1	1	6	3	22	1	0
52	12	1	3	15	8	7	4	1	0	0	7	0	1	0	0
53	247	90	271	236	132	57	227	69	0	0	63	0	2	0	0
54	241	108	348	403	296	180	197	54	4	3	3	11	82	3	0
55	145	81	118	234	419	101	12	125	3	2	19	8	60	3	0
56	1	0	1	1	2	1	0	1	0	0	0	0	0	0	0
57	32	15	33	58	175	38	60	9	0	0	33	0	0	0	0
58	59	15	71	84	110	72	38	13	1	0	97	1	11	0	0
59	104	39	50	160	393	98	45	153	1	1	7	4	31	1	0
60	84	12	43	49	143	46	29	12	1	1	206	2	17	1	0
61	5	3	2	5	5	4	4	1	0	0	3	1	5	0	0
62	249	302	239	230	499	304	46	75	1	1	369	3	21	1	0
63	77	24	61	79	142	57	40	18	2	1	5	5	36	2	0
64	17	36	18	36	93	76	41	28	2	2	1	7	54	2	0
65	5	11	17	14	42	39	37	24	1	1	0	2	19	1	0
66	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0
67	5	4	1	12	30	9	1	24	0	0	2	0	0	0	0
68	16	16	1	19	33	68	71	22	0	0	0	0	0	0	0
69	32	4	9	13	40	12	41	8	0	0	130	0	2	0	0
70	3	8	3	10	10	2	2	1	0	0	0	0	2	0	0
71	8	4	5	7	17	5	14	4	0	0	0	0	2	0	0
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	5,184	1,571	1,833	4,214	4,542	2,381	2,161	2,383	5	51	64	2,717	58	34	160
K	2,637	1,404	1,976	3,802	2,793	3,749	2,304	2,278	1,692	615	1,704	3	1,167	1,418	2,977
CONS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	8,075	8,257	5,494	8,551	14,079	1,713	12,060	834	105	50	278	1,539	472	109	249
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE	6,626	11,748	8,328	11,597	28,229	3,315	7,611	622	38	4	9	196	53	6	1
SUMA	**40,535**	**26,778**	**28,779**	**43,358**	**90,633**	**20,917**	**31,221**	**11,092**	**2,027**	**767**	**6,861**	**8,784**	**8,988**	**1,688**	**3,387**

	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1	8	5	0	2	2	91	6	926	415	3	1	0	16	1	1,464
2	1	19	3	0	0	2	0	3	1	0	0	0	0	0	4
3	0	0	0	0	0	1	0	6	3	0	0	0	0	0	541
4	4,200	2,147	3,386	2	28	1,272	2	50	2	9	0	2	14	0	10
5	34	243	36	37	24	390	75	1,327	867	57	10	10	146	10	22,332
6	4	27	10	21	52	892	47	579	99	24	1	22	46	4	1,006
7	0	0	62	4	145	1,232	12	240	37	12	0	1	95	2	323
8	5	59	1	9	585	68	21	209	70	14	1	2	40	6	147
9	15	60	1	21	28	129	15	342	115	16	1	2	37	7	120
10	2,311	3,262	18	200	93	403	516	784	123	6,121	450	2,030	283	55	411
11	508	1,012	121	739	323	3,165	706	684	300	507	15	60	261	10	1,475
12	5	26	3	24	22	139	27	117	79	18	1	2	25	2	169
13	4	18	4	12	94	1,180	872	269	84	147	1	3	151	3	145
14	57	68	21	19	51	6,232	312	134	61	17	1	2	44	3	238
15	0	0	167	28	575	3,042	47	91	62	27	2	6	41	2	69
16	108	309	1	165	1,004	2,773	304	311	159	77	8	43	178	11	192
17	55	105	6	47	17	517	38	118	105	45	4	27	57	5	85
18	185	238	0	181	37	3,123	164	170	84	56	8	41	83	6	421
19	44	370	1	399	149	1,072	574	427	165	198	27	154	209	13	241
20	3	50	3	52	81	484	1,072	155	108	318	3	4	74	3	99
21	8	65	10	32	31	294	48	90	55	405	21	233	163	5	46
22	1	39	0	18	54	1,531	54	145	76	44	1	11	95	4	516
23	25	217	0	119	60	585	80	116	50	332	60	356	239	14	93
24	174	119	0	3	7	63	9	48	59	19	1	3	13	1	27
25	88	68	0	1	4	36	5	28	34	11	0	2	7	1	15
26	602	503	2	11	28	269	40	203	249	79	3	13	54	5	112
27	854	635	2	14	35	339	51	257	314	100	4	16	68	7	142
28	1,227	838	3	18	47	448	67	338	414	131	5	21	89	9	187
29	126	81	0	4	10	99	15	75	91	29	1	5	20	2	41
30	220	141	1	7	18	172	26	130	159	51	2	8	34	3	72
31	1,257	805	3	40	103	983	147	744	910	288	11	46	196	19	411
32	3,753	5,061	12	37	93	891	133	674	825	262	10	42	178	18	373
33	1,869	743	0	1	8	26	3	70	66	81	1	0	1	0	41
34	170	111	0	991	323	326	37	192	179	68	5	3	40	2	357
35	19	21	0	76	3,580	736	90	366	139	18	5	6	8	8	143
36	28	395	148	111	220	25,001	156	1,063	1,018	276	35	64	1,100	44	681
37	9	17	0	68	148	326	536	260	136	804	7	11	40	10	119
38	0	24	0	30	134	258	53	1,100	432	82	17	36	100	7	227
39	0	5	0	3	3	136	32	118	179	23	7	7	30	3	114
40	9	273	462	21	213	402	368	5,446	954	1,440	22	34	4,963	85	58
41	0	1	0	0	12	13	12	103	37	14	9	2	70	2	10
42	0	4	1	4	11	28	14	296	60	97	7	600	117	15	8
43	1	28	3	16	78	253	544	4,651	364	7,876	351	1,286	7,481	30	106
44	3	80	2	19	21	190	7	311	178	17	2	1	64	1,162	160
45	3	64	2	11	65	1,691	100	337	141	78	5	14	78	9	472
46	0	39	0	16	7	90	60	371	137	18	2	9	66	7	86
47	0	12	0	6	7	34	107	505	163	15	3	21	19	3	212
48	2	388	294	66	177	863	214	800	452	184	13	35	169	34	1,047
49	7	133	1	39	27	124	24	233	87	705	9	122	271	76	64
50	22	430	124	92	119	1,849	454	1,618	1,449	554	35	107	391	44	1,080

	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
51	4	83	2	19	38	437	128	578	301	335	20	16	128	10	159
52	0	7	0	6	7	45	158	167	83	12	0	3	9	4	31
53	0	45	4	38	44	3,346	1,174	4,356	7,390	348	235	84	859	94	4,661
54	15	294	45	127	286	2,917	525	1,584	1,162	276	187	74	330	33	708
55	11	225	6	22	78	2,974	35	101	58	101	7	77	65	16	73
56	0	1	0	1	0	8	1	5	3	3	1	2	2	0	1
57	0	21	32	20	28	149	375	1,768	568	47	10	48	66	12	170
58	2	99	10	47	24	508	51	400	294	83	2	18	120	21	202
59	6	115	6	159	55	1,386	129	340	552	744	302	997	420	66	294
60	3	187	19	85	23	186	36	335	35	58	17	10	187	13	66
61	1	19	0	6	13	82	55	80	33	5	1	39	38	1	28
62	4	304	481	234	114	265	445	3,248	1,913	333	17	30	645	52	433
63	7	133	3	33	62	1,499	159	1,154	418	1,611	79	250	1,646	14	354
64	10	192	24	36	41	115	202	362	264	48	1	29	10	0	64
65	3	66	1	16	63	4	208	1,080	320	54	1	0	4	12	446
66	0	1	0	0	0	3	2	8	5	1	0	0	1	0	8
67	0	1	1	3	2	39	2	148	13	18	6	22	8	10	293
68	0	0	0	0	7	3	66	344	10	0	0	0	47	16	127
69	0	89	0	4	37	9	77	265	94	80	3	0	17	0	102
70	0	8	0	2	1	20	0	5	1	46	3	2	40	0	34
71	0	9	1	1	2	64	33	44	34	7	1	3	7	1	77
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	51	487	73	1,504	2,436	21,418	5,678	23,040	23,429	8,438	352	1,690	5,518	1,588	24,962
K	598	8,180	1,832	2,479	2,664	25,057	7,064	20,447	18,334	10,297	441	563	7,959	345	32,619
CONS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	994	1,780	412	797	2,086	12,559	-6,867	-75,962	-63,864	-4,626	-221	351	1,797	208	9,928
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE	10	193	0	81	2,639	855	52	1,173	45	2,463	39	527	1,316	69	1,306
SUMA	**19,748**	**31,902**	**7,868**	**9,552**	**19,705**	**138,212**	**18,090**	**12,700**	**3,845**	**42,547**	**2,694**	**10,358**	**39,207**	**4,359**	**113,657**

	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	1	3	17	3	13	2	3	22	11	5	7	3	2	4	1
2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	6	3	1	2	1	0	5	1	12	2	1	1	1	0
5	28	47	96	50	129	21	27	66	122	65	41	26	77	12	2
6	16	116	79	15	37	7	8	20	48	181	18	29	22	9	1
7	12	110	19	8	14	3	3	12	30	74	11	20	31	12	2
8	1,184	61	38	43	131	30	29	21	83	274	21	151	52	20	4
9	529	71	183	795	180	49	40	43	122	754	31	537	31	6	2
10	12	82	58	11	56	30	117	37	84	87	52	15	13	34	1
11	21	235	71	33	106	20	26	58	80	476	57	54	127	9	1
12	27	21	25	19	31	5	7	18	26	28	24	10	77	5	1
13	14	46	50	19	32	5	7	27	24	63	24	20	18	20	0
14	4	23	84	8	22	4	5	12	26	39	6	10	12	7	0
15	10	9	30	15	23	4	5	15	21	27	14	9	13	8	0
16	21	39	130	37	76	15	16	47	76	136	20	30	46	77	1
17	12	133	1,900	289	40	5	8	30	31	356	64	51	81	44	1
18	11	35	496	30	41	8	9	19	38	77	28	16	30	24	1
19	29	37	378	37	89	16	19	33	72	129	37	22	44	160	1
20	7	19	77	17	35	5	7	27	29	39	15	10	14	312	1
21	10	8	71	18	23	4	5	22	27	123	19	10	15	110	1
22	7	174	428	35	65	19	15	130	58	140	20	54	60	106	4
23	24	21	238	38	35	6	7	7	41	34	9	8	11	97	0
24	2	4	17	6	7	1	1	4	5	7	1	2	2	2	0
25	1	2	10	3	4	0	1	3	3	4	1	1	1	1	0
26	6	18	73	24	29	3	6	19	21	31	4	8	7	7	1
27	8	22	92	31	36	4	8	23	27	39	5	10	9	9	1
28	11	30	121	40	48	5	10	31	35	52	7	13	12	12	2
29	2	7	27	9	10	1	2	7	8	11	2	3	3	3	0
30	4	11	47	16	18	2	4	12	14	20	3	5	5	5	1
31	24	65	266	89	105	12	22	68	77	113	15	29	26	26	4
32	22	59	241	80	95	11	20	62	70	103	14	26	24	24	3
33	1	11	5	15	5	0	0	1	6	8	1	2	2	0	0
34	4	33	33	17	15	3	3	29	52	40	7	8	10	16	2
35	1	1	28	5	18	2	4	121	16	18	5	20	10	19	2
36	30	116	345	306	530	165	115	4,613	71	186	66	67	34	221	6
37	5	16	15	29	58	12	46	23	34	12	16	9	4	40	1
38	64	72	54	49	81	23	19	55	71	51	12	20	9	31	2
39	10	25	26	41	49	7	11	28	22	18	4	14	5	10	1
40	351	81	117	70	53	19	17	18	50	105	11	57	19	136	4
41	3	2	3	5	4	0	1	3	14	23	0	7	5	20	1
42	11	3	12	10	191	78	72	5	27	35	29	17	11	61	2
43	21	17	58	27	35	15	9	26	71	56	9	32	11	59	4
44	7	3	278	33	101	40	24	135	100	96	12	47	34	38	10
45	45	88	157	440	366	92	103	114	273	440	110	56	65	51	6
46	564	88	92	228	346	80	76	40	141	354	33	650	11	3	3
47	75	2,276	137	145	193	90	48	33	32	53	9	374	43	25	19
48	87	362	5,102	498	569	182	219	383	252	212	65	177	37	55	12
49	87	23	566	6,703	488	56	96	34	102	198	99	83	22	30	6
50	97	175	347	275	4,579	2,587	580	2,815	380	295	31	104	62	159	30

	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
51	14	21	29	37	50	1,664	33	2,338	188	109	8	24	16	88	4
52	1	0	11	1	542	3,335	740	70	11	5	0	6	2	56	1
53	320	955	936	587	1,902	203	390	742	781	662	125	512	195	235	42
54	180	364	523	258	909	492	235	1,381	3,930	271	122	128	38	131	4
55	74	25	427	92	24	5	5	272	162	2,974	123	174	64	68	13
56	1	1	3	16	2	0	0	2	3	5	143	1	0	2	0
57	205	170	345	112	678	317	169	84	116	41	18	713	22	17	13
58	108	64	200	149	11	4	3	32	84	48	31	79	402	10	1
59	87	203	315	254	28	2	6	275	173	157	12	47	19	762	5
60	9	30	13	57	1	0	0	10	21	141	8	13	3	23	73
61	22	12	73	54	12	3	4	13	15	25	2	45	15	8	1
62	43	15	523	174	1,098	222	238	478	1,081	431	81	108	28	74	12
63	24	26	160	148	101	261	69	173	108	103	13	30	20	61	4
64	22	2	320	68	45	2	9	36	67	66	221	71	27	35	15
65	6	5	312	20	40	9	9	34	66	64	35	34	15	16	7
66	2	1	2	1	2	0	0	1	1	1	0	2	0	2	0
67	18	8	53	16	24	4	5	11	75	64	2	55	25	51	8
68	25	6	111	0	71	10	15	51	80	21	4	63	34	61	12
69	9	3	23	31	96	8	19	50	121	98	12	38	20	10	9
70	1	1	13	8	4	1	1	1	112	2	4	0	0	13	0
71	1	4	5	3	3	2	1	19	14	7	4	6	3	159	2
72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	2,028	2,290	3,305	8,447	11,920	2,368	1,182	3,092	8,241	5,779	1,820	2,353	1,398	1,080	2,139
K	562	1,505	13,200	5,183	3,717	5,075	2,424	100,206	7,343	3,951	2,117	865	1,582	4,085	141
CONS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	2,940	1,438	2,938	3,320	8,450	2,167	558	11,019	8,363	2,382	310	975	454	686	649
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE	1,031	469	2,162	3,804	2,502	1,144	343	109	2,399	1,320	179	771	27	2,796	2
SUMA	**11,257**	**12,526**	**38,743**	**33,559**	**41,444**	**21,051**	**8,336**	**129,874**	**36,578**	**24,427**	**6,485**	**10,042**	**5,666**	**12,673**	**3,303**

	61	62	63	64	65	66	67	68	69	70	71	72
1	10	21	143	71	107	37	29	129	2	0	3	0
2	0	0	31	0	0	0	0	0	0	0	0	0
3	0	0	11	20	10	18	1	1	1	0	0	0
4	2	2	24	2	5	1	3	2	0	1	1	0
5	10	202	671	492	932	518	184	170	37	7	47	0
6	13	144	286	103	297	165	130	98	111	110	134	0
7	6	119	36	24	114	44	32	21	21	19	70	0
8	5	114	148	155	108	53	45	19	84	11	16	0
9	12	260	217	156	110	85	213	111	79	34	17	0
10	80	46	557	248	252	256	24	15	77	3	31	0
11	88	311	425	101	2,159	341	118	76	35	20	161	0
12	5	45	216	44	5,928	580	20	13	46	1	30	0
13	3	42	49	46	136	55	57	37	43	41	48	0
14	7	39	41	48	236	65	18	11	37	7	26	0
15	3	37	43	26	37	12	14	8	4	4	12	0
16	10	145	151	93	187	52	63	49	29	24	81	0
17	5	245	123	82	321	207	53	41	51	167	34	0
18	11	134	93	52	68	57	31	35	27	36	64	0
19	17	138	201	86	186	57	75	108	21	24	49	0
20	3	47	73	31	43	18	20	20	7	6	18	0
21	7	44	121	33	49	32	17	48	18	4	7	0
22	37	169	112	288	2,469	191	120	91	158	24	46	0
23	15	45	193	74	153	39	28	169	8	16	7	0
24	1	6	27	10	17	5	3	7	2	1	4	0
25	0	3	15	6	9	3	2	4	1	0	2	0
26	3	24	114	41	70	22	14	29	9	3	18	0
27	4	30	145	52	89	28	18	37	11	4	23	0
28	5	40	191	69	117	37	23	48	15	6	30	0
29	1	9	42	15	26	8	5	11	3	1	7	0
30	2	15	73	27	45	14	9	19	6	2	12	0
31	11	88	419	152	257	82	51	106	33	13	67	0
32	10	80	380	138	233	75	46	96	30	11	60	0
33	0	7	37	17	37	12	4	8	5	1	5	0
34	4	37	168	72	123	50	30	43	39	5	98	0
35	0	56	31	14	21	102	56	6	12	2	64	0
36	42	207	956	777	247	429	118	139	38	2	81	0
37	3	16	180	13	36	11	37	26	4	1	9	0
38	12	59	156	36	49	18	27	28	7	12	21	0
39	9	19	48	11	9	5	16	15	1	2	12	0
40	794	34	1,299	62	81	62	35	76	136	32	56	0
41	62	18	32	6	4	1	5	6	0	0	1	0
42	1,188	47	82	13	23	78	6	14	210	3	1	0
43	37	45	875	12	9	17	15	17	17	3	12	0
44	4	106	186	33	59	40	6	4	27	0	11	0
45	4,247	163	512	133	837	191	210	227	338	7	32	0
46	20	160	383	699	151	96	110	116	270	14	17	0
47	32	166	81	96	6	23	23	29	81	1	3	0
48	67	181	1,469	350	281	382	81	109	315	24	37	0
49	20	101	654	130	292	124	24	21	44	53	14	0
50	163	292	2,334	604	738	257	142	153	218	25	78	0

	61	62	63	64	65	66	67	68	69	70	71	72
51	15	80	106	25	85	17	37	57	11	8	25	0
52	3	15	21	22	37	3	1	1	0	0	6	0
53	101	687	1,578	304	187	104	561	558	7	0	473	0
54	94	165	368	188	420	237	409	153	324	34	116	0
55	5	292	1,021	114	27	30	81	69	6	8	7	0
56	0	2	5	1	2	1	1	1	0	0	0	0
57	102	81	248	42	21	54	74	102	142	3	12	0
58	20	42	65	90	3	20	257	67	39	14	28	0
59	172	68	265	75	44	45	123	117	13	76	93	0
60	3	84	26	23	16	25	23	23	46	15	3	0
61	445	27	29	10	6	7	27	30	7	2	1	0
62	48	2,076	1,886	602	1,300	461	25	127	128	9	198	0
63	54	57	313	59	52	45	101	131	22	4	15	0
64	34	153	28	376	56	185	5	11	27	12	24	0
65	0	75	44	75	5,495	250	21	33	16	4	15	0
66	0	1	10	3	46	71	1	1	7	0	2	0
67	245	107	88	32	3	3	1,611	805	10	2	2	0
68	233	115	40	8	3	5	670	940	3	3	5	0
69	0	87	16	15	26	117	10	10	23	7	12	0
70	0	1	243	76	83	13	2	3	17	80	2	0
71	6	17	656	9	129	95	16	24	15	1	108	0
72	0	0	0	0	0	0	0	0	0	0	0	0
L	1,193	12,835	36,736	33,573	28,727	7,498	3,004	4,825	2,956	581	2,375	8,347
K	311	1,908	14,826	12,469	10,441	3,313	6,110	658	318	335	5,339	0
CONS	0	0	0	0	0	0	0	0	0	0	0	0
AI	0	0	0	0	0	0	0	0	0	0	0	0
T	980	4,686	11,401	9,558	7,264	2,597	2,244	2,184	870	385	1,459	699
G	0	0	0	0	0	0	0	0	0	0	0	0
SE	469	2,757	611	271	77	8	436	39	15	26	386	0
SUMA	**11,628**	**30,777**	**85,485**	**63,881**	**72,319**	**20,261**	**18,260**	**13,630**	**7,796**	**2,399**	**12,383**	**9,046**

	L	K	CONS	AI	T	G	SE	SUMA
1	0	0	14,100	1,264	0	144	13,471	**66,564**
2	0	0	279	6	0	65	229	**1,761**
3	0	0	4,866	10	0	2	709	**7,170**
4	0	0	79	223	0	20	3,502	**55,787**
5	0	0	85,456	130	0	265	24,344	**201,862**
6	0	0	29,120	679	0	52	15,830	**62,812**
7	0	0	914	228	0	9	1,401	**10,197**
8	0	0	2,924	109	0	28	4,160	**18,484**
9	0	0	1,051	695	0	21	639	**10,576**
10	0	0	28,791	79	0	72	21,776	**86,998**
11	0	0	11,580	295	0	473	21,108	**84,726**
12	0	0	13,082	434	0	10,187	12,224	**47,538**
13	0	0	2,043	698	0	36	7,133	**27,643**
14	0	0	1,442	348	0	23	5,734	**21,602**
15	0	0	533	863	0	24	14,427	**53,841**
16	0	0	2,150	6,080	0	49	8,997	**40,535**
17	0	0	4,367	8,763	0	63	4,162	**26,778**
18	0	0	3,646	3,434	0	62	9,069	**28,779**
19	0	0	1,408	14,305	0	74	13,773	**43,358**
20	0	0	13,662	13,768	0	168	39,792	**90,633**
21	0	0	1,426	5,693	0	294	8,117	**20,917**
22	0	0	11,271	3,961	0	156	4,943	**31,221**
23	0	0	313	3,195	0	7	646	**11,092**
24	0	0	392	558	0	1	23	**2,027**
25	0	0	225	-48	0	1	0	**767**
26	0	0	1,659	701	0	5	1	**6,861**
27	0	0	2,097	783	0	6	253	**8,784**
28	0	0	2,765	-1,437	0	8	22	**8,988**
29	0	0	609	-302	0	2	0	**1,688**
30	0	0	1,064	-92	0	3	1	**3,387**
31	0	0	6,074	-138	0	17	25	**19,748**
32	0	0	5,507	359	0	16	464	**31,902**
33	0	0	878	10	0	3	19	**7,868**
34	0	0	3,748	146	0	729	70	**9,552**
35	0	0	2,463	43	0	2,630	1,540	**19,705**
36	0	0	8,184	81,691	0	2,052	2,351	**138,212**
37	0	0	13,625	74	0	18	195	**18,090**
38	0	0	3,301	490	0	122	1,551	**12,700**
39	0	0	2,335	222	0	24	61	**3,845**
40	0	0	8,095	102	0	1,383	6,155	**42,547**
41	0	0	757	2	0	67	1,214	**2,694**
42	0	0	2,142	235	0	385	3,711	**10,358**
43	0	0	1,988	105	0	4,513	3,067	**39,207**
44	0	0	129	5	0	4	86	**4,359**
45	0	0	93,648	102	0	678	5,760	**113,657**
46	0	0	3,150	475	0	96	1,067	**11,257**
47	0	0	1,747	2,130	0	2,178	698	**12,526**
48	0	0	14,936	1,450	0	599	2,295	**38,743**
49	0	0	784	12,844	0	474	6,404	**33,559**
50	0	0	7,211	83	0	26	2,967	**41,444**

	L	**K**	**CONS**	**AI**	**T**	**G**	**SE**	**SUMA**
51	0	0	11,053	122	0	16	1,377	**21,051**
52	0	0	2,367	4	0	6	359	**8,336**
53	0	0	90,586	437	0	249	239	**129,874**
54	0	0	2,507	5,243	0	614	2,648	**36,578**
55	0	0	960	6,804	0	355	3,630	**24,427**
56	0	0	9	4,204	0	1,708	329	**6,485**
57	0	0	170	107	0	50	1,092	**10,042**
58	0	0	297	249	0	65	34	**5,666**
59	0	0	1,198	93	0	2	398	**12,673**
60	0	0	5	12	0	17	2	**3,303**
61	0	0	8,028	33	0	248	1,891	**11,628**
62	0	0	662	182	0	89	2,667	**30,777**
63	0	0	2,661	2,544	0	67,260	1,424	**85,485**
64	0	0	15,308	4,881	0	38,494	492	**63,881**
65	0	0	14,916	719	0	46,882	126	**72,319**
66	0	0	9,618	7	0	10,430	6	**20,261**
67	0	0	9,086	318	0	4,414	331	**18,260**
68	0	0	7,223	8	0	2,482	171	**13,630**
69	0	0	5,199	31	0	90	17	**7,796**
70	0	0	1,409	48	0	2	9	**2,399**
71	0	0	10,466	21	0	35	80	**12,383**
72	0	0	9,046	0	0	0	0	**9,046**
L								
K								
CONS								
AI								
T								
G								
SE								
SUMA								