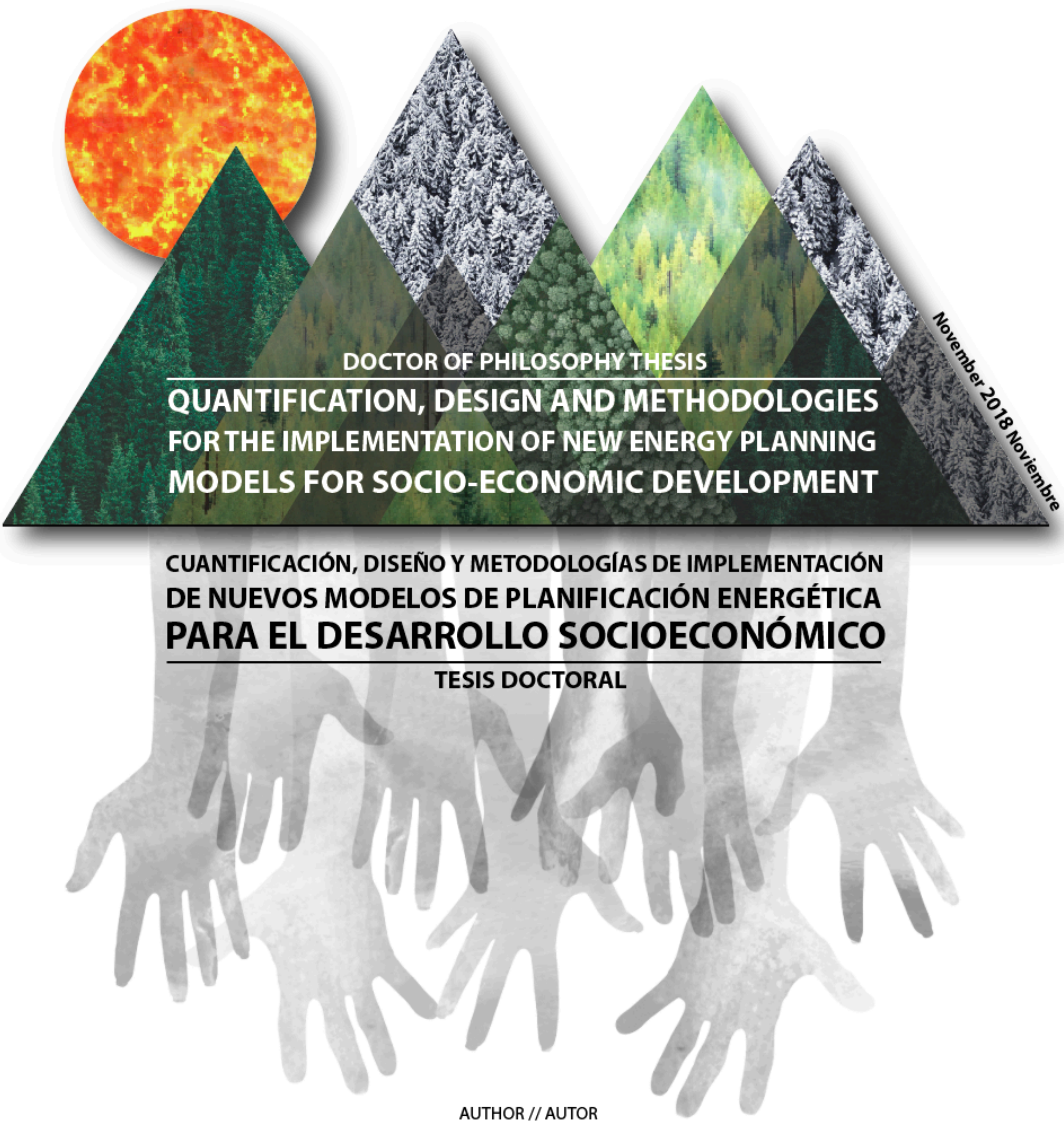

DOCTOR OF PHILOSOPHY THESIS

QUANTIFICATION, DESIGN AND METHODOLOGIES FOR THE IMPLEMENTATION OF NEW ENERGY PLANNING MODELS FOR SOCIO-ECONOMIC DEVELOPMENT

November 2018 Noviembre

CUANTIFICACIÓN, DISEÑO Y METODOLOGÍAS DE IMPLEMENTACIÓN DE NUEVOS MODELOS DE PLANIFICACIÓN ENERGÉTICA PARA EL DESARROLLO SOCIOECONÓMICO

TESIS DOCTORAL

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Universidad del País Vasco

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Los idiomas oficiales de esta tesis son el EUSKERA y el INGLÉS.
The official languages in this thesis are BASQUE and ENGLISH.
La presente versión, en castellano e inglés, ha sido realizada para facilitar su evaluación por el tribunal de la tesis, así como su posterior difusión.

Fields of Knowledge (UNESCO codes) // Áreas de Conocimiento (códigos UNESCO):

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[5312] – SECTORIAL ECONOMICS: [5312.05] - ENERGY
[5901] – POLITICAL SCIENCE: [5901.01] – INTERNATIONAL CO-OPERATION
[0712] – ENVIRONMENTAL PROTECTION TECHNOLOGY: [0712.04] – ENVIRONMENTAL ENGINEERING
[0713] – ELECTRICITY AND ENERGY: [0713.08] – ENERGY STUDIES

"Sé el cambio que quieras ver en el mundo."
"Be the change that you wish to see in the world."

Gandhi

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Doktorego-tesia, era indibidualean gauzatu behar den ezagutza akademikoko gai zehatz baten sakontze bertikala dugu. Nire izaera pertsonala dela eta, normalean, era horizontalagoan gai ugari batera jorratzeko ohitura izateagatik, berebiziko erronka izan da 2011z geroztik energia eredu berrien sorrera ikertzen duen tesi hau burutzea. Bide honetan, nahiz eta ikerketa bakarkakoa izan, bidelagun ugari izan ditut zorionez, eta eurei nire eskerrik beroena ematea ezinbesteko dut. Zuek gabe lan hau ezin izango litzateke burutu, ez teknikoki, ezta emozionalki ere.

Lehenik eta behin, nire bidelagun zaharrenari eman nahi nizkioke eskerrak, lehen zuzendari izan den Gorka Buenori. 2008. urtean, bere liburua irakurri ostean (*Energia Urrirako Mundu baterako Gida*), energiaren gaia era sakonagoan jorratzeko gogoa "piztu" zitzaidan. Gorkaren liburuan, lehen aldiz, alde teknikoa eta alde humanoaren uztartze sakona ikusi nuen, eta horrek duen garrantzia elkarbanatzen dudanez, berarekin harremanetan jarri, eta doktorego-tesiari ekiteko proposamena egin nion. Ordutik, igaro ditugun bideak luzeak eta askotarikoak izan dira; Pakistango mendietan energiak duen rol-a lantzen hasi eta Portland, Vancourver edo Wellington bezalako hirietan dituzten politika energetikoak aztertzeraino. Ibilian, iparra ere sarritan galdu izan dut/dugu, baina azkenik, Ekologistak Martxan Euskadi taldearekin egindako TRADEBU proiektuaren ostean, aztarna energetikoan zentratu gara, eta emaitza konkretuak lortzea posible izan da. Gorkari bihotz-bihotzez nire eskerrona adierazi nahi nioke, bide hori guztia elkarbanatzeagatik, eta hainbat ideiatan kide eta mentore ederra izateagatik. Eskertu zure eskuragarritasuna eta eskaini didazun denbora gauzatu dituzun milaka zuzenketetan ere.

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Graphic Index // Índice Gráfico

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Figure Index // Índice de Figuras

Table Index // Índice de Tablas

Akronimoak:

Acrónimos	Inglés (English)	Español (Spanish)
ADP	Absolute Decoupling Point	Punto de Desacople Absoluto
AR5	Fifth Assessment Report	Quinto Informe de Evaluación
CBA	Consumption Base Accounts	Mediciones en base al Consumo
CF	Carbon Footprint	Huella de Carbono
DI	Decoupling Index	Índice de Desacople
DF	Driving Forces	Fuerzas Motrices
ED	Ecological Debt	Deuda Ecológica
EEIT	Energy Embodied in International Trade	Energía Embebida en el Comercio Internacional
EF	Energy Footprint	Huella Energética
EI	Education Index	Índice de Educación
EP	Environmental Pressure	Presión Medioambiental
EU	European Union	Unión Europea
GDP	Gross Domestic Product	Producto Interior Bruto
GFC	Global Financial Crisis	Gran Recesión (Crisis Mundial Financiera de 2008)
GFN	Global Footprint Network	Red Global de la Huella
GMRIO	Global Multi Regional Input-Output	Input-Output Multi-Regional Global
HEF	Hidden Energy Flows	Flujos Energéticos Ocultos
HDI	Human Development Index	Índice de Desarrollo Humano
IEA	International Energy Agency	Agencia Internacional de la Energía
II	Income Index	Índice de Ingresos
ICES	Integrated Community Energy Systems	Sistemas Integrados de Energía Comunitaria
IPCC	International Panel on Climate Change	Panel Internacional sobre el Cambio Climático
IT	Information Technology	Tecnología de la Información
LCA	Life Cycle Assessment	Análisis de Ciclo de Vida
LEI	Life Expectancy Index	Índice de Esperanza de Vida
MBA	Movimento dos Atingidos por Barragens	Movimiento de los Afectados por las Represas
MF	Material Footprint	Huella de Materiales
MLP	Multi-Level Perspective Methodology	Metodología de Perspectiva Multinivel
OECD	Organisation for Economic Co-operation and Development	Organización para la Cooperación y el Desarrollo Económico
PB	Planetary Boundaries	Límites Planetarios
PBA	Production Based Accounts	Mediciones en base a la Producción
POCE	Plataforma Operária e Camponesa para Energia	Plataforma Obrera y Campesina para la Energía
ppp	Public-private partnership	Asociación público-privada
REC	Renewable Energy Cooperatives	Cooperativas de Energía Renovable
RES	Renewable Energy Systems	Sistemas de Energía Renovable
RLF	Rosa Luxemburg Foundation	Fundación Rosa Luxemburgo
SDGs	Sustainable Development Goals	Objetivos del Desarrollo Sostenible
TFC	Total Final Consumption	Consumo Final Total
TPEF	Total Primary Energy Footprint	Huella Energética Primaria Total
TPES	Total Primary Energy Supply	Suministro Energético Primario Total
UNDP	United Nations Development Programme	Programa de las Naciones Unidas para el Desarrollo
WIOD	World Input-Output Database	Base de datos Input-Output Global
e^x	Energy consumption of industrial sectors	Consumo energético de sectores industriales
v^x	Added Value of industrial sectors	Valor añadido de los sectores industriales
x^x	Gross Inputs of industrial sectors	Entradas brutas de los sectores industriales
Y^y	Final consumers energy demand	Demanda energética de los consumidores finales
Z^{yx}	Economic demand of industrial sectors	Demanda económica de los sectores industriales

Lista de publicaciones de la tesis doctoral

A) Tres artículos principales de la tesis:

A.1 ARTÍCULO:

(Q1-Impact Factor: 5.715)
Decoupling between human development and energy consumption within footprint accounts
Akizu, O., Bueno, G., Wiedmann T., Arto I., López-Guede, J.M., Moran D., Hernandez P. (2018)
Journal of Cleaner Production, 202 (2018) pp 1145-1157

A.2 ARTÍCULO:

(Q2-Impact Factor: 2.262)
Contributions of Bottom-Up Energy Transitions in Germany: A Case Study Analysis
Akizu, O., Bueno, G., Barcena, I., Kurt, E., Topaloglu, N., Lopez, J.M. (2018)
Energies 2018, 11(4), 849

A.3 ARTÍCULO:

(Q1-Impact Factor: 3.582)
Tracing the emerging energy transitions in the Global North and the Global South
Akizu, O., Urkidi, L., Bueno, G., Lago, R., Barcena, I., Mantxo, M., Basurko, I. Lopez, J.M. (2017)
International Journal of Hydrogen Energy, 42/28 (2017) pp. 18045-18063

B) Otras publicaciones en revistas:

Measuring global effectiveness of integrated electric energy systems.
Larrañaga, J.M., Zulueta, E., Lopez-Guede, J.M, Larrañaga, A., Akizu, O. (2017)
International Journal of Hydrogen Energy, 2017 (Impact Factor: 3.582)

Bases académicas en estudios universitarios técnicos para una transición energética.
Akizu, O., Sainz de Murieta, J., Bueno, G. (2016)
Ikastorratza e-Journal on Didactics, 2016, 17 (4) pag. 45-55
ISSN: 1988-5911 - Depósito legal: BI-3615-07

Transiciones energéticas para cambiar el clima
Leire Urkidi, Rosa Lago, Izaro Basurko, Martín Mantxo, Iñaki Barcena, Ortzi Akizu (2015)
VIENTO SUR, Número 142/Octubre 2015 (Pag. 83-90) - ISSN: 1133-5637 (Latindex)

Transiciones energéticas ante el cambio climático: problemáticas e ideas fuerza
Leire Urkidi, Rosa Lago, Izaro Basurko, Martín Mantxo, Iñaki Barcena, Ortzi Akizu (2016)
BOLETÍN ECOS 33 (Pag. 1-9) ISSN: 1989-8495 - FUHEM ECOSOCIAL

C) Artículos de conferencias internacionales:

Understanding the relationship between energy consumption and development during the Global Financial Crisis in Europe within Footprint accounting
Akizu, O., Bueno, G., Wiedmann T., Arto I., López-Guede, J.M. (2018)
ECRES – 6th European Conference on Renewable Energy Systems 25-27 June 2018, Istanbul

IELab dialogue with International Energy Agency: changing the global energy consumption patterns
Akizu, O., Bueno, G., López-Guede, J.M. Wiedmann T., Arto I., (2017)
IELab – Industrial Ecology Virural Laboratory Conference 2017 - Brisbane

Hidden Energy Flows: justice and responsibility in outsourcing goods and services
Akizu, O., Bueno, G., López-Guede, J.M. (2017)
EEETE -6th International Conference on Energy and Environment Tech. and Eqp. 2017 - London

The role of international energy dependency on national welfare
Akizu, O., Kurt, E., Bueno, G., López-Guede, J.M., Arto, I. (2017)
ECRES – 5th European Conference on Renewable Energy Systems (2017) Conference – Sarajevo

Ascertaining emerging German bottom-up energy transitions through case study analysis
Akizu, O., Bueno, G., Barcena, I., López-Guede, J.M. (2017)
ECRES – 5th European Conference on Renewable Energy Systems (2017) Conference – Sarajevo

Ascertaining the arising Energy Transition in Global North and Global South
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01 Resumen
Abstract

1 Abstract / Resumen

(SPANISH / ESPAÑOL)

Está internacionalmente aceptado el hecho de que el modelo energético actual es insostenible y que hay que realizar una transición a un modelo energético sostenible. Tres factores hacen dicha transición energética inevitable. Por una parte, según el Quinto Informe de Evaluación del Intergovernmental Panel on Climate Change (IPCC, 2015), la combustión global de los hidrocarburos que se utilizan en el sector energético constituye una de las causas principales del efecto invernadero. Más concretamente, las emisiones de CO_2 antropogénicas debidas a la combustión de los combustibles fósiles y producción de cemento, han pasado de ser 0,16 $GtCO_2eq$, en el año 1850, a ser 32,28 $GtCO_2eq$, en el año 2015; con un incremento del 20.175%.

Por otra parte, a causa del ya admitido fenómeno *Peak Oil*, resulta inevitable el cambio del actual modelo energético basado en combustibles fósiles, así como la integración de recursos energéticos renovables. Según la *Association for the Study of Peak Oil and Gas* (ASPO), "[…] la producción mundial de petróleo se reducirá en un 50% para el año 2030" (Zittel, 2012).

Por último, el actual modelo energético es uno de los principales causantes de las injusticias existentes entre el Norte Global y el Sur Global. Son ejemplo de tales injusticias: los impactos de la extracción de petróleo (Bozigar et al., 2016), los impactos sociales de las nuevas redes eléctricas en regiones aisladas (Valer et al., 2014), los impactos emocionales causados por los derrames de petróleo (León et al., 2014), la construcción de oleoductos en entornos rurales (Welford and Yarbrough, 2015) o la pobreza energética causada por las injusticias en el reparto de recursos energéticos (Alvarez, 2017; González-Eguino, 2015). Asimismo, la pobreza energética no sólo ha aumentado en el Sur Global, sino también en el Norte Global (en el llamado "cuarto mundo"); por ejemplo, en la Unión Europea, el 10,8% de la población tuvo dificultades para calentar sus hogares y otros tantos para pagar las facturas de electricidad (Pye and Dobbins, 2015).

El modelo consumista de los llamados países desarrollados (o el Norte Global) ha sido denunciado por las Naciones Unidas. Por ello, los Objetivos del Desarrollo Sostenible (*Sustainable Development Goals*, SDG) reclaman el cambio del actual modelo (UN, 2015). En concreto, el objetivo número 12, promueve el cambio de los actuales modelos de consumo; el objetivo 7, reivindica un modelo energético sostenible y universal; y el objetivo 10 promueve reducir las diferencias e injusticias entre diferentes países.

Al mismo tiempo, los Límites Planetarios (*Planetary Boundaries*, PB), nos muestran los límites de los recursos disponibles, ya que, según los últimos estudios, definen que el actual nivel de consumo es de 2 a 6 veces superior al sostenible (O'Neill et al., 2018). Por consiguiente, teniendo en cuenta el consumo global de energía (13.648 Mtoe en el 2015, según la Agencia Internacional de la Energía) y la población actual del planeta

(7.356 millones en el 2015, World Bank), la media de energía primaria disponible por persona podría oscilar entre 3,6 y 10,8 MWh·cap^{-1}·año^{-1}. Ello explica que los esfuerzos realizados en distintos estados para reducir el consumo energético hayan sido notorios. Por ejemplo, National Energy Efficiency Action Plans (NEEAPs) (European Commission, 2017) o Energy Efficiency Directive 2012/27/EU (European Parliament, 2012).

Sin embargo, existe un problema generalizado en las acciones de reducción de consumo energético, dado que la forma de medición del consumo energético de los países se realiza a través de Mediciones en base a la Producción (Production Based Accounts, PBA). En consecuencia, no se tiene en cuenta la energía embebida en productos y servicios importados o exportados (Akizu-Gardoki et al., 2018). Según el actual método de contabilidad energética, los países que han exportado la industria productiva a otros estados son considerados más sostenibles, ya que esos consumos energéticos no computan como nacionales, sino que computan como consumo de otros estados. Esto genera situaciones de "reducciones virtuales de energía" (Moreau and Vuille, 2018), donde los estados, pese a llegar a consumir más energía, contabilizan reducciones energéticas con motivo de desplazar el consumo fuera de las fronteras nacionales. Para hacer frente a ello han surgido las Mediciones en base al Consumo (Consumption Base Accounts, CBA) o las mediciones de las huellas, donde se analizan los consumos directos e indirectos derivados de los modelos de consumo de cada país, haciendo uso de la metodología Global Multi Regional Input-Output (GMRIO) (Kanemoto et al., 2012; Munksgaard and Pedersen, 2001; Peters, 2008; Wiedmann et al., 2007). La medición de las huellas permite entender la compleja realidad de los mercados globalizados, facilitando el alcance de los Objetivos del Desarrollo Sostenible (SDG).

Esta tesis se divide en tres apartados. En el primero, a través de un estudio cualitativo, se han analizado las transiciones hacia un modelo energético sostenible de cinco estados (Brasil, Ecuador, Cuba, España y Alemania) en el marco de un grupo de investigación multidisciplinar. En el segundo, se han analizado de forma cuantitativa las iniciativas energéticas más significativas de tipo *Bottom-up* de uno de los cinco estados (Alemania). En el tercero, teniendo en cuenta la huella energética, se han detectado los estados que llegan a incrementar su Índice de Desarrollo Humano, reduciendo su consumo energético. Para ello, se ha calculado el Índice de Desacople de 127 naciones. El fenómeno de desacople o el "Decoupling" es una metodología que permite medir si efectivamente se está avanzado hacia la transición energética.

Esta tesis es un aporte hacia la definición cualitativa y cuantitativa de las actuales transiciones energéticas, a través del análisis de casos de estudio. Se ha detectado, asimismo, la concurrencia de un cambio de valores en el Norte Global y en el Sur Global para permitir las transiciones energéticas. Además, teniendo en cuenta la huella energética, se han identificado seis "naciones ejemplares" entre las 127 analizadas, que han conseguido reducir su consumo energético de forma constate a la vez que han continuado incrementando su Índice de Desarrollo Humano.

(ENGLISH / INGLÉS)

The current energy model is unsustainable and it has been internationally accepted that a transition towards a sustainable energy model is required. There are three main factors which make this energy transition unavoidable. Firstly, according to the Fifth Assessment Report (IPCC, 2015) of the United Nations Intergovernmental Panel on Climate Change (IPCC), the burning of fossil fuels by the energy sector is one of the main factors responsible for global warming. More specifically, the CO_2 emissions produced by the anthropogenic burning of fossil fuels and cement production stood at 0.16 $GtCO_2eq$ in 1850, yet had soared to 32.28 $GtCO_2eq$ by 2015, a rise of 20,175 per cent.

Secondly, it has now been officially recognised that, as a result of reaching *Peak Oil*, a change from our fossil fuels-based energy system has become necessary and this means using renewable energy sources. According to the *Association for the Study of Peak Oil and Gas* (ASPO), "[…] world petroleum production will have fallen by 50% by 2030" (Zittel, 2012).

Thirdly, the current energy model is one of the main underlying reasons for social injustice in the Global South. Some examples of this injustice are: the emotional impact of petroleum spillages (León et al., 2014), the social impact of new electrical networks in remote areas, (Valer et al., 2014), the impact of petroleum extraction, (Bozigar et al., 2016), the impact of pipe-laying in rural areas (Welford and Yarbrough, 2015) and the energy poverty resulting from the lack of equity in energy distribution (González-Eguino, 2015) (Alvarez, 2017). Similarly, energy poverty has not only increased in the Global South but also in the Global North (in the so-called "Fourth World"). For instance, in the European Union (EU) 10.8% of citizens have had difficulties heating their homes and a similar proportion have had problems paying their electricity and gas bills (Pye and Dobbins, 2015).

The United Nations has drawn attention to the environmental and social impact of the consumerist models in Developed Countries (namely the Global North), and its *Sustainable Development Goals* (SDG) outline the necessary changes to the current model (UN, 2015). First of all, the 12th Goal underlines the need for a direct change in energy consumption patterns. Secondly, the 7th Goal calls for a reduction in the amount of fossil fuels consumed by the energy system. Finally, the 10th Goal aims to overcome the issue of inequity.

Similarly, the *Planetary Boundaries (*PBs) outline the limited resources available; according to the latest research, current energy consumption stands at between 2 and 6 times sustainable levels (O'Neill et al., 2018). As a result, if both global energy consumption (13,648 Mtoe in 2015) according to International Energy Agency (IEA) and global population (7.36 Billion in 2015, World Bank) figures are taken into consideration, per capita energy consumption should be between 3.6 and 10.8 $MWh\cdot cap^{-1}\cdot yr^{-1}$. For this reason, in different countries, significant steps have been taken to reduce energy consumption such as

National Energy Efficiency Action Plans (NEEAPs) (European Commission, 2017) and the Energy Efficiency Directive 2012/27/EU (European Parliament, 2012).

However, there is a significant issue with these actions, in that Production-Based Accounts (PBAs) have been used to measure national energy consumption. Consequently, the energy consumed in other states embodied in imports of foreign products and services is not taken into consideration (Akizu-Gardoki et al., 2018). In accordance with the current energy accounting system, countries that have offshored industrial processes and production services seem to be more sustainable, since offshored consumption is not taken into account. This situation has resulted in "virtual energy reductions" (Moreau and Vuille, 2018) whereby despite the fact that certain states are consuming more energy, because they do so beyond national borders, they appear to be consuming less. To counter this issue, Consumption Based Accounts (CBAs) —measures to quantify the Energy Footprint— have been created whereby the entire energy consumption resulting from national lifestyles is taken into consideration using the Global Multi-Regional Input-Output (GMRIO) methodology (Munksgaard and Pedersen, 2001), (Wiedmann et al., 2007), (Peters, 2008), (Kanemoto et al., 2012). Energy Footprint accounting enables us to understand the complex reality of the globalised international market and start out on the path towards reaching SDGs.

This thesis is laid out in three different sections. The first is a more general section with a cross-disciplinary team researching the transition towards a sustainable energy model being implemented in five selected states. The second section chooses one of these states (Germany) and conducts an in-depth analysis of three renowned national *Bottom-up* initiatives. The last section, taking the Energy Footprint into consideration, analyses the states which managed to increase their HDI without increasing national energy consumption, by comparing 127 states using the indicator known as the *Decoupling Index*. "Decoupling" is one of the indicators that allows us to find out whether or not energy transition is actually occurring.

This doctoral thesis aims to improve on the definition of the qualitative and quantitative characteristics of the energy transitions currently being implemented, and is based on practical case studies. Beyond this, it aims to define the change in values occurring which enables the energy transition in the Global South and the Global North. Finally, in different states, in accordance with their energy footprint, it has been observed that there are "exemplary states", as well as states where "virtual decoupling" between energy consumption and HDI takes place.

02 Introducción
Introduction

2 Introduction and Background / Introducción y Antecedentes

2.1 Origen de la tesis

Esta investigación nace en el Departamento de Expresión Gráfica y Proyectos de Ingeniería, y constituye un esfuerzo por analizar la sostenibilidad de los productos y servicios. Para poder medir la sostenibilidad, se ha medido la energía "embebida" en los mismos. Esta premisa ha dirigido el sentido de la tesis al amplio mundo de la energía, ampliando los límites del actual conocimiento de la ciencia en este ámbito.

2.1.1 Huella energética

La Huella Energética (EF, con origen en el concepto de Huella de Carbono, CF) es el eje central de esta tesis. Resulta cada vez más frecuente el análisis de los impactos "directos", tales como las emisiones CO_2 de un vehículo (ver *Figure-1-Figura*), el consumo de agua de un lavavajillas, o el consumo eléctrico de una televisión. Sin embargo, y gracias a las metodologías *Life Cicle Assessment* (LCA) y *Global Multi Regional Input-Output* (GMRIO) es posible hoy en día realizar además una estimación de los impactos indirectos. En esta tesis se ha empleado la metodología GMRIO, creada por el economista Wassily Leontief, y utilizada posteriormente en el sector de *Ecological Economics* (Cave, 1981). Gracias a esta metodología, se pueden medir los flujos de energía embebidos en los bienes y servicios (*embodied energy*) que importan y exportan las naciones. Dicha metodología está completamente aceptada por el mundo académico; es más, se ha convertido hoy en día en una herramienta puntera de investigación (Wiedmann and Lenzen, 2018).

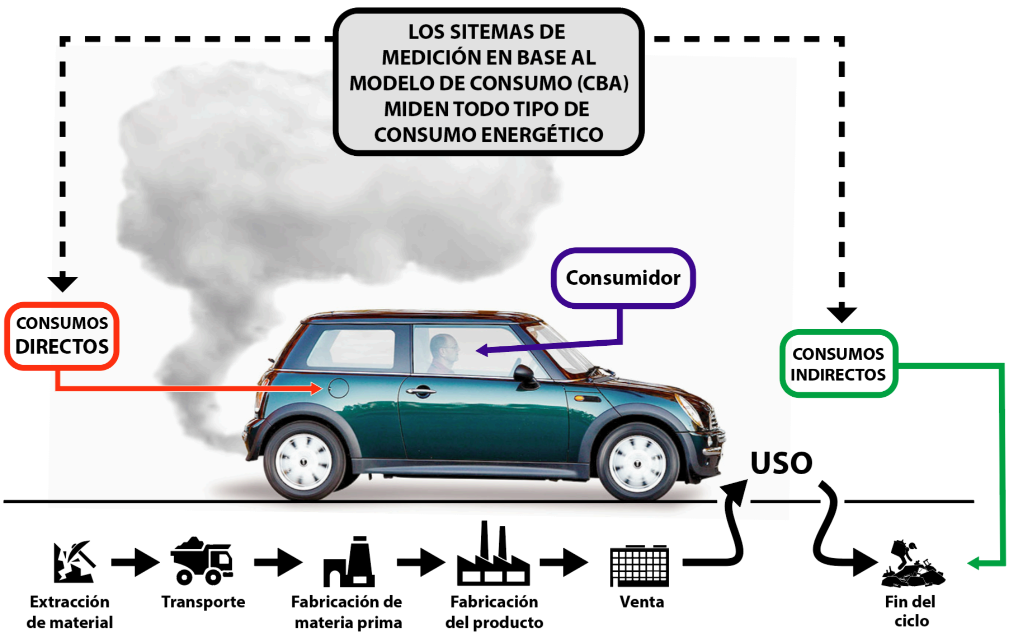

Figure-1-Figura. Los cálculos de Huella Energética (Consumption Based Accounts, CBA) miden los impactos directos e indirectos realizados por el consumidor.

2.1.2 Decrecimiento

El objetivo del decrecimiento consiste en obtener una mejor calidad de vida (tanto ambiental como social) a través de una reducción del consumo (Latouche, 2007; Weiss and Cattaneo, 2017). En esta tesis se ha realizado un esfuerzo por incluir dicho principio en el sector energético, analizando el origen de las reducciones de consumo energético que actualmente acontecen en países de una elevada demanda. En este estudio se ha integrado el "desarrollo socioeconómico" a través del Índice de Desarrollo Humano (HDI)

2.1.3 Democracia y Justicia Energética

Para poder cambiar nuestro modelo energético se considera necesario tener la libertad de poder tomar las decisiones sobre el mismo (Sovacool and Dworkin, 2015). Es por ello que la justicia y democracia energética son dos conceptos que han estado presentes a la hora de analizar el diseño de nuevos modelos energéticos sostenibles, así como sus modelos de integración, sobre todo durante el proceso de análisis de los cinco casos de estudio globales realizados en la primera fase, y en los tres casos de estudio locales realizados en Alemania.

2.1.4 Energías Renovables

Este estudio no pretende analizar las diferentes fuentes de generación de energía; por ello, a lo sumo, se realizarán mediciones de la presencia de las energías renovables, ofreciendo el resultado en forma de porcentaje. Es un hecho que las energías renovables son una pieza fundamental para la construcción del nuevo modelo de producción energético sostenible (Dóci et al., 2015; Geels, 2012). En esta tesis, sin embargo, se ha realizado un esfuerzo en medir los modelos de consumo sostenibles, más que los modelos de producción sostenibles, así como el impacto que pueden llegar a tener en los mismos las nuevas formas de organización social.

2.2 Modelo energético insostenible del siglo XXI

El actual modelo energético está basado en los combustibles fósiles. En el año 2015, el 84% de los 159 PWh que se consumieron a nivel mundial fue obtenido de fuentes no renovables (International Energy Agency, 2015). Como muestra la *Figure-2-Figura*, según la Agencia Internacional de la Energía (IEA), el consumo mundial de energía ha crecido un 95% desde el año 1978. La población mundial, mientras tanto, ha aumentado un 72% durante el mismo período (World Bank, 2017). En consecuencia, se ha mantenido casi constante por consiguiente la media de energía anual consumida por persona. Si hoy en día se pudiera realizar un reparto uniforme de los recursos energéticos que disponemos a nivel planetario, a cada persona le corresponderían 21,6 MWh. No obstante, esa media es meramente teórica, es decir, mientras el consumo promedio de ciertos estados asciende a 95 MWh (Luxemburgo, con 0,46 millones de habitantes), en otros estados se consumió de promedio 4 MWh de energía por persona (República Democrática de Congo, 77,26 millones de habitantes) en 2015. Según Vaclav Smil (Chiao et al., 2010; Smil, 2010), el consumo mundial en el año 1750 fue de 10 EJ, que se corresponde con 3,5 MWh por persona al año (según Naciones Unidas, había 791 millones de habitantes). Es decir, mientras ciertos países mantienen niveles energéticos de consumo similares a hace 250 años, el incremento ha sido muy significativo en otros.

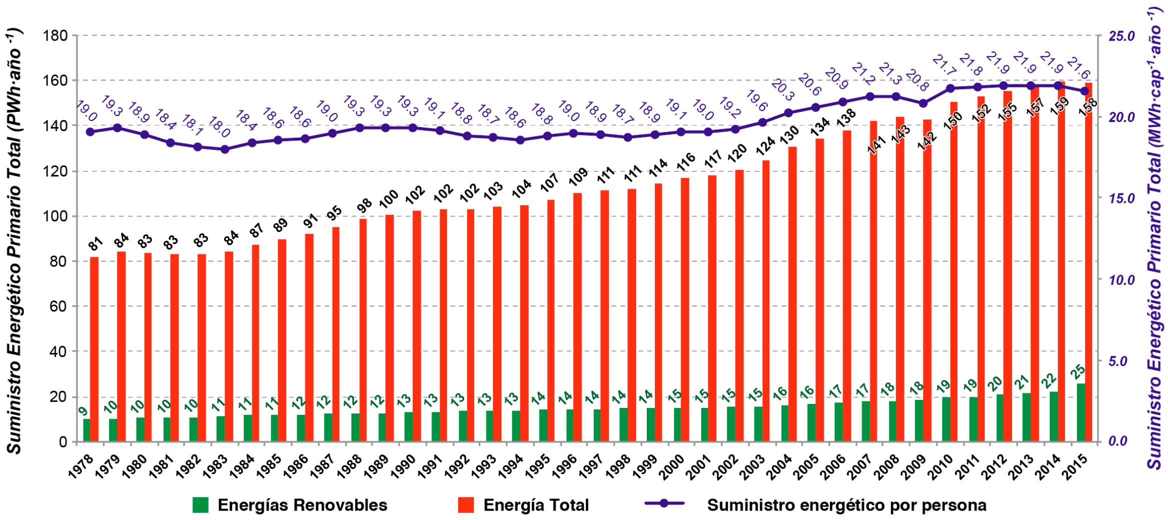

Figure-2-Figura. Abastecimiento energético global entre 1978-2015, presencia de las energías renovables y consumo medio de la energía primaria total (TPES) por persona.

En resumen, el actual modelo energético está definido por dos características: se basa en energías fósiles y tiene significativas las diferencias de consumo energético entre estados o clases sociales.

Según el Quinto Informe de Evaluación del *Intergovernmental Panel on Climate Change* (IPCC, 2015), el consumo de energías fósiles del actual modelo energético es la causa principal del efecto invernadero. A nivel global, en el año 1850 las emisiones antropogénicas debidas a la quema de combustibles fósiles fueron 0,16 $GtCO_2$ (IPCC, 2015), y en el año 2015 llegaron a emitirse 32,28 $GtCO_2$ (International Energy Agency, 2015), esto es, se produjo un incremento del 20.175%. Por consiguiente, "[…] la temperatura superficial del planeta Tierra sufrirá un aumento notorio en el siglo XXI en todos los posibles escenarios analizados. Según las predicciones, se incrementará la duración y la frecuencia de las olas de calor y aumentará la cantidad de las lluvias y la intensidad de las mismas en diferentes zonas del mundo. De la misma forma, subirá el nivel del mar, la temperatura y el nivel de acidez de los océanos." (IPCC, 2015).

Se considera que la única forma de evitar estos efectos es la reducción de la concentración del CO_2 en la atmosfera (Hansen et al., 2016). Según el artículo de James Hansen, ex director de la agencia NASA (Hansen et al., 2016), para evitar que la temperatura de la tierra aumente en 2 °C, como recomienda el IPCC, se debería dejar bajo tierra –sin quemar– una parte de los combustibles fósiles disponibles. McGlade y Ekins definieron que, para que el incremento de temperatura pueda ser inferior a los 2 °C, un tercio de las reservas de petróleo, el 50% de las reservas de gas y el 80% de las reservas de carbón, se deberían mantener bajo tierra, sin usar, hasta el año 2050 (McGlade and Ekins, 2015).

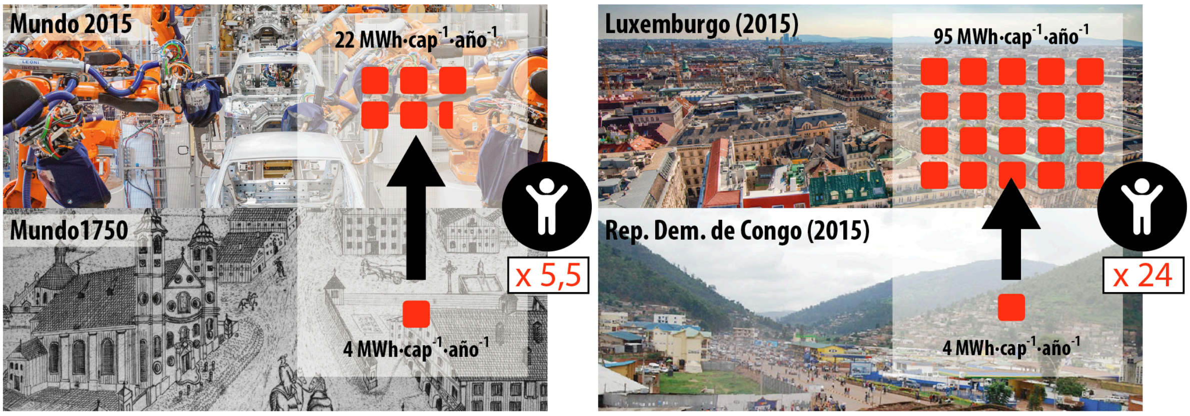

Figure-3-Figura. El consumo medio global de energía por persona se multiplicó por 5,5 entre 1750 y 2015. Sin embargo, en algunos estados se mantiene la media de consumo de hace 250 años.

Por otro lado, son insostenibles las injusticias sociales en la distribución de los recursos del actual modelo energético (por ejemplo, ver *Figure-3-Figura*), y sobre todo los impactos sociales que se generan con respecto a los estados del Sur Global: impactos de derrames de petróleo en comunidades rurales (León et al., 2014); impactos sociales por la integración de nuevas redes eléctricas en regiones aisladas (Valer et al., 2014); impactos en la extracción del petróleo (Bozigar et al., 2016); impactos en entornos rurales durante la construcción de oleoductos y gaseoductos (Welford and Yarbrough, 2015); pobreza energética generada por falta de igualdad en los procesos de reparto de energía en el actual sistema centralizado (González-Eguino, 2015); o la contaminación de aguas subterráneas, agotamiento de aquíferos o impactos en la salud generados por la fractura hidraúlica (Ladd, 2013). Los impactos sociales que genera el actual modelo energético no están además integrados en el precio de mercado de los combustibles fósiles (Bridges et al., 2015). Por otra parte, en lo que ese refiere a la construcción de nuevas instalaciones energéticas con fuentes renovables, existe el riesgo de que se repita la actual estructura vertical que caracteriza el modelo de propiedad de los combustibles fósiles, fundamentada en la construcción de mega-instalaciones centralizadas de gran impacto social. (Aledo et al., 2015), la deforestación y degradación de los terrenos a causa de la producción masiva de biocombustibles (Monteiro de Carvalho et al., 2015), o el impacto de grandes centrales eólicas (Aschwanden et al., 2018; Wróżyński et al., 2016).

Además de los impactos socio-ambientales del actual sistema energético, nos encontramos, según ASPO (Association for the Study of Peak Oil and Gas), a las puertas de los límites biofísicos del planeta: "[…] la extracción de petróleo se reducirá en un 50% para el año 2030" (Zittel, 2012).

Finalmente, este predominante modelo energético se encuentra ante una crisis de valores, ya que la productividad y el crecimiento económico han sido los indicadores del bienestar del sistema actual (Herrero, 2011). Como resultado de esta crisis de valores, y unido a las injusticias sociales y los impactos ambientales, han surgido movimientos globales para cambiar el sistema energético productivista (Dóci et al., 2015; Mattes et al., 2015), articulando el proceso de construcción y búsqueda de nuevos valores. Los valores capitalistas generalizados en los países del Norte Global, han dirigido a las compañías multinacionales de generación y gestión de la energía hacia el único objetivo de maximizar las ganancias económicas. En consecuencia, se han negado los beneficios de las actividades no-productivas, como puede ser el valor de "los cuidados" o la relevancia de la conservación de la vida (Herrero, 2011). Comunidades indígenas han reivindicado en determinadas zonas una gestión ambiental más cuidadosa de las minas de uranio, reparando en otros valores no-productivos (Graetz, 2015). Estos valores están siendo reconocidos por el mundo académico (Díaz et al., 2018), pero sus beneficios no son admitidos aún por el sector industrial o los mercados.

2.3 Transición Energética

Durante la historia, los cambios estructurales profundos del abastecimiento energético primario han sido definidos como transiciones energéticas (Smil, 2010). La energía es necesaria para la subsistencia del ser humano, y para poder saciar sus necesidades básicas, tales como la alimentación, el cobijo, la salud, el transporte o las necesidades sociales. El sistema energético presente en un momento histórico lo han limitado dos factores: el tipo de recursos energéticos disponibles y el desarrollo tecnológico del momento; por ello, la presencia de la biomasa a lo largo de la historia ha sido notorio (Solomon and Krishna, 2011). Como base, el ser humano necesita para fines alimenticios un promedio entre 2.000 y 2.500 Cal diarias (World Health Organisation, 2015). Además, de no respetar ese límite (a diferencia de otros consumos energéticos), consumiendo más o menos de dichas calorías, nuestra salud puede resultar seriamente dañada.

La primera transición energética aconteció hace cerca ochocientos mil años, cuando se pasó de usar la simple fuerza directa del ser humano al uso del fuego. A través de la combustión de la biomasa, los primeros seres humanos adquirieron la capacidad de obtener calor, luz o transformar alimentos *Figure-4-Figura*. Posteriormente, tras domesticar los animales, se pudo usar su fuerza para aumentar la energía disponible de trabajo. Al mismo tiempo, sucesivas invenciones (la rueda, la fuerza con palanca, las poleas, los barcos, etc.) multiplicaron la fuerza disponible o la potencia de trabajo. El uso de los recursos naturales (molinos de agua o de viento), también aumentó la cantidad de energía disponible. A continuación, la máquina de vapor tuvo especial relevancia, expandiendo el uso del carbón. En el siglo XIX, con la invención y difusión del motor de combustión interna, comenzó el uso generalizado del petróleo. Por consiguiente, es un hecho que la mayoría de las transiciones energéticas (salvo las civilizaciones desaparecidas por agotamiento de recursos) se han llegado a superar, tras un periodo de crisis, a razón de un aumento del consumo energético total.

Ello explica el hecho de que se haya dado por sentado que el aumento del consumo de energía de un país repercute en el progreso de la economía (incrementando el Producto Interior Bruto) y la calidad de vida del mismo país (Cabrera and Jaffe, 1998; Meadows et al., 1972). Es cierto de que históricamente el uso de una mayor cantidad de energía (como se puede apreciar en la *Figure-4-Figura), ha aumentado la capacidad de "trabajo", aumentado la cantidad de alimentos, los productos manufacturados o los servicios ofrecidos, y por lo tanto mejorando la calidad de vida de los habitantes* (Meadows et al., 1972). En consecuencia, el aumento del TPES se ha relacionado de forma proporcional con la calidad de vida obtenida. En 1998, Cabrera y Jaffe concluyeron que existía la misma relación lineal entre la energía eléctrica consumida y el aumento del GDP (Cabrera and Jaffe, 1998). Sin embargo, se ha descubierto más adelante, que dicha proporcionalidad entre consumo energético y la calidad de vida obtenida se debilita en los estados que tienen altos niveles de consumo energético (Arto et al., 2016; Martínez and Ebenhack, 2008; Pasternak, 2000).

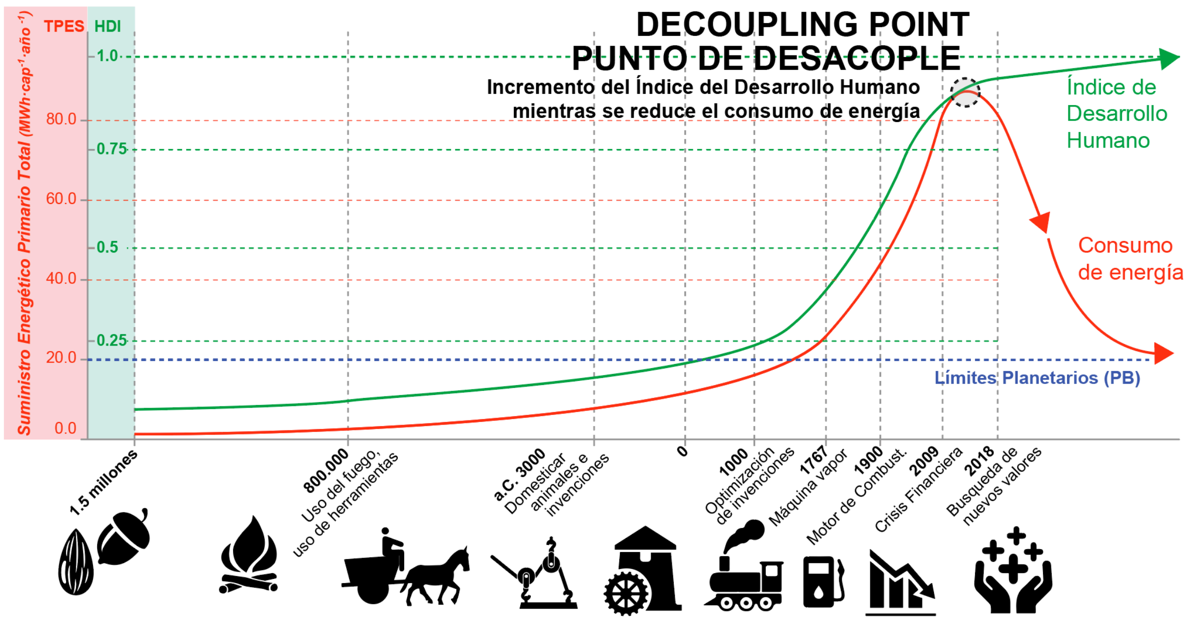

Figure-4-Figura. **El consumo energético y el Índice de Desarrollo Humano (HDI) alcanzado.**

Hoy en día, sin embargo, nos enfrentamos a una nueva situación en la que nos encontramos ante los límites físicos de los recursos de nuestro planeta. Nace además en distintos sectores sociales el sueño de crear un nuevo modelo energético que se base en los "cuidados", fomentando el cuidado del planeta y el cuidado entre los seres humanos

(Urkidi et al., 2015). En esta situación, distintas naciones han llegado a una nueva y diferente transición energética, en la que el consumo de energía se desacopla del bienestar o calidad de vida alcanzado (*Figure-4-Figura)*. Por primera vez en la historia, parece factible aumentar el Índice de Desarrollo Humano a la par que se reduce el consumo energético. Esta tesis desarrolla un esfuerzo para la comprensión de dicha relación en diferentes estados en el marco de esta venidera transición energética.

03 Objetivos
Goals

3 Goals / Objetivos

3.1 Objetivo General

El objetivo general de esta tesis reside en analizar nuevos modelos energéticos que posibiliten un desarrollo socio-económico sostenible. Este objetivo general comprende tres puntos: análisis cualitativo del diseño de nuevos modelos energéticos (1), análisis cuantitativo de nuevos modelos energéticos (2) y análisis del impacto en el consumo energético nacional causado por los modelos de integración de acciones en el sector energético (3).

Esta tesis se alinea, asimismo con tres de los Objetivos del Desarrollo Sostenible (Sustainable Development Goals, SDGs) de las Naciones Unidas (UN, 2015). En primer lugar, con el objetivo número siete, que reivindica un modelo energético sostenible y accesible para todo ser humano; en segundo lugar, con el objetivo número diez, que defiende la reducción de las diferencias económicas entre los individuos; y por último, con el objetivo número doce, que promueve la búsqueda de nuevos modelos de consumo sostenible.

3.2 Objetivos Específicos

Los tres puntos comprendidos en el objetivo general han dado lugar a los tres objetivos específicos de la tesis. En las próximas líneas se desarrolla cada objetivo específico (OE) y se resumen además en la ***Error! Reference source not found.***.

1. **OBJETIVO ESPECÍFICO_1:** consiste en analizar de forma cualitativa el diseño de nuevos modelos energéticos. El objetivo específico trata de comprender, a través de un estudio cualitativo, cómo se está desarrollando la transición energética en distintos estados. Se pretende analizar y comparar, a través del uso de la investigación multidisciplinar – integrada dentro del proyecto de investigación TRADEBU (Urkidi et al., 2015)–, las transiciones energéticas experimentadas en cinco estados previamente seleccionados (Cuba, Ecuador, Brasil, España y Alemania). Entre los casos de estudio, se han seleccionado países del Norte Global y del Sur Global, a fin de poder comparar las dinámicas, problemáticas y logros de los llamados países desarrollados y no desarrollados.

2. **OBJETIVO ESPECÍFICO_2:** además del estudio cualitativo, este segundo objetivo pretende cuantificar los logros de las transiciones energéticas de tipo *Bottom-up.* Para ello, se ha elegido un solo estado de los previamente analizados en el OE_1: Alemania. El objetivo específico es analizar los tres casos de transición energética más significativos y ofrecer resultados cuantitativos de los logros de cada proceso de transición. Se pretende, además, comparar la realidad energética media del

estado con la de cada caso de estudio, para poder valorar hasta qué punto se ha podido alcanzar un cambio significativo.

3. **OBJETIVO ESPECÍFICO_3:** comparar a escala mundial en diferentes naciones la relación que existe entre la energía consumida y el Índice de Desarrollo Humano (HDI) alcanzado. Para ello, se tiene que calcular, en primer lugar, la huella energética, teniendo en cuenta la energía importada y exportada embebida en productos y servicios de cada estado. A continuación, tras concluir la relación entre la huella energética y el HDI en cada país, se identificarán los "países ejemplares". Los paises ejemplares, se caracterizarán por ser capaces de reducir su consumo energético a la par que aumentan su Índice de Desarrollo Humano, generando una situación de desacople o "decoupling".

Figure-5-Figura. Resumen de los objetivos específicos de la tesis doctoral.

Cada objetivo específico ha dado lugar a una publicación en revista internacional de impacto (Q1 o Q2).

04 Hipótesis
Hypothesis

4 Hypothesis / Hipótesis

A continuación se exponen las hipótesis que corresponden a los tres objetivos específicos previamente establecidos (Capítulo 3) en esta tesis, previendo los resultados de las mismas:

1- Están surgiendo distintas iniciativas de transiciones energéticas en determinados estados. En estas transiciones, se prevé que, además de los componentes técnicos, sean relevantes los desencadenantes y componentes sociales. En estas transiciones que están aconteciendo, tanto en el Norte Global como en el Sur Global, se percibe además que la participación y presencia de la ciudanía y de los movimientos sociales es notoria. Por el contrario, se cree que el rol de los estados y las compañías multinacionales de energía no está siendo activa, o de ayuda, en estos procesos de cambio, empujados por la inercia del Business As Usual. Es por esto que se prevé la necesidad de que exista en las transiciones energéticas una unificación entre los objetivos del estado y la ciudadanía. Al mismo tiempo, se pronostica que deberán tomarse en cuenta los relevantes valores no-productivos que se están trabajando en varios estados del Sur Global a la hora de diseñar los nuevos modelos energéticos de los estados del Norte Global.

2- Se predice que los logros que se están obteniendo en las transiciones energéticas de tipo *Bottom-up* son significativos. Se cree que estos logros se pueden manifestar en el aumento de la integración de las energías renovables o en la reducción del consumo energético, con respecto a medias del mismo entorno. En este sentido, se prevé que en esta tesis se realice una identificación concreta de los logros de las transiciones energéticas de tipo *Bottom-up.* Además, se cree que en el caso concreto de Alemania, la compenetración de los movimientos estatales de transición energética y los movimientos de base (tipo *Bottom-up*) puede acelerar una transición energética general.

3- A la hora de analizar la transición energética a nivel global, se prevé que, a pesar de que en determinados estados se reivindica el haber reducido las tasas de consumo energético (como en Dinamarca, Austria, Suiza, etc.) nos podamos encontrar frente a una "reducción virtual", causada por la exportación de la producción industrial a otras naciones. Se cree que la medición total del consumo energético de los países a través de la huella energética, puede ser indispensable para poder dar lugar a una verdadera transición energética. Además, se pronostica que se pueda reducir el consumo energético, mientras se continúa aumentando el HDI. Se sospecha que los actuales "estados energéticamente referentes" o ejemplares (como por ejemplo Alemania y Dinamarca), no estén correctamente seleccionados con motivo de no tomarse en consideración la huella energética. Los estados referentes futuros serán seguramente diferentes en caso de que se tenga en cuenta la necesidad energética total de los modelos de consumo de los estados.

05 Metodología
Methodology

5 Methodology / Metodología

En esta tesis doctoral se han empleado tres metodologías principales: el estudio multidisciplinar, el análisis "estudio de caso" y la metodología de análisis de *Global Multi-Regional Input-Output*.

5.1 Multidisciplinary research / Investigación Multidisciplinar

La primera parte de esta tesis se ha desarrollado (incluso se podría decir creado) dentro del proyecto de investigación TRADEBU (Urkidi et al., 2015). Tomando como base el estudio multidisciplinar, se ha desarrollado un artículo publicado en una revista científica de categoría Q1 (Akizu et al., 2017). En general, el sector de la energía se ha alejado del sector social. Por consiguiente, resulta especialmente difícil detectar, y posteriormente evitar, los impactos sociales del actual modelo energético. El objetivo de este estudio multidisciplinar es precisamente ofrecer distintas perspectivas a la investigación que permitan identificar de forma correcta los impactos del actual modelo y presentes procesos de cambio. Se han tenido en cuenta en esta investigación aportaciones de profesores de la universidad, investigadores y personas pertenecientes a movimientos sociales. En el primer artículo científico que conforma esta tesis, se han reflejado las conclusiones de los distintos puntos de vista presentes. En la investigación, en general, Izaro Basurko, Martin Mantxo y Rosa Lago han aportado la visión de los grupos o movimientos sociales; Iñaki Barcena ha trabajado la visión socio-política; Leire Urkidi ha dirigido la visión geo-social; y el autor de la tesis (Ortzi Akizu) ha aportado la visión ingenieril y de la cooperación para el desarrollo.

5.2 Case study analysis / Análisis "estudio de caso"

En los dos primeros artículos de esta tesis, la metodología principal ha sido el análisis de casos de estudio. Este tipo de análisis permite la investigación cualitativa y cuantitativa de iniciativas o acciones previamente seleccionadas y el análisis de los nuevos fenómenos sociales o modelos conceptuales que se están generando en la sociedad (Yin, 2009).

El análisis de casos de estudio posibilita abordar una investigación profunda desde perspectivas múltiples de las características o particularidades de un proyecto concreto, una idea política, un programa o un sistema, en el contexto de la "vida real" (Simons, 2009). Para complementar la metodología de "estudio de caso", Thomas defiende que "un caso de estudio debe englobar dos elementos: unidad política e histórica, que se define como el 'sujeto' o tema, y el marco analítico o teórico, que se define como el 'objeto'" (Thomas, 2011).

Por otra parte, debe especificase que los casos estudio que se han trabajado en el primer objetivo específico de esta tesis han sido seleccionados por los expertos que han participado en el proyecto TRADEBU (profesorado de la Universidad del País Vasco, activistas de Ecologistas en Acción Euskadi, e investigadores de Parte Hartuz y Ekopol). La elección de los casos de estudio del segundo objetivo específico, sin embargo, se ha efectuado a partir de la relevancia de las inciativas energéticas *Bottom-up* existentes en Alemania. Es decir, los tres casos analizados se han seleccionado teniendo en cuenta la popularidad de cada caso en buscadores genéricos de internet y de su presencia (computando el número de citas de las mismas) en buscadores online de investigaciones científicas (Akizu-Gardoki et al., 2018).

A la hora de aplicar esta metodología, se han realizado encuestas cualitativas y cuantitativas en las comunidades y movimientos analizados. Cada comunidad o iniciativa ha sido personalmente visitada y se han llevado a cabo las entrevistas necesarias para obtener la información.

La metodología Multi-Level Perspective (MLP) se ha empleado en investigaciones similares por el amplio espectro de resultados que ofrece (Geels, 2012). En nuestro caso, sin embargo, se consideró que el análisis de "estudio de caso" era más apropiado, a efectos de poder centrarnos en las comunidades que generan los cambios de modelos y no perder el foco en agentes exteriores (regionales o nacionales). Así, los agentes exteriores han sido también analizados, pero en menor medida que con la metodología de MLP.

5.3 Global Multi-Regional Input-Output (GMRIO) / Input-Output Multi-Regional Global

En el tercer artículo de esta tesis se han realizado las Mediciones en base al Consumo (CBA). Es decir, se ha calculado la Huella Energética Primaria Total (Total Primary Energy Footprint, TPEF) partiendo del Suministro Energético Primario Total (Total Primary Energy Supply, TPES) que provee la Agencia Internacional de la Energía (International Energy Agency, IEA). Para ello, se ha hecho uso de la metodología GMRIO y la base de datos económica "Eora 26"(Lenzen et al., 2012). Se han tenido en cuenta 189 estados y 26 sectores productivos. Para poder calcular el TPEF de cada estado se ha usado la metodología desarrollada por Wassily Leonfief, que más tarde ha sido usada para el análisis de impactos ambientales (Lenzen et al., 2004; Oita et al., 2016; Owen et al., 2017; Wiedmann et al., 2007).

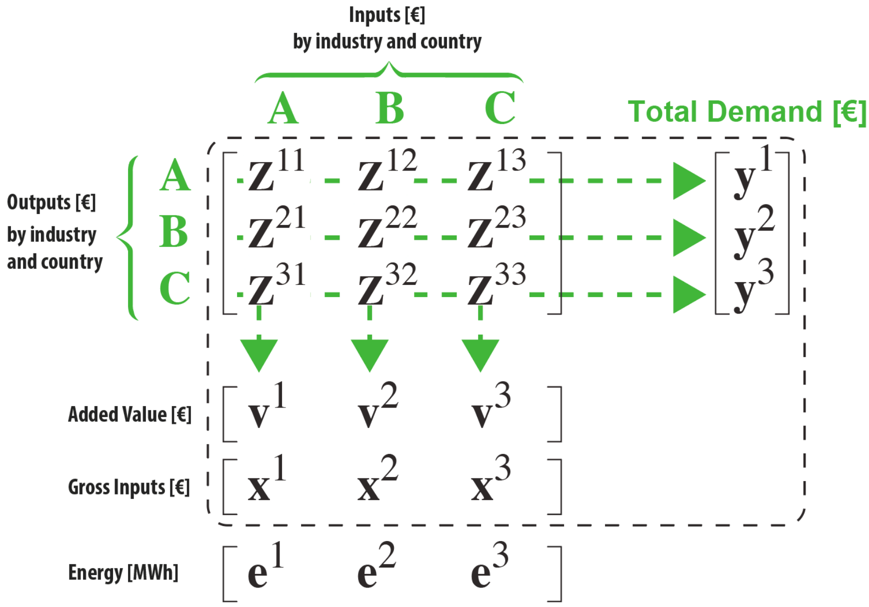

Figure-6-Figura. Esquema general de la metodología GMRIO usada en la tesis.

De esta forma, se han conseguido modificar los cálculos realizados de Mediciones en base a la Producción (PBA), que corresponden al vector **e**. El vector **e**, que está organizado computando los consumos de cada una de los 26 industrias para cada país, se transforma teniendo en cuenta las necesidades finales de productos y servicios que tienen los habitantes de cada país por sector (matriz **Y**), tal y como se aprecia en la *Figure-6-Figura*. Este método se conoce como la "Ecuación de Leontief" y en ella: la matriz **Z** representa las entradas y salidas económicas entre sectores industriales; la matriz **Y** representa la demanda económica final de los consumidores por sector; y el vector **x** representa el consumo económico total de cada sector industrial por país (ver *Figure-6-Figura*).

06 Análisis Global
Global Analysis

6 1_ARTIKULUA / PAPER_1:

TRACING THE EMERGING ENERGY TRANSITIONS IN THE GLOBAL NORTH AND THE GLOBAL SOUTH

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Abstract

During recent centuries, in the Global North, every energy crisis has been overcome, sooner or later, with a transition that has led to an increase in the average per capita energy consumption. Currently, due to the environmental and social impacts of the dominant high-consumption and fossil-fuels based energy model, we are seeing some initiatives that pursue a transition towards a democratic, low-carbon and low-energy consumption energy system. This work analyses some of the socio-cultural, technological, economic and political factors that are leading to different multi-scale transitions towards low-energy societies around the world. It examines several different cases of transition and proposals from the Global South and Global North. Furthermore, given the limitations of the local or partial nature of these case studies, we also analyse their national energy contexts taking into account the hidden energy flows. These data integrate the total energy needed to provide the goods and services consumed by citizens and indicate the sectors that should be targeted to bring about genuine change, which sometimes differ from the transition paths signposted by national governments. The specific lessons extracted from the case studies in this research may contribute to a social learning process, promoting democratic and sustainable energy models in a number of regions of the world: *Peak Oil* could be an

opportunity; energy needs to be equitable, not only renewable; there should be more sincerity and transparency in public energy data communication; energy should be controlled in a public or cooperative way; citizens should take control of their own investments in the energy sector; energy should be a right, not a commodity; community-based consumption could reduce energy consumption; and sustainable urban development should be implemented in cities and towns, where energy consumers could also become producers.

Keywords:

energy transitions, energy democracy, revolving doors, hidden energy flows, energy literacy

Highlights:

- Social fairness should be taken into account in the upcoming energy transition.

- Analysed *Bottom-up* transition cases drastically reduced their energy consumption.

- Energy should be a right, not a commodity.

- Public energy management is a key factor in the upcoming energy transition.

6.1 Introduction

Human beings have always needed energy to satisfy their basic requirements such as food, shelter, health, transportation, and social needs. The energy used for these purposes has been the result of a combination of the availability of a particular resource and the technological development for processing the available resource. Hence, biomass energy has dominated throughout history (Solomon and Krishna, 2011). More recently, new factors have influenced the choice of resource, related to the economic and political strategies first of countries, and then of international brands. There is no longer a direct relationship between the personal human needs of inhabitants and the chosen energy source. All these factors have generated shifts in resource use, and we call these energy transitions. However, there has been a constant trend during these energy transitions in industrialised cultures: a greater amount of energy has been consumed per inhabitant after each transition. According to Smil, the world's total primary energy supply (TPES) increased from just over 10 EJ in 1750 (taking into account that according to the UN there were 791 million inhabitants and the consumption per capita per year was 3,500 kWh) to about 400 EJ in the year 2000 (Chiao et al., 2010) (taking into account that according to the UN there were 6.52 billion inhabitants and the consumption per capita per year was 17,000 kWh) with a 4,000% increase in the total worldwide consumption of resources in the last 150 years.

This is the reason why until recent years the historical indicator of development, GDP, was considered to have a causal relationship with the energy consumption level (Soytas and Sari, 2003), since in the last decades of economic growth "energy use increased in almost direct proportion to the economy" (Hall and Klitgaard, 2011). With more emphasis on the Global South, the increase in GDP is still directly related to the increase in energy consumption (Bulut and Yıldız, 2016) although new efforts are being made to promote low-cost and low-energy product development (Firat, 2014). Nevertheless, two critical points arise here, firstly that the increase in energy consumption has been totally unfair between different countries (Arto et al., 2016), as well as among the different social classes in the same country. China is one of those countries in which these phenomena are most readily observed (Li et al., 2014). Secondly, if new indicators are used to measure the development of a country such as the Human Development Index (HDI), the causal relationship between energy consumption and the level of development ceases to exist in high HDI level countries. According to Martínez et al. (Martínez and Ebenhack, 2008) there are no countries with both a HDI above 0.7 and a per capita energy consumption (PCEC) below 400 kgoe per year (4,700 kWh), and no country with both an extremely low HDI and a PCEC value superior to 800 kgoe (9,300 kWh). Nevertheless, this direct relationship between HDI and PCEC is not directly proportional in "energy-advantaged nations" where excess energy is spent with no real improvement in the quality of life. This hypothesis agrees with that of Dias, who argues that there could be "a 1.2 tep (14,000 kWh) consumption reduction from developed countries with no significant life quality loss to help reduce the natural resource depletion." (Dias et al., 2006), (Arto et al., 2016). A later study by Steinberger states that to obtain a 70-year life expectancy there is a trend towards a reduction in the energy required. Whereas in 1975 100 GJ (27,800 kWh) per capita of primary energy were annually needed, by 2005 the energy required fell sharply to 74 GJ (20,600 kWh), and the same study outlines that if this trend continues, by 2030, "a life expectancy of 70 will be correlated with only 24 GJ (6,700 kWh)" (Steinberger and Roberts, 2010).

Apart from that, we are seeing glimpses of a new transition brought about by a new problem, namely the global impact of our present energy model. The main impact is environmental (especially climate change). According to the 2014 Assessment Report of the Intergovernmental Panel on Climate Change (IPCC): "Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise." Furthermore, the only way to avoid this effect seems to be to achieve "negative emissions", i.e., extraction of CO_2 from the atmosphere (Hansen et al., 2016).

Secondly, there is the social impact caused by the unfair pattern of energy resource extraction or energy generation: in energy generation processes such as in dams (Aledo et al., 2015), the emotional impact caused by oil spills (León et al., 2014), the social impact of new electricity grids in remote regions (Valer et al., 2014), the impact of oil extraction (Bozigar et al., 2016), deforested and degraded land due to large plantations for biofuels (Monteiro de Carvalho et al., 2015), the impact of pipe line constructions on rural areas (Welford and Yarbrough, 2015), groundwater contamination, the depletion of aquifers and the effects on public health of hydraulic fracking (Ladd, 2013), and the energy poverty arising from inequalities in the energy distribution process (González-Eguino, 2015). The current costs of the external social impacts of energy production are not reflected in market prices (Bridges et al., 2015).

Furthermore, there is the crisis of values derived from the emphasis on productivity in a system in which growth is the centre of all well-being (Herrero, 2011). The inequality and the environmental problems associated with this capitalist system have led to several global protests and an alternative global value-articulation process. The capitalist values of the Global North have forced the energy generation companies to use economic income performance as their only point of reference, and this has meant neglecting any non-production related benefits. It has been observed that in areas inhabited by First People (Indigenous People), there have been calls for less invasive uranium mining as other non-production related values were asserted by the indigenous communities (Graetz, 2015).

Thus, it is evident that the current energy regime, highly consumption-based, profit-driven and fossil fuel-based, is in need of a shift (Elzen et al., 2005), (Verbong and Geels, 2010). The term 'regime' refers to the dominant structures, institutions, practices, paradigms and economics around a specific technology, ecosystem or societal function and 'transitions' are defined as non-linear regime shifts (Verbong and Loorbach, 2012). Each historical energy transition has been advocated to address multiple challenges faced by previous energy systems (Markard et al., 2012). Nevertheless, unlike previous transitions, which were driven mainly by the dominant social actors (e.g. governments or large economic-industrial clusters), the upcoming transition is not supported by the main national political and economic forces.

Confronting this dilemma, most policymakers and many transition scholars expect that 'green' innovation will be sufficient to bring about low-carbon transitions (Geels et al., 2014) and that *Peak Oil* may trigger a transition to other energy sources, such as innovative solar or nuclear technologies (Smil, 2012), (Bradford, 2008), (Weiss and Bonvillian, 2009). Nevertheless, concerned by this technocratic idea, other important sectors within academia are exploring the transition potential of the different existing actors, offering a social perspective on the energy problem. In these incipient research works, small-scale *Bottom-up* movements have strong relevance (Dóci et al., 2015), (Mattes et al., 2015) and their methods are disseminated in order to change the current energy paradigm (van der Schoor and Scholtens, 2015). Our research group shares this concern and attempts to figure out the feasible strategies to apply in the arising energy transition and to fill the research gap in the literature on two topics.

Firstly, a lack of research analysing integrated energy transition in the Global North and Global South has been detected. Most cases in the available literature focus on the specific transition cases of northern countries, whereas there is an absence of literature analysing the possible energy transition taking into account both global realities.

Secondly, almost all the solutions initially focusing on energy transition ultimately only focus on the electricity sector. Furthermore, the solutions mainly refer to electricity cooperatives, acting mainly on household electricity consumption (especially in the Global North), which represents just 3.35% of the energy globally consumed, or sometimes citing the global electricity consumption which still only accounts for 12.38 % (International Energy Agency, 2015). The integration of renewable electricity in northern countries is a well-studied topic in emerging social energy transitions: renewable electricity expansion in the UK through cooperatives, analysed with empirical case studies (van der Horst, 2008); renewable electricity cooperatives in Toronto (Girvitz and Lipp, 2005); renewable electricity cooperatives in Denmark, Netherlands, UK, Germany and Austria (Schreuer and Weismeier-Sammer, 2010); the influence of cooperatives within renewable energy promotion in EU countries (Haas et al., 2011); UK renewable energy and climate policy analysis by renewable electricity generation (Geels, 2012); UK electricity system analysis using MLP (Multi-Level Perspective) (Geels et al., 2014); renewable electricity feasibility in the EU (Trainer, 2013); the Netherlands' renewable electricity communities (Dóci et al., 2015) (where the heating issue has been tackled); the power for social transformation by electricity cooperatives in Germany (Debor, 2014); electricity cooperatives and public management of electricity in Wales, Spain and Germany (Kunze and Becker, 2015); citizens' renewable electricity cooperatives, limitations and opportunities in Europe (Huybrechts and Mertens, 2014); low carbon electric transitions in the UK (Chilvers and Longhurst, 2016); sustainable renewable electricity communities in Spain (Romero-Rubio and de Andrés Díaz, 2015); and the German electricity transition supported by Energiewende (Haas and Sander, 2016). In the Global South scientific literature dealing with the "energy transition" has generally considered this as a more far-reaching phenomenon, not just focused on the electric sector, or electricity cooperatives: energy transition in the transportation sector in Brazil (Solomon and Krishna, 2011); new policies to support energy transition in specific sectors in Brazil (Silveira and Johnson, 2016); the national decision-making process for oil extraction development in Ecuador (Fierro, 2016); the role of Cuban society in the energy transition in 1990 (Friedrichs, 2010); and small-scale renewable technologies for energy transition in Cuba (Cherni and Hill, 2009).

In this paper, we attempt to view "energy" not only as electricity consumed by households but also as a worldwide extraction and transformation resource that keeps our production system alive. This means that a new energy model should not merely involve a switch from a fossil electricity generation source to a renewable one, or a management shift, but a "radical social change" within the whole production and service system (Friedrichs, 2010). Thus, it has been detected that there is a research gap when empirically assessing North and South mixed case studies, confronting the energy model as a global problem. It has been detected that the conceptual results of a mixed case study analysis between North and South could provide new insights to help move towards a sustainable and fair global energy model. It has been considered that this research could be complementary with more worldwide generic energy transition theoretical models that play out future scenarios (Friedrichs, 2010), (Capellán-Pérez et al., 2015). There has been previous research, exploring the impacts of a northern open economy on the Global South and the global environment (Garmendia et al., 2016), and this article continues with this philosophy (Martinez-Alier, 2001) and focuses specifically on the energy sector.

To address this topic, the principal aim of this research paper is to identify some of the key socio-cultural, economic, political and technological factors in bringing about different multi-scale transitions towards low-energy societies throughout the world.

The analysis of these factors has been approached by examining the challenges, successes and failures of the transitions studied, which may contribute towards a social learning process in other regions of the world. How might different countries act in order to create a new democratic low-carbon energy transition? Moreover, this analysis leads to key questions being asked regarding the organisation of the energy system: What do societies use energy for? Who are the real beneficiaries of the current energy model?

The case studies to be analysed were selected based on two criteria: they represent processes towards low-carbon and low consumption systems (they are not finished transitions and some of them are civil society proposals) and they involve a democratisation of the energy model through different strategies (the transition is led by civil society or the process involves the creation of a public energy system). They are very heterogeneous experiences in an aim to encompass the diversity of different paths towards energy transition. In general, they are local in scale or partial processes, which provide interesting insights but have certain limitations. In order to present a fuller picture of the cases, we have also analysed the energy data for the countries in which the case studies took place. This study analyses the energy models of Spain, Germany, Cuba, Ecuador and Brazil and the selected local transition cases. We have also added other countries' national data for comparison purposes due to their non-standard energy behaviour (Denmark and China). Hence, we have analysed the energy consumption of different sectors (as well as transformation losses, the energy industry's own consumption and energy distribution losses), the CO_2 emissions, and the sources of the energy supply. Firstly, we identified the different ways to communicate the quantitative energy goals of the different nations in their move towards a low-carbon democratic energy model. Secondly, the Hidden Energy Flows (HEF) or the Energy Debt for each country were included in the data, in an attempt to find out the total energy consumption. Thirdly, the data analysed was then regrouped in order to highlight the most critical sectors requiring change to make our future energy model more efficient.

The large contextual differences and economic disparities between the Global North and South have caused differences between the ongoing energy transitions. On the one hand, in the Global North, the high levels of energy consumption require energy-decrease, as well as de-growth scenarios; as an absolute or relative dematerialisation (Martínez-Alier, 2012) with an equitable downscaling of production and consumption that increases human welfare and enhances ecological conditions at local and global level (Schneider et al., 2010). According to some research studies, primary energy use per capita in the most industrialised countries, on average, should be reduced at least four times, until reaching the current average consumption (Capellán-Pérez et al., 2015). Being more specific, northern countries should limit their energy consumption to 21,970 kWh/year, which could provide a HDI of 0.78 (Dias et al., 2006). Furthermore, a recent research study has demonstrated that in small scale communities a 90% primary energy reduction has been achieved with a communal living model actually improving levels of life quality (Boyer, 2016).

On the other hand, in the Global South the situation is more complex as both energy consumption levels and HDI levels remain low. This is why the coming energy transition involves not one but several different transitions, based on the respect for each country's opportunities. This paper aims to contribute towards supporting a change towards a sustainable energy model, defining sustainable not only as the concept of meeting the needs of the present without compromising the ability of future generations to meet their own needs (Daoutidis et al., 2016), but also as meaning socially fair and equal.

Finally, it should be said that this work involves more in-depth research based on an already published exploratory survey where the case studies presented here were initially analysed (Urkidi et al., 2015).

6.2 Methodology

In the same way, the analysis of the energy sector has normally been divided into independent disciplines such as economics, social studies, politics, geography, engineering… and "practitioners of these disciplines normally publish their research in separate journals" (Fouquet and Pearson, 2012).

Special effort was taken in this research to involve political, environmental and engineering researchers in an aim to offer multidisciplinary insights into prospective transitions. Furthermore, besides academic researchers, those working within social movements have also been incorporated into the main research team.

Secondly, an attempt has been made to have a clear perspective regarding the interpretation of the data. Germany, as in the case of other northern European countries, is usually considered, socially (Elcacho, 2015), (de la Fuente, 2016) and academically (Romero-Rubio and de Andrés Díaz, 2015), (Pegels and Lütkenhorst, 2014) a country that is heading towards a sustainable energy model, a global example for other countries to follow. To avoid confusion, a comparison has been made between the data for both highly developed countries and developing countries interpreting both from different perspectives.

This work has used the case study approach, which enables us to progress with research on the diverse emerging phenomena or conceptual patterns (Yin, 2009). According to Simon (Simons, 2009) "Case study is an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in a '*real life*' context.". In order to complete the definition of case study, Thomas (Thomas, 2011) argues that "a case study must comprise two elements: a practical, historical unity, which I shall call the subject of the case study, and an analytical or theoretical frame, which I shall call the object of the study.".

The selection process for the case studies has been a participatory process coordinated by the main research team, in which experts on energy at the University of the Basque Country, activists from the social movements Ecologists in Action and Engineers Without Borders and researchers from the research teams Parte Hartuz and Ekopol have participated. In the meeting different case studies were identified and what were considered the five most significant cases were selected.

Lastly, quantitative and qualitative questionnaires were conducted with the principal representative of each community/social movement. Each case was visited, and interviews carried out on location, with more than 15 people interviewed per case.

Table-1-Tabla. Analysed case studies.

Country	Subject	Section
Ecuador	Oil struggles in the Amazon rainforest	6.4.1
Brazil	Limits and impacts of the renewable hydroelectric generation	6.4.2
Cuba	How to face an oil shortage	6.4.3
Germany	Community based emerging new energy models	6.4.4
Spain	Electric energy market struggles	6.4.5

It has to be stressed that broad scope analysis, like the current one using empirical analysis, although less detailed than other studies using MLP, can provide a broader approach than MLP (Geels, 2012). Although the most extensive methodology in the analysis of transitions is the MLP method, in this research it has been considered more appropriate to use the more empirical case study analysis in order to focus on the society that is generating the change, and not on the external (regional or national) actors, even though the latter have also been analysed (at a lower level than in the MLP methodology).

6.3 Preliminary analysis of the case studies framework

This section is devoted to presenting the national energy framework of the case studies, analysing in a quantitative way the energy consumption levels. More specifically, *subsection 6.3.1* deals with the indicator of total energy consumption by country, while *subsection 6.3.2* addresses where this energy has been consumed.

6.3.1 Energy consumption of countries including hidden energy debt and avoiding misleading communication

It has often been stated that since 1990 Germany and Denmark are the countries which have best achieved the reduction percentages of emissions of greenhouse gases, in terms of kgCO_2eq levels, whereas developing countries have increased their emissions. Ironically, the same data could be presented in two different ways, depending on the reality we aim to reflect. The first interpretation could be: "Northern countries like Germany, thanks to their energy efficiency policies, have reduced their per capita emissions since 1990; Germany's has been reduced by 21.94% and Denmark's by 30.27%, whereas, the Global South countries like China, Ecuador or Brazil have increased their per capita emissions by 241%, 90.15% and 83.74% respectively." *Figure-7-Figura*. The same data could be interpreted as follows: "In 2013, German per capita emissions are among the highest in the world, followed by the emissions of China, emitting 18.65% less; Ecuador, emitting 72.86% less; and Brazil, 75.57% less emissions per inhabitant." This point shows the risk of adopting perception-based reduction strategies (such as the European 20/20/20 targets) where the most pollutive countries in 1990s, especially those from the Global North, would always have an advantage in terms of reaching reduction targets. Nevertheless, countries that are and have been less pollutive, especially those in the Global South, have more difficulty reaching this perception-based reduction target.

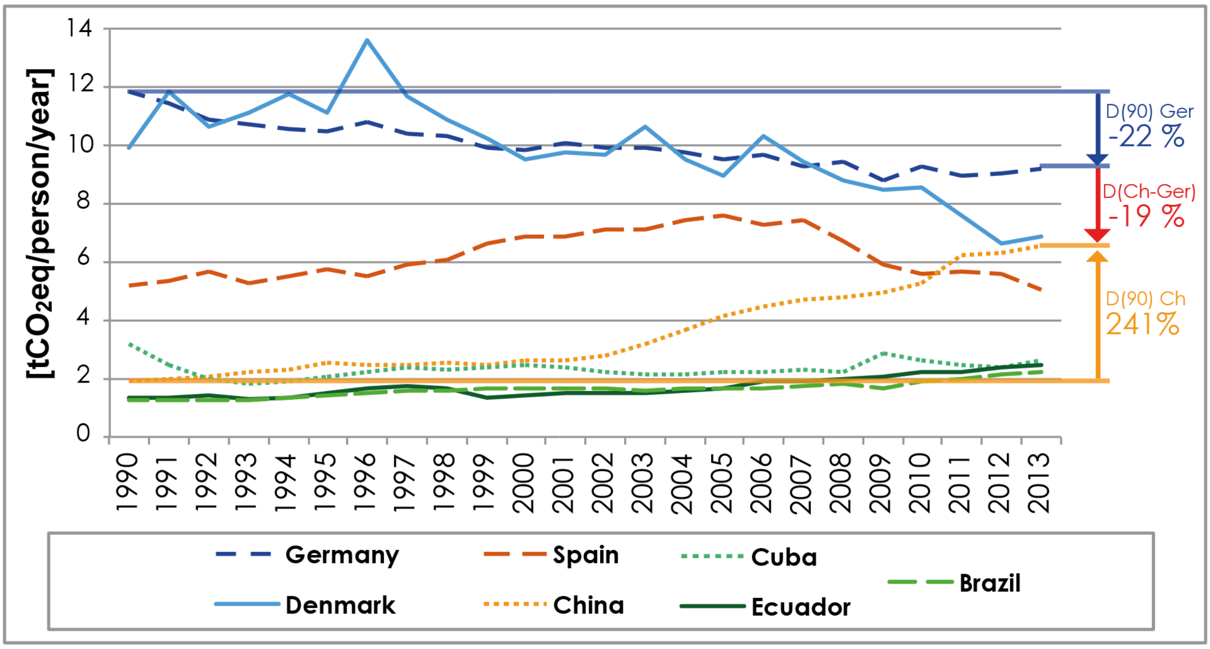

Figure-7-Figura. Tons of CO_2eq emission coming from the fuel consumption for the energy supply of a country (own elaboration from IEA data (International Energy Agency, 2015)).

A similar effect occurs when countries like Denmark or Germany declare that their renewable integration in the electric energy production is 48.07% and 26.02% respectively, whereas in the Cuban or Chinese model the renewable integration was 4.35% and 20.56% in 2013 according to the International Energy Agency (IEA). The same data could be provided saying that each Danish and German citizen has 26,100 and 40,200 kWh/yr energy consumption coming from fossil fuels and nuclear power in the primary energy supply while Cuban and Chinese inhabitants consume an average of 10,600 kWh/yr and 23,000 kWh/yr respectively, as can be seen in *Figure-8-Figura*. The Brazil and Ecuador cases are even better, where the renewable electricity percentage is higher than in Germany or Denmark and the fossil fuel and nuclear presence in TPES is far lower.

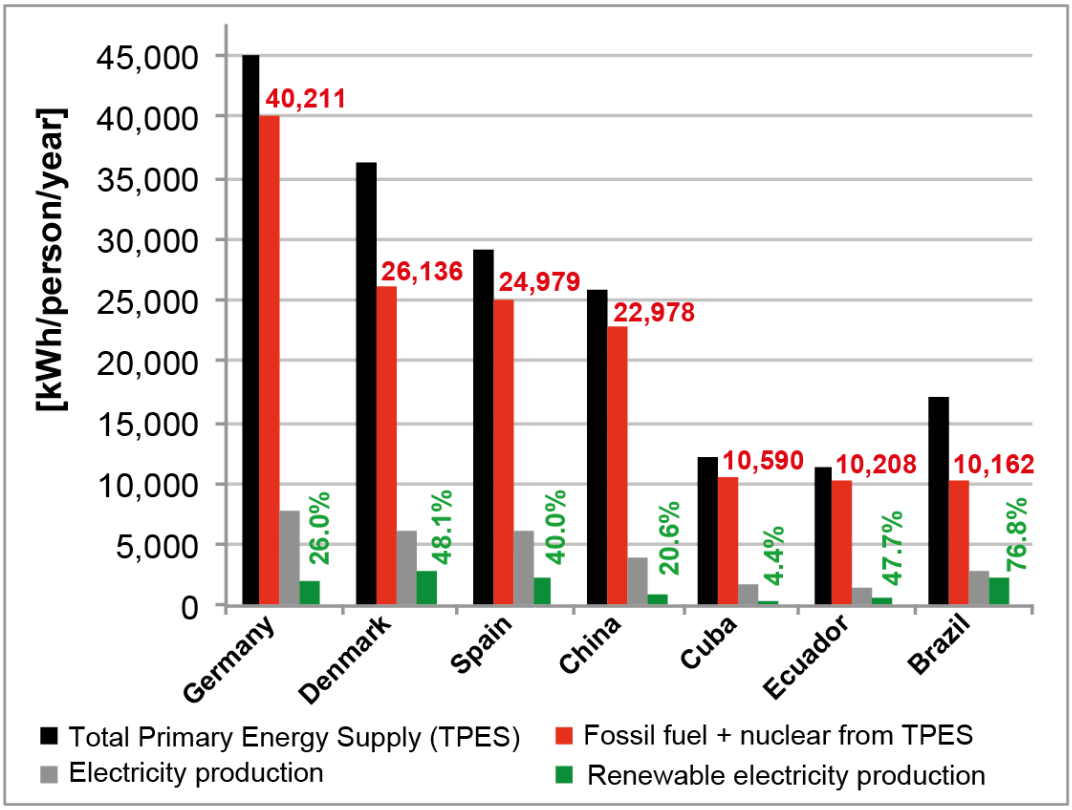

Figure-8-Figura. Variation in the integration of renewable energy in electric energy production versus the presence of fossil fuels and nuclear in the primary energy supply (own elaboration from IEA data).

Furthermore, the above data does not include the energy embodied in international trade (EEIT) or the Hidden Energy Flows (HEF): the energy that a country (especially northern ones) consumes in other countries (especially southern ones) by outsourcing services and goods manufacturing. *Figure-9-Figura* shows the "territorial perspective" used by the IEA to measure the energy consumption of a country, which means that all the energy sold in a country is computed as that country's use, regardless of who is purchasing and actually consuming that energy; whereas if instead a "consumption-based" perspective is used, energy indirectly consumed by a country in other nations in the form of imported goods and services should be measured and assigned to the consumer country, not to the producer (Arto et al., 2016).

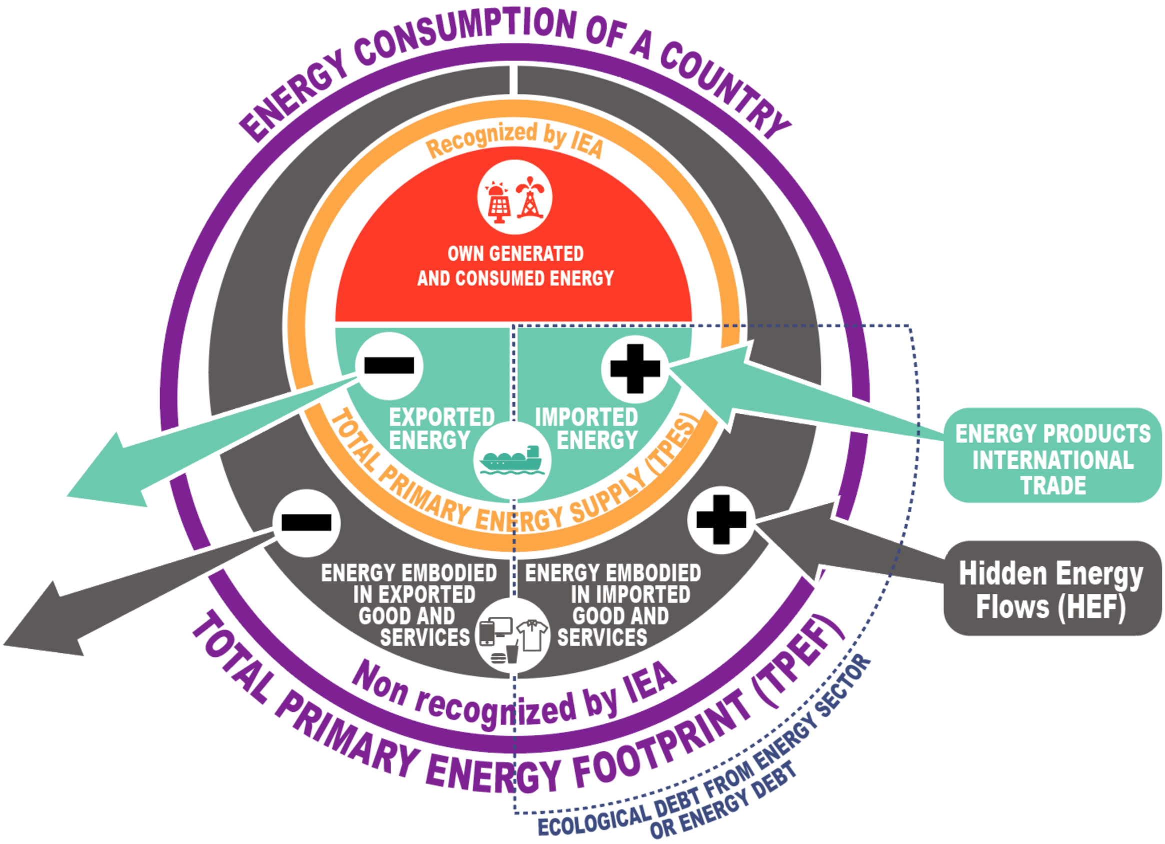

Figure-9-Figura. Hidden Energy Flows meaning (own elaboration).

The concept of EEIT has been initially detected as an "Ecological Debt" that the Global North has with the Global South (Martinez-Alier, 2001), (Muradian and Martinez-Alier, 2001), (Barcena et al., 2009). This "Ecological Debt" recognises the impact of northern consumerism on the southern countries' society and environment. From this generic term, within some social movements the concept "Energy Debt" has been used to refer specifically to the ecological debt of the energy sector (Urkidi et al., 2011), (Urkidi et al., 2012). "Energy Debt" is divided into two parts: the imports of energy resources from other countries, which are included in the IEA data; and the EEIT (Arto et al., 2016), not recognised as energy consumption by the IEA, as explained in *Figure-9-Figura*. The concept "Energy Debt" is too abstract to quantify whereas the EEIT specifically defines the difference between total primary energy supply (TPES) and the total primary energy footprint (TPEF). Our research team uses the term "Hidden Energy Flows" (HEF) to define the EEIT, supported by the theoretical concept of indirect or "hidden flows" referring to those hidden in the imported goods (Dittrich et al., 2012).

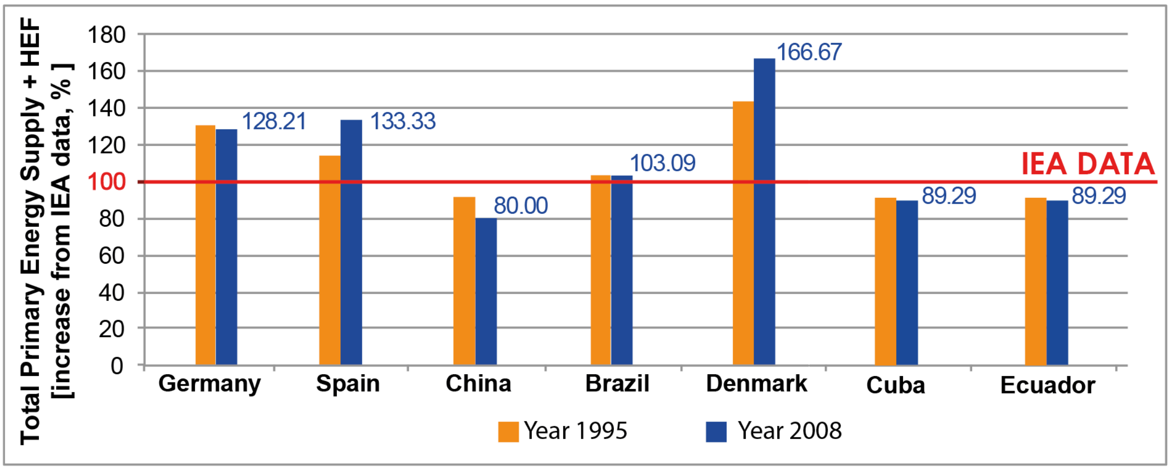

Figure-10-Figura. Percentage increase from IEA energy consumption data to Total Primary Energy Footprint data of the same country (TPEF) in 1995 and 2008, taking into account the HEF (own elaboration from (Arto et al., 2016)).

If the HEF are taken into consideration, northern countries like Germany or Spain consume respectively 28.21% and 33.33% more energy than their TPES (Arto et al., 2016). However, this northern energy consumption and the associated CO_2eq emissions are computed to the countries where the goods were manufactured. *Figure-10-Figura* shows the percentage increase from the IEA data that creates the HEF (Arto et al., 2016) (Cuba and Ecuador are integrated with other states (Arto et al., 2016)). A similar effect has been cited in technological improvements with lifecycle approaches (Patyk, 2009).

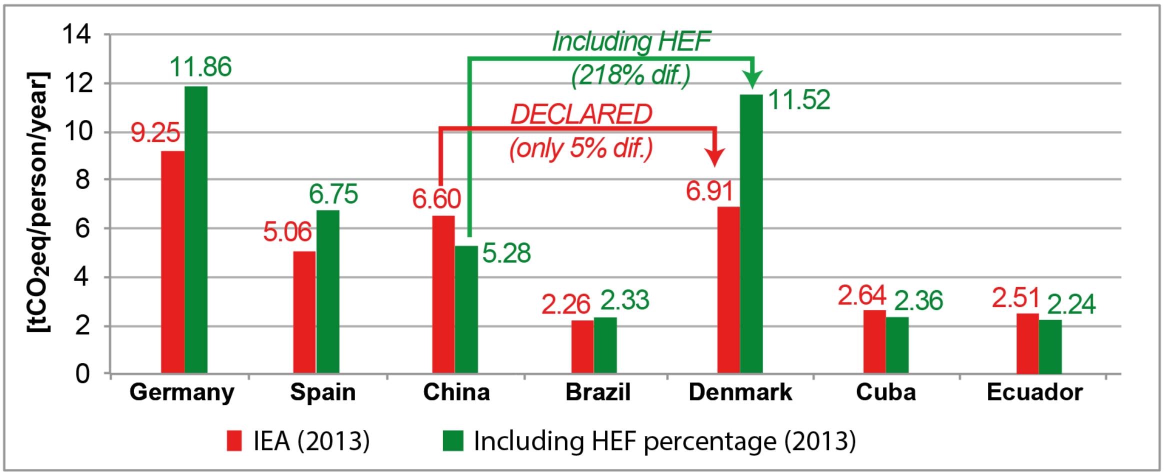

Figure-11-Figura. Tons of equivalent CO_2 emissions from IEA 2013 data (red), and total consumption-based emissions including the increase due to the HEF (green). Own elaboration, *Figure-14-Figura*.

Currently, energy literacy studies do not include this important factor (Sovacool and Blyth, 2015). Introducing the HEF data to the emission values (including them proportionally in considering that the emission rate of the increased consumed energy is equivalent to the national rate), countries that apparently have the same CO_2 emission data as Denmark per capita according to the IEA, e.g. China with 6.60 and Denmark with 6.91 tCO_2eq, in the new calculations the data changes to 5.28 and 11.52 respectively, see *Figure-11-Figura*. So it could be said that in the first case "according to the International Energy Agency, in accordance with the territorial perspective, in Denmark, CO_2 emissions per capita are just 5% higher than in China per capita" or "Denmark's average emissions per capita are 218% that of China". Important reports on sustainability measurement like the Environmental Performance Index 2016 Report, elaborated by Yale University, do not take into account the HEF, and hence give a completely distorted view of the reality of a country considered a reference in sustainable energy (Hsu et al., 2016). Actually, in recent years the HEFs are increasing in most of the Global North Countries (Arto et al., 2016).

In general, inhabitants from the Global South countries like China, Cuba or Ecuador have less CO_2eq emissions than the real ones, whereas the Global North countries analysed produce more emissions than those stated. In the Brazilian case it could be said that the HEF balance stands at approximately zero.

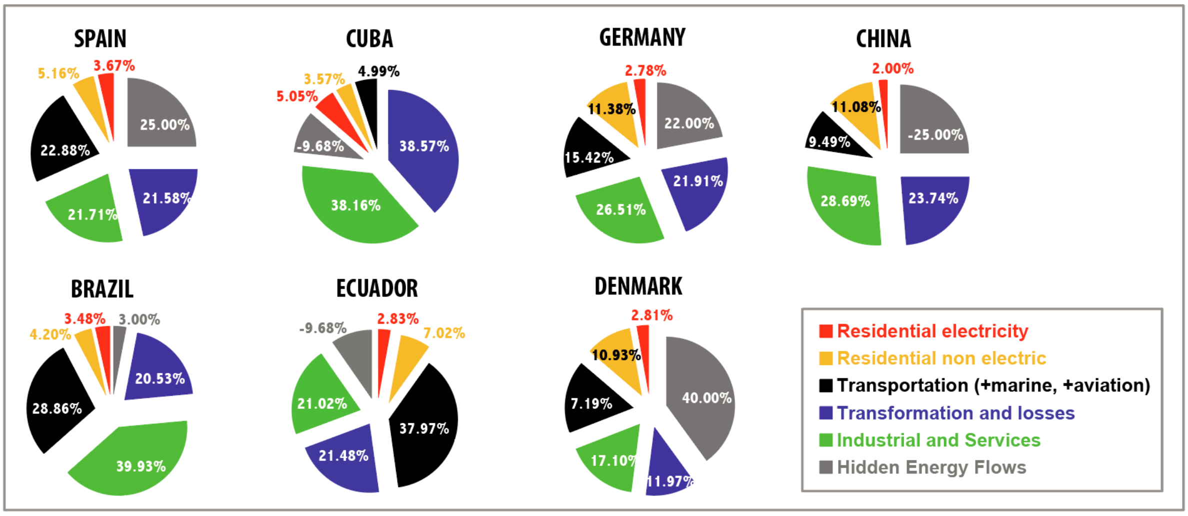

Figure-12-Figura. Germany, Denmark, China, Spain, Cuba, Brazil and Ecuador primary energy supply reshaping (Elaborated by the authors from the International Energy Agency data and integrating HEF).

6.4 Results

This section presents the findings achieved in the analysed case studies. Taking into account that core changes need to be made to the current energy model, in each case study the significant proposals which could help to bring about profound changes leading to transitions towards a democratic low-impact energy model have been analysed. These proposals or ongoing transitions are diverse: some of them are lifestyle and production changes (Cuba, Germany, Spain), others are proposals by civil society (Ecuador, Brazil); some are local or regional projects (Germany, Ecuador) and other national-scale transitions or proposals (Cuba, Spain, Brazil).

6.4.1 Ecuador: oil struggles in the Amazon rainforest.

(See Supplementary Information 13.1)

6.4.2 Brazil: limits and impacts of renewable hydroelectric generation.

(See Supplementary Information 13.2)

6.4.3 Cuba: how to tackle an oil shortage

(See Supplementary Information 13.3)

6.4.4 Germany: emerging new community-based energy models.

In the German case, four different initiatives contributing to energy transition have been analysed.

First, the village of Feldheim, characterised for being the only village in Germany to be electrically self-sufficient and supplied 100% by renewable energies. Common citizens rarely have the right to choose which kind of energy technology to invest their own savings in. Electricity cooperatives have enabled individuals to decide how household electric energy is generated, but unfortunately, this affects a very limited energy sector (2.78% in Germany); as well as quite a limited economic sector (household energy expenditure), as the average electricity bill of a 3 member family raised up to €85/month in Germany in 2014 (Thalman and Wehrmann, 2017), less than 3% of an average single person's gross monthly earnings, according to World Bank data (€3,973). Generally, people keep most of their savings in a bank, where this money is used to make investments in different production sectors and their respective energy model. Accordingly, the owner of the savings does not have the right to choose which kind of energy generation technology is being funded with their savings. Banks take the decision to invest in the most profitable form of energy generation and the only aspect that they communicate to their customers is the yield their money has produced. In fact, they are not even informed whether or not they have been funding forms of fossil fuel or nuclear power generation or even as to the resulting impact on the environment and on social inequality. Hence, essentially investors have no control over the energy system that they are using. In 1995 in Feldheim, the "Energiequelle" cooperative was created, supported by a student named Michael Raschemann. Today there are 47 mills with 74.1 MW installed capacity. Furthermore, they have installed different energy sources to diversify the energy generation capacity: in 2004 a 500 kW biogas plant, a biomass plant with 0.5 MW generation capacity for emergency purposes and a 2.25 MW capacity solar photovoltaic generation plant were all installed. In 2013, electricity production in Feldheim was 135.9 GWh while consumption stood at 855.95 MWh ("Village of Feldheim: Energy self-sufficient district of the town of Treuenbrietzen in Germany's county Potsdam-Mittelmark," 2014), only 0.63% of its electricity production was consumed. In addition they consumed 2.57 GWh of locally produced thermal energy.

Secondly, the eco-village Sieben Linden; where they approach energy transition by creating an austere community and changing the values of material consumption. Unlike many global experiences based on the "sacrifice" of rejecting the materialist luxuries of a "modern technological lifestyle", the Sieben Linden community lives "austerity" as a gain in happiness and in a high quality of life. According to their own calculations they have achieved a reduction of 77% of the primary energy supply in comparison with the German average. The first step towards low energy consumption was to reduce material and energy consumption through the communal use of resources by having a shared kitchen and dining room, reducing private space in homes to 16 m2 and having an additional 16 m^2 in public buildings, car and appliance sharing, as well as communal food and energy generation. At the same time there have been processes to build low energy consumption houses, i.e. Villa Strohbund, built in 2002, which according to a Kassel University study conducted in 2002, had absorbed more than 15 tCO_2eq during its construction (Stengel, 2014). A conventional home, insulated with the same insulating properties (with heating consumption of 50 kWh/m^2 per year), is estimated to emit 10.51 tCO_2eq in its construction. This home not only has zero emissions but also becomes a fixer of the CO_2 retained in the wood and straw it is made from. The study emphasizes that the energy consumed during the construction, was between 2 and 5% of that consumed for a house of the same insulating properties (Dyck, 2014). The whole experience of constructing a low impact straw bale house reinforced the need to measure household energy expenditure and to set limits. The electrical engineer W.D. has become the advisor on energy consumption measurement in the eco-village. "Our goal is to live in an energy model where each person only uses its proportional corresponding part of resources of the country; we would like to ascertain that every person on this planet, and future generations as well, have the same right to use the resources" (extracted from interview). Based on this commitment, a calculation has been made in Sieben Linden regarding the amount of forestland that would correspond to each German citizen if there was an equitable distribution, in order to use the wood resources coming from this land as a heating energy resource. This is how they currently use 2,200 m2 of sustainable managed forests per person in order to extract 1,452 kWh of heat energy per year.

Thirdly, the "Solar Settlement" neighbourhood; where an energy transition has been implemented through changes in terms of architecture and urbanism. Located in the Vauban neighbourhood of Freiburg and designed by architect Rolf Dish, Solar Settlement (or Solariedlung) is one of the most internationally recognised sustainable housing complexes in the world (Freytag et al., 2014). Rolf Dish applied the PlusEnergy concept in this complex of 59 homes, a shopping centre, offices and a parking area, the first housing community in the world to present a positive energy balance (Heinze and Voss, 2009). Rolf

Dish came up with the concept PlusEnergy in 1994, in the pilot home called Heliotrope, also located in the suburb of Vauban. PlusEnergy implies that the energy consumed in a building is lower than the energy it produces (Disch, 1994), the balance includes the electrical or thermal energy externally purchased and the excess of generated electricity sold to the grid. In this new energy model, consumers play a new role in the energy system, becoming energy producers due to the installation of renewable energy generation technologies. According to 2013 data, in Solar Settlement there is an average photovoltaic electric generation capacity of 6,280 kWh per year per household. Furthermore, the average electric consumption per household is 2,598 kWh per year and the average thermal consumption per year stands at 2,821 kWh, with the two adding up to a total consumption of 5,419 kWh, 13.7% lower than the energy produced.

Lastly, the Rosa Luxemburg Foundation (RLF), based in Berlin whose aim is to achieve a publicly managed democratic energy system (Urkidi et al., 2015). The RLF defines the energy transition as an energy-shift, sharing the national idea of Energiewende, which can be described from two points of view, from a technical and from a political perspective. The technical part refers to the transition from the use of hydrocarbons, the use of renewable resources for energy production. Whereas the political part divides the integration of renewable energies into two groups: one that leads to large-scale installations under the continuous control of large energy companies; and another that leads to an increasingly decentralised, more democratic and socially aware energy model. The idea of public energy management, specifically that of electricity, has been analysed in depth by the RLF, by Conrad Kunze and Sören Becker who in 2014 published a survey of initiatives existing in Europe in favour of a democratisation of energy (Kunze and Becker, 2014). This study highlights the process that took place in Berlin, to publicise the energy management supported by RLF. In 2010 the debate within social movements in Berlin started to move towards energy democracy, a concept integrating energy, climate issues and grassroots participation, stating that "the decisions that affect our lives should be taken jointly and without taking into account the principle of profit". After a long process, the association Berliner Energietisch forced the Senate to hold a referendum to vote on the need for a community-based management of the public power supply. The referendum took place on 3 November 2013 with the YES vote winning. However, only 24.1% of citizens voted, below the minimum 25% required to make the vote valid (Blanchet, 2015). The process did not achieve its goal, nevertheless the moral victory was won: a vast majority of 83% were in favour (Kunze and Becker, 2015), and social movements continue to work towards this goal.

6.4.5 Spain: struggles within the electrical energy market

(See Supplementary Information 13.4)

6.5 Discussion

Each case study in this article shows us a strategy and a different way to progress towards a democratic and sustainable energy system.

The Feldheim case study in Germany shows us how it is possible to create a local self-supply of energy and be a provider of 100% renewable energy if the necessary commitment and investment is available. In this case, it is important to highlight how the participants invested their savings in implementing a socially and environmentally sustainable project and chose to manage their funds communally as opposed to using traditional banking methods. Other German cases, in addition to the solar self-consumption and South American biomass experiences, show us that small-scale renewable energy development is possible in some cases with the available technology. Beyond communal and local experiences, progress towards increasingly renewable models in urban neighbourhoods or cities in Germany makes it clear that renewable energy development is possible in large non-rural areas. These assumptions coincide with a number of authors of the initial literature review, who assume that the consumption model has to change and use electricity of renewable origin as the main energy vector, in order to ensure the feasibility of a system based on renewable energy (Trainer, 2013).

On the other hand, energy generation and consumption cooperatives in Spain are promoting large-scale demand for renewable energy. With this we are not stating that renewable production should move towards centralisation but towards expansion and proliferation, prioritising best practices and decentralised energy generation.

In fact, the losses due to centralised production and distribution models (primary supply that is lost before being consumed) are a significant percentage of our total energy consumption. These losses stand at 42.7% in Cuba, 23.8% in Ecuador, 21.9% in Germany, 21.6% in Spain and 20.5% in Brazil. Renewable based (avoiding fossil fuel burning) local production, to be consumed on site, would dramatically help reduce these losses.

In any case and even anticipating the most favourable scenarios regarding institutional, social and corporate commitment to renewable energy, the average energy consumption in the Global North should decrease (Kunze and Becker, 2015) for others to be able to reach acceptable levels of energy well-being. Furthermore, it could be said that energy poverty does not only affect the Global South countries, as also in the Global North cases of energy poverty are on the increase (Tirado Herrero et al., 2014). Thus, it should be taken into account that certain specific individuals in the Global North could also increase their energy consumption, especially their residential energy consumption.

But how could Global North countries achieve an average energy reduction? There is a wall preventing end energy consumers from distinguishing those activities consuming the most energy. A wall erected partly by the extensive energy transformation supply chain existing between consumers and the origin of the resources but which is mainly the result of the constant volley of confusing messages from the media and from a financial structure which demands that energy consumption be maintained and which disseminates disinformation regarding this. We should add to this the way in which energy consumption is measured, as the energy costs in other countries regarding the production of goods, which are then imported and purchased by us, are not taken into consideration. This is known as energy debt. If we take this factor into account, the real energy consumption of allegedly sustainable Northern countries (Germany, Denmark) increases significantly. We believe that finding out the real origin of our energy consumption, and hence knowing which economic activities consume the most energy, is the first step towards planning a collective energy transition.

The average energy consumption levels indicate that, among the countries analysed, Germany (including its energy debt with other countries (Arto et al., 2016)) is the one with the highest primary energy consumption 59,800 kWh/person/yr, whereas the Global South countries consume up to 79% less energy than Germany. The most significant case is Cuba where primary consumption is 79% less than that of Germany and actually rising a high Human Development Index (HDI) close to 0.8 (*Appendix A, Table-4-Tabla*). Furthermore, we do not share the view that, in general, Germany is an example of "rapid proliferation" of renewable energy (Romero-Rubio and de Andrés Díaz, 2015). Nonetheless, it should be highlighted that in Germany there are different experiences where energy consumption is similar to the Cuban average, showing us how a change based on conscious self-containment and communal organisation methods can significantly reduce consumption.

The Cuba case study shows that it is possible to have both a high HDI and low energy consumption. This is due to the fact that despite the low purchasing power and low individual energy consumption, public and universal social benefits have been maintained and these facilitate a good standard of living. In this section we share the idea that the use of renewable energies is directly linked to de-growth in consumption (Kunze and Becker, 2015). However, we would not want to idealise the case of Cuba as we are fully aware of not only the inequalities existing in the country but also of the energy poverty which certain communities and families have protested against. Furthermore, the decision to adopt austere energy living was not a direct choice made by citizens but rather a reflection of political decisions. Nevertheless, it is interesting to highlight the fact that maintaining public services and intensifying community bonds based on mutual help may alleviate the decrease in quality of life as a result of a decrease in individual access to energy.

Table-2-Tabla. Scheme to bring together the learnings from the five case studies with exemplary approaches.

Country	Brazil	Cuba	Ecuador	Germany	Spain
Case studies	MAB and POCE	National Energy Transition	YASunidos	Feldheim, Solar Settlement, Rosa Luxemburg Foundation and Sieben Linden Ecovillage	Som Energia
Geopolitical location	Global South	Global South	Global South	Global North	Global North
Scale	International	National	National	Local (and a National case)	Regional-National
Social Character	Democratic. Triggered by Amazonia reserve endangered.	Democratic. In answer to the state energy model based on dams.	Authoritarian. Imposed by the internal and external conditions (shortage of oil, blockage, ideology…).	Democratic. Triggered by particulars' ethical and environmental aspirations.	Democratic. In answer to corruption in the energy sector.
Socio-Cultural Goals	- There is a need to answer the question “Energy, for what and for whom?” before building a new power generation plant. - Create social meeting spaces to share energy system know-how.	- *Peak Oil* had been overcome with the unity of a solid community. Nevertheless, this has been a *Top-down* process enforced on citizens and the goal would be to replicate this achievement in a voluntary way.	- The indigenous community requests leave the “Oil under the Soil”, in order to maintain their “good living” values (Sumak Kawsai).		- Transversalise the energy problem, reach out to civil society and enrich the energy debate.
Economic Goals	- “Water and Energy are not commodities but the rights of citizens”.		- The Sumak Kawsai concept should expand to other economic sectors. - Overcome the discourse vs. praxis conflict of government with an economic alternative that dissociates itself from transnational oil companies.	- Communal investment in renewable energies to maintain control over decisions regarding investment of funds in the energy sector: controlling impact and achieving responsibility.	
Political Goals	- Unity between different and seemingly opposing collectives: this shows the convergence of interests of the population in energy transition. - Inform and empower civil society by democratising knowledge about the energy sector in order to create a critical mass able to take decisions. - Get support from politicians by raising awareness.	- Pooling citizen, farmer and scientist skills and expertise to manage the crisis and seeking the effective mutual support of the government on public terms.	- Social engagement, awareness-raising and mobilisation are crucial in order to maintain the political struggle against pressure from corporations or the international community.	- Public management of energy utilities in cities and towns can be requested and achieved.	- Energy lobbies and corruption should be opposed (i.e. “revolving doors”) and Cooperative Electric Providers are paving the way towards this goal. Increasing the democratisation of the energy system.
Technological Goals	- Development and use of appropriate low-tech technologies to achieve energy sovereignty.	- Shows the capacity to maintain decent standards of living despite lower fossil fuel consumption based on changes to core production (agriculture), transport and organisation and by maintaining public services.	- Non-extraction of petroleum, through effective management, as a feasible social, institutional and economic objective.	- Austere community life as an alternative to the goal of technological efficiency to sharply reduce primary energy consumption. - Applying the PlusEnergy concept in neighbourhoods and houses, consumers have the opportunity to become producers.	- Cooperatives manifest the possibility of change towards renewable energies.

If we analyse the share of primary energy consumption (including HEF), it is observed that only 2% (China), 3% (Ecuador, Germany, Denmark), 4% (Brazil, Spain), and 6% (Cuba) of energy is consumed at home as electricity (*Figure-11-Figura*). This means that residential electricity consumption is not the critical point in our energy system. As such, transformation should be more systemic in order to make a real impact on reducing total primary consumption. It is necessary to change, among other things, the production model, the approach to mobility and the logics of consumption in order to move towards real transition. Regarding this point we fully agree with Haas et al. (Haas and Sander, 2016) where it is stated that the current energy transition strategy (based on the Energiewende case, although the conclusion may be generalised to the cases of electricity cooperatives) is limited to an electricity transition, and that this only partially challenges the dominant ecological and societal relations. With respect to this, we do not share the analytical procedure of considering "renewable energy system" and "renewable electricity power" to be the same, as occurs in certain research works (Debor, 2014), (Dóci et al., 2015).

Regarding the strategies to democratise the energy system and to socialise change, the case studies also present interesting lessons. In Spain, the proliferation of energy cooperatives and social movements linked to energy, in addition to the increase in energy poverty, has led to greater knowledge and protests concerning the issues of the energy oligopoly and the revolving doors, hence improving the national energy literacy. Furthermore, these cooperatives represent a new energy organisation model in terms of their non-profit and cooperative nature and their grassroots participation.

The Brazil and Ecuador case studies show that if protests in favour of energy transition are to be influential, it is essential to create multi-sector networks, going beyond practical and local experiences, and to organise large awareness-raising campaigns with widespread participation. This way, the participation of different social stakeholders in the "Plataforma Operária e Camponesa para Energia" in Brazil managed to overcome specific problems and to introduce new elements into the energy debate: the search for a popular, fair and sustainable energy project for Brazil. In Ecuador, educational and academic work conducted on the Yasuní proposal managed to a posteriori form a more widespread mass movement such as YASunidos and to maintain the debate on oil extraction and possible energy transitions alive in Ecuadorian society. Even if the Yasuní case may be understood by some authors (Fierro, 2016) as a missed opportunity in institutional or material terms, the process of the struggle still continues to show relevant outcomes in social and educational terms.

In Cuba the situation is a little different due to the importance of the State and its specific energy history. The government institutions consider that energy is a public asset and a social right and they have incorporated discourses regarding renewable energy. However, these projects have not been developed equally in civil society and the "cultural energy revolution" is yet to take place.

All these achievements and strategies in energy transitions, extracted from the proposed five case studies, have been grouped in *Table-2-Tabla* with the aim of complementing a variety of actions carried out in each case study. It seems likely that only an integration of several lessons learned from the different cases could lead to a materially feasible transition, and that without a combination of several factors for change it seems difficult to consolidate a medium-scale energy transition. The regrouping has been carried out respecting the four axes of analysis that were established at the beginning of the research: socio-cultural, economic, political and technological.

In respect to the social axis, it should be noted that the case studies consider *Peak Oil* as an opportunity to change the current energy model, with special focus on a change in citizen values. Hence, there is an attempt to transversalise the energy problem to the debate on lifestyles. This implies increasing awareness of fundamental questions, such as why we need so much energy, and what for.

Secondly, the economic axis, the need to consider access to energy as a basic social right, and not as a commodity to speculate with, has been identified; or, as proposed by the Ecuadorian indigenous culture, the need to extend the Sumak Kawsay theory to the economic sector. Furthermore, it has been demonstrated that a conscious communal use of the private economy in renewable technologies could be profitable. Nevertheless, real deadlocks appear when an attempt is made to overcome the powerful extractivist economy, especially when conflicts between the discourse and the praxis emerge in national politics.

Thirdly, the political axis shows a need for transparency and information from politicians towards civil society, in order to create a joint proactive strategy to overcome the current crisis. There is also a general view of the existence of an "enemy", usually identified within transnational energy corporations and supported by the personal interests of some corrupt politicians. This phenomenon has been partially overcome on a small scale with the creation of energy cooperatives but as yet any attempts to return many municipal and regional energy utilities to public management have largely failed to succeed.

Lastly, it should be noted that the technological axis focuses more on how to integrate existing solutions than on developing new sustainable technologies with the idea that a future technological leap would resolve by itself the conflict of sustainability. At the same time, the non-extraction of fossil fuels from the soil is a clear concept to be included in the technological section, as a symbolic shift towards a less technological energy model requiring less energy consumption per se.

6.6 Conclusions

The energy model is so closely related to most aspects of our lives that proposing a change regarding energy involves rethinking how we consume, how we produce, how we work, how we organise ourselves, how we socialise, how we see ourselves, ultimately how we live.

The impact generated by the present energy system, especially in the Global South, is unquestionable and the current goals regarding efficiency, renewable energy integration and CO_2 emissions, centred on technical enhancements, should be complemented with social aims bringing about a democratisation of energy with two core goals: on the one hand to seek equality in the share of resources and in the search for joint solutions for both North and South, namely that of justice; and on the other hand, to reinforce community solutions whereby new energy management methods have a direct effect on lifestyle and subsequently on the use of energy.

In addition to these two core goals, this study underlines the importance of achieving energy literacy, in order to be able to develop awareness about the impact generated by our current energy system which is disguised by the fact that production is carried out overseas, by other social classes or simply because this impact seems distant in time to future generations. Energy democratisation inevitably entails responsibility not only concerning the environment but also regarding the rest of society, including future generations.

Table-3-Tabla shows the specific proposals, taken from the data analysis process, which aim to avoid any confusion generated by the communication of the targets achieved by each country as they progress towards a sustainable energy model. This study considers that presenting the data more clearly (i.e. by avoiding percentage values or renewable integration or emission reduction compared to 1990) is useful to detect the countries that are currently the most sustainable in terms of energy. This might also avoid idolising aesthetic policies that have not led to any progress in removing carbon from the national energy model.

Table-3-Tabla. Recommendations for improved interpretation of public data.

Concept	Recommendations
CO_2eq emission reduction from 1990	It is important to present the absolute current CO_2eq emissions per capita and to compare all the countries with one absolute unique value not a relative self-compared reduction from a specific year.
20/20/20 goals	It is important to have absolute targets and not percentage values. Percentage targets only perpetuate the differences between countries.
Integration of renewable energy	It is important to present the absolute value of fossil fuel plus nuclear energy consumption per inhabitant.
Energy Embodied in products	It is necessary to integrate the Hidden Energy Flows (HEF) into the national energy consumption average in order to prevent countries outsourcing their industrial production from appearing energetically sustainable. Currently this phenomenon has a generally positive effect on the Global North countries and a negative one on the Global south.

Figure-13-Figura groups together all the conclusions drawn from each case study according to the four core approaches of this research: Socio-cultural, economic, political and technological. An effort has been made to further summarise the discussion section in

Table-2-Tabla, whereby the major trigger factors detected in the energy transition case studies have been summarised for them to be used as learning for other incipient energy transition cases. This learning, irrespective of whether it was taken from Global North or Global South case studies, could be considered for use in both contexts, hence facilitating progress towards a fair energy model where there is no need to constantly differentiate between what are commonly named "developed countries" and "developing countries".

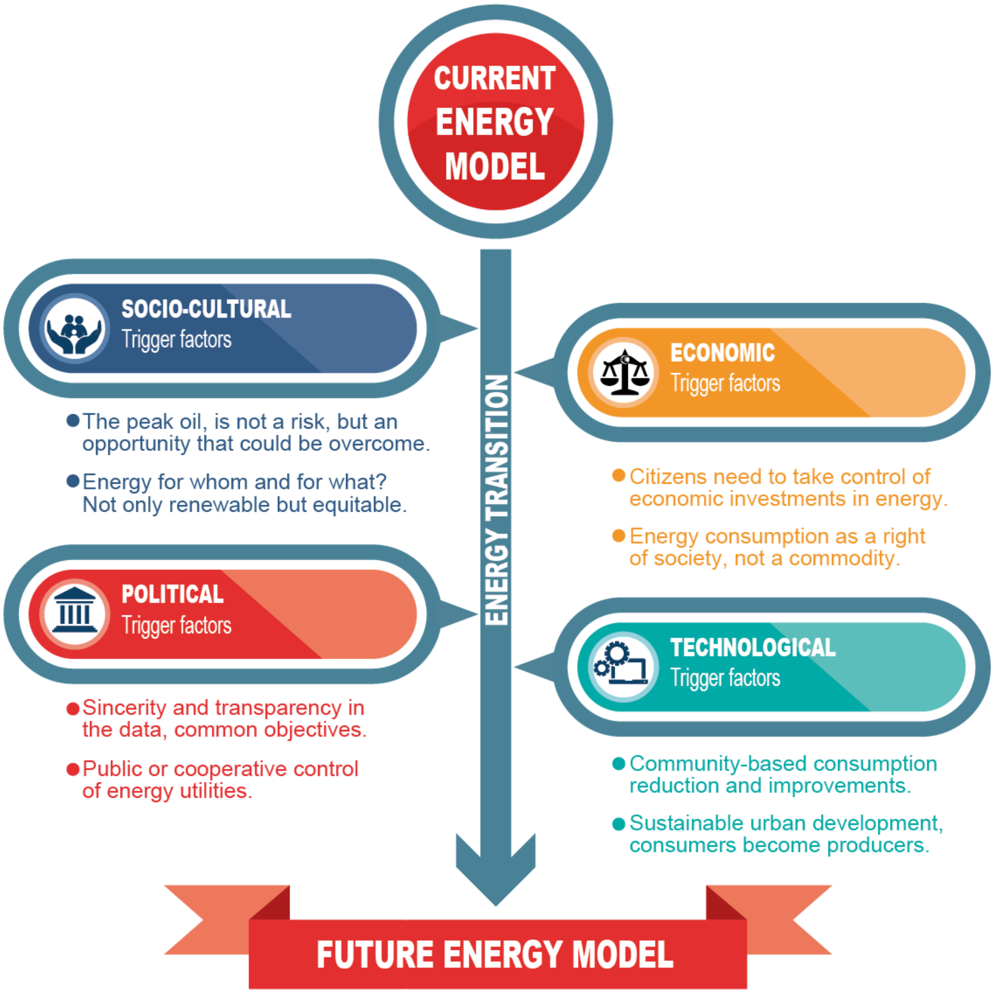

Figure-13-Figura. Some of the energy transition trigger factors (own elaboration).

All these conclusions and approaches may be seen as a social lesson to help progress towards a democratic and sustainable energy transition. However, we believe that each region, in accordance with its own economic, technological and socio-political characteristics, should create its own transition, bringing together some of these approaches and others not covered in this study. This issue opens up new lines of research. Indeed, further research is needed to continue exploring quantitatively and qualitatively the diversity and direction of ongoing and future energy transitions around the world.

6.7 Acknowledgements

The authors are grateful to the Basque Agency for Development Cooperation for the financial support to carry out this project (PRO-2013K3/0034), to all the members of the case studies analysed in this project that voluntarily answered the qualitative and quantitative interviews, to the European Union, Ministry of Turkey and National Agency of Turkey for the support of this project under the Project Code: 2015-1-TR01-KA203-021342 entitled Innovative European Studies on Renewable Energy Systems. The authors would finally like to thank the reviewers, who have thoroughly reviewed the manuscript and have greatly contributed towards enhancing its quality.

6.8 Appendix A

Table-4-Tabla: Summary of the mix of data that have been analysed, integrating International Energy Agency (International Energy Agency, 2015), United Nations Development Programme (UNDP, Human Development Report 2015) (Jahan et al., 2015) and Arto el Al. (Arto et al., 2016) data. It needs to be specified that IEA data and UNDP data are from 2013 and the Hidden Energy Flows data are from 2008 since these are the latest available data, it is considered for further research to improve the analysis including 2013 Hidden Energy Flows data.

		GERMANY		SPAIN		CUBA		BRAZIL		ECUADOR		DENMARK		CHINA	
	Inhabitants	82.1		46.59		11.27		200		15.74		5.61		1367.19	
	HDI	0.915		0.874		0.768		0.752		0.730		0.923		0.723	
	TPEC/TPEF	78%		75%		112%		97%		112%		60%		125%	
1	Total primary consumption according IEA	45,140.20		29,229.77		12,125.26		17,131.51		11,373.15		36,281.05		25,799.67	
	tCO2eq Emissions according IEA	9.25		5.06		2.64		2.26		2.51		6.91		6.60	
2	Primary + Aviation and Marine Bunkers	46,653.04	100%	31,920.20	100%	12,320.91	100%	17,464.42	100%	11,956.48	100%	39,306.90	100%	26,048.56	100%
	Transformation losses of electricity	10,404.65	22.30%	6,733.31	21.09%	4,696.69	38.12%	1,806.23	10.34%	1,556.54	13.02%	4,119.73	10.48%	6,040.93	23.19%
	Centraliced heat use losses	319.31	0.68%	-	0.00%	-	0.00%	-	0.00%	-	0.00%	1,434.94	3.65%	408.81	1.57%
	Oil-Gas-Coal transformation Losses	2,382.93	5.11%	2,451.03	7.68%	564.18	4.58%	1,889.48	10.82%	1,287.48	10.77%	2,287.58	5.82%	2,681.75	10.30%
	Electricity uses for production	4,523.00	9.69%	3,175.22	9.95%	605.59	4.92%	1,684.38	9.64%	816.82	6.83%	3,346.11	8.51%	2,434.44	9.35%
	Industrial non electrical consumption	5,098.66	10.93%	3,530.05	11.06%	3,622.15	29.40%	3,756.32	21.51%	1,339.37	11.20%	3,156.86	8.03%	5,968.83	22.91%
	Services non electrical consumption	3,048.11	6.53%	724.94	2.27%	20.70	0.17%	64.87	0.37%	13.34	0.11%	2,243.91	5.71%	422.66	1.62%
	Non energy use	3,089.04	6.62%	1,256.82	3.94%	266.05	2.16%	919.45	5.26%	372.09	3.11%	569.82	1.45%	1,407.08	5.40%
	Transport + Bunkers	9,221.79	19.77%	9,739.00	30.51%	680.12	5.52%	5,196.16	29.75%	5,027.64	42.05%	11,259.06	28.64%	2,471.67	9.49%
	Residential non electric	6,809.30	14.60%	2,194.86	6.88%	486.54	3.95%	756.64	4.33%	929.48	7.77%	7,160.13	18.22%	2,887.45	11.08%
	Residential electriciy	1,662.04	3.56%	1,561.57	4.89%	688.41	5.59%	626.56	3.59%	375.05	3.14%	1,842.54	4.69%	521.05	2.00%
	Others	20.89	0.04%	905.49	2.84%	693.58	5.63%	653.45	3.74%	316.50	2.65%	1,796.79	4.57%	793.91	3.05%
	Estatistics and Transfers	74.04	0.16%	- 352.08	-1.10%	- 3.11	-0.03%	110.78	0.63%	- 75.60	-0.63%	89.42	0.23%	10.00	0.04%
3	Total primary consumption with Hidden Energy Flows	59,811.59	100%	42,560.27	100%	11,000.82	100%	18,004.56	100%	10,675.43	100%	65,511.51	100%	20,838.85	100%
	tCO2eq Emissions with Hidden Energy Flows proportion	11.86		6.75		2.36		2.33		2.24		11.52		5.28	
	Hidden Energy Flows (HEF)	13,158.55	22.00%	10,640.07	25.00%	- 1,320.10	-12.00%	540.14	3.00%	-1,281.05	-12.00%	26,204.60	40.00%	- 5,209.71	-25.00%
	Transformation losses of electricity	10,404.65	17.40%	6,733.31	15.82%	4,696.69	42.69%	1,806.23	10.03%	1,556.54	14.58%	4,119.73	6.29%	6,040.93	28.99%
	Centraliced heat use losses	319.31	0.53%	-	0.00%	-	0.00%	-	0.00%	-	0.00%	1,434.94	2.19%	408.81	1.96%
	Oil-Gas-Coal transformation Losses	2,382.93	3.98%	2,451.03	5.76%	564.18	5.13%	1,889.48	10.49%	1,287.48	12.06%	2,287.58	3.49%	2,681.75	12.87%
	Electricity uses for production	4,523.00	7.56%	3,175.22	7.46%	605.59	5.50%	1,684.38	9.36%	816.82	7.65%	3,346.11	5.11%	2,434.44	11.68%
	Industrial non electrical consumption	5,098.66	8.52%	3,530.05	8.29%	3,622.15	32.93%	3,756.32	20.86%	1,339.37	12.55%	3,156.86	4.82%	5,968.83	28.64%
	Services non electrical consumption	3,048.11	5.10%	724.94	1.70%	20.70	0.19%	64.87	0.36%	13.34	0.12%	2,243.91	3.43%	422.66	2.03%
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	Estatistics and Transfers	74.04	0.12%	- 352.08	-0.83%	- 3.11	-0.03%	110.78	0.62%	- 75.60	-0.71%	89.42	0.14%	10.00	0.05%

Table-4-Tabla. Summary of the data used in section 3.

6.9 Appendix B

Figure-14-Figura: This figure compares the Carbon Footprint (CF) data, calculated using direct data from GTAP-MRIO or WIOD databases (Arto et al., 2014), with IEA country production-based emission data, and lastly with an own elaborated estimation of CF. This last estimation has been carried out starting from the HEF (Arto et al., 2016) multiplied by the average emissions of a country, making the assumption that the HEF has the same average rate than directly consumed energy. *Figure-14-Figura* shows that data error is acceptable for the analysed case study countries (an average error of +10.72% and -5.26%). This has been the procedure to obtain the data provided for total consumption-based emissions in year 2013 in *Figure-11-Figura*. In this process, data from Exibase 2.1 have not been considered, since they differ significantly from the results provided by the GTAP-MRIO and WIOD databases (Tukker et al., 2014), (Tukker et al., 2016).

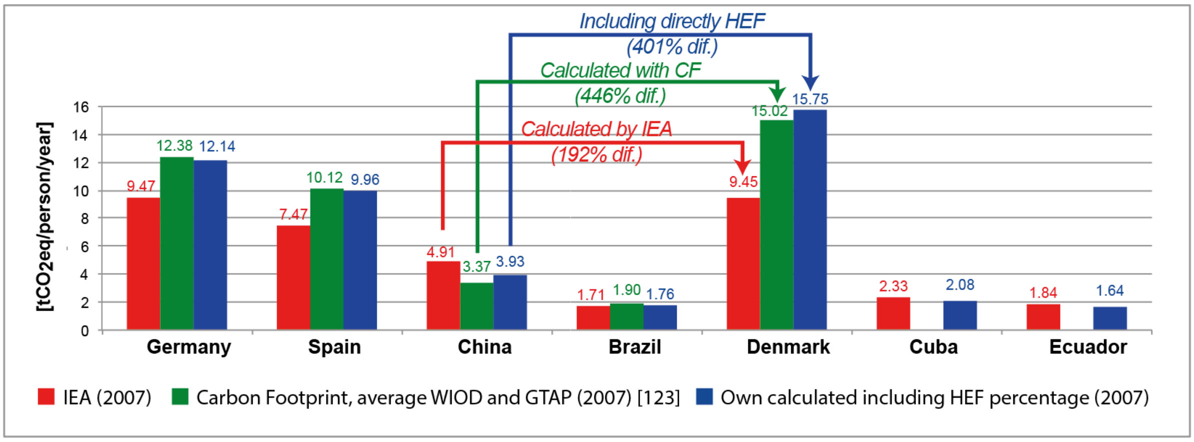

Figure-14-Figura. Comparison of carbon emissions and CF data of 2007 in order to develop *Figure-11-Figura*.

07 Análisis Local
Local Analysis

7 2_ARTIKULUA / PAPER_2

CONTRIBUTIONS OF BOTTOM-UP ENERGY TRANSITIONS IN GERMANY: A CASE STUDY ANALYSIS

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Abstract

Within the context of an energy transition towards achieving a renewable low-impact energy consumption system, this study analyses how *Bottom-up* initiatives can contribute to state driven *Top-down* efforts to achieve the sustainability related goals of (1) reducing total primary energy consumption, (2) reducing residential electricity and heat consumption, and (3) increasing generated renewable energy and even attaining self-sufficiency. After identifying the three most cited German *Bottom-up* energy transition cases, the initiatives have been qualitatively and quantitatively analysed. The case study methodology has been used and each initiative has been examined in order to assess and compare these with the German national panorama. The novel results of the analysis demonstrate the remarkable effects of communal living, cooperative investment and participatory processes on the creation of a new sustainable energy system. The study supports the claim that *Bottom-up* initiatives could also contribute to energy sustainability goals together within the state driven plans. Furthermore, the research proves that the analysed *Bottom-up* transitions are not only environmentally and socially beneficial but they can also be economically feasible, at least in a small scale, such as the current German national *Top-down* energy policy panorama.

Keywords:

energy transition; energy democracy; community management; bottom-up transitions; energy sovereignty; energy justice

7.1 Introduction

The need to change the current energy system is now an accepted fact on a global level. Three main factors make this energy shift unquestionable. Firstly, burning fossil fuels is one of the most important factors behind global warming according to the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC-AR5) (IPCC, 2015). Global anthropogenic emissions of CO_2 caused by fossil fuels, cement production and flaring were 0.16 $GtCO_2$/year in 1850, and 34.88 $GtCO_2$/year in 2011; a 21,800% increase. Secondly, the impending phenomenon known as *Peak Oil* means that the current energy system based on fossil fuels should be shifted towards the consumption of other resources. According to the Association for the Study of *Peak Oil* and Gas (ASPO) "[…] world oil production might be down by 50% around 2030." (Zittel, 2012). Thirdly, the current fossil-fuel based energy system, from a social fairness perspective, is creating unjust situations in the Global South: the emotional impact of oil spills (León et al., 2014), the social impact of new electricity grids in remote regions (Valer et al., 2014), the impact of oil extraction (Bozigar et al., 2016), the impact of pipeline constructions in rural areas (Welford and Yarbrough, 2015), and/or the energy poverty arising from inequalities in the energy distribution processes (González-Eguino, 2015). Similarly, there have been increases in energy poverty in the Global North, for instance, in the European Union (EU), where 10.8% of inhabitants have experienced difficulties in keeping their homes warm and a similar percentage in paying their electricity bill (Pye and Dobbins, 2015).

Hence, there is an urgent need for an energy transition towards a new democratic energy system with a low social and environmental impact. In the process of identifying the approach to adopt, there has been a trend towards considering this transition in mainly technological manner as a switch away from using fossil and nuclear fuels in favour of renewable sources. Germany, like other northern European countries, is considered as, socially (de la Fuente, 2016; Elcacho, 2015; Noya, 2016) and academically (Pegels and Lütkenhorst, 2014; Romero-Rubio and de Andrés Díaz, 2015) leading the way towards a sustainable energy system, and a global example for other countries. Germany currently has the most photovoltaic panels installed in the world with 38.2 GW (International Energy Agency, 2015), and has the greatest wind power capacity in the EU with 44.9 GW (Corbetta et al., 2016). Germany's effort in officially enhancing the Energiewende initiative is especially remarkable from a social aspect (Haas and Sander, 2016).

The German Energiewende (in English "energy transition" or "energy shift") is an unprecedented national energy transition phenomenon that started nearly 30 years ago as a result of the social mobilisation during the antinuclear protests, after which successive governments have manifested their clear ideas for creating a sustainable energy system (Hake et al., 2015). The goal of the Energiewende is ambitious, aiming to decarbonise the economic system, reducing greenhouse gas emissions by 40% by 2020 (relative to 1990 levels), and by 80–95% by 2050 (Röttgen, 2013). For this purpose, several *Top-down* actions were held in Germany in the frame of Energiewende. The most significant was integrated in 2000 after the liberalisation of the electric market, integrating significant feed-in tariffs to boost the installation of solar and wind generation systems. This phenomenon has not only been considered as a set of policy measures, but also as a social process (Morton and Müller, 2016) mixing *Top-down* and *Bottom-up* concepts. The second most significant action in Energiewende was held in 2011, when the phase-out of nuclear power by 2022 was established (Joas et al., 2016).

Nevertheless, if we define sustainable as meeting the needs of the present without compromising the ability of future generations to meet their own needs (Daoutidis et al., 2016), the current proportion of integration of renewable energies is definitively insufficient, 11% of the total primary energy supply in 2013. It is here that *Bottom-up* initiatives come into play, supporting and enhancing the *Top-down* state-based initiatives (Böhringer et al., 2017) to create a wider response in the integration of renewable energies, gaining responsibility of the current energy system impacts and raising the democratic decision-making processes. In fact, recent research has demonstrated that "decentralised initiatives have played a crucial role in the expansion of renewable energy systems (RES) in the German energy system" (Beermann and Tews, 2017).

In this study, it is considered that up-coming energy transitions are not a simple shift in generation technology, from fossil to RES, but are rather a social shift in the energy management and consumption system (Becker et al., 2017). Some research have already detected that the creation of a new energy system (until now mainly analysed in the integration of RES technology (Kirchhoff et al., 2016)) is not a clear and simple technological shift, but is closely connected to the ethics and morals of the inhabitants that consume this energy (Becker et al., 2017),(Sovacool and Dworkin, 2015). The connection between the use of energetic resources and social organisation has already been stated (Curreli et al., 2016). Thus, in this research "energy transition" is understood to be the path to obtain global "energy justice" (Sovacool and Dworkin, 2015) through "shared responsibility" (Gallego and Lenzen, 2005; Lenzen et al., 2007).

The need to accelerate the transition process to sustainable energy systems has already been detected due to the limits of the current *Top-down* strategies that need to be complemented and improved (Jefferson, 2008). The high potential of integrating decentralised renewable energies has also been noted (Perea-Moreno et al., 2018). Some authors have already referred to the importance of supporting the *Bottom-up* networks in order to obtain deep behavioural changes (Leach et al., 2012). Furthermore, it has been found that *Bottom-up* initiatives, even if considered "niches", could impact in offering shielding, nurturing and empowering sustainability transitions (Smith and Raven, 2012). In this context, special effort has been made to understand the potential contribution of grassroots movements in cities to support sustainable transitions (Wolfram, 2018). It has been stated that broader contexts, such as cities, can promote the grassroots initiatives or also vice versa, when materialising urban sustainability transitions (Håkansson, 2017). More specifically, in Berlin, within the context of the "remunicipalisation" process of the electricity utility, and under Energiewende, the relevance of *Bottom-up* initiatives has been argued, not only in implementing a local energy policy but, by creating a specific framing or vision of an energy transition (Blanchet, 2015). Grassroots initiatives have been defined as stimulators of collective action to trigger the gain of responsibility and sustainable consumption goals, and prototypical candidates for societal changes (Grabs et al., 2016). Similarly, the importance to include social-parameters in the analysis of the development of the incoming energy transitions has been revealed (Moallemi and Malekpour, 2018).

Therefore, it has become relevant to further analyse the social parameters of energy transitions and especially to quote the achievements of the *Bottom-up* initiatives. Thus, the main objective of this paper is to detect the specific achievements of the selected German *Bottom-up* initiatives in their energy transition process so as to assess whether there are elements that enable one to state that there has been a contribution from the *Bottom-up* initiatives to help achieve the national goals. This main objective has been divided into two specific goals; the first one is to qualitatively analyse each case by identifying and classifying the different actions carried out in the energy transition process. The second one is to quantitatively analyse how the new energy system created in each case study diverges from the national average. The differences in energy consumption reduction have been measured according to the total primary energy supply (TPES), residential electricity consumption and the percentage of integration of renewable energies in the consumption system.

The structure of the remaining paper is as follows: *Section 7.2* gives a background on the German energy consumption system, *Section 7.3* describes the methodology used, *Section 7.4* analyses each of the case studies in-depth, *Section 7.5* shows the findings obtained from a quantitative and qualitative point of view, and finally, *Section 7.6* presents our most significant conclusions.

7.2 Overview of the German Energy Consumption System

In order to have an overall vision of Germany's energy consumption system, two main aspects have been considered. Firstly, the current average energy consumption level in Germany, and secondly the sectors where the major consumption of energy normally occur.

7.2.1 Current Energy Consumption Levels in Germany

To define German energy consumption levels in relation to other countries, its total primary energy supply (TPES) (International Energy Agency, 2015) has been compared against its Human Development Index (HDI) (United Nations Development Programme (UNDP), 2014). In *Figure-15-Figura* and *Figure-16-Figura*, 40 countries (chosen through the World Input-Output Database, WIOD, selection criteria (Timmer et al., 2015)) have been compared. *Figure-15-Figura* shows that Germany is an exemplary case of "medium energy consumption level" and a high HDI amongst high energy consuming countries such as Canada, Luxemburg, the United States, and Finland.

In contrast, countries in the Global South consume less TPES than Germany, yet most achieve an adequate level of HDI. For instance, Indonesia, which presents a high HDI value (whereby "high" HDI according to the United Nations Development Program, UNDP, is equal to or higher than 0.7 (United Nations Development Programme (UNDP), 2014)), has an average energy consumption which is 78% lower than that of Germany.

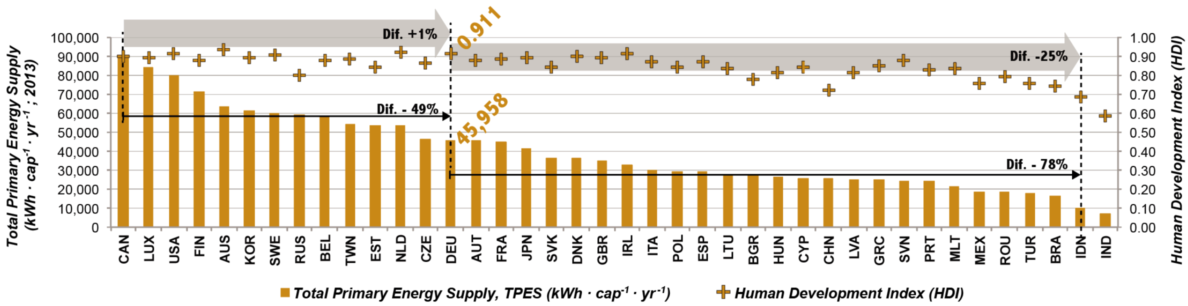

Figure-15-Figura. Primary energy supply versus the Human Development Index, based on International Energy Agency (IEA) and UNDP 2013 data.

The high energy consumption of countries in the Global North, such as Canada, and even to an extent in Germany in comparison with that of the Global South, could be justified as the only way to achieve a high HDI. *Figure-15-Figura* confirms what previous studies have shown: the causal relationship between energy consumption and the level of development ceases to exist in high HDI countries (Martínez and Ebenhack, 2008).

High energy consumption, justified in terms of reaching a high HDI, is not a problem per se. The problem arises when energy consumption data is compared with the ecological footprint (EF) data of the so-called "developed countries". This set of data was collected from the Global Footprint Network (GFN) (Global Footprint Network, 2014). When comparing the per capita EF data against the per capita TPES data, it is observed that there is a strong correlation between the two. Furthermore, when comparing the EF against the HDI (*Figure-16-Figura*), it is observed that only two countries, India and Indonesia, are considered "sustainable" according to the amount of resources used. These two countries maintain their resource consumption below 1.7 global hectares, within the capacities of a single planet Earth. The average German per capita energy consumption of 45,959 kWh/year corresponds to an EF of 5.3 global hectares, requiring the resources of 3.12 planet Earths; clearly unsustainable. It is observed that Indonesia, with a per capita energy consumption of 10,099 kWh/year, a figure 78% (*Figure-15-Figura*) lower than the German consumption, is the first country among those compared to fall within the parameters of a sustainable EF (≤1.7 gha, *Figure-16-Figura*).

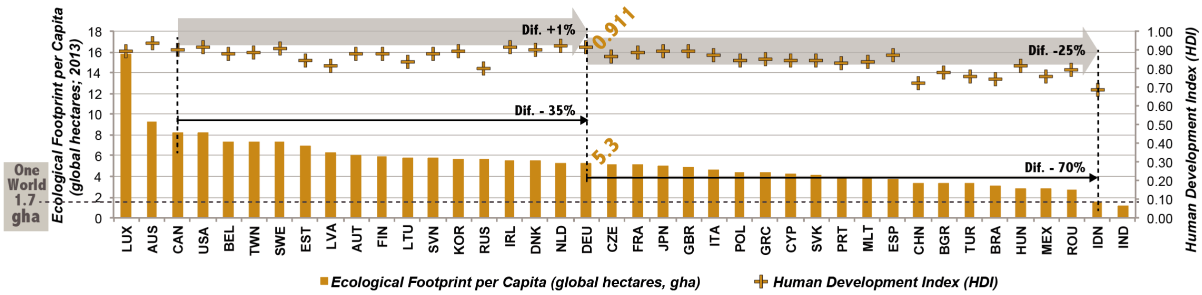

Figure-16-Figura. Ecological Footprint versus the Human Development Index, based on GFN and UNDP 2013 data.

For this reason, analysing *Bottom-up* initiatives that could trigger a massive reduction of TPES is of particular importance for the present paper. Energy transitions are considered not only to be a technological approach for increase the renewable energy generation, but also to promote a new life style in which living with new values may help to achieve more sustainable consumption levels. This led us to ask whether there exist different *Bottom-up* cases with energy consumptions of 78% lower than the national average within Germany, with the aim to proportionally reduce the Ecological Footprint to 1.7 gha while maintaining a high level of HDI. These *Bottom-up* initiatives could be considered as models for energy sustainability to be replicated in a global energy transition.

7.2.2 Current Major Energy Consumption Sectors in Germany

In order to forecast potential sectors for reducing the TPES, the German national consumption data has been reviewed and summarised in *Figure-17-Figura*, which was elaborated by regrouping the IEA data into a Sankey diagram and creating four large consumption groups: electricity consumed in private homes; energy consumed in products, services or transportation (including heat as a service); energy lost in transformation or distribution processes; and the Hidden Energy Flows (HEF) (Akizu et al., 2017).

Figure-17-Figura shows that the first critical point in the German energy consumption system is the low amount of electricity directly consumed in the residential sector: only 3.7% of the TPES. This shows that trying to reduce residential electricity consumption should not be the principal strategy to reduce the TPES. Changes which a priori could reduce energy consumption, such as purchasing new A+++ low electricity consumption appliances, reduce residential electricity consumption but may increase the energy consumed due to the life cycle of the appliances. Therefore, any action to make reductions within this 3.7% of the national energy system could have serious effects of leading to an increase in the energy consumed in the other 96.3% as a consequence of product manufacturing and transportation. For this reason, this paper outlines that the actions aimed at reducing electricity consumption in private households are not considered sufficient to bring profound changes to the energy system. However, due to its ease of measurement, household electricity consumption level has been quantified as a secondary parameter. Most of the studies in Renewable Energy Cooperatives (REC) focuses on providing renewable electricity to citizens (Brummer, 2018; Herbes et al., 2017; Mignon and Rüdinger, 2016; Viardot, 2013). RECs significantly enhances the social capital and democracy (Brummer, 2018), but it should be emphasised that they mainly focus on the 3.7% of the TPES (*Figure-17-Figura*). Thus, this paper makes an effort to consider the total primary energy supply in its complexity, with all the difficulties involved.

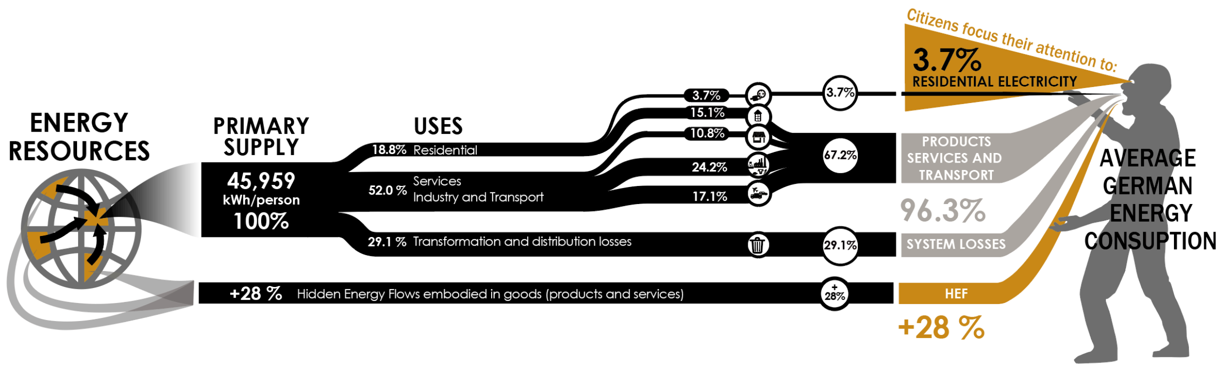

Figure-17-Figura. German energy system consumption per capita in 2013, based on IEA data.

Secondly, *Figure-17-Figura* shows that 29.1% of TPES is lost in "transformation and distribution losses". This is mainly (92.2%) due to the use of fossil fuels during the electricity generation processes in a centralised way. In other words, the greater the use of energy from fossil fuels, the higher the rate of loss in the transformation processes used to generate electricity.

Thirdly, the massive consumption of products and services of the current occidental culture is reflected in the diagram. With only the energy embodied in nationally produced goods taken into account, *Figure-17-Figura* shows that 67.2% is used to produce goods, services and transportation.

Lastly, data from Arto et al. (Arto et al., 2016) was used in the chart to include the energy embodied in imported goods and services consumed in other countries. The large amount of imported goods and services create the Hidden Energy Flows (HEF) phenomenon (Akizu et al., 2017), which increases the overall energy consumption value of most countries of the Global North, such as Germany. Therefore, the average national energy consumption in Germany should not be defined as 45,959 kWh but as 28% higher (Arto et al., 2016).

Taking the third and fourth point together, the high relevance of energy embodied in goods and services can be better appreciated. A similar conclusion was already reached in 2006 by the European Commission in its report "Energy Technologies: knowledge, perception, measures" published by Eurobarometer. It was recognised that the trend towards overestimating the impact of energy consumption in housing was a relevant policy consideration, noting that "… respondents seem to have a somewhat vague idea of the ranking of energy consuming sectors: the impact of transport is underestimated while the impact of the housing (heating, lighting, electric equipment and air-conditioning) is overestimated." (Eurobarometer, 2006). This paper has attempted to go further in this direction and to consider *Bottom-up* energy transition initiatives a comprehensive way to approach a real shift away from the current energy system towards a low consumption, low impact model.

Figure-17-Figura has been summarised using the Consumption Base Accountability (CBA) approach (Moran and Wood, 2014), but in order to understand the influence of other industrial sectors, the energy uses could be aggregated in a different way than the one used in this paper. For instance, the Energy Performance of Buildings Directive (Directive 2010/31/EU) states that worldwide, 40% of all energy is consumed in buildings. This takes into account not only the electricity and thermal energy consumed in households, but also that of industrial and services buildings. In this paper, the main goal is to identify and disaggregate the direct electricity consumed residentially from that embodied in products and services. For this purpose, industrial and services buildings have been considered as part of the infrastructure required to create goods and provide services.

7.3 Methodology

A case study approach was used to enable us to clarify the specific results and contributions of selected *Bottom-up* energy transition initiatives in Germany. Although similar studies have been approached using the Multi-Level Perspective (MLP) methodology (Geels et al., 2014), broad scope analysis, like the current one using empirical analysis, although less detailed than other studies using MLP, could focus more on the achievements of the society that is generating the change, and not on the external (regional or national) actors (Geels, 2012). The "case study" method does not require the control of behavioural events and focuses the analysis on contemporary events (Yin, 2009). According to Simon (Simons, 2009) "Case study is an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in a 'real life' context". In each case study, the subject and the object of the case are identified; "a case study must comprise two elements: a practical, historical unity, which I shall call the subject of the case study, and an analytical or theoretical frame, which I shall call the object of the study." (Thomas, 2011).

The first step was to select the cases, identifying the eight most important *Bottom-up* energy transition cases in Germany within low energy consumption intentional communities or ecovillages (1) energetically self-sufficient rural villages (2) and sustainable urban neighbourhoods (3). *Figure-18-Figura* shows the popularity according to the general society in internet (number of citations in the Google search engine) and scientific journals (number of citations in the Scopus search engine). The most cited in each category has been selected. In *Table-5-Tabla* the subjects and objects in the three selected cases have been defined.

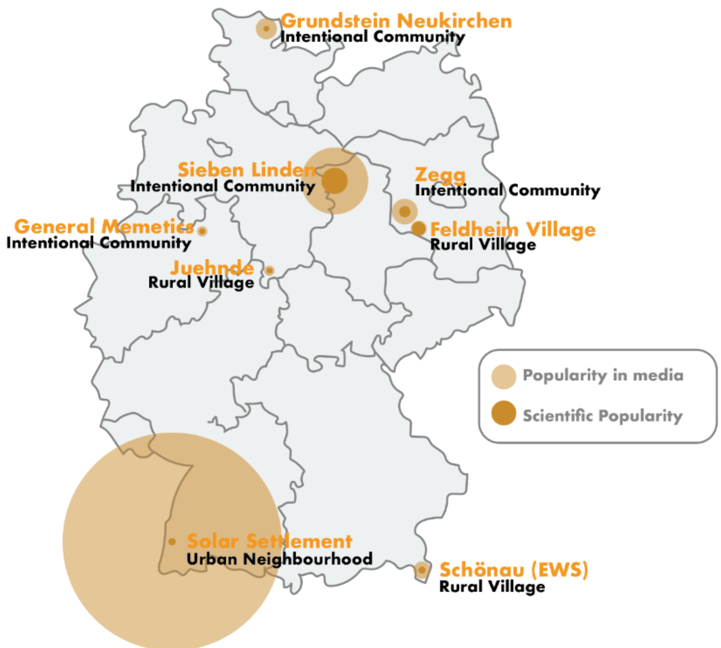

Figure-18-Figura. Popularity of *Bottom-up* energy transition cases in Germany.

Qualitative and quantitative questionnaires were developed in situ for community members in order to collect the energy consumption model description and data of each case. Cases were pre-analysed, contacted, and visited by the main author, conducting interviews of the community members. The goal of qualitative questionnaire was to understand the trigger factors for each energy transition and the underlying collective philosophy so as to describe the nature of each transition. Whereas in the quantitative questionnaire, the goal was to understand if an approximate calculation of the TPES could be made, and to analyse the electricity consumption and the self-produced renewable energy in each case study. Questionnaires were developed by a multidisciplinary research team with the participation of researchers from the University of the Basque Country, "Ecologistas en Acción Euskadi" grassroots confederation, and "Engineers Without Borders", a non-governmental organisation, as a part of a wider project (Akizu et al., 2017). In each case study, main coordinators or communication representatives were interviewed in order to gather the official data. The findings were compared against the data of average national energy system. The measurement of electric and thermal energy consumption in households is more accurate and affordable than the measurement of the TPES of an initiative. Consequently, in this study, several assumptions were made to obtain a raw TPES value, and were clearly explained in each case study. Although the available data are limited, they are enough to observe that in all case studies, significant results were achieved in comparison with national consumption average trends.

Table-5-Tabla. Three case studies analysed.

Initiative	Subject	Object
Sieben Linden (Category: Intentional community, ecovillage)	"A group of people", united by grassroots anti-nuclear movements, created a low-energy consumption community.	Communal use of resources, rather than technological efficiency to reduce energy consumption.
Feldheim (Category: Rural village)	Energy self-sufficient village, linked to a renewable energy generation cooperative.	Economic viability of energy transitions.
Solar Settlement (Category: Urban neighbourhood)	An architect, inspired by sustainable building and living principles, builds an energetically sustainable neighbourhood that produces more electricity than it consumes.	The role of sustainable residential areas in energy transitions.

7.4 Case Studies

7.4.1 Sieben Linden

Sieben Linden is an "ecovillage", recognised by the Global Ecovillage Network (GEN) (Litfin, 2013). 140 people (100 adults and 40 children), inhabit it. The original group was created in Gorleben, during the anti-nuclear protests of the 1980s. For this reason, the ideology of the Sieben Linden "intentional community" has been closely linked with the aim of creating a sustainable energy system. It currently co-owns 80 hectares, of which 45 are forestland. In the future, the village expects to reach a population of 250 and 300 inhabitants. This is considered the optimum number of members to have the right balance between sustainability and efficiency in resource management.

Unlike other similar experiences, based on a personal "sacrifice" to achieve sustainable living consumption standards, this community views "austerity" as a gain in happiness by providing a high quality of life in an attempt to achieve a minimalistic material lifestyle. This is achieved through a communal and participatory model of resource management where they have quantified their total energy consumption in kWh per capita. This basic calculation permits the community to choose the adequate patterns and technologies, and to promote a responsible approach towards the environment in all energy consumption (food supply, building material supplies, electricity generation, water purification systems, etc.).

One of the pillars of sustainability in the community has been architecture and the design of places to live. As a general rule, each person has the right to have a maximum amount of 16 m^2 of private space in his or her own house, and 16 m^2 of communal area in the ecovillage; reducing the energy requirement to build, maintain, and to heat in these spaces.

In Sieben Linden, the buildings are designed to consume as little energy as possible. The first home built in the ecovillage, named "Villa Strohbund", was built with no machinery or fossil fuels, using only local or recycled materials. In this first home, the ambitious challenge was to consume only 10% of the primary energy consumed in traditional homes, following the goals dictated by the book "Greening the North" (Sachs et al., 1998). The energy consumed during the construction of Villa Strohbund was between 2% and 5% of that consumed by a house of the same insulating properties (50 kWh/m^2 per year for heating purposes) (Litfin, 2013), (Stengel, 2014).

The second important pillar of the Sieben Linden energy system was to have a "one earth equivalent energy footprint". To make this measurable target, the community aims to obtain all the resources (especially for heating and lighting) from their own land. The community has an internal energy advisor who states: "Our goal is to live in an energy system where each person only uses the proportional corresponding part of resources of the country; we would like to ascertain that every person on this planet, and future generations as well, have the same right to use the resources" (Dyck, 2014). Based on this commitment, a calculation has been made in Sieben Linden regarding the amount of forestland that would correspond to each German citizen if there was a national equitable distribution. At the same time, the energy from their own forest, grown and managed sustainably, was assumed to be the easiest way to guarantee a non-negative impact energy source (Dyck, 2014), with zero net carbon emissions, neutral in CO_2 (Bracmort, 2016). According to the basic calculations of the community, if the total amount of land of Germany was equitably divided, given that Germany has an area of about 360,000 km^2 and 80 million inhabitants, the available area per capita should be 4500 m^2 per person, of which 2200 m^2/person are forests for wood extraction (see *Table-6-Tabla*).

Table-6-Tabla. Equitably divided use of available land in Germany (data provided by Sieben Linden community (Dyck, 2014)).

Land Use in Germany	($m^2 \cdot cap^{-1}$)	(%)
Land used for food	1600	36
Land used for Forestry purposes	2200	49
Non-usable land (road, rivers, city…)	700	16
Total available land per capita in Germany	**4500**	**100**

The calculations estimated in Sieben Linden, shown in *Figure-19-Figura*, indicate that by managing biodiversity properly, of 2,200 m^2 of forestland, 6.5 m^3 per hectare per year could be cut down. Of this, around 23% (1.5 m^3) is left in the field to increase biodiversity, and 5 m^3 of timber is used as firewood, equivalent to 1,650 kWh embodied thermal energy. This energy could be extracted in efficient stoves with an annual rate of 1,450 kWh residential heat per person and year.

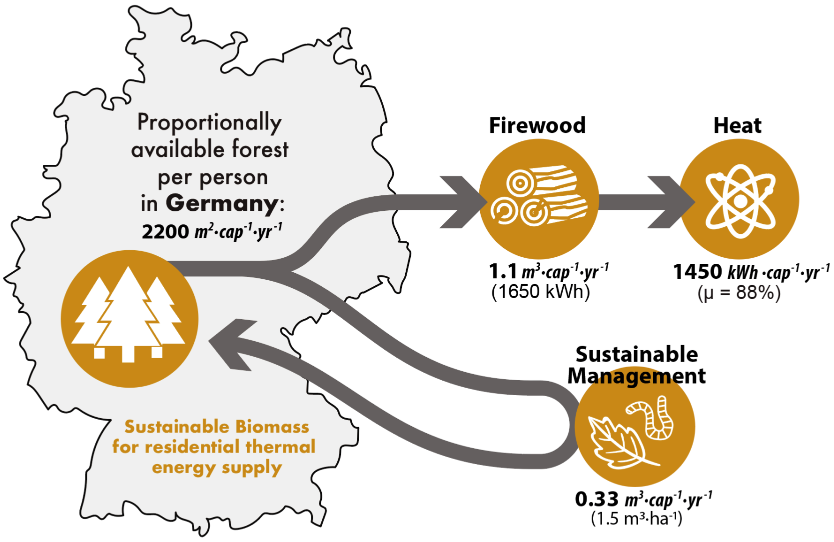

Figure-19-Figura. Sustainable managed forests firewood based energy extraction capacity in Germany according an equitable sharing, concept developed by Sieben Linden ecovillage.

These basic calculations conclude that, with the current 40 hectare forest owned by the ecovillage, Sieben Linden is consuming 30% more wood than their corresponding national average: instead of harnessing 2,200 m^2 they are using 2,857 m^2 per person to generate 1.43 m^3/person of firewood. In order to lower their thermal energy consumption, and by linking this to the primary aim of building sustainable shelters, Sieben Linden has built more efficient homes, such as the "Libelle" house. In this efficient house, due to the installation of 66 m^2 thermal solar roof panels and a heat accumulation water-tank of 10,000 L, solar heating power of 1,980 kWh/person per year is achieved. In the Libelle house, wood consumption is reduced by up to 0.6 m^3/person annually; taking into account that each person consumes 0.5 m^3 of wood in public spaces, the total consumption stands at

1.1 m^3/person, exactly the theoretically fair quantity based on national consumption. However, their new goal is to continue experimenting by using less industrialised products (such as solar panels) to avoid the consumption of the embodied energy contained in industrial products (Chastas et al., 2016). *Table-7-Tabla* shows the average annual thermal and electricity consumption of a person in Sieben Linden (Dyck, 2014). It can be observed that the energy consumed in homes is 60% less than the national average.

Table-7-Tabla. **Residential energy consumption per person in 2013.**

Residential Consumption Items	Sieben Linden Community (kWh·cap^{-1})	Germany (2013, IEA) (kWh·cap^{-1})
Heating	3500 (firewood + solar)	5650
Residential Hot Water	600 (firewood)	793
Cooking	400 (propane)	595
Electricity	350 (300 solar + 50 grid)	1586
Generation, transmission and distribution losses	130 (propane and grid)	3535
TOTAL	**4980**	**12,159**
Compared to the National consumption level	41%	100%

The third important pillar of energy sustainability has been the reduction of items or tools within the communal use of them. Owning less industrial products enables the community to reduce the embodied energy consumed in the equipment manufacturing process. In Sieben Linden there is an average of one washing machine for every ten people and one car for every twelve people (the average rate in Germany is one car for every 1.5 people (International Monetary Fund, 2005)). There is a "free store" at the entrance to the community house where clothes and used objects are exchanged, giving them a longer life. It is also significant that they have not only drastically reduced the number of private vehicles, but their use (approximately 300 km/person annually).

Lastly, the fourth pillar is the food supply system. Sieben Linden currently produces 70% of all the fruit and vegetables it consumes with an aspiration to become 100% self-producers. The rest is purchased from an ecological wholesaler. In addition, all the meals served in the common dining room are vegetarian or vegan, significantly reducing the energy and greenhouse emissions needed to produce, process and transport food (Hoolohan et al., 2013).

To conclude, in *Table-8-Tabla* the complete energy consumption has been summarised, forecasting the TPES of the ecovillage. Although there may be some inaccuracies in these first calculations (especially in the case of the industry and services and non-energy uses consumed in the community (Dyck, 2014)), the data provides us with insight into this energy transition case. Indeed, *Table-8-Tabla* shows that Sieben Linden's primary energy consumption could be about 77% lower than the German national consumption. The aggregation of the data in *Table-8-Tabla* was elaborate following the criteria shown in *Table-7-Tabla*, but here transformation and distribution losses have been proportionally incorporated into each sector, whereas in *Table-7-Tabla* they were identified as one separate item.

Table-8-Tabla. TPES per person in 2013.

Area	Sieben Linden Community ($kWh \cdot cap^{-1}$)	Germany ($kWh \cdot cap^{-1}$)
Residential	4980	12,159
Transport (food and persons)	4800	11,059
Industry, Goods and Services	1000	18,307
Non energy uses	0	4434
TPES	**10,650**	**45,959**
Compared to the National consumption level	23%	100%

In summary, in Sieben Linden the human need for a different cultural approach to life (German Commission for UNESCO, 2009) has helped move towards an energetically sustainable model. This cases shows that "the shift from fossil to renewable energy could potentially counter the growth orientation of economic activity" (Kunze and Becker, 2015).

7.4.2 Feldheim

The village of Feldheim is characterised as being the only electrically self-sufficient village in Germany with 100% of its electricity supply coming from their own generated renewable systems. Feldheim supports 128 inhabitants with several business activities. The main activity is livestock farming, comprising two medium-size farms, one with 400 cattle and the other with 600 pigs, that mainly feed on local fodder and vegetables. For this reason, in the calculations contained in this paper, the thermal and electric energy required in the village has been considered as TPES, considering that the energy embodied in goods exported from the village and the goods imported into the village are similar.

In Feldheim, the community decided to create its own renewable energy generation system and to have the right to choose where to invest their savings, in which energy generation source and technology and not to delegate or deny any responsibility for this impact in the banking system. In our current society, most citizens are seldom given the right to choose the kind of energy generation technology in which to invest our own savings. People generally keep their savings in the bank, where the money is then used to invest in different sectors and different forms of power generation. Banks tend to invest in the power generation that provide the fastest return on investment and only communicate the sums of these returns to their customers. The investors have a reduced control over the energy system that they are funding and lack responsibility in terms of the generated socio-environmental impacts. These impacts are often not evident to the actors since they are hidden from them due to three factors: they occur physically far, far in time (becoming exponential in the future), and affect a different social class from which they were produced.

The decision to create an own renewable and low-impact energy system was started in 1995 by creating "Energiequelle" energy cooperative (von Bock und Polach et al., 2015). In this process, three highly complex concurrent factors were the base of the creation of the cooperative: the availability of the energy infrastructure, the knowledge of economic funding models, and in particular, the necessary approval and active participation of all partners (Kunze and Busch, 2011). During the creation process, the participants realised that this form of managing their savings was environmentally, socially and financially profitable as a direct result of the revenues.

Today there are 47 windmills with 71.1 MW of installed capacity, producing 175.1 GWh per year. A small 500 kW biogas plant was also built to provide electricity and to heat community houses and shelters for cattle rearing throughout a 3000 m long district-heating grid. In addition, a 2.25 MW solar photovoltaic generation plant was built. A 400 kW biomass plant was also constructed for emergencies, which is normally not functional but is ready in the event of a power outage. The advantage of biomass is that wood can easily be stored long term, to be used when other renewable sources are unavailable.

Lastly, Feldheim has become a reference for its new experimental technology program for lithium batteries. As a solution to the intermittent nature of power generation and the inability to store renewable energy, a 10 MW ion-lithium pilot plant was launched. This puts into practise the concept of Integrated Community Energy Systems (ICES), which is a "more bottom–up solution which can capture all the benefits of distributed energy resources and increase the global welfare […]", as well as a "comprehensive and integrated approach for local energy systems where communities can take complete control of their energy system and capture all the benefits of different integration options […]" (Koirala et al., 2016).

In 2013, as shown in *Table-9-Tabla*, electricity production in Feldheim stood at 135.9 GWh and consumption at 855.95 MWh ("Village of Feldheim: Energy self-sufficient district of the town of Treuenbrietzen in Germany's county Potsdam-Mittelmark," 2014), meaning that only 0.63% of its electricity production was self-consumed. The rest was sold to the grid and to the national energy market. In addition, they consume 2.57 GWh of locally-produced thermal energy. This means that the assumed TPES, if we combine the electric and thermal consumption, comes to 3425.95 MWh/year, or 26,765 kWh/year per capita. This basic calculation does not account for the energy embodied in all the products and services that the citizens of Feldheim consume outside of the village of Feldheim. However, it has accounted for the total energy requirements for the meat production system, which is mainly consumed outside of the community, in an aim to approximate a real TPES level. This means that these first calculations could be improved in further research by incorporating these parameters.

Table-9-Tabla. Electrical and thermal energy production in Feldheim (data provided by the Neue Energien Forum Feldheim).

Energy Type	Installed Energy Power (MW)	Yearly Produced Energy (GWh·year^{-1})
Wind	74.1	128.8 electric
Biogas	0.5	4.4 electric + 2.4 thermal
Biomass	0.3	0.17 thermal
Solar PV	2.25	2.7 electric
TOTAL	**77.15**	**135.9 electric + 2.57 thermal = 138.47**

Energiequelle has come to play a crucial role in the village and the project has become "a joint project by the residents, the local Farmers' Cooperative and Energiequelle" ("Village of Feldheim: Energy self-sufficient district of the town of Treuenbrietzen in Germany's county Potsdam-Mittelmark," 2014). This partnership between citizens, private cooperatives, and public management, creates a local public-private partnership (ppp). This model is not only a successful form of energy management, but also encourages improved human relationships, as "Feldheim shows a high degree of cooperation among actors, including formal arrangements between the village as a political body and the renewable energy company Energiequelle." (von Bock und Polach et al., 2015).

It is estimated that in 1995, before the electricity generation system of the village was changed, €500,000 was spent each year on the electricity and thermal energy supply (Shahan, 2014) (accounting for not only residential demand, but the demands of the medium-size pig and cattle farms). Nevertheless, they are currently consuming the most cost-effective supply of thermal energy in Germany and in 2014, when the average price stood at 28 c€/kWh, in Feldheim they were paying only 17.4 c€/kWh (Shahan, 2014). Regarding electricity, the cost is even lower, at 9 c€/kWh.

From an economic perspective, the community has emphasised that electricity-grid investments were made with private funds whereas the district heating received a grant of 50% of its total cost: €1.73 million ("Village of Feldheim: Energy self-sufficient district of the town of Treuenbrietzen in Germany's county Potsdam-Mittelmark," 2014). As for the subsidised payment rates for wind electricity production, the German government previously financed wind projects for up to 20 years at 8.93 c€/kWh (Gipe, 2012). However, in 2014 this figure was reduced to 8.9 c€/kWh for the first five years, and later on to 4.95 c€/kWh (Bundesanzeiger, 2014). In these particular cases it can be seen how an incentive to use renewable electricity through grants, if done properly, contributes towards encouraging energy transition and helps society to move beyond the fossil fuel energy system. This experience confirms a Fraunhofer Solar Institute report which, providing a comparison of production costs of each technology in Germany (Kost et al., 2013), affirms that the cost of electricity from onshore wind plants can equal the costs of coal and combined cycle gas generation plants.

Nevertheless, this case study shows that large national energy companies do not always support these kinds of energy sovereignty initiatives. During this process, in order to facilitate the integration of the electricity generated, the cooperative requested that E.ON, a privately-owned energy supplier, integrate renewable resources directly into their network, but the refusal of E.ON encouraged Energiequelle to build its own network in Feldheim. Having seen that it was feasible, E.ON and three large German companies proceeded to block other attempts to create local networks, which is why other sustainable communities only use 40–60% from renewable sources (Shahan, 2014).

7.4.3 Solar Settlement

Located in Vauban (Freiburg) and designed by architect Rolf Disch, Solar Settlement is one of the most highly acclaimed sustainable urban neighbourhood or housing complexes in the world (Freytag et al., 2014). Disch applied the PlusEnergy concept in this complex of 59 dwellings, shopping centre, offices, and parking area. It is the first housing community in the world to have a positive heat and electric energy balance (Fastenrath and Braun, 2016; Heinze and Voss, 2009). Disch coined the concept PlusEnergy in 1994 to signify that the energy consumed in a building is lower than the energy produced (Disch, 1994). The balance includes the electrical and thermal energy externally purchased and the excess of generated electricity sold to the grid. The consumers therefore get to play a new role in the energy system by becoming energy producers.

Planning for the Solar Settlement began in 1997 with the buildings constructed between 2000 and 2006, within the Vauban district, where sustainability was becoming an important leitmotiv. The Vauban neighbourhood, created in the 1990s, is called the "green neighbourhood" by the Freiburg city council (Mayer, 2013). Its origins go back to the Self-governed Independent Shelter Initiative (SUSI) (Coates, 2013). The SUSI community, formed by young people seeking a new lifestyle system, set up an 'intentional community' (Brown, 2002),(Kozeny, 2002). They sought a sustainable lifestyle: consuming local organic products, reducing their energy consumption, using only public transport and bicycles, regenerating natural green spaces in the neighbourhood, generating their own heat and electricity, etc. This encouraged more people in the area to build sustainable buildings, especially passive houses (Delleske, 2005). Today, 5500 people live in 100 buildings in Vauban, emitting an annual average of 0.5 tonnes of CO_2 per capita, compared to the city average of 8.5 tonnes per capita (Williams, 2016).

This formed the context behind the development of the Solar Settlement apartment complex. Together with urban planners from the city of Freiburg, Disch planned the area as coherent real estate and aimed to sell it after construction to private homeowners. The total investment for residential buildings and the service building amounted to €51.6 million. However, before work started, the banks were only willing to grant mortgages for houses with buyers in place and for this reason, the "Freiburger Solarfonds" (Freiburg solar real-estate funds) were created. These private real estate funds collected money from investors for the housing units that could not be sold to private investors, to rent them out to tenants after construction (Freytag et al., 2014).

Hence, there are two different types of ownership models for the Solar Settlement houses and solar photovoltaic installation on roofs. While half are private, the other half belongs to the "Freiburger Solarfonds" cooperative. In the second case, the houses are rented out to families, but the electricity produced on the roof is sold by the cooperative to the grid. Despite this, the balance between the electric energy generated and surplus electric thermal energy consumed, remains positive if average consumption levels are assumed. Solar Settlement apartments are 75–162 m^2 (Disch, 2006) and most are 3-story with a 60 m^2 garden each. The current average occupancy rate is 2.9 people per house (Freytag et al., 2014) and they are occupied by upper middle class families with high incomes (Mittelbronn, 2014).

Disch also tackled energy use in the transport sector and the transportation model for the neighbourhood. The complex was designed as a vehicle-free area with pedestrian and cycle access, changing the design of the houses to hold a wooden shed for bicycles, instead of a garage. The community has been carefully integrated into the neighbourhood and into the city of Freiburg in terms of public transportation, with tram access included in the design.

Adjacent to the housing complex, a service centre called "The Sun Ship", the first commercial building with PlusEnergy certificate, was designed. The building is located on the main street and acts as a barrier to sound and pollution, contributing to the peace and tranquillity of the Solar Settlement. On the "Sun Ship"'s two underground floors are 138 parking spaces for residents, service area staff and customers. On the ground floor are two organic supermarkets whose function is to promote local products; a company specialising in the sale of natural pharmaceutical remedies; a social bank contributing to the local development projects based on ethical principles; and a Research Institute Ökoinstitut e.V. (EcoInstitute) which has been developing projects to reduce energy consumption since 1977. One of its most significant publications was "Laying down the pathways to Nearly Zero-Energy Buildings" (Kranzl et al., 2014) addressed to politicians. Historically, the institute has encouraged the development of sustainable culture, offering research facilities and technical support to social movements, for example to those fighting nuclear energy, of which the recent study on "The Risks of Nuclear Energy" is an example (Mohr and Kurth, 2014). The other four stories hold offices, for organisations mostly working on engineering and sustainable architecture, such as the Rolf Disch architecture studio, and services such as healthcare. Finally, on the deck, nine of the dwellings of the project complex are located.

The power utility company used by the vast majority of the inhabitants is ElektrizitätsWerke Schönau (EWS). This company was set up in the town of Schönau by the local anti-nuclear movement, which emerged after the Chernobyl accident. EWS defines itself as "nuclear-free sustainable" energy, guaranteeing a 100% renewable source energy supply. The firm is managed as a cooperative where "Citizenship is the owner". EWS also promotes the reduction of residential electricity consumption and send consumers a scale to show whether their consumption figures are either "very suitable", "adequate", "high" or "excessive" in each electricity bill. The EWS recommendation is to consume between 375 kWh and 725 kWh of residential electricity per person, annually.

This research study has taken the electricity and thermal data for four families in order to verify that the PlusEnergy concept is being achieved. *Table-10-Tabla* shows the calculations for the average electricity and thermal consumption per person. The average figure for thermal energy requirements was 19.45 kWh/m^2, almost in line with the Passive House certificate level. The electricity consumption was 577 kWh/person, in compliance with EWS recommendations, which is significant. As a further step, *Table-11-Tabla* compares the total energy production per house with their average energy consumption. The average consumption per house is currently 13.7% lower than the corresponding electricity generated by the photovoltaic system located on the building roofs.

Table-10-Tabla. Consumption table for Solar Settlement families.

	Family_1	Family_2	Family_3	Family_4	Average	Values
Adult	2	2	2	2	2	-
Infants	3	2	3	2	2.5	-
Household size (m^2)	160	160	130	130	145	-
			Electricity (kWh·year^{-1})			
2011	3335	2389	2500	2088		
2012	3399	-	2431	2440	2598	577 kWh·cap^{-1}
2013	-	-	2202	-		
			Heater + Hot Water (kWh·year^{-1})			
2012	-	-	2593	2329	2821	19.45 kWh·m^{-2}
2013	4002	3200	2393	2408		626 kWh·cap^{-1}

Finally it should be outlined that some authors have pointed to whether the goals of equality, justice and sustainable ideas should be linked with market-oriented growth (Mössner, 2015). Some authors consider that the Solar Settlement energy sovereignty project in Freiburg is directly linked to the neoliberal style of development and as such is directly opposed to the idea of "sustainable development": "the idea of 'sustainable development' in its current form is nothing more than an oxymoron" (Mössner, 2015). At the same time, this project has been criticised for being no more than an "urban legend and appears as rather detached from the local residents' practices and daily routines of living the Solarsiedlung" (Freytag et al., 2014). These theoretical criticisms do not completely counter the findings of this paper since in this case study, the main focus regarding energy reduction goals has been on heat and electricity reduction in households rather than on the importance of measuring TPES. In Solar Settlement the TPES has been estimated, in considering the reduction of residential heat and electricity consumption to be the only reduction gained in comparison with the national average TPES.

Table-11-Tabla. Accomplishment of the PlusEnergy concept in Solar Settlement: production and consumption table.

(A) Solar Settlement Photovoltaic production		
Installed solar generation capacity	333	kW
Average generation	314	$MWh \cdot year^{-1}$
Average total generation by house	**6280**	$kWh \cdot year^{-1} \cdot home^{-1}$
(B) Solar Settlement Electric and Thermal consumption		
Average electric consumption per household	2598	$kWh \cdot year^{-1} \cdot home^{-1}$
Average thermal consumption per household	2821	$kWh \cdot year^{-1} \cdot home^{-1}$
Average total consumption per household	**5419**	$kWh \cdot year^{-1} \cdot home^{-1}$

7.5 Results

7.5.1 Quantitative Results

The quantitative results provide the necessary information to evaluate the specific achievements in the energy transition processes of the selected case studies. The analysis takes into account the energy consumption reduction accomplished and the self-produced renewable energy. Although the accuracy is expected to be improved in future analysis, it could be observed that in all case studies, significant results were achieved in comparison with trends in national consumption.

Summarising the TPES, as shown in *Figure-20-Figura (a)*, the most important quantitative result has been achieved in Sieben Linden ecovillage, where, due to changes to their material lifestyle and as a consequence of their consumption system, residents were able to reduce TPES by 77% in comparison with the national average. This means that (assuming the correlation between energy and global use of resources) from the average national ecological footprint (EF) of 5.3 gha (*Figure-16-Figura*), in the ecovillage they have an EF of 1.2 gha. Therefore, taking into account that 1.7 gha is the maximum limit for using "the resources of one single world", we could roughly assume that the Sieben Linden ecovillage could be defined as being energetically sustainable. Similarly in Feldheim, the TPES is 42% lower than the national average, but in this case the energy consumed by the village from the outside in the form of goods and services needs to be calculated more accurately in future analysis. In order to forecast the TPES for Solar Settlement, due to the lack of data it has been assumed that reduction of residential heat and electricity consumption is the only reduction achieved against the national average TPES.

Although representing just 3.7% of the national TPES, the residential electricity consumption in *Figure-20-Figura (b)*, shows that in the Solar Settlement neighbourhood, they are able to reduce the average household electricity consumption by 66% and by 79% in Sieben Linden. However, building materials used in the Solar Settlement have apparently higher quantity of embodied energy than locally purchased low-tech materials used in

Sieben Linden. Further Life Cycle Analysis comparative studies could be done to clarify the significance of these figures. In order to calculate the household electricity consumption in Feldheim, due to the lack of data, it has been assumed that the same percentage reduction in TPES will be reached in residential electricity consumption. It should be underlined that in any event, reductions in residential electricity consumption cannot be used as a benchmark to forecast a real energy transition.

According to the self-generation capacity of renewable energy shown in *Figure-20-Figura (c and d)*, it can be observed that while the German national average has the capacity to generate almost 5000 kWh of renewable energy, which represents 11% of the national TPES, the Feldheim case study shows that this amount could be significantly increased. With the right investment, they have reached a production level of 1 million of kWh per year and per person, over 4000% of the state average. This demonstrates that there are considerable opportunities for RES integration when new social and economic models are implemented. Nevertheless, further research is required to analyse whether this goal could be achievable without public subsidies in investments or the feed in tariffs. In Solar Settlement, 16% integration has been reached, somewhat higher than the national average. Lastly, in Sieben Linden, it is shown that although the renewable energy generated is 9% lower than the national average, due to the reduction of TPES needs, they have achieved a 41% integration of renewable energy, almost four times the national average. This shows how reducing TPES could directly benefit the creation of a renewable based sustainable energy system.

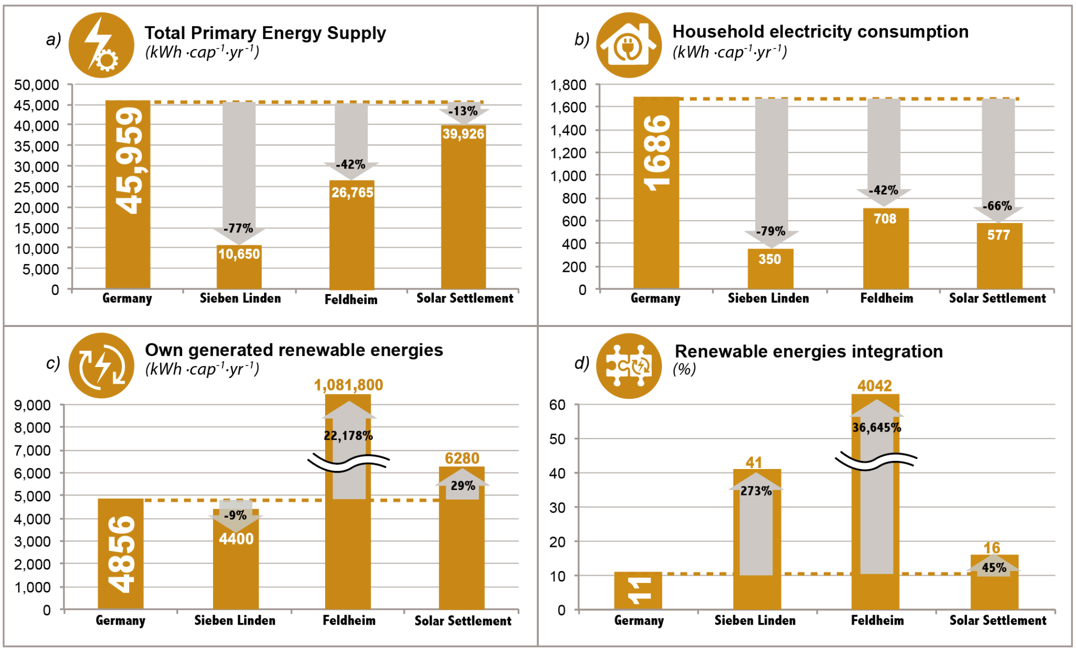

Figure-20-Figura. Goals achieved in the three case studies in comparison with the national average.

It should be emphasised that, as shown in *Figure-17-Figura*, RES integration not only reduces the social and environmental impact of the energy system, but also reduces the loss sustained during energy transformation and transportation processes (entropic energy loss owing to the use of a centralised fossil-fuel based system) which make up 29.1% of the TPES in Germany.

7.5.2 Qualitative Results

Table-12-Tabla outlines the most important learnings for the creation of a sustainable energy system, which have been identified in the three case studies. Firstly the "achievements" of each case have been pinpointed, to provide other *Bottom-up* initiatives and communities with the key learnings to contribute to their own moves towards their own energy transition. Secondly, given that each case has also encountered difficulties during their transition process, the major challenges faced have been presented in order to raise awareness of these and to encourage reflection as to how to overcome them.

Table-12-Tabla. Qualitative results extracted from the case studies.

	Achievements	Challenges
Sieben Linden	- The communal use of the space, and the construction of low energy consumption infrastructures (during their full life cycle, and not only when using them) could be a solid base to start a transition process. Participatory processes help during the creation of new living concepts. - Using local resources like local firewood not only increases the awareness of the availability of such resources, but also enables consumption to be measured within parameters of replicability.	- There are difficulties when measuring the real dependency on national public services, such as transport infrastructures, health, education, security, political framework, etc. - It is not yet known how to scale up small low-energy consumption communities to regional and national level where personal human connections become weaker.
	- A shift in consumption values based in voluntary and satisfactory austerity, and on a communal use of products and services, leads to a sharp decrease in total primary energy consumption. A change in the food supply system towards a local vegetarian diet could directly affect the energy consumption.	- How to handle the needs for privately produced technological products (such as cars, computers, cell-phones, solar panels, etc.) or the private managed banking system has not yet been properly defined.
Feldheim	- Communal economic investment in renewable energy technology makes low carbon energy generation systems economically affordable. - The opportunity to decide in which generation technology (wind, nuclear, solar, coal, etc.) to invest their own savings makes individuals and communities directly responsible for the social and environmental impact of the energy model created. - The community has created new jobs in the energy sector and has also participated as an experimental research center.	- How to move towards a high electricity vector use model. In order to become energy self-sufficient the community is trying to shift other indirect forms of consumption, such as transportation, to the electric grid. - How to become an electric island. The community needs to invest funds in an experimental energy storage system. - How to achieve same RES integration goals without public subsidies during installation or feed in tariffs. - How to measure the real TPES

		consumption of the neighbourhood in a more accurate way.
Solar Settlement	- Energy consumers also become energy producers with the PlusEnergy concept which breaks down the current "wall" between producers and consumers. - The fast development of private sustainable initiatives can be greatly accelerated in sustainability-sensitive environments such as sustainable neighbourhoods, as happens with Solar Settlement in Vauban.	- How to reduce the overuse of technological solutions containing high quantities of concealed embodied energy. The PlusEnergy concept does not account for the energy consumed by these infrastructures and houses during the full product life cycle. - How to measure the real TPES consumption of the neighbourhood in a more accurate way.

7.6 Conclusions and Policy Implications

As stated, the main goal of the paper is to detect the specific achievements of the selected German *Bottom-up* initiatives in their energy transition process, especially analysing the reduction of total primary energy consumption (1); reduction of residential electricity and heat consumption (2); and the increase of renewable generated energy and even attaining self-sufficiency (3).

The case studies show that the national goals are achieved better than in the average German city/town structure. Therefore, within the current German structure, *Bottom-up* initiatives are able to significantly boost a change in the energy system. These *Bottom-up* case studies show that within the energy transition, technological improvements are losing their status as the only important factor. In contrast, social factors and their direct effect on both reducing energy consumption and enhancing high integration of renewable energy, are being seen as increasingly important aspects.

The existence of *Bottom-up* communities is especially relevant as this gathers a sufficient amount of people (a critical mass) to put energy transition ideas into practise. Definitively, moving towards a sustainable energy system means increased discussion of communal or public energy uses, their impact, approaches to energy management and the decision-making processes involved. Thus, a creation of a new energy system seems to be closely linked to the democratisation of the current energy system.

Likewise, the awareness and the aims of *Bottom-up* intentional communities to achieve social and environmental energy justice is a catalyst for participatory processes to generate actions aimed at changing the current energy system. These participatory processes play a critical role in constructing new infrastructures and buildings for energy-efficient models, as shown especially in the Sieben Linden case study, with reductions of up to 77% in TPES. In these initiatives it has been detected that the social engagement of architects, designers and engineers to maintain an active dialogue with the user, in order to adapt their designs more effectively to the real energy needs of people and communities, brings a new model of communal living with direct effects on energy consumption. In a similar way, the Solar

Settlement case study shows that social and environmentally aware communities, such as the Vauban neighbourhood, where there is already a trend towards a more sustainable approach to life, are fertile atmospheres where individuals, such as architects, could take further steps in sustainable proposals, for instance the PlusEnergy concept.

Lastly, these three case studies show that the new energy system can be economically viable when personal savings are invested in community projects, shown especially in Feldheim, when renewable energy generation systems are installed for its own consumption and selling purposes, since (for electricity) these have shown production figures of 4000% higher than those for consumption. Furthermore, deciding collectively where to invest personal savings is a way of reclaiming the responsibility for our personal role in "energy justice".

Figure-21-Figura graphically synthesises the conclusions drawn in this paper, which are direct assumptions from the qualitative and quantitative results. This research demonstrates that the *Bottom-up* analysed initiatives can contribute relevant achievements in enhancing the absolutely necessary energy transition, contributing to the national strategy to accelerate gaining the stated goals.

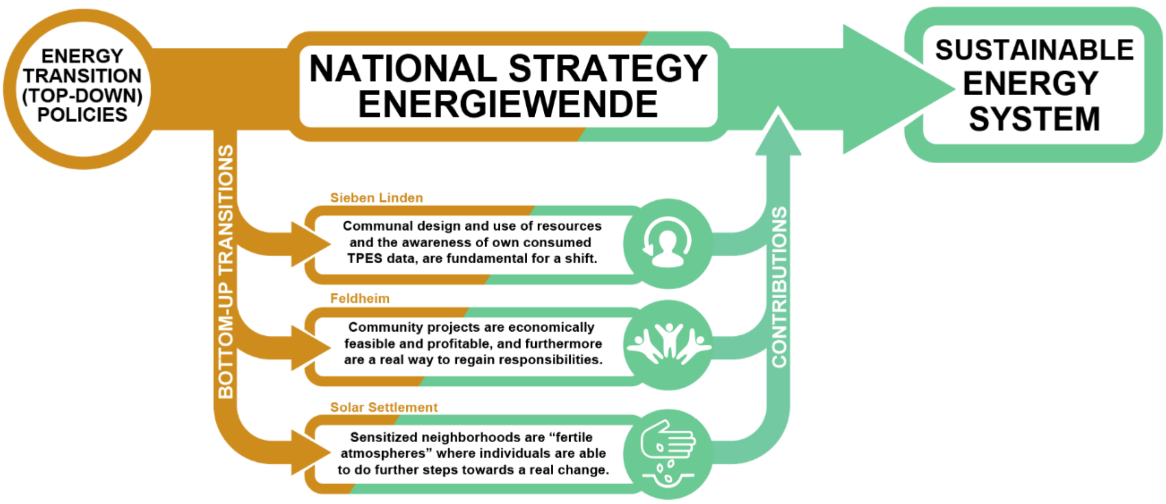

Figure-21-Figura. Summary of contributions from the analysed *Bottom-up* transitions to national transition strategy.

Due to the close relationship between *Top-down* and *Bottom-up* initiatives in Germany, such as the feed-in tariffs, it is difficult to isolate the specific effects of *Bottom-up* initiatives from the national *Top-down* ones. Thus, the achievements found in this study need to be carefully understood in a national context. Further studies should be done in order to define how the proposals of *Bottom-up* initiatives could successfully be replicated in the reality of other countries in order to boost a global low socio-environmental impact energy transition.

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08 Desacople
Decoupling

8 3_ARTIKULUA / PAPER_3

DECOUPLING BETWEEN HUMAN DEVELOPMENT AND ENERGY CONSUMPTION WITHIN FOOTPRINT ACCOUNTS

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Abstract

Historically, the growth of energy consumption has fuelled human development, but this approach is no longer socially and environmentally sustainable. Recent analyses suggest that some individual countries have responded to this issue successfully by decoupling Total Primary Energy Supply from human development increase. However, globalisation and international trade have allowed high-income countries to outsource industrial production to lower income countries, thereby increasingly relying on foreign energy use to satisfy their own consumption of goods and services. Accounting for the import of embodied energy in goods and services, this study proposes an alternative estimation of the Decoupling Index based on the Total Primary Energy Footprint rather than Total Primary Energy Supply. An analysis of 126 countries over the years 2000-2014 demonstrates that previous studies based on energy supply highly overestimated decoupling. Footprint-based results, on the other hand, show an overall decrease of the Decoupling Index for most countries (93 out of 126). There is a reduction of the number of both absolutely decoupled countries (from 40 to 27) and relatively decoupled countries (from 29 to 17), and an increase of coupled countries (from 55 to 80). Furthermore, the study shows that decoupling is not a phenomenon characterising only high-income countries due to improvements in energy efficiency, but is also occurring in countries with low Human Development Index and low energy consumption. Finally, six exemplary countries have been identified, which were able to

maintain a continuous decoupling trend. From these exemplary countries, lessons have been identified in order to boost the necessary global decoupling of energy consumption and achieved welfare.

Keywords: decoupling index; energy footprint; energy democracy; energy transitions; consumption based accounts; sustainable development goals

Highlights:

- Energy footprint accounts show an overall decrease of decoupling for most countries.
- Six exemplary countries show a maintained decoupling of HDI from energy requirement.
- Permanent or temporary decoupling has been detected in 89 countries.
- Both high and low-HDI countries can achieve temporary decoupling.

8.1 Introduction

In order to achieve a global sustainable a use of energy resources, energy consumption needs to respect socially fair and environmentally viable Planetary Boundaries (O'Neill et al., 2018). The introduction reviews the literature to establish the required energy to achieve development and define sustainable energy boundaries. Within this context, the decoupling phenomenon has been observed, in which energy consumption can be reduced while increasing countries development levels.

8.1.1 Energy consumption requirements

The correlation between the energy consumption and welfare of a country has been a well discussed topic. There is general agreement in the literature that a certain amount of energy consumption is fundamental to the economic progress and social development of a country (Wu and Chen, 2017). Nevertheless, there is still no consensus regarding the minimum thresholds of energy consumption needed to achieve acceptable living standards. Krugmann and Goldemberg (1983) found that between 11.5 and 15.7 MWh per capita per year was the cost of satisfying the basic human needs. Subsequently, an economic minimum requirement of 7.25 MWh per capita per year was identified (Grabl et al., 2004). Comparatively, Martínez and Ebenhack (2008) identified that 9.3 MWh per capita per year ($MWh \cdot cap^{-1} \cdot yr^{-1}$) were necessary to maintain the HDI level above 0.7, and 33.7 MWh in order to uplift the HDI value above 0.9. With 2005 data, it was stated that an average consumption of 16.7 $MWh \cdot cap^{-1} \cdot yr^{-1}$ was enough to achieve a 0.8 HDI value (Steinberger and Roberts, 2010). Subsequently, using the Life Expectancy parameter, Mazur (2011) detected that all nations consuming above 40 $MWh \cdot cap^{-1} \cdot yr^{-1}$ have life expectancies near 80 years. Similarly, in 2012 it was detected that energy consumption of above 43.8 $MWh \cdot cap^{-1} \cdot yr^{-1}$ does not necessarily lead to a higher Quality of Life Index (Pasten and Santamarina, 2012). Finally, Steckel et al. (2013) found that 27.8 MWh·cap^{-1}·yr^{-1} could very likely maintain the HDI higher than 0.9.

8.1.2 Energy consumption boundaries

In order to match human energy needs to available energy, current research attempts to understand how much energy is accessible worldwide as well as which the physical and sustainable Planetary Boundaries (PB) are (Rockström et al., 2009), in order to preserve the Earth System in a resilient and accommodating state (Steffen et al., 2015). The natural limits of global energy resources were recognised by the scientific community for the first time in the 1970s (Meadows et al., 1972). Currently, forecasting the *Peak Oil* is a constant challenge for the scientific community (Pargman et al., 2017). Current fossil-fuel-based global energy consumption threshold needs to be lowered, since is has been defined as: environmentally unsustainable (Inman, 2008), (IPCC, 2015), (Gies, 2017), socially unfair (Sovacool et al., 2016) (Eisenstein, 2017), and further economic losses and crises have been forecasted (Hsiang et al., 2017) (Fouquet, 2017) (Inman, 2013).

In response to the knowledge of energy limitations, as well as an attempt to promote an equal opportunity to the access of energy for all citizens in the world, in 1998 the Swiss Government promoted the "2000 Watt Society" (Stulz et al., 2011). The initiative had the ambitious target of reducing 60% of the Total Primary Energy Supply (TPES) from 41 to 17.52 MWh·cap^{-1}·yr^{-1} (Heeren et al., 2012). However, 18 years later, in 2015, the TPES of the country was still 34.46 MWh·cap^{-1}·yr^{-1} (International Energy Agency, 2015). But this figure does not include the energy consumed in other countries embodied in imported products and services, which has been growing in recent decades (Arto et al., 2016).

The shift towards renewable energy sources has been stated to be environmentally indispensable (IPCC, 2015) and even beneficial in economic or social terms globally (Jacobson and Delucchi, 2011) (WWF, 2011) (Jacobson et al., 2015) (Teske et al., 2015) (García-Olivares, 2016) and nationally (Kucukvar et al., 2017), as demonstrated by using the Triple Bottom Line methodology (Slaper and Hall, 2011). According to optimistic studies, a 100% renewable energy supply for 139 countries could be possible within 2050, while actually maintaining the global energy consumption of 2012 (Jacobson et al., 2017). In this respect, even if all the countries in the world could be able to maintain 2012 consumption levels within renewable generation (13,267,620 ktoe, International Energy Agency, IEA), maintaining human population in 2012 levels (7100 millions) each individual would have the equal right of consuming a Total Primary Energy Footprint of 21.9 MWh·cap^{-1}·yr^{-1} of fully renewable energy. Nevertheless, limits for renewable energies have been discovered. For example, taking into account the land usage in the case for the solar resource, has concluded that a global transition to domestically produced renewable solar energy will be physically unfeasible to maintain current energy consumption levels (Capellán-Pérez et al., 2017). Other research has considered a strong limit in renewable energy penetration; in an optimistic scenario, the total installed capacity of renewables is forecasted to saturate at around 1.8 TW in 2030 (Hansen et al., 2017) and maximum global production capacities of around 145,000 TWh in 2050 (Capellán-Pérez et al., 2014).

Being aware of these limits, Cullen et al. (2011) analysed the capacity of reduction of TPES through savings and efficient management and concluded that a 73% reduction would be feasible. A global energy consumption reduction from 475 $EJ \cdot yr^{-1}$ to 129 $EJ \cdot yr^{-1}$ (based on the 2005 data) was identified as feasible, reducing energy use from buildings, transport and industry (Cullen et al., 2011). This baseline would give each citizen the equal right to consume of 4.7 $MWh \cdot cap^{-1} \cdot yr^{-1}$. Nevertheless this reduction capacity has been contrasted based on the difficulty of reducing current energy consumption levels; especially due to the strong correlation between energy consumption and economic growth (Sorrell, 2015).

Lastly, due to the limitation of the Planetary Boundaries, has been found that generally the current resource consumption level is 2 to 6 times the sustainable level one (O'Neill et al., 2018). Thus, taking into account the present global energy consumption (13,647,367 ktoe in 2015, IEA) and assuming the positive condition that population figures will be maintained (7,355 millions in 2015, World Bank), energy consumption should be reduced to between 3.6 and 10.8 $MWh \cdot cap^{-1} \cdot yr^{-1}$.

8.1.3 Decoupling

Being aware of the limited availability of energy (renewable or less), the decoupling between energy consumption (and its impacts) and the achieved welfare has been defined as a "key issue" to reach the Sustainable Development Goals (SDGs) (UNEP, 2011), (UNEP, 2014). This issue establishes how humanity should be able to maintain current life standards in developed countries and promote development in low-income countries without affecting the environmental bio-capacity of the Earth. To accomplish the decoupling challenge, technological innovations (eco-efficiency and system innovations) have been seen as the main leverages (UNEP, 2011), (UNEP, 2014). As a secondary aspect, the need to encourage change in consumption patterns, to reduce the consumption of resources while achieving improvements in quality of life, has been identified as an influential factor (UNEP, 2014). These objectives are aligned with "Goal 7" of SDG (UN, 2015) where the sustainable energy availability is recognised as a right for all individuals, "Goal 10" of SDG, where equality between countries is recognised, and finally "Goal 12" where sustainable consumption ways are claimed.

Since 1970, the relation between consumed energy and gained GNP or GDP has been widely studied and has assessed the possibility of decoupling (Bullard and Foster, 1976), (Meadows et al., 1972), (Nilsson, 1993). In 2002, an extensive study was developed by the Organisation for Economic Co-operation and Development (OECD, 2002), where indicators to measure the Environmental Pressure (EP) from specific Driving Forcers (DF) were classified, and the variation ratio between EP and DF during a certain period was defined as the Decoupling Factor (DF). Mielnik and Goldemberg (2002) analysed the decoupling phenomena in 20 developing countries, concluding that technology improvements due to foreign investments could promote a decoupling. Decoupling was also analysed in the transportation sector, between consumed energy and provoked emissions (Tapio, 2005). Diakoulaki and Mandaraka (2007) analysed the decoupling between emissions and industrial growth within the 14 EU countries, finding that a considerable effort has been done for decoupling. Decoupling between environmental impacts (measured in CO_2eq emissions) and GDP has also been analysed in Brazil (de Freitas and Kaneko, 2011), and between consumed energy and GDP in China (Zhang et al., 2015). Both studies concluded that technology played an important role in decoupling in Brazil, reducing the carbon intensity of the generation mix, and in China, increasing the energy efficiency (energy intensified effect). In China was founded that decoupling was also a result of the rapid economic growth of the country (Wang, 2011).

A more recent study, that analysed the decoupling phenomenon in eight countries, concluded that decoupling, is more present and constant in developed countries (Wu et al., 2018). Wu et al. (2018) used a specific Decoupling Index (DI) of Impact-GDP-Technology (IGT) in different countries within GDP and TPES, where this decoupling is clearly observed in developed countries such as the UK, France, and USA. In the study, absolute decoupling and relative decoupling terms were used to clearly distinguish the achievements of different countries.

Nevertheless, relating the decoupling phenomenon to technological advancements of the developed countries, has already been considered for re-evaluation (Moreau and Vuille, 2018). When integrating footprint accounting in resource consumption measurements, it was found that the decoupling between economic achievements and environmental impacts was "smaller than reported or even non-existent" (Wiedmann et al., 2015), due to exporting production chains to other countries. Moreau and Vuille (2018) states that decoupling is still under discussion due to the "virtual decoupling" concept. The "virtual decoupling" occurs when a developed country argues to reduce energy consumption, while in reality has only exported the industrial production chains to other less developed countries (Moreau and Vuille, 2018), thus national energy measurements are not able to detect this consumptions. As a result, even if decoupling has been defined as a necessary factor to achieve sustainable goals, it is not clear which countries and when reach decoupling – or simply have export high energy consumer industry to other countries –, and whether there is an impetus to attain it.

8.1.4 Accounting for total primary energy consumption

In order to determine decoupling, energy consumed by a country may be measured in different ways that affect the results. The Total Primary Energy Supply of a country (TPES) and the Total Final Consumption (TFC) have been the most popular indicators when measuring energy consumption, both defined by the (International Energy Agency, 2015). TPES is the sum of TFC and the losses of the energy transformation and distribution sectors (Goldemberg and Siqueira Prado, 2011). However, TPES and TFC are both Production Based Accounts (PBA), where energy consumption is measured within the boundaries of a country (Peters, 2008). In present day, the massive outsourcing of industrial production chains and services (especially from high-income countries to low-income ones), causes the total energy consumption of high-income countries appears to be smaller, since part of it is outsourced and accounted for in other countries (Arto et al., 2016).

To address this occurrence, scientists have used Consumption Base Accounting (CBA). CBA was initially used for Carbon Footprint measurement (Munksgaard and Pedersen, 2001), (Peters, 2008), (Peters and Hertwich, 2008), (Kanemoto et al., 2012), (Barrett et al., 2013) using the Global Multi Regional Input-Output (GMRIO) methodology (Wiedmann and Lenzen, 2018). Footprint accounting has become a well-established method to trace the total resource needs and environmental impacts of a country's consumption (Wiedmann et al., 2007), (Galli et al., 2012), (Hoekstra and Wiedmann, 2014), (Wiedmann et al., 2015).

Using the same GMRIO methodology, the "Energy Footprint" concept was developed (Arto et al., 2016). This considers the energy embodied in imported goods and services that is consumed in other countries, and is defined as Total Primary Energy Footprint (TPEF). TPEF allows relocating the energy accounts according to the final consumers.

It needs to be clarified that the concept of Energy Footprint has been used either for specific industrial processes (processing with the LCA methodology) or to calculate whole countries' energy footprints (such as in this research, using the GMRIO methodology). Generally, when the term Energy Footprint is used to calculate the external energy use of specific industrial manufacturing or resource extraction processes, the concept Cumulative Energy Demand (CED) is used and Life Cycle Assessment (LCA) methodology is more frequent (Röhrlich et al., 2000), (Huijbregts et al., 2010), (Puig et al., 2013). Nevertheless, in this research, Energy Footprint specifically refers to the CBA energy consumption of a determinate whole country.

Several studies have been developed in this field, taking into account different databases (GTAP, WIOD, OECD, Eora and EXIOBASE) as well as different countries (Chen and Lin, 2008), (Wiedmann, 2009), (Mativenga and Rajemi, 2011), (Chen and Chen, 2013), (Heinonen and Junnila, 2014), (Arto et al., 2016), (Lan et al., 2016). The latest research in the energy field prioritised comparing the accuracy of results when calculating the energy footprint (Owen et al., 2017), (Min and Rao, 2017); forecasted future energy scenarios (Kucukvar et al., 2017), (Kaltenegger et al., 2017); as well as computed energy footprint calculations based in single years (Wu and Chen, 2017), (Chen and Wu, 2017), (Rocco et al., 2018), (Chen et al., 2018), (Wood et al., 2018), (Zhang et al., 2018).

Despite these advancements, the decoupling phenomenon between the TPEF and subsequent achieved welfare has not been addressed in a broad way through –analysing contemporaneously several countries– with the use of a Decoupling Index and Energy Footprint accounts. Given the precedent "virtual decoupling" detected in Switzerland (Moreau and Vuille, 2018), the possibility of studying decoupling in several countries within a footprint account perspective is especially relevant.

8.1.5 Study aims

The objective of this study is to analyse unsolved decoupling phenomena between Total Primary Energy Footprint (TPEF) and achieved welfare (measured with HDI) among 126 countries from 2000 to 2014. The presence of the decoupling effect in developed and non-developed countries has been studied, in an attempt to define any link between the level of development in a country and the achievement of decoupling.

For this purpose, the TPEF of 126 countries has been calculated using CBA during 2000 and 2014. With these data, the Decoupling Index (DI) between consumed energy and achieved HDI (defined in Methodology section) has been calculated, analysing the difference between TPES and TPEF results. Secondly, TPEF based DI versus gained HDI has been analysed and countries have been classified in four decoupling types. At this stage, exemplary countries have been identified dividing the Decoupling Index in four year gaps: 2000-2004, 2004-2008, 2008-2012 and 2012-2014, where maintained decoupling has been achieved. Thirdly, country-based, time series have been developed in order to more accurately observe the decoupling trends of exemplary countries. Lastly, temporary decoupled countries have also been detected in order to understand which countries could achieve future absolute decoupling trends.

Section 8.2 of this research illustrates the Global Multi-Region Input-Output method used. Section 8.3 breaks down results divided in the above defined four parts and in Section 8.4, the results are discussed. Finally, Section 8.5 provides recommendations and implications for improved policy making.

8.2 Methods and data

8.2.1 GMRIO calculation

Global Multi Regional Input-Output (GMRIO) methodology has been used to calculate the Total Primary Energy Footprint (TPEF) from the initial Total Primary Energy Supply (TPES) obtained from the International Energy Agency (IEA). This has been accomplished using the 26 industry sector based Eora database economic information for 189 countries (Lenzen et al., 2012). A more detailed version of this database, with 15,909 sectors, is available (Lenzen et al., 2013) but, since the original energy data from the IEA matches better with 26-sector version of Eora, the former has been considered more appropriate for the purpose of this research. It must be clarified that the Eora 26 database estimates the economic sectorial data of certain industries in some countries, thus when using these data to calculate the TPEF of a country, the errors already reported in economic matrixes will be reflected in the calculated footprints. According to Moran and Wood (2014), after performing a sensitivity analysis within a harmonised carbon footprint satellite account, differences between Eora, WIOD, EXIOBASE and GTAP databases are smaller than 10% in most major economies. Reducing uncertainty in MRIO analysis has been identified as relevant work for the future standardisation of results (Rodrigues et al., 2018), but it is out of the scope of this paper.

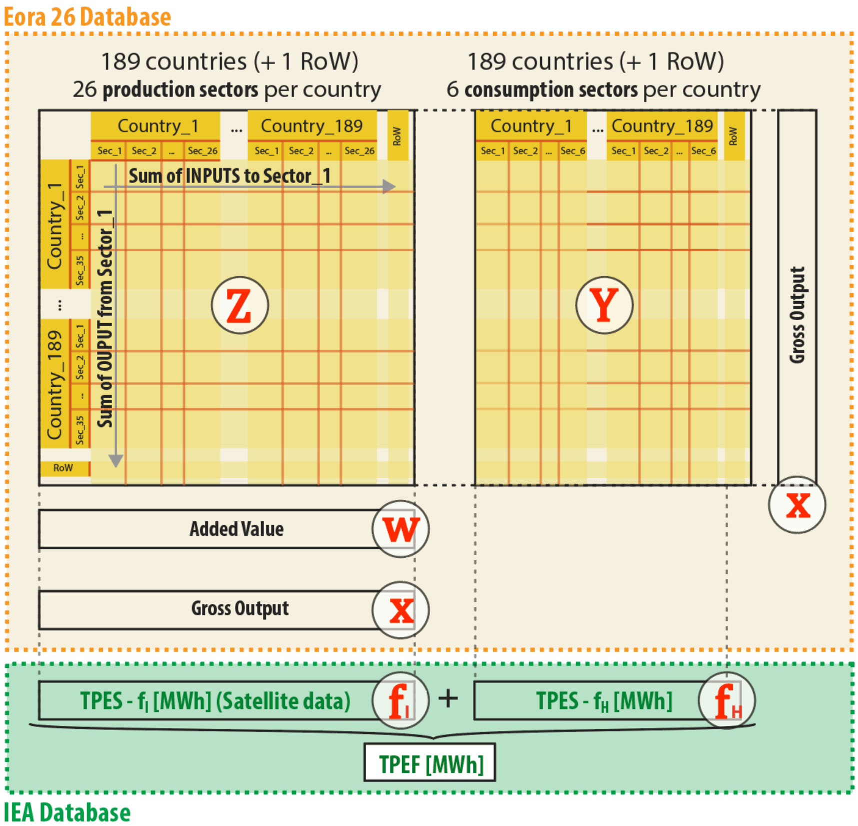

Figure-22-Figura. Global Multi-Regional Input-Output (GMRIO) structure with the Eora 26-sector database (orange) and TPES data from IEA (green). The final block in the original version of Eora reports 6 categories of final demand for each country. For the sake of simplicity, for each one, we have aggregated the 6 categories by country into one. Adapted from Miller and Blair (2009).

A standard, environmentally extended, demand-driven input-output model has been used (see *Figure-22-Figura*) to calculate the TPEF of countries (Owen et al., 2017), (Oita et al., 2016), (Lenzen et al., 2004), (Wiedmann et al., 2007). In order to relate IEA TPES energy data with the Eora 26 economic database, a row vector of satellite data of energy consumption for each industrial sector by country was created ($\mathbf{f_I}$) following the criteria indicated in *Supplementary Table 8.7.1*. The TPES is the sum of energy consumption by industries ($\mathbf{f_I}$, a row vector with information on the energy use of 189 countries and 26 sectors) and the direct use of energy per household ($\mathbf{f_H}$, a row vector with information on energy use per household in 189 countries). This method, also known as the Leontief equation, follows the sequence of equations below. Firstly, the energy consumption coefficient per unit of industrial output (c vector) has been calculated, where diag stands for the diagonalisation of a vector, as:

$$c = f_I \cdot \left(diag(x)\right)^{-1} \quad (1)$$

The technical coefficients matrix (A) has been calculated, and from this in turn we arrive at the Leontief Inverse (L):

$$A = Z\left(diag(x)\right)^{-1} \quad (2)$$

$$L \equiv (I - A)^{-1} \quad (3)$$

Next, the total (i.e. a scalar) industrial energy embodied in the products and services demanded by country r (g_I^r) is obtained using the standard demand-driven IO model:

$$g_I^r = cLy_{TOT}^r \quad (4)$$

Where y_{TOT}^r is a column vector (4915 x 1) representing the total final demand of goods and services by country *r*.

Finally, we obtain the total TPEF of country *r* as the sum of the industrial energy embodied in the products and services (g_I^r) and the energy consumed directly by final users (g_H^r).

$$g^r = g_I^r + g_H^r \quad (5)$$

In this study, due to the insufficiency of the energy consumption country-based satellite data, and the extant difficulties of cross-referencing the results of MRIO analysis with HDI data, we have however obtained the results for 126 countries out of the total 189 Eora database countries.

8.2.2 Human Development Index

The Human Development Index has been the selected indicator to compare the consumed energy with the achieved welfare of a country; as this accounts for the economic advantages but also improvements in human well-being (Sen, 1992). Data has been derived from UNDP

(UNDP, 2015) and has been processed in order to obtain average trends, which have been used to validate the final conclusions of the project. HDI, shown in Equation 6, is the geometric mean of Income Index (II), Life Expectancy Index (LEI) and Education Index (EI), based in the aggregation of economic, health and education level of a country (UNDP, 2017).

$$HDI = \sqrt[3]{LEI \times II \times EI} \qquad (6)$$

8.2.3 Decoupling Index

The decoupling phenomena, has been most frequently graphically observed (Wiedmann et al., 2015), (Steinberger and Roberts, 2010). Nevertheless, the Decoupling Index (DI) (Wang, 2011), (Wu et al., 2018), is a crucial parameter that enables to compare the achievements of a single country over time, or to compare different countries with each other. The DI allows understanding how countries are reducing environmental burdens (in this case energy consumption) while increasing their development status. The difference between relative decoupling and absolute decoupling is especially important since the latter implies an energy reduction in absolute terms. The DI_{GDP} has been a development from the well known *I=PAT* formula (Wu et al., 2018), obtaining the final Equation 7; where *g* represents the average increase of GDP, and *t* represents the average decline rate of energy consumption per unit of GDP between the selected years (Supplementary Note 1 shows how the left side of Equation 7 is equal to the right side).

$$DI_{GDP} = \frac{t}{g} \times (1+g) = \frac{\Delta GDP(\%) - \Delta TPES(\%)}{\Delta GDP(\%)} \qquad (7)$$

$$\mathrm{DI} = \arctan\left(\frac{\Delta\mathrm{HDI}(\%)}{\Delta\left(\frac{\mathrm{EnergyConsumption}}{\mathrm{P}}\right)(\%)}\right) \qquad (8)$$

In this study, Equation 7 has been used as a reference to create Equation 8, replacing GDP by HDI and adding the population variable P, the DI_{HDI} (referenced as DI) is achieved. The results have been calculated in degrees due to the differences between GDP and HDI. The use of degrees allows having a clearer visual range, since the HDI values have the maximum value of 1.0 whereas GDP does not present a specific maximum. Equation 8 shows how *Figure-23-Figura* has been created, the increase of HDI and energy consumption have been included in percentage.

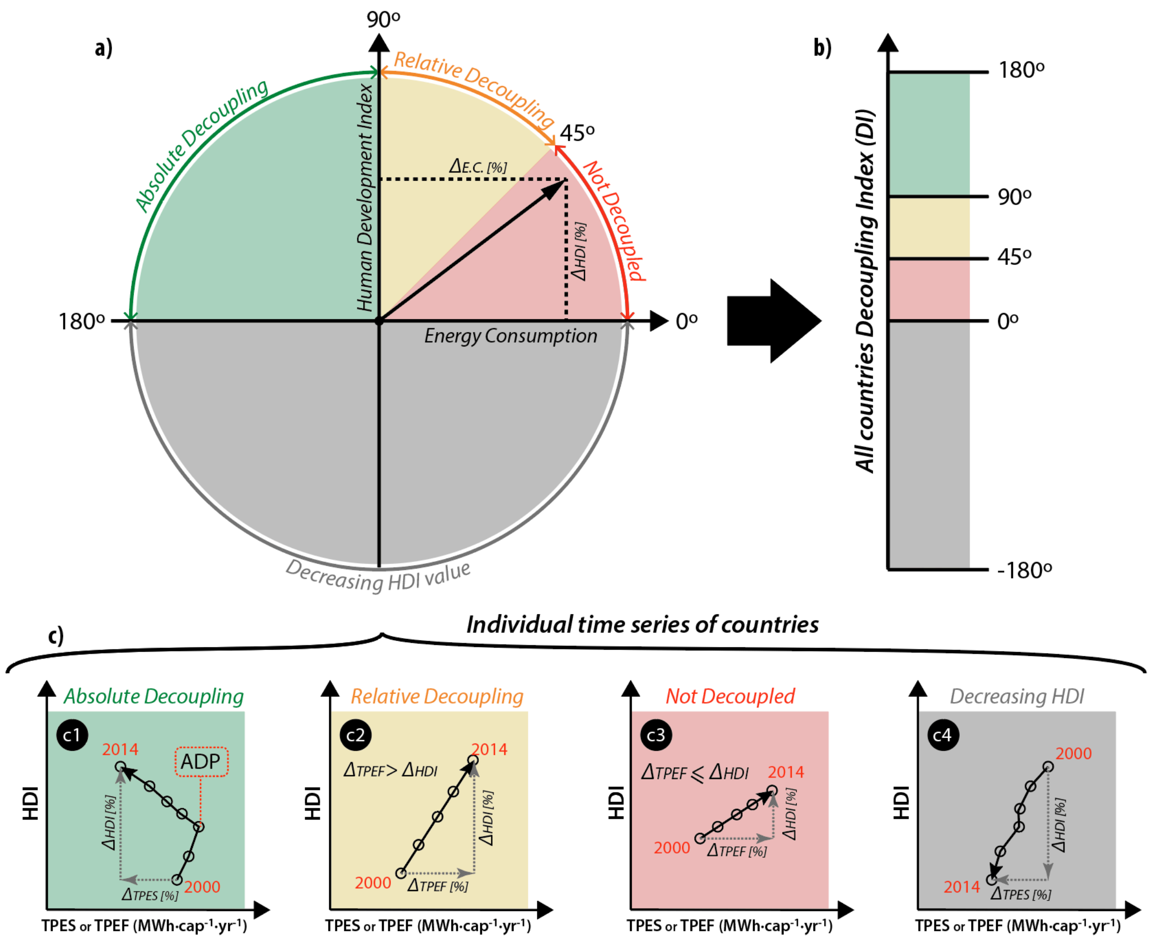

Figure-23-Figura. Decoupling Index indicator between HDI and energy consumption.

It must be clarified that Equation 8 results range, due to the use of ARCTAN, was originally from -90 to 90, since the formula itself is not capable of distinguishing whether the variation of HDI or energy consumption is positive or negative on their own. Thus, in order to properly identify the negative or positive symbols, Matlab has been used, generating a results range from -180 to 180 degrees (see Supplementary Note 8.7.2). *Figure-23-Figura (a)* shows how the results have been identified in quadrants (Zhang et al., 2017), and Figure-23-Figura (b) shows how these quadrants have been converted into a linear visualisation mode; this allows the comparison of the results of DI with a single vertical arrow according to TPES and TPEF data as shown later in *Figure-24-Figura*. Four different trends have been identified among countries shown in *Figure-23-Figura (c)*, according to the Decoupling Index methodology:

c1. **Absolutely decoupled countries (90 to 180°).** Those who are reducing their TPES (or TPEF) and increasing their HDI. *Figure-23-Figura (a)* shows how the Absolute Decoupling Point (ADP) could be graphically identified in the annual series. ADP corresponds to the point after which energy consumption started reducing while still HDI is still increasing. (e.g. FRA: HDI +5%, TPEF -10%, DI 153º)

c2. **Relatively decoupled countries (45 to 90º).** Those countries that need to increase their energy consumption to increase the HDI value, but the percentage of energy consumption increase is lower than the increased HDI percentage. (e.g. MOZ: HDI +39%, TPEF +7%, DI 80º)

c3. **Not decoupled countries (0 to 45º).** Countries that need to increase their energy consumption at least in the same or greater percentage that the increase of the achieved HDI value. (e.g. NOR: HDI +3%, TPEF +11%, DI 17º)

c4. **Reduction of HDI (0º to -180º).** In this case two different subsections could be distinguished. Firstly, there is a scenario where energy consumption increases, and secondly one where consumption decreases. This last situation might happen in cases such as wars or deep national crisis. Eventually, in high-developed countries, a momentary soft decrease of HDI could be justified in order to achieve planned energy reductions. (e.g. SYR: HDI -6%, TPEF -30%, DI -168º)

8.3 Results

Results have been divided into four subsections matching the specific aims of the study (Section 8.1.5).

8.3.1 Decoupling Index as measured by TPES and TPEF

The index has been calculated according to the methodology introduced in *Section 8.2.3*. *Figure-24-Figura* shows that the Decoupling Index (DI) changes significantly in many countries when considering TPES or TPEF data. There is a general trend of decreasing the DI in most of the countries (93 countries out of 126 decrease their DI while 33 increase it). The number of absolutely decoupled countries have been reduced from 40 to 27, the number of relatively decoupled countries have been reduced from 29 to 17 and instead the amount of coupled countries have increase from 55 to 80 using TPEF account.

This general trend to reduce the DI of countries when using TPEF accounts occurs due to an energy consumption increase in percentage in comparison with TPES accounts, while maintaining the same HDI gain. In high-income countries, even though the imported embodied energy has been generally slightly reduced since the Global Financial Crisis (GFC, or Great Recession) (Mazumder, 2018), is still higher than in 2000; and in low-income countries imported embodied energy has been slowly growing since 2000. Thus, during the analysed time period, low-income countries and high-income countries in general have a worse Decoupling Index with TPEF accounts. Therefore, even if the sum of the TPES and TPEF of all countries is equal, same quantity of energy consumption is extracted from exporter countries to be relocated in importer ones; in the Decoupling Index, a there is not a balance between countries that increased and decreased the DI value when using TPEF accounts (*Supplementary Figure 8.7.1*).

Countries that have an absolute decoupling within TPES, such as AUS, CAN, KWT, NLD, NOR, ROU, SVK, CHE and TJK, are coupled when using TPEF data; meaning that their consumption implies larger levels of energy than their production for the same level of HDI. Similarly, some countries that are shown to have a relative decoupling with TPES values, appear to be coupled under TPEF accounts, such as AZE, BWA, HRV, GHA, KEN, NPL, NZL, PRY, POL, MDA, SRB and YEM. Other countries, which are shown to be in absolute decoupling situation with TPES, are only relatively decoupled according to TPEF data, such as: DOM, FIN, LUX and UKR.

On the other hand, a total of 33 out of 126 countries improved their DI value when using TPEF accounts. The highest variations occurred in 3 countries; BLR, which seems to be coupled according to TPES calculations, is absolutely decoupled; and MEX and MLT, which are relatively decoupled according to TPES measurements, are absolutely decoupled in TPEF terms.

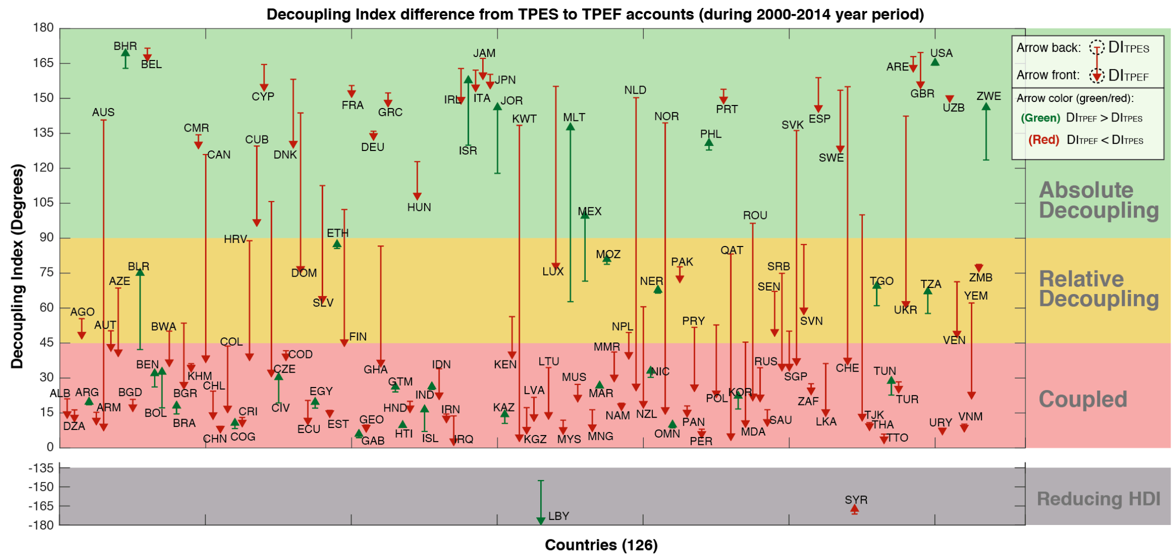

Figure-24-Figura. The arrows start in the DITPES and end in the DITPEF,, and both are calculated using consumption based accounts (CBA), during the 2000-2014 period. The red arrows show how in 93 countries (from the analysed 126 ones) TPEF reports a smaller DI than that offered by TPES data, and the green arrows show how in 33 countries the TPEF identifies a greater DI than that detected by TPES data.

8.3.2 TPEF based Decoupling Index versus HDI

Figure-26-Figura shows the relation between the development level (in terms of HDI) and the achieved DI (based on TPEF accounts) in 2000-2014 split into four periods: 2000-2004, 2004-2008, 2008-2012, and 2012-2014. It can be seen that every period follows a very different pattern.

Noticeably, although decoupling is generally less present when TPEF data is used, successive years indicate increasing numbers of countries that are reaching the absolute decoupling (*Figure-26-Figura* and *Figure-27-Figura*). Nevertheless, some high-HDI countries, that have been absolutely decoupled during the first three periods, are not anymore decoupled during the last period (USA, DEU, DNK) (*Figure-27-Figura*).

Intriguingly, it is remarkable that countries with extremely low HDI, have achieved temporary in periods 2 and 3 (NER, YEM, ZWE, MOZ) (*Figure-26-Figura*). However, there are fewer less-developed countries that are absolutely decoupled during the last period or are able to maintain the decoupled trend long term.

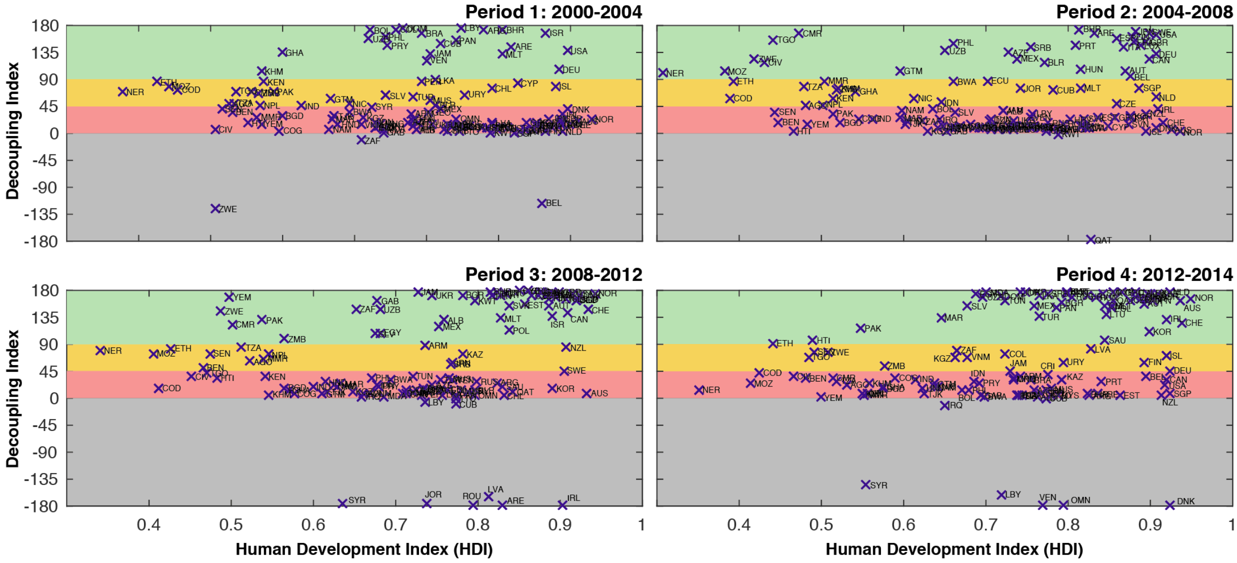

Figure-25-Figura. In this figure, DITPEF and its relation with HDI have been analysed. The main goal of this figure is to understand the general trends of countries, shown by the "dark" areas of the charts. As can be seen, in Period 1 the only "dark" area is in the dependent (red) zone, while in Period 3 and Period 4, new "dark" areas appear in the absolutely decoupled (green) zone.

Figure-27-Figura has been created by zooming into *Figure-26-Figura* in order to better understand the countries that could serve as a reference for "best practice" countries, with an HDI value between 0.8 and 1.0 and a Decoupling Index between 90° and 180°, manifesting an absolute decoupling.

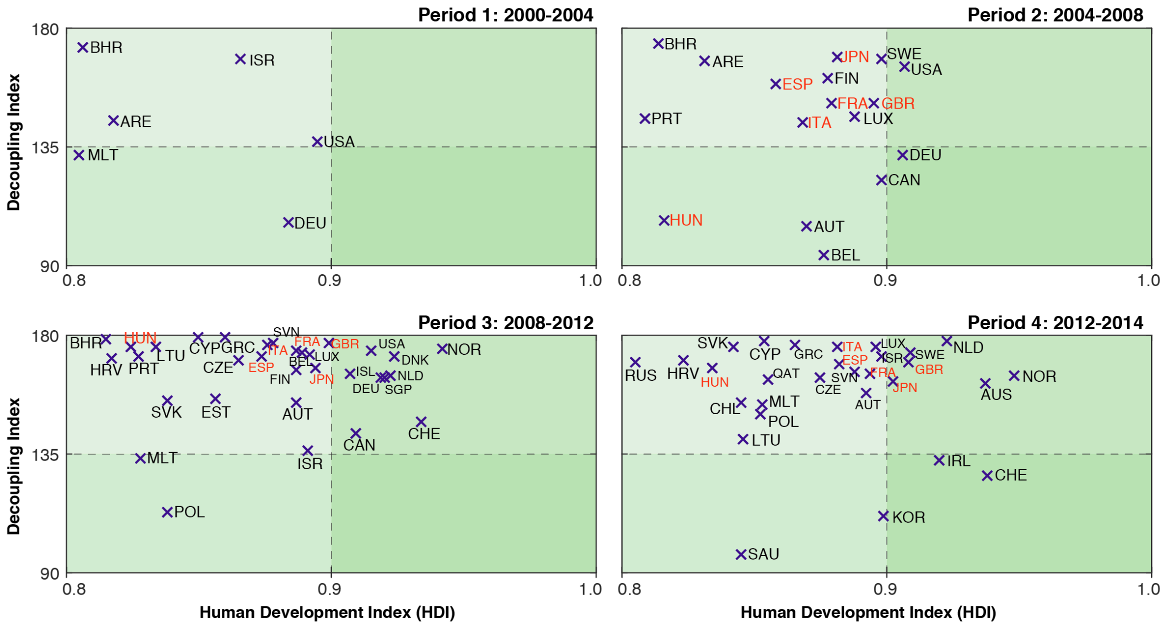

Figure-26-Figura. DI and HDI relation according TPEF accounts, during the four different periods. Exemplary countries (red) have been identified when at least in 3 periods have been able to maintain an absolute decoupling trend.

Figure-26-Figura shows that there is not a single country with a maintained absolute decoupling since 2000, and only 6 countries from the 126 analysed have an HDI above 0.8 and are manifesting a continuous absolute decoupling since 2004 (and also in average from 2000 to 2014): ESP, ITA, HUN, GBR, JPN and FRA. It could be understood that these countries are exemplary countries, which are achieving a maintained reduction of their energy consumption, while maintaining a gain in HDI.

8.3.3 Time series performances

Time series were developed for each of the 126 countries from year 2000 to 2014, and those for the six exemplary countries detected in the previous subsection have been shown in *Figure-27-Figura*, in order to better understand their dynamics. Has been found that, firstly, exemplary countries present more gradual and stable energy reductions during recent years, which were achieved in two ways: reducing energy consumption inside the country (observed from TPES curve) and reducing embodied energy consumption in goods and services imported from other countries (observed from TPEF curve), while increasing HDI. Hungary, Italy and Spain are the countries that have reached the major reductions in their TPEF values, with 29%, 30% and 33%, respectively.

Secondly, all of the exemplary countries have been affected by the GFC increasing the reduction value of the TPEF from previous years. Nevertheless, all of them have been able to maintain the HDI increase tendency. This means that the crisis phenomena could be seen as an opportunity to reach reduction goals, rather than a risk, if it is properly managed (Schneider et al., 2010).

Additionally, a large difference in consumption is observed when Absolute Decoupling Point (ADP) was reached, meaning that each country could find its own strategy in order to improve their current consumption levels (*Figure-27-Figura*). France, Japan and the United Kingdom present the highest ADP value, with 60 to 65 MWh·cap^{-1}·yr^{-1}, and Hungary the lowest, with 36 MWh·cap^{-1}·yr^{-1}. Spain and Italy found the ADP at 48 MWh·cap^{-1}·yr^{-1}.

Finally, a critical observation was made that all of the exemplary countries have a higher TPEF than TPES, meaning that all of them are net importers of energy embodied in goods and services. This means that achieving a decoupling could be harder for net embodied energy exporter countries (such as China or India). It has been observed that generally only 14.2 % of the absolutely decoupled countries are net embodied energy exporters, whereas from the relatively decoupled or coupled countries, net embodied energy exporters make up 41.2% and 41.3% respectively (*Supplementary Table 8.7.2*). This has been measured by comparing the obtained DI_{TPEF} and the corresponding Hidden Energy Flow (HEF, HEF = TPES/TPEF-1, (Akizu et al., 2017) (Akizu et al., 2018)) of each country (*Supplementary Table 8.7.2*).

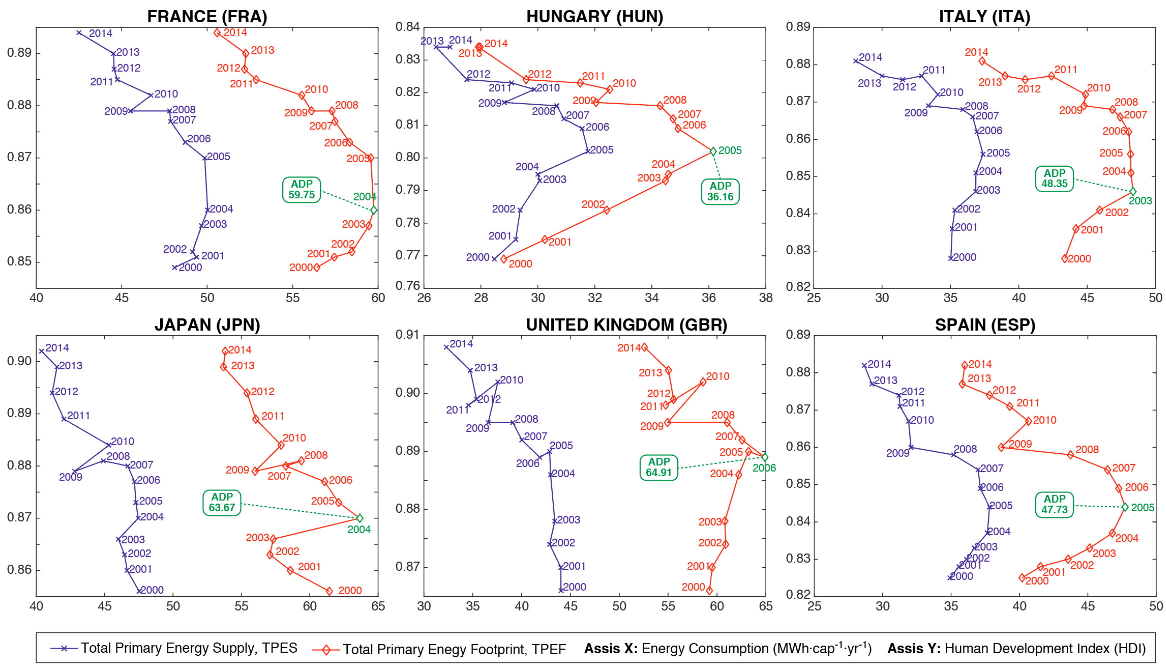

Figure-27-Figura. The consumed TPES and TPEF and the achieved HDI of the six exemplary countries during the 2000-2014 period. The Absolute Decoupling Point (ADP, green) has been highlighted in the TPEF line of each country.

Figure-28-Figura shows which industrial sectors (defined by the Eora database, *Supplementary Table 8.7.1*) present higher energy reductions in the exemplary countries. Direct electricity consumed at homes been included in the industrial sector 24 ("Private

Households"). A sectorial divergence is notorious. While in some countries, such as HUN or GBR, reduction in "Private households" energy consumption has been significant (3-4%), in other countries, such as JPN or ITA, reductions in "Construction" sector have been more relevant (1-4%). "Electricity, Gas and Water" and "Petroleum, Chemical and Non-Metallic" sectors have notorious reductions in almost all the countries. It has been observed that "Transportation" sector has not any significant reduction in any of the exemplary countries. "Electrical and Machinery" sector has variations in reductions; JPN has been able to reduce the energy consumed in this sector, while the rest of the exemplary countries are increasing the energy consumption in it. Trade sectors have generally suffer a slight reduction, while "Financial and Business activities" have experienced a generally slight increase.

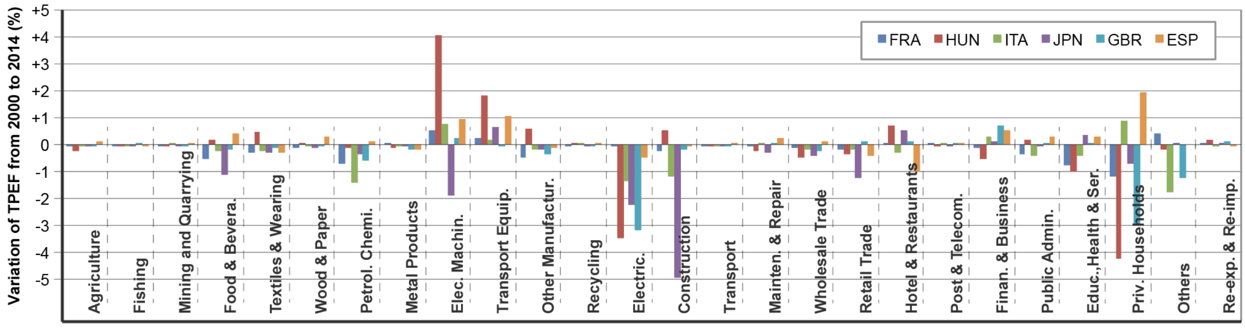

Figure-28-Figura. Percent increase or decrease of energy consumption by sector (according to TPEF accounts) from 2000 to 2014 for the six exemplary countries.

8.3.4 Temporary or permanent decoupling

In this subsection, countries that have manifested a temporary decoupling in one or more years have been identified. *Figure-29-Figura* shows that from the 126 countries analysed, taking into account the TPEF values, 89 have reached a permanent or temporary decoupling; from which 27 (as shown in *Figure-24-Figura*) are permanently decoupled and 62 have experienced a temporary decoupling. Temporary decoupling means that at least in one year have been able to reduce TPEF while increasing their HDI value. The TPEF value at which these countries have reach the temporary decoupling, is drastically different among countries. Some countries have been able to decouple with a TPEF inferior than 20 MWh·cap^{-1}·yr^{-1} (especially in Africa), whereas others have decoupled with a TPEF superior than 180 MWh·cap^{-1}·yr^{-1}. Achieving a temporary decoupling – even if less relevant than achieving an average absolute decoupling –, reveals the possible 62 candidate countries that could be able to reach a maintained decoupling in the incoming years (*Supplementary Figure 8.7.2* and *Supplementary Figure 8.7.3*).

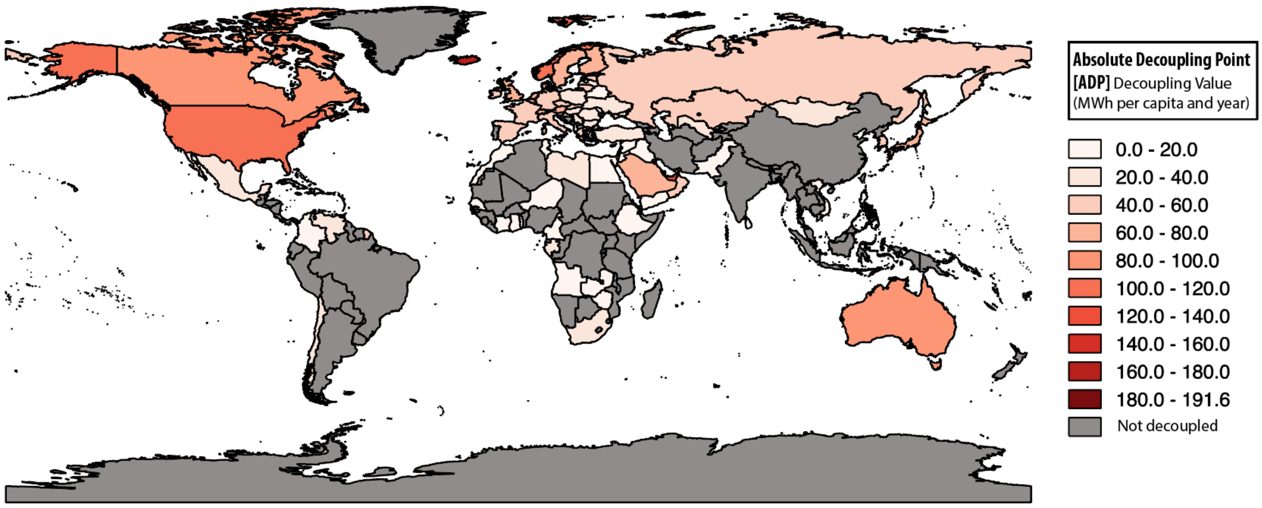

Figure-29-Figura. From the analysed countries, 89 countries have been temporarily or permanently decoupled during the 2000-2014 period according TPEF accounts.

8.4 Discussion

8.4.1 General discussion

In order to achieve global energy justice (Sovacool et al., 2016) and gain a global equal share of energy resources, most developed countries should reduce their current energy consumption (as explained Section 8.1). Nevertheless this reduction does not imply necessarily a reduction of citizen's wellbeing. The possibility of meeting a decoupling between energy consumption and HDI allows countries to transit towards a low socio-environmental impact energy system. Furthermore, this could enhance a fair share of global energy resources among countries, boosting international energy justice. In this study, six countries have been identified (FRA, HUN, ITA, JPN, GBR, ESP), which are already experiencing the decoupling phenomenon in a maintained way. Until the present day, mainly the "degrowth movement", recognised by the scientific community (Weiss and Cattaneo, 2017), has made clear proposals for reducing resources consumption in order to reach better global living standards. The energy degrowth proposal, due to the possibility of increasing development (welfare) while reducing energy consumption, has the potential to become an international energy transition strategy.

In order to analyse DI, this study shows that consumption-based accounts must be used; since results are more complete than traditional TPES-based analyses. Only footprint-based accounts are able to reflect the current reality of the internationally globalised goods and services market. The use of TPEF data, instead of TPES, brings most of the analysed countries towards a more coupled situation between energy consumption and HDI. Calculations that have been carried out with TPES (Wu et al., 2018) are only able to offer an interesting but partial perspective of the energy consumption decoupling, generating a "virtual decoupling" in numerous countries (such as AUS, CAN, LUX, CHE, etc.). This study shows that footprint accounts need to be taken into account to avoid "virtual decoupling", not only in developed countries, but even in non-developed ones. This is particularly significant when defining worldwide energetically exemplary countries to follow.

As a positive result of the research, it has been noted that absolute decoupling has been permanently or partially achieved within very different energy consumption and HDI values by 89 countries (*Figure-29-Figura*). Absolute decoupling has been achieved from high-energy consumption countries as QAT, ISL and LUX (with a TPEF between 192-169 MWh·cap^{-1}·yr^{-1}and a HDI between 0.83-0.89), to low energy consumption ones as YEM, SEN and NER (with a TPEF between 4-2 MWh·cap^{-1}·yr^{-1} and a HDI between 0.35-0.49). This gives an optimistic nuance to the incoming necessary energy transition process, meaning that regardless of the energy intensity of a country, there is room of improvement for energy consumption reductions in every national reality and maintain or increase the HDI. Furthermore, it could be observed in *Figure-25-Figura*, shows that more countries are able to reach an absolute decoupling in the last period (2012-2014) than previously, showing a clear international tendency to move towards lower energy consumption realities.

This study shows that according to the analysed 126 countries, there is much left to do to trigger the necessary worldwide decoupling required to reach sufficient energy consumption reduction in developed countries, and boost the increase of HDI in less-developed ones to achieve the sustainable use of global energy resources, with low socio-environmental impacts. Nevertheless, positive performances have been found, observing that more countries have been achieving important decoupling targets in recent years, especially between 2012 and 2014.

8.4.2 Exemplary countries

Although achieving a temporary absolute decoupling can frequently occur, maintaining this tendency in the long-term, in order to clearly reduce the energy consumption of a country while increasing its HDI, has been found to be challenging. From the 126 countries analysed, only 27 have shown an average absolute decoupling during the total year gap of 2000-2014 (*Figure-24-Figura*), and only 6 of them, within the HDI above 0.8, have shown a maintained absolute decoupling during the last three year gaps, 2004-2008, 2008-2012 and 2012-2014 (*Figure-26-Figura* and *Figure-27-Figura*). These exemplary countries show three relevant aspects.

Firstly, the gradual energy reduction is a constant trend in most of them, avoiding drastic reductions. Energy reductions have been achieved inside the country boundaries (most probably due to the energy efficiency achievements: eco-efficiency and innovation), but also within the imported energy embodied in goods and services. Reached energy reductions during 14 years have been significant, and three of the exemplary countries (ESP, ITA, HUN) have been able to reduce around 30% of their TPEF. According to the sectorial distribution of reductions, achievements in the electric production sector have been notorious in all countries, as well as in the petrochemical sector. Reductions in the construction and the household sectors are also relevant in some countries. Thus, it is noticed that each country has its own strategy to reduce the TPEF, reducing energy consumption from significantly different economic sectors.

Secondly, the GFC has positively impacted in the exemplary countries regarding this scope, provoking ulterior reductions in their energy consumption while still increasing the HDI value. This allows citizens to understand the crisis as an opportunity (Schneider et al., 2010).

Finally, all of the exemplary countries are net embodied energy importers. This should be taken into account to improve international relations promoting the support to most industrial producer countries, enhancing their increase of HDI while maintaining low levels for their per capita energy consumption. The recognition of the current imports of embodied energy in goods and services is a key factor. Importer countries need to be aware of the privileges that this brings to them (such as to allow an easier decoupling between energy consumption and welfare), and fair economic payments for imported embodied energy should be promoted. Compensation systems, such as the ones developed in carbon footprints in global scale (Pezzey and Jotzo, 2013), (Meng et al., 2018) or in ecosystem services in a more national or regional scale (Reed et al., 2017), could be implemented in the energy field.

8.5 Conclusions and Policy Implications

In the current globalised market, with large amount of goods and service exchanges among countries, it is compulsory to take into account the energy embodied in trade if an integral energy consumption diagnosis is desired. Countries can no longer understand their energy consumption accounts using TPES data directly drawn from the International Energy Agency database. Instead, TPES data needs to be complemented with TPEF calculations in order to avoid distortion of energy consumption pattern realities.

Exemplary countries, the ones that have achieved a maintained decoupling among consumed energy and improved HDI, have developed it via gradual energy consumption reductions as opposed to drastic energy consumption reduction performances. These reductions could be achieved by two paths; firstly by enhancing the integration of eco-efficiency and innovation tools within national boundaries (in particular within the electricity, petrochemical, construction and private houses sectors), and secondly via supporting the reduction of imported energy embodied in products and services from other countries which in turn triggers energy sovereignty. Despite the lack of clearly identified environmentally sustainable and socially fair global energy threshold, most developing countries seem to have a margin to increase their energy consumption in order to increase their HDI. However, this increase could be supported and expedited by international collaborations with energy efficient standards across developing countries through Kyoto Protocol-type clean development mechanisms or technology transfers (UNEP, 1998).

The study shows, that economic crises are an opportunity to gain decoupling. In all of the six exemplary countries, the 2009 Global Financial Crisis (GFC) enhanced their energy reduction while increasing their HDI.

Net embodied-energy exporter countries have been found especially weak when trying to achieve a decoupling reality; thus, in order to create a global absolute decoupling trend, solidarity towards and collaboration with net embodied-energy exporter countries should be increased. Building upon the recognition of trade in embodied energy trade and on quantitative information on energy footprints, international cooperation on reducing global energy demand should be designed.

This work contributes to "Goal 7" of SDG (UN, 2015), promoting insights to reach a sustainable energy system for all individuals. The work also contributes towards the achievement of "Goal 10" of the SDG, fostering the reduction of inequality among countries, and "Goal 12", enhancing sustainable consumption patterns.

8.6 Acknowledgment

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8.7 Supplementary Material

Next supplementary figures, tables and notes have been added to support the better understanding of the study.

Supplementary Note 8.7.1: *The next validation shows how the original formula (left side of Equation 7) and the one used in this research to create Equation 8 (right side of Equation 7), are the identical.*

FIRST VALIDATION

$$DI = \frac{t}{g}(1+g)$$

$$\begin{cases} G = G_0(1+g)\ ; \quad g = \frac{G}{G_0} - 1 \\ T = T_0(1+t)\ ; \quad t = 1 - \frac{T}{T_0} \\ E_0 = G_0 \cdot T_0 \\ E = G \cdot T \end{cases}$$

Replacing:

$$DI = \frac{t}{g}(1+g) = \frac{1 - \frac{T}{T_0}}{\frac{G}{G_0} - 1} \cdot \frac{G}{G_0}$$

$$\frac{T}{T_0} = \frac{E}{G_0} \cdot \frac{G_0}{E_0}\ ;$$

$$DI = \frac{1 - \frac{E}{G_0} \cdot \frac{G_0}{E_0}}{G - G_0} \cdot G$$

$$DI = \frac{G - \frac{E}{E_0} \cdot G_0}{G - G_0}$$

SECOND VALIDATION

$$DI = \frac{\Delta\ GDP\ (\%) - \Delta\ TPES\ (\%)}{\Delta\ GDP\ (\%)}$$

$$\begin{cases} \Delta\ GDP\ (\%) = \frac{G - G_0}{G_0} \cdot 100 \\ \Delta\ TPES\ (\%) = \frac{E - E_0}{E_0} \cdot 100 \end{cases}$$

Replacing:

$$DI = \frac{\frac{G - G_0}{G_0} \cdot 100 - \frac{E - E_0}{E_0} \cdot 100}{\frac{G - G_0}{G_0} \cdot 100}$$

$$= \frac{G - G_0 - \frac{E - E_0}{E_0} \cdot G_0}{G - G_0} = \frac{G - G_0 - (E - E_0)\frac{G_0}{E_0}}{G - G_0} =$$

$$= \frac{G - G_0 - \frac{E}{E_0} \cdot G_0 + G_0}{G - G_0} = \frac{G - \frac{E}{E_0} \cdot G_0}{G - G_0}$$

DI: Decoupling Index
E: energy consumption in a certain year
G: GDP in a certain year
T: anual energy consumption per unit of GDP
g: GDP annual **growth** rate from the base year to the n year
t: annual rate of **decline** in energy consumption per unit of GDP

Supplementary Note 8.7.2: *In order to offer the full quadrant range of answers to Equation 8, in the algorithm used in the calculations, ARCTAN limitations have been corrected using "if" commands in Matlab. This way authors were able to amplify the -90 to 90 results range to -180 to 180. The DI value was corrected as follows:*

if ANGLE ARCTAN<0 and DELTA_HDI<0

ANGLE ARCTAN = ANGLE ARCTAN +180;

elseif ANGLE ARCTAN>0 and DELTA_HDI<0

ANGLE ARCTAN = ANGLE ARCTAN -180;

Supplementary Table 8.7.1: *Matching between TPES data obtained form International Energy Agency (IEA) and Eora Database 26 sectors to create the TPES satellite data.*

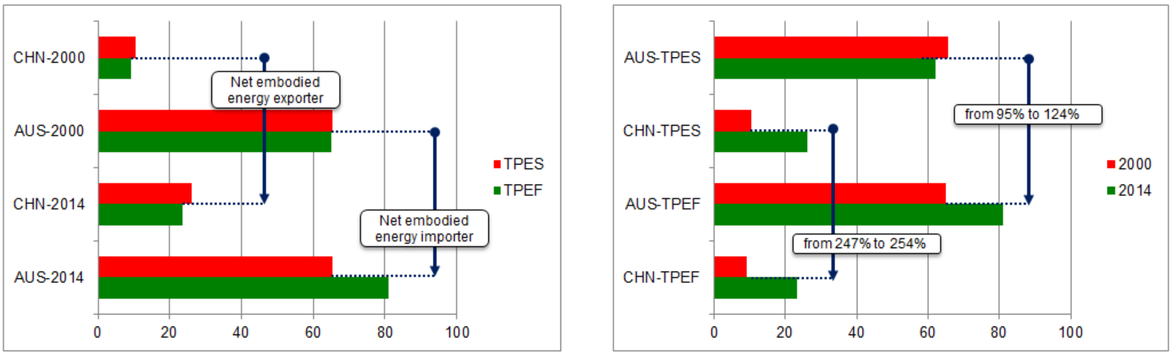
Sector number (Eora)	Sector Description (Eora)	Sector matching (IEA)	
		Final Consumption IEA	**Losses IEA**
1	Agriculture	L_82: Agriculture/forestry	-
2	Fishing	L_83: Fishing	-
3	Mining and Quarrying	L_63: Mining and quarrying	-
4	Food & Beverages	L_64: Food and tobacco	-
5	Textiles and Wearing Apparel	L_68: Textile and leather	-
6	Wood and Paper	L_65: Paper, pulp and print L_66: Wood and wood products	-
7	Petroleum, Chemical and Non-Metallic Mineral Products	L_58: Chemical and petrochemical L_59: Non-ferrous metals L_60: Non-metallic minerals	L_26: Coke ovens (transf.) L_27: Patent fuel plants (transf.) L_29: Oil refineries (transf.) L_30: Petrochemical plants (transf.) L31: Coal liquefaction plants (transf.) L_34: Charcoal production plants (transf.)
8	Metal Products	L_57: Iron and steel	L_24: Blast furnaces (transf.)
9	Electrical and Machinery	L_62: Machinery	-
10	Transport Equipment	L_61: Transport equipment	-
11	Other Manufacturing	L_69: Non-specified (industry)	-
12	Recycling	-	-
13	Electricity, Gas and Water	-	L_15: Main activity producer electricity plants (transf.) L_16: Autoproducer electricity plants (transf.) L_17: Main activity producer CHP plants (transf.) L_18: Autoproducer CHP plants (transf.) L_19: Main activity producer heat plants (transf.) L_20: Autoproducer heat plants (transf.) L_21: Heat pumps (transf.) L_22: Electric boilers (transf.) L_23: Chemical heat for electricity production (transf.) L_36: Energy industry own use L_54: Losses
14	Construction	L_67: Construction	L_28: BKB/peat briquette plants (transf.)
19	Transport	L_70: Transport	-
15	Maintenance and Repair	L_81: Commercial and public services (Proportionally divided according to the Eora 26 "Z" matrix).	-
16	Wholesale Trade		
17	Retail Trade		
18	Hotels and Restaurants		
20	Post and Telecommunications		
21	Financial Intermediation and Business Activities		
22	Public Administration		
23	Education, Health and Other Services		
24	Private Households	L_80: Residential	-
25	Others	L_84: Non-specified (other) L_85: Non-energy use	L_12: Transfers L_13: Statistical differences
26	Re-export & Re-import	-	-
TOTAL	**100 %**	**100 %**	

A) Increase (AUS) and decrease (CHN) of energy consumption with TPEF accounts (MWh·cap^-1·yr^-1)

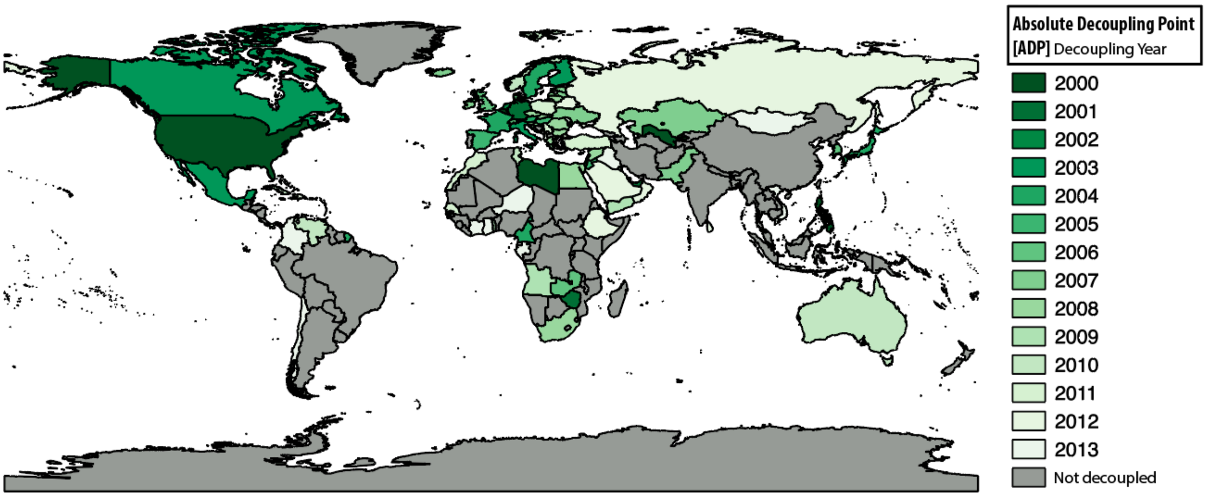
	TPES	TPEF	TPEF/TPES
AUS-2014	65.5	81.07	124%
CHN-2014	26.11	23.45	90%
AUS-2000	65.5	65.13	99%
CHN-2000	10.56	9.23	87%

B) Decrease (AUS and CHN) of Decoupling Index, due to percentage increase in energy consumption with TPEF (MWh·cap^-1·yr^-1)

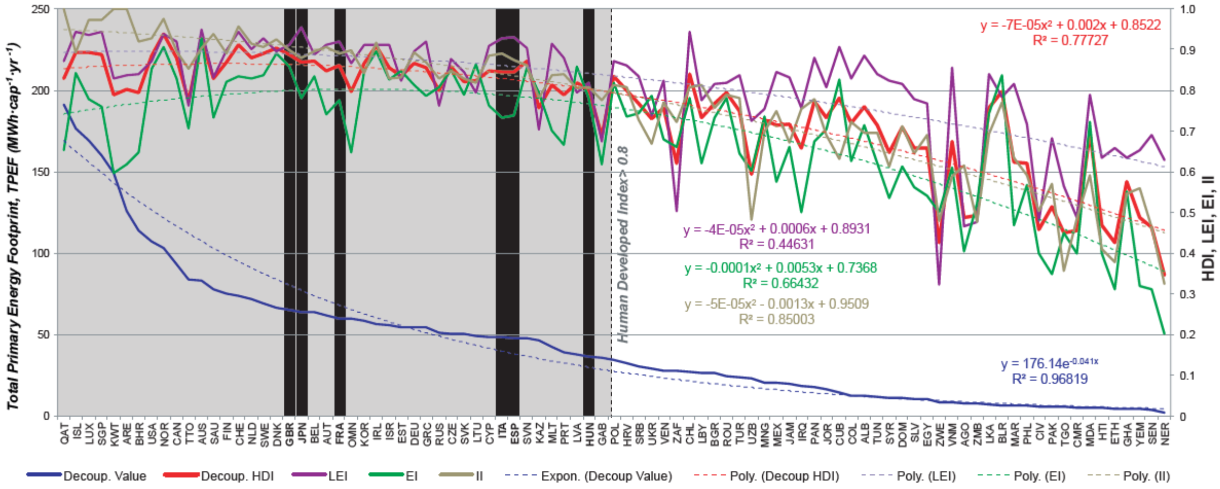
	2000	2014	2014/2000
CHN-TPEF	9.23	23.45	254%
AUS-TPEF	65.13	81.07	124%
CHN-TPES	10.56	26.11	247%
AUS-TPES	65.5	62.11	95%



Supplementary Figure 8.7.1: *Example of how the Decoupling Index (DI) decreases in embodied energy exporter countries (CHN) and embodied energy importer countries (AUS). In both of them, the DI is lower when TPEF accounts are considered instead of TPES ones. This occurs due to a higher percentage increase of energy use within TPEF accounts between 2000 and 2014. The figure shows how countries are net embodied energy importers or exporters (a) and how the percentage difference in energy increase is greater in both countries (b) with footprint accounts.*



Supplementary Figure 8.7.2: *89 countries experienced temporary or permanent decoupling between the year 2000 and 2014. The year that the decoupling was reached is shown in the figure above.*



Supplementary Figure 8.7.3: *The 89 temporarily and permanently decoupled countries (exemplary countries in black lines) ordered from left to right according the higher TPEF where decoupling was achieved (in vertical axis Y1). A line has been traced in the value of 0.8 HDI, which is understood as the bottom limit of high HDI according to UNDP. To the left of the line, countries with a higher decoupling than 35 MWh·cap^{-1}·yr^{-1} can be found. In order to better understand the characteristics of the 89 decoupling countries, HDI data (in vertical axis Y2) has been disaggregated in Life Expectancy Index (LEI, purple), Education Index (EI, green) and Income Index (II, orange). It is observed that while the high II levels of high-TPEF consumer countries are able to maintain their decoupling trend, the low EI (below 0.7) of some high-TPEF countries might make sustained decoupling difficult. On the contrary, high LEI of some medium-low TPEF countries might support their capacity to achieve sustained decoupling.*

Supplementary Table 8.7.2: *Decoupling Index values (DI_{TPES} and DI_{TPEF}) during the 2000-2014 year period by country and country codes. Countries have been listed from greatest to lowest according their DI_{TPEF} , from the most absolutely decoupled country to the most coupled ones, and lastly the ones where HDI has been reduced. In the rightmost column, Hidden Energy Flow (HEF) has been added (HEF =TPEF/TPES-1), which shows the percentage increase/reduction of energy that countries display if imported energy embodied in goods and services is taken into account (Akizu et al., 2017). Absolute decoupled countries have been identified in green, relatively decoupled ones in orange, coupled countries in red and countries whose HDI value has decreased in grey. Negative HEF countries have been marked yellow.*

Country	Code	DI_TPES (2000-2014)	DI_TPEF (2000-2014)	HEF (Average 2000-2014)
Bahrain	BHR	162.89	168.73	-23%
Belgium	BEL	171.55	168.30	-3%
USA	USA	164.25	164.68	14%
UAE	ARE	167.92	163.76	4%
Jamaica	JAM	167.17	160.55	20%

Israel	ISR	129.90	157.16	42%
UK	GBR	169.69	156.66	50%
Japan	JPN	160.31	156.56	30%
Cyprus	CYP	164.55	155.57	70%
Italy	ITA	162.12	155.33	30%
France	FRA	155.50	152.88	19%
Uzbekistan	UZB	150.93	150.73	-8%
Portugal	PRT	153.92	150.12	34%
Ireland	IRL	162.83	150.01	36%
Greece	GRC	152.34	148.79	62%
Spain	ESP	158.89	146.47	23%
Zimbabwe	ZWE	123.56	145.56	-13%
Jordan	JOR	117.83	145.55	23%
Malta	MLT	62.74	136.92	75%
Germany	DEU	135.90	134.49	12%
Denmark	DNK	158.18	131.12	52%
Cameroon	CMR	134.38	130.81	7%
Philippines	PHL	127.84	130.25	3%
Sweden	SWE	153.51	129.10	5%
Hungary	HUN	122.86	108.89	9%
Mexico	MEX	71.57	99.02	5%
Cuba	CUB	129.54	97.54	14%
Ethiopia	ETH	85.58	86.77	-22%
Mozambique	MOZ	78.80	80.44	5%
Luxembourg	LUX	155.17	78.79	64%
Zambia	ZMB	78.74	77.99	3%
Dominican Republic	DOM	143.77	77.40	8%
Belarus	BLR	42.21	74.48	-81%
Pakistan	PAK	77.69	73.36	-10%
Togo	TGO	61.03	68.92	1%
Niger	NER	66.41	67.22	16%
Tanzania	TZA	57.69	66.54	-2%
El Salvador	SLV	112.57	64.53	23%
Ukraine	UKR	142.38	62.35	-21%

Slovenia	SVN	87.28	59.62	5%
Senegal	SEN	67.17	50.36	18%
Venezuela	VEN	71.32	49.65	-4%
Angola	AGO	55.48	49.18	5%
Finland	FIN	102.31	45.99	-8%
Austria	AUT	50.28	43.92	31%
Azerbaijan	AZE	68.62	41.63	-8%
Kenya	KEN	56.34	40.76	11%
Nepal	NPL	49.53	40.51	7%
Croatia	HRV	88.91	39.91	20%
DR Congo	COD	41.70	39.88	4%
Canada	CAN	125.90	39.09	-3%
Switzerland	CHE	155.02	38.06	80%
Slovakia	SVK	136.21	37.87	22%
Botswana	BWA	50.11	37.35	88%
Ghana	GHA	86.61	37.20	2%
Serbia	SRB	74.92	35.50	7%
Singapore	SGP	50.11	35.44	131%
Cambodia	KHM	36.16	35.01	10%
Czech Republic	CZE	105.72	32.97	-1%
Nicaragua	NIC	30.27	32.49	15%
Bolivia	BOL	17.18	32.04	-8%
Benin	BEN	26.15	31.40	7%
Myanmar	MMR	41.17	30.82	-3%
Cote dIvoire	CIV	19.30	29.72	-14%
Tunisia	TUN	22.66	28.13	5%
Bulgaria	BGR	53.54	27.72	-21%
Netherlands	NLD	150.31	26.95	13%
Paraguay	PRY	51.74	26.63	29%
Morocco	MAR	25.84	26.13	-7%
Turkey	TUR	28.35	26.01	26%
India	IND	25.10	25.79	-5%
Guatemala	GTM	24.04	25.68	12%
South Africa	ZAF	27.54	25.25	-16%
Poland	POL	52.75	24.01	8%

Yemen	YEM	62.21	23.46	-1%
Indonesia	IDN	34.00	23.17	-10%
Romania	ROU	96.40	22.66	0%
Russia	RUS	34.40	22.25	-17%
Mauritius	MUS	27.26	22.16	75%
South Korea	KOR	16.70	21.75	0%
New Zealand	NZL	60.55	19.53	8%
Argentina	ARG	18.50	19.19	3%
Egypt	EGY	17.09	19.10	1%
Namibia	NAM	19.19	18.48	79%
Bangladesh	BGD	20.82	18.03	4%
Honduras	HND	19.98	17.58	7%
Brazil	BRA	14.56	17.51	1%
Colombia	COL	43.70	17.51	31%
Norway	NOR	139.48	16.86	30%
Sri Lanka	LKA	36.20	15.96	0%
Iceland	ISL	7.05	15.88	-9%
Panama	PAN	18.01	15.71	35%
Estonia	EST	16.08	15.52	5%
Albania	ALB	21.04	15.12	28%
Lithuania	LTU	34.47	14.75	36%
Chile	CHL	24.35	14.68	-4%
Tajikistan	TJK	100.01	14.00	-1%
Latvia	LVA	21.70	13.84	37%
Kazakhstan	KAZ	10.51	13.82	-14%
Algeria	DZA	16.29	13.61	-32%
Iran	IRN	14.54	13.23	0%
Ecuador	ECU	20.37	12.34	13%
Armenia	ARM	15.28	12.33	18%
Saudi Arabia	SAU	16.39	11.72	-8%
Costa Rica	CRI	13.04	11.48	22%
Moldova	MDA	45.37	11.25	-71%
Congo	COG	8.29	10.14	12%
Thailand	THA	10.85	9.90	-14%
Australia	AUS	140.74	9.80	13%

Mongolia	MNG	16.38	9.44	-14%
Oman	OMN	8.64	9.38	-25%
Viet Nam	VNM	10.21	9.28	-10%
Georgia	GEO	9.84	9.21	35%
Haiti	HTI	8.99	9.14	3%
China	CHN	9.26	8.85	-14%
Kyrgyzstan	KGZ	17.28	8.41	-2%
Malaysia	MYS	11.90	8.30	-28%
Uruguay	URY	8.27	8.08	45%
Peru	PER	8.04	6.57	17%
Qatar	QAT	83.22	5.63	-23%
Gabon	GAB	4.36	5.40	6%
Kuwait	KWT	138.41	5.15	13%
Trinidad and Tobago	TTO	5.93	4.28	-50%
Iraq	IRQ	13.74	3.46	-7%
Syria	SYR	-171.36	-168.37	-13%
Libya	LBY	-145.06	-175.20	-42%

09 Resultados
Results

9 Results / Resultados

9.1 Primer Apartado. Transiciones energéticas en el Sur Global y en el Norte Global

Los resultados de los cinco casos de estudio se han clasificado y sintetizado en siguiente *Table-13-Tabla*:

Table-13-Tabla. Resultados del primer apartado, de los casos estudio de Brasil, Cuba, Ecuador, Alemania y España.

CASOS DE ESTUDIO	APRENDIZAJES EXTRAÍDOS
Brasil Movimientos MBA y POCE.	1- El agua y la energía no son mercancías con las que se puede hacer negocio o especular, sino un derecho de los ciudadanos. En tanto que son derechos, deben de ser gestionados por la sociedad, a través del estado, de una forma democrática, al margen de los intereses de las empresas privadas. En los procesos de transición energética hay que responder a las preguntas de "¿Energía para quién?" y "¿Energía para qué? En base a la primera pregunta, un nuevo modelo debe garantizar el derecho a la energía de toda la sociedad. En base a la segunda, un nuevo modelo debe cubrir las necesidades de la sociedad, respetando los valores del momento histórico a través de la participación. 2- Es necesario el fortalecimiento de las relaciones entre la ciudadanía para poder llevar a cabo una transición energética. El proceso de reivindicación de los derechos será el resultado de una unión, para poder hacer frente a los poderes macroeconómicos. En este sentido, es fundamental la formación de la ciudadanía en el conocimiento energético. 3- En el camino hacia la soberanía energética, se debe de fomentar el uso de las "tecnologías apropiadas" (*appropriate technologies). Estas tecnologías, a través de maquinaria desarrollada a pequeña escala, hacen uso de los diferentes recursos renovables locales.*
Cuba Transición Energética Nacional.	1- El *Peak Oil* es un límite que se puede superar con la fuerza de una comunidad unida. Además, se puede alcanzar un alto nivel de calidad de vida (HDI) reduciendo el consumo de hidrocarburos. La experiencia de Cuba de los años 90 puede ser una referencia para afrontar la actual crisis del agotamiento de los recursos energéticos. 2- El intercambio de conocimientos es imprescindible para la transición energética. Hay que construir un sistema productivo

	local más unido entre diferentes sectores (sector agrícola, sector industrial, la investigación científica y la sociedad urbana) para poder realizar una transición energética integral. 3- Estos procesos de austeridad que han marcado una reducción del consumo energético han sido de carácter obligatorio en Cuba, externamente provocados y no por una decisión voluntaria. Por ello no existe ninguna seguridad de que esta transición se hubiera podido dar de forma intencional desde una solicitud voluntaria mayoritaria.
Ecuador El movimiento social YASunidos.	1- Es imprescindible integrar los principios del "Buen Vivir" o "Sumak Kawsay" en el proceso de transición energética para poder revertir los actuales valores consumistas. Basados en la defensa de la vida, y siendo conscientes de las consecuencias, las comunidades indígenas han decidido "dejar el petróleo bajo tierra" ("keep the oil under the soil"). 2- Hay que evitar las relaciones de interés que existen entre el gobierno y las empresas transnacionales de hidrocarburos, para poder crear nuevos lazos entre la ciudadanía y el gobierno. 3- Se considera necesaria una movilización social para que acaezca una transición energética.
Alemania Comunidades de Feldheim, Solar Settlement y Sieben Linden. El movimiento social de la Fundación Rosa Luxemburgo.	1- Es posible crear un sistema basado al 100% en energías renovables, en caso de que los inversores se organicen de forma comunitaria y exista la ayuda tácita del estado (Feldheim). 2- El modo de vida y la gestión comunitaria pueden llegar a reducir significativamente el consumo de energía primaria, a través de un cambio profundo en el estilo de vida y modelo de consumo (Sieben Linden). 3- Las nuevas propuestas arquitectónicas pueden cambiar profundamente los niveles de consumo de los edificios, llegando a producir tanta energía como la que consumen (Solar Settlement). 4- Es necesaria una movilización social y un sistema de votación para poder reconvertir las empresas privadas de suministro energético a entidades de gestión pública (Rosa Luxemburg Foundation).
España La cooperativa energética Som Energia.	1- El efecto de "puertas giratorias" es una de las razones principales de la insostenibilidad del actual modelo energético. Hay que anular las relaciones de interés entre los políticos y las empresas privadas para poder avanzar hacia una transición energética sostenible.

	2- Hay que transversalizar el conocimiento del sector energético y su gestión en la sociedad para fomentar la creación de un nuevo modelo. Hoy en día la ciudadanía no disponemos de oportunidades para poder tomar decisiones sobre nuestro modelo energético ni para poderlo comprender en su integridad. Hay que socializar los conocimientos energéticos. 3- Las cooperativas energéticas pueden promover la integración de las energías renovables. Así como han demostrado las incipientes cooperativas energéticas, la gestión compartida de la economía en el sector energético acarrea beneficios sociales y ambientales.

9.2 Segundo apartado. Los movimientos energéticos *Bottom-up* en Alemania

Los resultados de los tres casos estudio analizados han sido los siguientes:

Table-14-Tabla. Los resultados del segundo apartado muestran los aprendizajes extraídos de las comunidades de Sieben Linden, Solar Settlement y Feldheim.

CASOS DE ESTUDIO	APRENDIZAJES EXTRAÍDOS
Sieben Linden Ecoaldea	1- El uso común de los espacios y los edificios de bajo consumo energético (durante todo su ciclo de vida), son la base de una transición energética sólida. En la creación de nuevos estilos de vida, los procesos participativos son vitales. 2- El uso de los recursos energéticos locales, además de aumentar la consciencia de los impactos sociales y ambientales, ofrece la posibilidad de generar modelos de consumo replicables. 3- Un cambio del modelo de consumo basado en una austeridad voluntaria y satisfactoria, puede llegar a reducir drásticamente los niveles de consumo de TPES. 4- Reducción de consumo de energía con respecto a niveles nacionales: • TPES: -77% (En el Estado: 45.959 kWh·cap^{-1}·año^{-1}) • Consumo eléctrico en el hogar: -79% (En el Estado: 1.686 kWh·cap^{-1}·año^{-1}) 5- Nivel de integración de las energías renovables: • Integración local: 41% (En el Estado: 11%)
Feldheim Aldea rural	1- Para que las inversiones en tecnologías de energías renovables puedan ser rentables, se ha experimentado que realizarlas de forma comunitaria puede llegar a ser una solución.

	2- El poder elegir en qué tecnología energética (solar, eólica, nuclear, carbón, …) invertir los ahorros de cada persona, brinda al individuo o a la comunidad la posibilidad de ser responsable directo de los impactos socio-ambientales del modelo energético que está creando. 3- La comunidad ha conseguido generar nuevos puestos de trabajo y convertirse en centro experimental de investigación energética a través de sus inversiones en el sector de la energía. 4- Reducción de consumo de energía con respecto a niveles nacionales: • TPES: -42% (En el Estado: 45.959 $kWh·cap^{-1}·año^{-1}$) • Consumo eléctrico en el hogar: -42% (En el Estado: 1.686 $kWh·cap^{-1}·año^{-1}$) 5- Nivel de integración de las energías renovables: • Integración local: 4.042% (En el Estado: 11%)
Solar Settlement Barrio urbano sostenible	1- Gracias al concepto *PlusEnergy*, los consumidores/as de energía también se convierten en productores/as. Esto rompe el "muro" que existe hoy día entre productores y consumidores. 2- La creación del barrio Solar Settlemente hay que entenderlo dentro del barrio sostenible Vauban de Friburgo. Es decir, en entornos donde la sostenibilidad tiene su relevancia, se aceleran los procesos privados de desarrollo sostenible. 3- Reducción de consumo de energía con respecto a niveles nacionales: • TPES: -13% (En el Estado: 45.959 $kWh·cap^{-1}·año^{-1}$) • Consumo eléctrico en el hogar: -66% (En el Estado: 1.686 $kWh·cap^{-1}·año^{-1}$) 4- Nivel de integración de las energías renovables: • Integración local: 16% (En el Estado: 11%)

9.3 Tercer apartado. Desacople entre el consumo energético y el Índice de Desarrollo Humano, en base a cálculos de huella energética.

Las conclusiones más relevantes de la investigación se han resumido en la siguiente ***Error! Reference source not found.***:

Table-15-Tabla. Resultados del tercer objetivo específico.

Nº	APRENDIZAJES EXTRAIDOS
1	Es imprescindible el uso de la contabilidad con TPEF para poder medir la reducción total del consumo de energía de un país. La diferencia del Índice de Desacople (DI) obtenido a través del PBA o CBA es significativo. Esta diferencia hace que se creen situaciones de "desacople virtual", donde según el computo con el TPES existe una reducción de consumo energético, pero al tener en cuenta el TPEF se percibe que el consumo de energía no se ha reducido a lo largo del tiempo, sino que se ha exportado el consumo fuera de los territorios nacionales, siendo computado en otros estados. Por ejemplo, en el caso de China, el TPEF es 11% inferior al TPES, por contra, en Dinamarca el TPEF es 60% superior que el TPES. Aunque en varios estados parece que según el DI calculado con el TPES están "completamente desacoplados" (Australia, Canadá, República Checa, Kuwait, Holanda, Noruega, Suiza y Tayikistán), se observa que están "completamente acoplados" o son completamente dependientes del consumo energético para incrementar su calidad de vida, según la contabilidad de TPEF. Sucede lo contrario en Bulgaria, Malta y México, donde están más desacoplados que lo que manifiesta la contabilidad basada en TPES.
2	Cuando se confronta en diferentes estados el Índice de Desacople en base al TPEF con el Índice de Desarrollo Humano (HDI) obtenido, se observa que el "desacople total" es más frecuente en países desarrollados. Aunque también es de remarcar en ciertos países en vías de desarrollo con reducido consumo energético (<4 MWh $cap^{-1} \cdot año^{-1}$), también se dan casos de desacoples puntuales en ciertos años. Este resultado puede llegar a tener dos interpretaciones contrapuestas: por una parte el hecho de que se debe ayudar a los países no desarrollados en el proceso de desacople, y por otra parte, que los procesos de desacople puntuales pueden llegar a darse en estados de diferente nivel de desarrollo, dado que existe siempre un margen de reducción energética sin llegar a afectar el nivel de HDI del país.
3	Se han detectado seis estados referentes a nivel global en el proceso de desacople, los cuales han mantenido su DI durante los últimos años. Estos estados son Inglaterra, España, Francia, Japón, Italia y Hungría. Todos ellos, que cumplen con la condición de tener un HDI superior a 0,8 (que indica un nivel de desarrollo "muy elevado"), se encuentran desde el año 2004 en desacople absoluto. Es decir, han conseguido reducir su consumo energético en base al TPEF, mientras siguen aumentando su nivel de desarrollo, medido con el HDI. Hungría, Italia y España son los que más han conseguido reducir su TPEF, en un 29%, 30% y 33% respectivamente.
4	Es imprescindible alcanzar el desacople absoluto o puntual para aspirar a la sostenibilidad energética global, es decir, no depender del incremento de nuestro consumo energético para poder mejorar el HDI del país. Sin embargo, se observan situaciones muy diferentes en países desarrollados y no desarrollados. En los países desarrollados el desacople es inevitable, sin embargo, en ciertos países en vías de desarrollo, se ve viable un aumento del consumo energético, siempre y cuanto se respeten los límites planetarios de recursos (PB).

10 Discusión
Discussion

10 Discussion / Discusión

La transición hacia un modelo energético sostenible está en marcha, tanto en el Sur Global como en el Norte Global. Esta transición se basa en un profundo cambio de los valores (Herrero, 2011), siendo necesario un cambio de perspectiva para visualizar el actual sistema productivo (Herrero et al., 2011).

Para visualizar el sistema energético con nuevos ojos o nuevas gafas, se han analizado en los primeros dos artículos de esta tesis diferentes transiciones energéticas que están surgiendo en el mundo. En ellas, queda patente la necesidad del cambio de valores para poder dejar de lado la mercantilización de la energía, reivindicando de forma directa la defensa de la vida (Akizu et al., 2017), e integrando incluso nuevos valores como los de las culturas indígenas (Díaz et al., 2018).

Al analizar tres de los casos *Bottom-up* más relevantes de Alemania, dentro de los casos estudio del Norte Global, se ha confirmado cuantitativamente la materialización de una transición energética (Akizu et al., 2018). Debe advertirse que los tres casos *Bottom-up* analizados han recibido una ayuda significativa desde el Estado alemán, dentro del contexto nacional de *Energiwende*. Se ha detectado que, en un caso concreto, se ha reducido el consumo energético primario en un 77% con respecto a la media nacional. Al contrario, cabe recalcar que en otros estados se ha detectado la falta de ayuda por parte del estado en la transición energética sostenible, actuando incluso como freno del mismo (por ejemplo en los casos de Brasil, Ecuador y España) (Akizu et al., 2017) (Capellán-Pérez et al., 2018).

Por último, en lo que se refiere al panorama global de la transición energética, se observa que a causa de la externalización de los procesos industriales a otros estados, las diferencias entre países del Sur Global y países de Norte Global se hacen evidentes. Las mediciones en base al TPES, indican que el Norte Global es energéticamente cada vez más sostenible (Akizu-Gardoki et al., 2018). Los procesos de la exportación de la industria tuvieron su comienzo en la década de los 70 (Žitkienė and Blusytė, 2015), primero en el contexto de sectores de producción industrial, sobre todo en relación con la industria de la automoción, y después en el sector de las tecnologías de la información (IT) (Donald F. Blumberg, 1998). Estas exportaciones se han relacionado en el ámbito de la investigación social con un colonialismo moderno, ya sea en el sector energético (Batel and Devine-Wright, 2017), en el sector agrícola (Azadi et al., 2013), o en el sector industrial (Nolan et al., 2016). A su vez, el desarrollo de nuevas infraestructuras energéticas y tecnologías de transporte y logística han hecho posible la explotación masiva de los recursos de otros países, sin un intercambio equitativo justo, y con impactos sociales y ambientales destructivos (Batel and Devine-Wright, 2017). Algunos investigadores han resaltado que las decisiones individuales de consumo adoptadas en el Norte Global pueden llegar a afectar de forma directa a otros estados (Sovacool and Dworkin, 2015); por ejemplo el consumo de hidrocarburos y las guerras internacionales que derivan de ellas. Esto da pie a la creación del concepto de "justicia energética".

Esta tesis doctoral pretende fomentar la consciencia de nuestro consumo energético real (CBA) y la interiorización de los impactos de la misma, para poder avanzar hacia una justicia energética internacional. Ya en el año 1979, Hans Jonas reivindicaba la necesidad de afrontar las responsabilidades de nuestro modelo energético (Jonas, 1979). Para poder ser consecuentes y responsables ("respons abilitas", capacidad de responder) ante nuestro modelo energético, es imprescindible tener un profundo conocimiento del mismo. Ha llegado el momento de dejar de ser simples engranajes de nuestro sistema energético (Arendt, 2007) y ser creadores activos de él. La medición de la huella energética nos lleva a repartir las responsabilidades entre consumidores y productores del sistema energético (Gallego and Lenzen, 2005). En este camino, es imprescindible ser conocedores del panorama energético de consumo a nivel global (Akizu-Gardoki et al., 2018).

Los tres artículos resultantes de esta tesis doctoral contribuyen al reparto de las responsabilidades derivadas del actual modelo energético. Los dos primeros analizan la viabilidad de un nuevo modelo y el tercer artículo contribuye hacia la "alfabetización energética" necesaria para la creación de un nuevo sistema.

11 Conclusiones
Conclusions

11 Conclusions / Conclusiones

(SPANISH / ESPAÑOL)

Las principales conclusiones de esta tesis doctoral se han resumido en la *Table-16-Tabla:*

Table-16-Tabla. Conclusiones resumidas.

APARTADOS	CONCLUSIONES
1	La transición energética implica el confluir de las realidades de los países del Sur Global y del Norte Global, en un proceso justo y cuidadoso que respete las diferentes identidades y sus valores. En este proceso, será imprescindible el reconocimiento de los impactos sociales y ambientales que genera el modelo energético a efectos de poder distribuir las responsabilidades correspondientes. La energía debe de ser considerada un derecho universal y no una mercancía con la que se pueda especular. El agotamiento del actual modelo energético, basado en combustibles fósiles, no tiene por qué terminar en un final catastrófico. El agotamiento de los hidrocarburos puede ser considerado un incentivo u oportunidad de cambio hacia un sistema sostenible. Las estructuras comunales o cooperativas energéticas pueden ser una oportunidad adecuada, para, que a través de un cambio de valores, fortalecer el proceso de transición energética.
2	En Alemania, dentro del modelo consumista del Norte Global, existen comunidades intencionales de tipo *Bottom-up* que han conseguido logros significativos en el proceso de transición energética, colaborando de forma constructiva en el proceso nacional de transición (*Energiewende*). Su éxito se basa en acciones de tipo tecnológico y social, siendo especialmente relevante la contribución de las nuevas formas de organización social para obtener resultados concretos en los procesos de transición. Los sistemas energéticos autogestionados, creados en las comunidades intencionales, pueden incrementar de forma notoria el porcentaje de integración de las energías renovables, así como reducir de forma drástica el consumo energético primario. Todo ello resulta, además, económicamente viable.
3	A la hora de medir la dependencia energética de diferentes estados, es significativa la relevancia del Índice de Desacople (DI); y para poder alcanzar la sostenibilidad es necesario alcanzar un Desacople Absoluto. Es decir, resulta vital reducir el consumo energético mientras se pueda mantener o incrementar el Índice de Desarrollo Humano (HDI) de un país.

	Se ha detectado que cuando se tiene en cuenta la Huella Energética en el indicador DI, desciende considerablemente el número de países desacoplados. Además, por norma general, los países desarrollados, generan una deuda energética oculta (Hidden Energy Flows, HEF) con respecto a los países del Sur Global. Es necesario, por tanto, computar la energía embebida en productos y servicios importados y exportados para poder realizar una transición energética sostenible real.

Esta tesis doctoral espera contribuir al cumplimiento de los objetivos de desarrollo sostenible (SDG) número siete, diez y doce de las Naciones Unidas (UN, 2015), promoviendo un modelo energético accesible a toda la ciudadanía, buscando reducir las desigualdades, y generando un modelo de consumo sostenible, respectivamente.

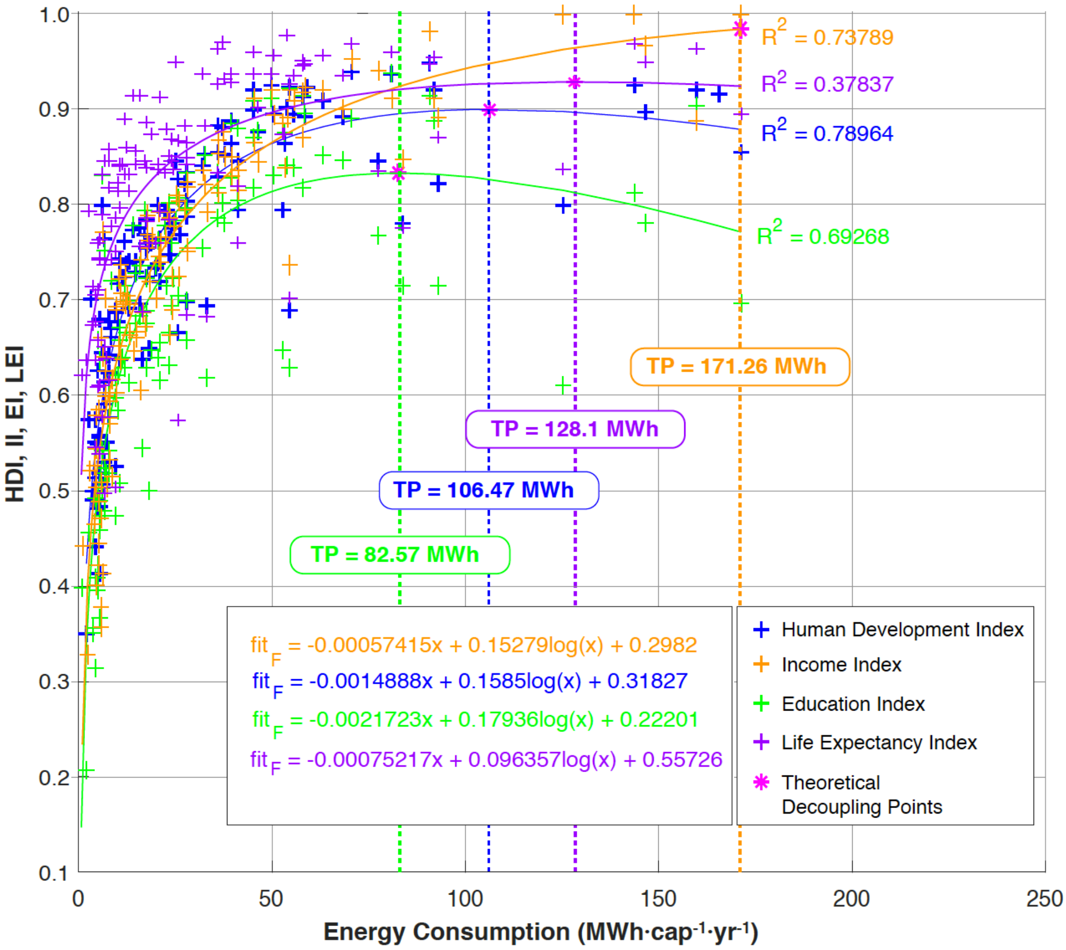


Figure-30-Figura. **Relación del consumo energético con respecto al HDI, II, EI y LEI.**

Los esfuerzos realizados en esta tesis doctoral para poder contribuir a una transición energética, han dado lugar, sin embargo, a la aparición de nuevas preguntas. Dar respuesta a dichas preguntas será labor de futuras líneas de investigación. La primera pregunta de investigación se puede observar en la *Figure-30-Figura*. En ella se ha detectado el Turning Point (TP), o un cambio de dirección en la relación del consumo energético y el correspondiente nivel de vida alcanzado. Históricamente, se ha considerado que el consumo energético y el nivel de vida alcanzado (medido por el GDP) eran proporcionales (Meadows et al., 1972). Incluso el consumo eléctrico se ha considerado proporcional al nivel de vida alcanzado (Cabrera and Jaffe, 1998). Más tarde, se detectó que el nivel de bienestar llegaba a saturarse en los estados de alto nivel de consumo energético (Arto et al., 2016; Martínez and Ebenhack, 2008; Nadimi and Tokimatsu, 2018; Pasternak, 2000; Steckel et al., 2013). Pero en esta tesis doctoral, los datos hacen un guiño a mostrar una situación más grave: donde los niveles de consumo energético masivos podrían incluso llegar a provocar una reducción de la calidad de vida en los estados. Sin embargo, esta nueva hipótesis aún no se puede confirmar, se tendría que realizar una investigación más exhaustiva, analizando dinámicas particulares de cada país, o con agrupaciones de países de similares características. Por desgracia, se trata de un campo que está fuera de la línea de investigación de esta tesis, que podría llegar a abordarse en una investigación postdoctoral.

En la tesis doctoral también se detecta una segunda línea de investigación: en las investigaciones de tipo *Bottom-up*, se podría integrar el concepto de huella energética en los casos de estudio locales (Akizu et al., 2018). Es cierto que en la mayoría de iniciativas Bottom-up, dada su tendencia a buscar una soberanía energética, podría ser mínima la media de energía embebida en productos y servicios importados o exportados. Sin embargo, para mejorar los resultados de este tipo de investigaciones locales (como es el caso del segundo artículo de esta tesis), la inclusión del factor de la huella energética podría resultar de interés. La dificultad técnica que ello puede llegar a implicar sería, por supuesto, considerable, sobre todo adaptando las tablas *Input-Output* globales a realidades concretas locales, con la falta de datos que ello conllevaría. Otra posible forma de abordar dicho problema, sería a través de la integración del análisis LCA (Life Cycle Assesment) al análisis GMRIO, haciendo uso de metodologías híbridas (Wiedmann et al., 2011), tal y como se ha realizado en determinados cálculos de huella de carbono.

(ENGLISH / INGLÉS)

The main conclusions in this Doctoral Thesis have been summarised in *Table-17-Tabla*:

Table-17-Tabla. Concise Conclusions

Section	Conclusions
1	In order to implement the energy transition, the reality of the Global South (Cuba, Ecuador, Brazil) and that of the Global North (Germany, Spain) need to be combined, in a fair responsible relationship whereby the different identities of the citizens are fully respected. Within this process, it shall be essential to accept the environmental and social impact of the energy systems and to share out the responsibility for these impacts. Energy should be seen as a right for all people and not a product to be used in exchange for private profit purposes. The drying up of the system based on fossil fuels should not be approached a catastrophic ending but rather by visualising it as an opportunity to implement the creation of a sustainable energy system. Both communal and cooperative structures, that provide a change in values of the Global North, are a fertile land to promote new energy transitions.
2	In Germany, within a Global North consumerist model, there are still significant achievements being made regarding energy transition, with intentional community *Bottom-up* type initiatives being undertaken in cooperation with nationwide transition movements (Energiewende). The success of the latter is based on both technological and social action, highlighting the relevance of new social organisation in energy transitions, and contributing to enhancing national transition movements. These self-managed energy systems —organised in intentional communities— demonstrate how it is possible to significantly increase the percentage of integration of renewable energies and how TPES consumption could be drastically reduced. *Bottom-up* initiatives have even shown how these achievements are economically viable.
3	It is clear that the Decoupling Index (DI) is a significant indicator when measuring energy dependence in different states. On the road towards sustainability, it is essential to achieve Absolute Decoupling; meaning reducing total energy consumption, while quality of life (HDI) is maintained or even enhanced. In the DI indicator, when the Energy Footprint is taken into account, in several regions it has been detected that more energy is consumed than it was initially thought. Consequently, the developed areas of the Global North are channeling Hidden Energy Flows (HEFs) towards the areas in the Global South. Hence, it is essential to quantify the energy consumed embodied in imported goods and services when aiming to implement a real energy transition.

This doctoral thesis directly promotes the seventh SDG (UN, 2015) by supporting a sustainable energy model for all inhabitants. Likewise, it encourages the achievement of the tenth UN SDG by implementing efforts to reduce the inequities between different regions. Thirdly, this research paper supports the twelfth UN SDG by promoting patterns of sustainable consumption.

Even while reaching the end of this doctoral thesis, further questions have been identified. In order to answer these questions new research lines will be required. The main line of research is outlined in *Figure-30-Figura*. The figure shows that a Turning Point (TP) has been detected between energy consumption and the corresponding achieved quality of life (HDI). Throughout history, improving quality of life (measured by GDP) has been considered directly related to increasing primary energy consumption (Meadows et al., 1972), and increasing electricity consumption (Cabrera and Jaffe, 1998). More recently, it was observed that there exists the saturation of achieved welfare in high-energy consumption countries (Arto et al., 2016; Martínez and Ebenhack, 2008; Nadimi and Tokimatsu, 2018; Pasternak, 2000; Steckel et al., 2013). Furthermore, the data in this doctoral thesis point to a more serious trend, showing that the overconsumption of energy could lead to a reduction in quality of life. Nonetheless, this affirmation cannot be implemented yet, as further in-depth research is required and this would also entail research conducted on a state-by-state basis. Unfortunately, this line of research extends beyond the confines of this doctoral thesis, but could be analysed thoroughly in a Postdoctoral research.

As a result of this thesis, it has also been observed that further follow-up research needs to be conducted when quantifying the energy consumption of *Bottom-up* case studies', and integrating into these the energy footprint accounts (Akizu et al., 2018). Even the fact that *Bottom-up* type case studies as a rule tend to lean towards energy sovereignty, and have low amount of energy consumption embodied in the Input and Output of products and services, the integration of Energy Footprint accounts might be helpful in order to improve calculations. This conclusion has been mentioned in the second article of this thesis (Akizu et al., 2018). Integrating Energy Footprint accounts into small *Bottom-up* initiatives would be relatively difficult on a technical level, and would require the creation of Input-Output tables based on provincial-level data, as there are geographical areas lacking this type of data. In order to overcome this problem, a valid approach would be the use of a hybrid of LCA (Life Cycle Assessment) and GMRIO methodology (Wiedmann et al., 2011).

12 Referencias
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13 Información Suplementaria

Supplementary Information

13 Supplementary Information // Informazio gehigarria

14 Ecuador: oil struggles in the Amazon rainforest.

(Written by Martin Mantxo, corrected and referenced by Ortzi Akizu)

Petroleum became the base of the Ecuadorian economy in 1973, with the maximum percentage reaching 50%. This year Ecuador has seen a GDP growth of 24%, an unprecedented leap in both the 20th and 21st centuries. In the last 10 years, petroleum has been Ecuador's main export representing between 43% and 66% of total exports and between 43% and 59% of the total state budget (Guaranda, 2011).

The oil "boom" led to loans being made available for Ecuador: while foreign debt stood at USD 260.80 Million in 1971, in 1981 it had risen to USD 5,869.8 million. This caused the crisis between 1983 and 1986, which led to the intervention of the International Monetary Fund (IMF). Subsequently the total revenue from petroleum operations was used to pay off the debt. Currently, the state has accumulated an even greater debt due to the construction of essential energy infrastructures and installations. Between 2009 and 2011 the debt with China stood at over USD 7,847 million (Chicaiza, 2014).

On the other hand, the remaining profit coming from the international oil trade is invested mainly in subsidies to diesel and petrol, benefiting specially people with greater resources, the ones who use most the private cars ("Combustibles son el mayor peso que tiene el Estado en subsidios," 2013). Furthermore, the electrical energy obtained from the new generation plants has not directly benefited either the country or its inhabitants. The price of electricity in Ecuador was, and still is, higher than other countries taking into account the living standards. For instance, in Northern Dakota, also an oil producer region, in 2015 the price of one kWh was USD 8.32 cents according the U.S. Energy Information Administration, instead in Ecuador, according ARCONEL the price for household electricity consumption was USD 9.32 cents. The state debt, with no direct benefits passed on to citizens, led to the political stability reflected in the 11 different governments between 1979 and 2007 as a result of mass citizen protests.

Another negative effect of the oil boom was its huge impact on the environment. Over time this led to reaction from society, which resulted in the emergence of an environmental movement. One of the organisations to emerge was Acción Ecológica which in 1995 participated in the creation of the international network Oilwatch (Oilwatch, 2007). At present, Oilwatch represents 50 tropical countries suffering the effects of the oil companies. One of their slogans was "Leave the Oil in the Soil" which despite how utopian that might sound, in Ecuador they attempted to put this into practice. Yasuní Park was the space where this proposal was to be realised.

Yasuní Park occupies nearly one million hectares of rainforest in the Ecuadorian Amazon,

with 150 species of amphibians, 121 species of reptiles, 598 species of birds, between 169 and 204 species of mammals and between 2,113 and 3,100 species of flora. UNESCO designated it as a Biosphere Reserve in 1989. The Biosphere Reserve is home to the Huaorani indigenous people and peoples in voluntary isolation such as the Taromenane and the Tagaeri. Theirs is a society of satisfied needs, so-called "affluent societies" (Urkidi et al., 2015). Nevertheless, below the Yasuní area soil lays USD 3,268 million worth of crude oil.
In 2000, Acción Ecológica proposed a "post-oil Ecuador", based on concepts such as an oil moratorium, energy sovereignty, food sovereignty, renewable energy, etc. By the 2007 elections a new unified left candidacy had been created called Alianza PAÍS which, among other proposals, adopted the grassroots proposal to not exploit the petroleum in Yasuní, becoming the first oil dependent country to propose leaving the oil reserves in the ground (Fierro, 2016). After its victory, the Alianza PAÍS government pushed forward both the Iniciativa Yasuní ITT (Vallejo et al., 2015) and the offer of financial compensation for the unextracted petroleum. As a country in debt and suffering economic intervention, the richer countries, and especially those having the biggest impact on the climate and on the environment, are made to participate, to pay the compensation. Not extracting petroleum from Yasuní means preventing both the destruction of part of the Amazon rainforest and the emission of 407 million tCO_2eq. These countries have to contribute half of what Ecuador would obtain by exploiting this petroleum, approximately USD 3,532 billion. The UN created the Yasuní Trust Fund to manage these contributions and to ensure they are used for the ends stipulated by the State of Ecuador. Some governments committed themselves to this: Spain, Iran, United Arab Emirates, Turkey and Germany.

However, at the same time the new Correa government had taken on new debt and the petroleum was the only asset available in the economy to pay this off. On 9 January 2010, Correa refused to sign the Trust, alleging that the conditions had been imposed by the contributing governments. Meanwhile, the government also came into conflict with the areas affected, at times resorting to force, delegitimisation, which then extended to the environmental and indigenous rights movements.

YASunidos was launched in 2013 as a national movement for the defence of Yasuní and as a way to influence the government or to fight external pressure from oil companies, creditors or the IMF. "This utopia of thinking of a Yasuní in a post-oil Ecuador, of us not depending on natural resources, is beautiful and is born with YASunidos. It was an exercise in direct democracy from being in the street, speaking to people... and this began to make the government nervous." [6]. Hence, on 27 August 2013 the Government lashes out violently against YASunidos (Calle, 2014).

On 22 May 2014, the Government granted Petrobras permission to explore for oil in Yasuní. This company is now operating in Yasuní in Block 31. Despite the concession belonging to a national company, it has been agreed that the petrol is to be exported to China. The other company with a concession is Andes Petroleum, a subsidiary of China National Petroleum Corporation and SINOPEC.

Grassroots movements and the international community have continued to work towards a new paradigm where oil is left under the soil and to foster other values respecting traditional cultures and their Good Living. For this reason, the Ecuador case study is a key reference in terms of energy transition due to its proposal to leave the oil under the soil and to its being the only country in the world whose government took this proposal and tried to put it into practice on an international level. Furthermore this proposal is in line with climate change objectives. According to an article in Nature, James Hansen director of NASA stated that in order not to surpass the limit of two degrees of global warming established by the Intergovernmental Panel on Climate Change, it is not sufficient to set limits for CO_2 produced by burning fossils fuels but "we must identify a portion of the fossil fuels that will be left in the ground" (Inman, 2008). A recent study confirms this theory: "a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2°C" (McGlade and Ekins, 2015).

15 Brazil: limits and impacts of renewable hydroelectric generation.

(Written by Izaro Basurko, corrected and referenced by Ortzi Akizu)

The growing Brazilian economy is highly dependent on a large-scale infrastructure energy system, especially in order to satisfy the needs of its industrial sector. Furthermore, the oil and gas extraction sector, with the prominent role of the national company Petrobras, is a main supporter of current economic development, 10.4% of the Brazilian Gross Domestic Product (GDP) (Guilhoto et al., 2007). Nevertheless, the Brazilian state is concerned with moving towards a sustainable energy model, despite this creating a divergence in energy-dependence objectives.

What is considered to be one of the most successful (Solomon and Krishna, 2011) energy transitions occurred in the Brazil transport sector, where a coordinated State strategy has been implemented in order to shift from an oil-based transportation system to one based on sugarcane-ethanol. As a result, the percentage of alcohol-based car sales rapidly increased from less than 1% of total sales in 1979 to 96% by 1985 (Solomon and Krishna, 2011). In 2010, Brazil had become the largest biofuel producer in the world with 492,844 b/d. In February 2015, the Brazilian government raised the ethanol blend requirement in gasoline to 27% (US. Energy Information Administration, 2015). In contrast, the transition to biofuels has been severely criticised, since although it could be a potential low-carbon energy source, whether biofuels offer carbon savings or not is highly dependent on how they are produced (Fargione et al., 2008).

Yet the most controversial energy transition issue of Brazil is that towards the promotion of large-scale hydropower, which is directly related to the industrial energy consumption of the country, especially of the aluminium industry (Fearnside, 2016). The contradictions of a supposedly renewable energy, such as hydroelectric, have set out the direction and content of the transition proposals (Abbasi and Abbasi, 2012). In the country, around 34,000 km2 of fertile land has been flooded to create over 2,000 dams (Stancich, n.d.), of which 625 are hydroelectric (MOVIMENTO DOS ATINGIDOS POR BARRAGENS – MAB, 2010). In 2014 63.23% of the electricity in Brazil was generated hydroelectrically according to the IEA (International Energy Agency, 2014). Presently, 15 large (>30 MW) hydroelectric dams are being built in Brazil and the 2012-21 Energy Expansion Plan foresees the building of another 37 generation plants (Fearnside, 2016).

In this context the Movement of People Affected by Dams (Movimento dos Atingidos por Barragens, MAB) was founded in the late 1970s. In the early years, they called for "fair compensation" for the affected people but their claims have gradually changed, evolving towards their current situation. Hydropower is considered as a renewable energy but the MAB states that hydraulic power generation in Brazil has had a major environmental impact and had also directly affected more than one million people by 2005 (Marcondes Martins and Lelo Bellotto, 2005), most of whom have not been compensated yet (e.g. 22,315 people have been affected with the building of only 3 dams, Estreito, Serra Quebrada and Santa Isabel by the aluminium smelting companies (Fearnside, 2016)).

The MAB claims that it is necessary to answer the question: Who planned and organised the energy sector in Brazil? (Bermann, 2002). Hydroelectricity-generated problems are not only about a struggle of people affected by dams. The MAB states that the current energy model and energy policy respond to both market demand and corporate greed and aim to increase productivity and consumption with their only goal being to generate the largest amount of private profit possible. The MAB defines the current Brazilian energy system as follows (extracted from interviews):

- Privatisation and control of privately owned transnational companies concerning energy issues. The energy sector is controlled by large international corporations.
- The Brazilian electricity sector is fragmented in terms of generation, transmission, distribution and commercialisation. Each one of these areas is controlled by financial capital. The priority for each sector is to transfer wealth to shareholders and speculation occurs with assets such as rights, water and the environment, in an aim for higher profit.
- The price of electricity in Brazil was separated from the reality of production costs within the system. With the internationalisation of energy use for large industrial companies (such as the aluminium melting sector), electric energy has become one of the main national products, generating huge profits for shareholders.
- The increasing exploitation of energy workers and the violation of the human rights of those affected. Since privatisation started, there has been no increase in the total

number of sector workers but two-thirds of sector workers are being paid lower salaries than before (Fearnside, 2016).
- The state organisation has made the financial system and the energy system serve the interests of privately owned companies. The structure of the state is acting to depoliticise the energy debate and also to pass a set of laws and regulations whose single aim is to consolidate the high return on investment of the industry throughout the supply chain, whereby domestic consumers sustain and guarantee these high profits in the sector.

Given this general national situation, the MAB claims that "water and energy are not commodities" but a basic need for citizens. The Workers and Peasants Energy Platform (Plataforma Operária e Camponesa para Energia, POCE) was created in an aim to have an impact on national energy policy-making. The POCE was the result of discussions between organisations of farmers and local inhabitants regarding the energy model they wanted to construct. These debates began between 2008 and 2010. In 2008, the MAB organised a course on energy in Rio de Janeiro inviting several labour unions, university professors and social movements that were interested in the situation and in energy policies in Brazil. Here unions from the public oil sector met the POCE adding new claims regarding the privatisation of the oil industry. Indeed, this encounter between peasant movements affected by energy projects and workers from the energy sector is one of the key innovations and potentials in this project.

The POCE proposes a social energy project for Brazil, based on sovereignty, distribution of wealth and popular control. Women have played a remarkable role in this struggle giving visibility to social values on reproduction and the role of energy in their lives (PTM Mundubat and Movimento dos Atingidos por Barragens, 2011), (Mundubat, 2011). The proposals made by the platform can be summarised in the following points (extracted from interviews):

- Advancing the transformation and construction of national instances for more widespread democracy, popular engagement and control over the decisions concerning social energy policy.
- Making political and institutional changes to move beyond the market-driven energy model; greater state control over energy prices and energy purchasing should be made through the regulated market, with greater transparency of regulatory agencies.
- Reinforcing state energy companies with greater state participation and even the creation of a state monopoly so that gas and oil are made 100% public through Petrobras and Electrobras.
- Returning amortised power stations to state hands and a majority stake of state companies in energy consortiums.
- Developing the industrialisation of the entire energy supply chain, moving towards full technology sovereignty, incentivising research and the petroleum potential in Brazil.
- Improving working conditions and valuing workers.

- Guaranteeing the rights of the affected areas through a national reparation policy for those affected by the dams.
- Energy integration solidarity with South America, developing this to guarantee public participation and grassroots struggles and technology transfer. The aforementioned aims to reinforce national sovereignty against transnational companies.
- Respect for the environment and minimisation of social and environmental impact especially in the pre-construction stages. For this, it is proposed that public consultation be conducted, popular participation be encouraged and more environmental education programmes provided.
- Incentivising the economy and researching new energy sources with less impact on the environment. The platform also proposes the diversification of renewable energy.

The deterritorialisation and reterritorialisation caused by hydroelectric plants could be an opportunity to generate points of social empowerment in order to advance towards the implementation of the energy transition (Rocha, 2016).

16 Cuba: how to tackle an oil shortage

(Written by Iñaki Barcena, corrected and referenced by Ortzi Akizu)

Cuba, the American Caribbean socialist island, developed its own unique expertise in social and economic subsistence, especially in the terms of energy, after the disappearance of the so-called "Socialist Camp" or “Soviet Bloc”. Fuel imports decreased by 71% between 1989 and 1993, and the Cubans, actively encouraged to do so by the regime in Havana, relied on social networks and non-industrial modes of production to cope with energy scarcity (Friedrichs, 2010).

Since 1960, the Cuban energy system has been constrained by two key factors that led the nation to an integral energy crisis. On the one hand the major energy dependence of Cuba on the COMECON (Council for Mutual Economic Assistance) markedly worse after the dismantling of the USSR in 1991 and on the other hand the economic blockade (intensified in 1992 with the Torricelli Act) that the United States of America has imposed on Cuba for over half a century (Figueredo and Larrosa, 2010). The traumatic socio-economic situation experienced in Cuba in the so-called "special period" after 1991 is an interesting example showing an unsought energy transition imposed by the sudden collapse of its energy model.

The two factors discussed above meant that in this "special period in peacetime" (from early-to mid-1990s) Cuba lost more than 50% of its imports and more than 85% of its foreign trade. GDP fell by 50% in the period from 1989 to 1993, falling from USD 20 billion to half that amount and this had devastating effects on the population of the island. According to the EIA (US Energy Information Administration), between 1990 and 1994 electricity consumption in Cuba decreased drastically by 30.2% (from 13.24 to 9.24 TWh). In addition to power outages and mobility and transport problems, Cubans experienced a shortage of "everything", mainly food. Nevertheless, food scarcity had a surprisingly positive effect on the health of Cubans, rapid declines in cases of diabetes and heart disease accompanied by an average population-wide loss of 5.5 kg in weight (Franco et al., 2013), due to less smoking and a lower daily energy intake and increased physical activity. Later, mainly from 2002 to 2010, the population-wide increase in weight was immediately followed by a 116% increase in the prevalence of diabetes and 140% increase in the incidence of diabetes (Franco et al., 2013).

Our interest in choosing this case is to balance the positive lessons of the Cuban experience, during and after the special period. As Richard Heinberg pointed out in 2006 "Cuba survived an energy famine during the 1990s, and how it did so constitutes one of the most important and hopeful stories of the past few decades. It is a story not just of individual achievement, but of the collective mobilisation of an entire society to meet an enormous challenge" (Morgan, 2006). Cuba showed the world that *Peak Oil* could be faced and overcome in a collective way. Although it was not a democratic decision taken by the inhabitants or a free choice by the government, in 2003 Cuba was the only country in the world to achieve a 0.8 Human Development Index value, while also maintaining the ecological footprint below the area of one world (WWF, 2006), and the proportional 1.5 ha per people as a demand on the biosphere (Suárez et al., 2012). For this reason it could be said that in 2003 Cuba was the only sustainable country in the world, attaining appropriate living standards within sustainable levels of ecological footprint. In 2013, although in Cuba 87.34% of the energy supply came from fossil fuels, an average Cuban citizen consumed 71.07% less fossil fuels than a German citizen and 59.48% less than a Danish citizen, without taking into account the Hidden Energy Flows.

There are many lessons and exemplary experiences we can take from the various transitions occurring in Cuba in the last 60 years, particularly in the so-called "special period" between 1989 and 1995. According to Julio Torres Martinez (from Cubasolar) Cuba is facing its 3rd energy transition, the first came with coal, the second with crude oil and petroleum and the third would come progressively with energy-saving and efficient renewable energies with the government aim for these to come to 24 % of the primary energy supply by 2030 (Urkidi et al., 2015).

One of the biggest lessons we can draw from the Cuban experience is that the Cuban socialist state has ensured the viability of the project despite the US trade embargo, isolation and the hardship of the special period. However, this does not mean that Cuban society as a whole, despite being the "most sustainable" in the world in 2003 (WWF, 2006) has evolved culturally to make a conscious and democratically elected commitment to an energy transition based on low consumption and renewable resources.

The "special period" of the early 1990s led to a severe generalised stress test that the Cuban people were able to overcome due to the strong commitment of the structures of the socialist state to place universal interests above individual interests and the combined expertise of the public, farmers and scientists to manage the crisis by seeking mutual support (Santiago Muíño, 2016).

The current situation of energy dependence on oil in Cuba and the necessary implementation of new energy policies now require a cultural shift towards sustainability and this remains a major challenge for the socialist state and for the Cuban people.

The consumerist aspirations of a vast majority of the Cuban people who crave the living standards of the middle classes of the capitalist countries show that this cultural change will not be easy and that the increase, albeit slight, in social and economic differences may endanger the fundamental achievements of the Revolution.

The energy issue is a challenge to move in either one direction or the other. If Cuba is the most "sustainable" country in the world, this is related to the control that the Cuban socialist state exerts on society and the energy issue is central to this.

As observed in this research paper, in the Cuban energy system, the main stakeholder is the state and its political institutions, with its many inherent advantages, although there are also disadvantages such as paternalism and bureaucracy.

Based on low-tech and community support, Cuba has demonstrated that it has the technical and human resources required for the production of the bio-energy equipment necessary for a fair, democratic and sustainable energy transition. But this transition will not occur if the majority in Cuban society aspire to a Global North modus vivendi and consumerist desires are imposed on the logic of power as a public service. That is, if energy in Cuba becomes simply a market commodity.

17 Spain: struggles within the electrical energy market

(Written by Rosa Lago, corrected and referenced by Ortzi Akizu)

The regulation of the Spanish market is not very favourable for renewable energy deployment and only 14.54% of the total primary energy supply comes from renewables (International Energy Agency, 2015). In Europe, major fossil fuel companies and energy utilities such as Total, Iberdrola, E.On and Enel have together adopted a dominant position in trade bodies such as the European Wind Energy Association (EWEA) and the European Photovoltaic Industry Association (EPIA) in order to slow down the transition to clean energy and to facilitate the use of natural gas (Neslen, 2015). Similarly, large electricity companies are acting as lobbies to curb the growth of renewable energies in Spain. This oligopoly is reinforced by the concept known as “revolving doors” whereby former government officials are hired to occupy senior positions in large firms and vice versa, in an aim to seek favourable legislation and favourable regulation of the electricity market. Over 50 politicians, among them two ex-presidents, have been found to be involved in this by the most important national newspapers, El Mundo and El País (Iglesias, 2016).

The oligopoly blames renewable energies for the tariff deficit in electricity, due to the feed-in-tariffs (FITs) they received. Renewable energy advocates blame other costs as unjustified or over-valued for the deficit (nuclear moratorium, nuclear waste management, Competence Transition Costs, CESUR auctions...) and they argue that renewable energies bring noticeable price reductions in wholesale electricity markets (Gallego-Castillo and Victoria, 2015).

As a consequence, the Spanish government changed the regulations and reduced FITs by successive royal decrees (Decree Law 1578/2008 and Decree Law 14/2010) until they were eventually cancelled through Royal Decree 1/2012 and Royal Decree Law 9/2013. On top of this, Spain's government has recently imposed a "sun tax" on self-consumption systems (Royal Decree 900/2015) charging both on a capacity and a generation level. The Spanish photovoltaic industry and renewable energy advocates are outraged by this as they argue that consumers already pay charges for maintaining the grid and this is a second tax on the same aspect. The National Competition Commission and the National Energy Commission (Comisión Nacional de la Competencia and la Comisión Nacional de la Energía) consider that this tax is discriminatory and makes the projects financially unviable, causing a "serious dysfunction" against the efficiency enshrined in European Union directives (Europa Press, 2013).

Given this negative scenario, Som Energia was launched in the summer of 2010 in Girona (Catalonia) by a grassroots group aiming to consume 100% renewable energy. At that time there was no cooperative in Spain to commercialise electricity from a completely renewable origin, and as a result the inspiration came from Europe. This is a non-profit green energy consumption cooperative and its basic activities are the generation and marketing of renewable energy. It aims to achieve a 100% renewable model and energy sovereignty, i.e. a democratic system serving the interests of citizens and not a small number of companies. Currently, Som Energia supplies 156 GWh certified 100% renewable by the CNMC (Comisión Nacional de los Mercados y la Competencia) (CNMC, National Commission on Financial Markets and Competition, 2015) to end customers with 3.3% own production and the rest purchased on the electricity market from producers of certified green electricity. In 2012 Eurosolar recognised the work of the cooperative, awarding it the European Solar Prize. Som Energia is part of the European Federation of Renewable Energy Cooperatives (REScoop).

To promote energy sovereignty, the cooperative Som Energia bases its internal operations on assembly meetings: anyone can join by contributing EUR 100 to the cooperative; partners have the right to participate and vote at the annual meeting. In the 2014 annual assembly twelve bases were established throughout the State, and topics involving new technologies were discussed and voted on (Arizkun, 2014).

The platform "Plataforma por el nuevo modelo energético" (Platform for a New Energy Model) represents energy cooperatives such as Som Energia and other organisations, and it is committed to campaigns in favour of renewable energy self-consumption. Feed-in-tariff schemes aside, self-consumption refers to the proportion of energy directly used in the building in which the energy generation system is located. For instance, a photovoltaic system (PV) will be sized in accordance with the consumption of the house in which it is installed, and the homeowner will be billed by the net metering (the difference between the electricity bought and the amount fed into the public grid generated by the PV panels). This practice is becoming increasingly important worldwide in the photovoltaic market (International Energy Agengy, IEA, 2015).

Self-consumption with photovoltaic in Spain is financially viable because the price of the PV modules has fallen sharply in recent years and the cost of PV electricity is even lower than the price of the electricity available from the distribution grid. In other words, "grid parity" has been achieved. Ricard Jormet is the owner of the restaurant Lasal del Varador (Mataró, Catalonia) where PV and solar thermal panels have been installed, and in his words, it pays off:

"Hot water comes from the solar thermal panels, and it is also used for radiant floor heating, so the energy bill for the restaurant is really low. Only for electricity, I paid € 12,000 in 2012, and even though electricity got more expensive, in 2013 I paid € 5,500. Therefore I am saving € 6,000 per year which I can reinvest in the project." (Jormet, 2014).

In addition to the projects based on self-consumption, Som Energia is also working on other initiatives: Generation kWh attempts to deploy self-consumption even if the renewable electricity system is not located in the same building where it is consumed. Investors will recover their investment in the electricity bill by discounting as much kWh as the electricity system has produced in accordance with their share. The initiative Recupera el Sol (Recover the Sun) aims to purchase installations for sale, especially photovoltaic systems, whose number has grown significantly since the Spanish government started regulating the reduction and eventual cancellation of feed-in tariffs (Palmada, 2014).

In Spain, there are currently several green energy consumption non-profit co-operatives which have been created following the example of Som Energia (GoiEner, Zencer, NosaEnerxía…) with a total number of 35,000 members and even more electricity contracts. These are still low figures compared to the size of the electricity oligopoly but the numbers are constantly growing. Furthermore, the investments made by the green cooperatives in new projects are providing the renewable energy sector with deployment opportunities.

The current energy system is not sustainable, and the social and environmental impacts that it generates are unmanageable. Furthermore, it is headed towards continuous economic crisis. To change this energy system, first of all we need to clearly quantify the energy consumed by our consumerist lifestyles. Secondly, examples of emerging sustainable energy system designs and integration plans need to be analysed both quantitatively and qualitatively. In this Ph.D. thesis, these two points have been studied through three international articles, on the one hand, calculating the energy embodied in the goods and services of countries, and on the other hand, providing deeper insights into current cases of ongoing energy transition.

El modelo energético actual no es sostenible, a causa de los impactos ambientales e injusticias sociales que genera. Además, la gestión de tipo top-down del modelo energético basado en combustibles fósiles ha abocado en constantes crisis durante la última década. Para la transición a un modelo sostenible es imprescindible, por una parte, cuantificar la cantidad de energía que consumimos a causa de nuestro estilo de vida y modelo de consumo. Por otra parte, es necesario realizar un estudio cualitativo y cuantitativo de los nuevos modelos energéticos sostenibles que se están generando y de sus modelos de integración. Ambos puntos se han trabajado en esta tesis, analizando las transiciones energéticas actuales, y por otra parte realizando el cálculo de la energía embebida en productos y servicios.

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