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# **Supplementary Information**

# Energy Intensity of the Spanish Economy A Useful Work Study

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## I. World Energy Balances description

The World Energy Balances database from the IEA includes a large amount of energy data at the country level from 1960 to the current year. Here the focus is on the "Final Energy Consumption" category, which is basically the input data to the Spanish Exergy Analysis.

The final energy consumption data is split in 4 main economic sectors "Industry", "Transport", "Others" and "Energy own use", and each one is subdivided in economic subsectors as displayed in Table 1.

Energy industry own use	Industry	Transport	Others
Coal mines (energy)	Iron and steel	World aviation bunkers	Residential
Oil and gas extraction (energy)	Chemical and petrochemical	Domestic aviation	Commercial and public services
Blast furnaces (energy)	Non-ferrous metals	Road	Agriculture/forestry
Gas works (energy)	Non-metallic minerals	Rail	Fishing
Gasification plants for biogases (energy)	Transport equipment	Pipeline transport	Non-specified (other)
Coke ovens (energy)	Machinery	World marine bunkers	
Patent fuel plants (energy)	Mining and quarrying	Domestic navigation	
BKB/peat briquette plants (energy)	Food and tobacco	Non-specified (transport)	
Oil refineries (energy)	Paper, pulp and print		
Coal liquefaction plants (energy)	Wood and wood products		
Liquefaction (LNG) / regasification plants (energy)	Construction		
Gas-to-liquids (GTL) plants (energy)	Textile and leather		
Own use in electricity, CHP and heat plants (energy)	Non-specified (industry)		
Pumped storage plants (energy)			
Nuclear industry (energy)			
Charcoal production plants (energy)			
Non-specified (energy)			

Table 1: Final energy consumption - economic subsectors

Each couple (Economic subsector, Energy carrier) is ascribed to a final end use in the Mapping phase. In order to describe the mapping more easily in Section II, we bundle energy carriers following Table 2, which is based on the IEA classification<sup>1</sup>.

<sup>1</sup> This classification can be found online at <a href="https://www.iea.org/statistics/resources/balancedefinitions/">https://www.iea.org/statistics/resources/balancedefinitions/</a> , last accessed 28/12/2018

Coal & Coal Products	Oil & Oil Products	Natural Gas	Combustible Renewables	Electricity
Sub-bituminous coal	Fuel oil	Natural gas	Biogases	Electricity
Blast furnace gas	Gas/diesel oil excl. biofuels		Biogasoline	
Brown coal (if no detail)	Liquefied petroleum gases (LPG)		Primary solid biofuels	
Coal tar	Motor gasoline excl. biofuels		Biodiesels	
Coke oven coke	Other kerosene		Non-specified primary biofuels and waste	
Coke oven gas	Crude oil		Charcoal	
Hard coal (if no detail)	Petroleum coke		Industrial waste	
Other bituminous coal	Refinery gas		Municipal waste (non-renewable)	
Gas works gas	Aviation gasoline		Municipal waste (renewable)	
Patent fuel	Gasoline type jet fuel		Solar thermal	
Anthracite	Kerosene type jet fuel excl. biofuels		Geothermal	
Coking coal	Lubricants			
Gas coke	White spirit & SBP			
	Bitumen			
	Naphtha			
	Other oil products			
	Paraffin waxes			
	Ethane			
	Natural gas liquids			

Table 2: Carriers groups as used in the mapping process

# II. Mapping details

The mapping performed is fully described in Table 3, 4, 5 and 6.

Economic subsector	r Energy carrier	Final end use
1. Iron and Steel	Coal & Coal Products	Industrial heat/furnace - HTH.1200.C
	Oil & Oil Products	Industrial heat/furnace - HTH.1200.C
	Oil & Oil Products - Gas/diesel	Industry static diesel engines
	oil excl. biofuels	
	Natural Gas	Industrial heat/furnace - HTH.1200.C
	Combustible Renewables	Industrial heat/furnace - HTH.1200.C
	Electricity	20% MD – Electric Motors
		75% HTH.1600.C - Electric heaters
		5% Lights – Electric lights
2. Chemical and	Coal & Coal Products	34% Industrial heat/furnace – MTH.200.C
petrochemical		33% Industrial heat/furnace – HTH.600.C
-		33% Industrial heat/furnace - HTH.800.C
	Oil & Oil Products	34% Industrial heat/furnace – MTH.200.C
		33% Industrial heat/furnace – HTH.600.C
		33% Industrial heat/furnace - HTH.800.C
	Oil & Oil Products - Gas/diesel	Industry static diesel engines
	oil excl. biofuels & Motor	
	gasoline excl. biofuels	
	Electricity	47.5% MD - Electric motors
		15.8% MTH.200.C - Electric heaters
		15.8% MTH.600.C - Electric heaters
		15.8% MTH.800.C - Electric heaters
		5% Lights – Electric lights
	Natural Gas	34% Industrial heat/furnace – MTH.200.C
		33% Industrial heat/furnace – HTH.600.C

		33% Industrial heat/furnace - HTH.800.C
	Combustible Renewables	34% Industrial heat/furnace – MTH.200.C
		33% Industrial heat/furnace – HTH.600.C
		33% Industrial heat/furnace - HTH.800.C
3. Non-ferrous meta	als Coal & Coal Products	25% Industrial heat/furnace – MTH.200.C
		25% Industrial heat/furnace – HTH.600.C
		25% Industrial heat/furnace – HTH.800.C
		25% Industrial heat/furnace – HTH.1000.C
	Oil & Oil Products	25% Industrial heat/furnace – MTH.200.C
		25% Industrial heat/furnace – HTH.600.C
		25% Industrial heat/furnace – HTH.800.C
		25% Industrial heat/furnace – HTH.1000.C
	Oil & Oil Products - Gas/diesel	Industry static diesel engines
	oil excl. biofuels	
	Electricity	47.5% MD - Electric motors
		11.9% MTH.200.C - Electric heaters
		11.9% MTH.600.C - Electric heaters
		11.9% MTH.800.C - Electric heaters
		11.9% MTH.1000.C - Electric heaters
		5% Lights – Electric lights
	Natural Gas	25% Industrial heat/furnace – MTH.200.C
		25% Industrial heat/furnace – HTH.600.C
		25% Industrial heat/furnace – HTH.800.C
		25% Industrial heat/furnace – HTH.1000.C
	Combustible Renewables	25% Industrial heat/furnace – MTH.200.C
		25% Industrial heat/furnace – HTH.600.C
		25% Industrial heat/furnace – HTH.800.C
		25% Industrial heat/furnace – HTH.1000.C
4. Non-metallic	Coal & Coal Products	20% Industrial heat/furnace – MTH.200.C
minerals		80% Industrial heat/furnace - MTH.1200.C
	Oil & Oil Products	20% Industrial heat/furnace – MTH.200.C
		80% Industrial heat/furnace - MTH.1200.C
	Oil & Oil Products - Gas/diesel	Industry static diesel engines
	oil excl. biofuels	
	Electricity	20% MD - Electric motors
		12.5% MTH.200.C - Electric heaters
		62.5% MTH.1200.C - Electric heaters
	Natural Gas	20% Industrial heat/furnace – MTH.200.C
		80% Industrial heat/furnace - MTH.1200.C
	Combustible Renewables	20% Industrial heat/furnace – MTH.200.C
		80% Industrial heat/furnace - MTH.1200.C
5. Transport	Coal & Coal Products	50% Industrial heat/furnace – MTH.200.C
Equipment		50% Industrial heat/furnace - MTH.600.C
	Oil & Oil Products	50% Industrial heat/furnace – MTH.200.C
		50% Industrial heat/furnace - MTH.600.C
	Oil & Oil Products - Gas/diesel	Industry static diesel engines
	oli excl. Diofuels	47.50 MD Electric maters
	Electricity	47.3% WID - Electric motors
		25.75% MITH.200.C - Electric neaters

		23.75% MTH.600.C - Electric heaters 5% Lights – Electric lights
	Natural Gas	50% Industrial heat/furnace – MTH.200.C 50% Industrial heat/furnace – MTH.600.C
6. Machinery	Coal & Coal Products	50% Industrial heat/furnace – MTH.200.C 50% Industrial heat/furnace – MTH.600.C
	Oil & Oil Products	50% Industrial heat/furnace – MTH.200.C 50% Industrial heat/furnace - MTH.600.C
	Oil & Oil Products - Gas/diesel oil excl. biofuels	Industry static diesel engines
	Electricity	47.5% MD - Electric motors 23.75% MTH.200.C - Electric heaters 23.75% MTH.600.C - Electric heaters 5% Lights – Electric lights
	Natural Gas	50% Industrial heat/furnace – MTH.200.C 50% Industrial heat/furnace - MTH.600.C
	Combustible Renewables	50% Industrial heat/furnace – MTH.200.C 50% Industrial heat/furnace - MTH.600.C
7. Mining and quarrying	Coal & Coal Products	50% Industrial heat/furnace – MTH.200.C 50% Industrial heat/furnace - MTH.600.C
1 , 0	Oil & Oil Products	50% Industrial heat/furnace – MTH.200.C 50% Industrial heat/furnace - MTH.600.C
	Oil & Oil Products - Gas/diesel oil excl. biofuels & Fuel oil	Industry static diesel engines
	Electricity	47.5% MD - Electric motors 23.75% MTH.200.C - Electric heaters 23.75% MTH.600.C - Electric heaters 5% Lights - Electric lights
	Natural Gas	50% Industrial heat/furnace – MTH.200.C 50% Industrial heat/furnace – MTH.600.C
8. Food & Tobacco	Combustible Renewables Coal & Coal Products Oil & Oil Products	Industry static diesel engines Industrial heat/furnace - MTH.100.C
	Oil & Oil Products - Gas/diesel	Industry static diesel engines
	Electricity	47.5% MD - Electric motors 47.5% MTH.100.C - Electric heaters 5% Lights – Electric lights
	Natural Gas Combustible Renewables Combustible Renewables -	Industrial heat/furnace - MTH.100.C Industrial heat/furnace - MTH.100.C Industry static diesel engines
9. Paper, pulp and	Coal & Coal Products	Industrial heat/furnace - MTH.100.C
hun	Oil & Oil Products Oil & Oil Products - Gas/diesel oil excl. biofuels	Industrial heat/furnace - MTH.100.C Industry static diesel engines
	Electricity	47.5% MD - Electric motors 47.5% MTH.100.C - Electric heaters

	N + 10	5% Lights – Electric lights
	Natural Gas	Industrial heat/furnace - MTH.100.C
10 W J J J	Compustible Renewables	Industrial heat/furnace - MTH.100.C
products	Coal & Coal Products	Industrial neat/furnace - MTH.100.C
	Oil & Oil Products	Industrial heat/furnace - MTH.100.C
	Oil & Oil Products - Gas/diesel oil excl. biofuels	Industry static diesel engines
	Electricity	47.5% MD - Electric motors
		47.5% MTH.100.C - Electric heaters
		5% Lights – Electric lights
	Natural Gas	Industrial heat/furnace - MTH.100.C
	Combustible Renewables	Industrial heat/furnace - MTH.100.C
11. Construction	Coal & Coal Products	Industrial heat/furnace - MTH.100.C
	Oil & Oil Products	Industrial heat/furnace - MTH.100.C
	Oil & Oil Products - Gas/diesel oil excl. biofuels	Industry static diesel engines
	Electricity	80% MD - Electric motors
		15% MTH.100.C - Electric heaters
		5% Lights – Electric lights
	Natural Gas	Industrial heat/furnace - MTH.100.C
	Combustible Renewables	Industrial heat/furnace - MTH.100.C
	Combustible Renewables -	Industry static diesel engines
	Biodiesels	
12. Textile and leather	Coal & Coal Products	Industrial heat/furnace - MTH.100.C
	Oil & Oil Products	Industrial heat/furnace - MTH.100.C
	Oil & Oil Products - Gas/diesel oil excl. biofuels	Industry static diesel engines
	Electricity	47.5% MD - Electric motors
	-	47.5% MTH.100.C - Electric heaters
		5% Lights – Electric lights
	Natural Gas	Industrial heat/furnace - MTH.100.C
	Combustible Renewables	Industrial heat/furnace - MTH.100.C
13. Non-specified	All	Disaggregated in other economic
(industry)		subsectors according to the main report

Table 3: Mapping of the "Industry" economic sector

Economic subsector Energy carrier		Final end use	
1. Domestic aviation	Oil & Oil Products	Airplanes	
2. Domestic navigation	Coal & Coal Products	Boat engines	
	Oil & Oil Products	Boat engines	
3. Rail	Coal & Coal Products	Steam (coal) trains	
	Coal & Coal Products – Patent	Diesel trains	
	Fuel		
	Oil & Oil Products	Diesel trains	

	Electricity	Electric trains
4. Road	Oil & Oil Products – Biodiesels	Biodiesel cars
	Oil & Oil Products – Biogasoline	eBiogasoline cars
	Oil & Oil Products - Gas/diesel	Diesel cars
	oil excl. biofuels & Liquefied	
	petroleum gases (LPG)	
	Oil & Oil Products - Motor	Petrol cars
	gasoline excl. biofuels & Natura	1
	Gas	
	Oil & Oil Products – Natural gas	s Natural gas vehicles
T 11 4		• •

Table 4: Mapping of the "Transport" economic sector

Economic subsector	Energy carrier	Final end use
1. Agriculture/forestry	Coal & Coal Products	Industrial heat/furnace - MTH.100.C
	Oil & Oil Products	Tractors
	Oil & Oil Products - Liquefied	Industrial heat/furnace - MTH.100.C
	petroleum gases (LPG)	
	Electricity	70% MD - Electric motors
		15% MTH.100.C - Electric heaters
		15% Lights – Electric lights
	Natural Gas	Industrial heat/furnace - MTH.100.C
	Combustible Renewables	Industrial heat/furnace - MTH.100.C
	Combustible Renewables –	Tractors
	Biogasoline	
2. Residential	Coal & Coal Products	Domestic heat/furnace
	Coal & Coal Products – Gas	Lighting town gas
	works gas	
	Oil & Oil Products	Domestic heat/furnace
	Electricity	Breakdown in:
		MD – Domestic Motors
		LTH.20.C - Domestic electric heaters
		MD - Domestic appliances
		Cooling - air conditioning
		Light - Electric lights
		according to Section 4.
	Natural Gas	Domestic heat/furnace
	Combustible Renewables	Domestic heat/furnace
3. Commercial and public	Coal & Coal Products	Industrial heat/furnace - LTH.20.C
services		
	Oil & Oil Products	Industrial heat/furnace - LTH.20.C
	Oil & Oil Products - Gas/diesel	Industry static diesel engines
	oil excl. biofuels & Motor	
	gasoline excl. biofuels	
	Electricity	Breakdown in
		MD - Commercial motors

		LTH.20.C - Domestic electric heaters
		MD - Domestic appliances
		Cooling - air conditioning
		Light - Electric lights
		according to Section 4.
	Natural Gas	Industrial heat/furnace - LTH.20.C
	Combustible Renewables	Industrial heat/furnace - LTH.20.C
	Combustible Renewables –	Industry static diesel engines
	Biodiesels & Biogasoline	
4. Fishing	Oil & Oil Products	Boat engines
	Combustible Renewables	Boat engines
5. Non-specified (others)	All	Disaggregated in other economic subsectors according to the main
		report
· · · · · · · · · · · · · · · · · · ·	Table 5: Mapping of the "Others"	economic sector

Table 5: I	Mapping	of the	"Others"	' economic	sector
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Economic subsector	Energy carrier	Final end use	
1. Blast Furnaces	Oil & Oil Products	Industrial heat/furnace - HTH.1200.C	
2. Coal mines	Oil & Oil Products	Mining engines	
	Coal & Coal Products	50% Industrial heat/furnace - MTH.200.C	
		50% Industrial heat/furnace - HTH.600.C	
	Natural Gas	50% Industrial heat/furnace - MTH.200.C	
		50% Industrial heat/furnace - HTH.600.C	
	Electricity	47.5% MD - Electric motors	
		23.75% MTH.200.C - Electric heaters	
		23.75% HTH.600.C - Electric heaters	
		5% Light - Electric lights	
3. Coke ovens	Coal & Coal Products	Industrial heat/furnace - HTH.1000.C	
	Oil & Oil Products	Industrial heat/furnace - HTH.1000.C	
	Natural Gas	Industrial heat/furnace - HTH.1000.C	
	Electricity	47.5% MD - Electric motors	
		47.5% HTH.1000.C - Electric heaters	
		5% Light - Electric lights	
4. Gas works	Coal & Coal Products	Industrial heat/furnace - HTH.600.C	
	Electricity	47.5% MD - Electric motors	
		47.5% HTH.600.C - Electric heaters	
		5% Light - Electric lights	
5. Nuclear industry	Electricity	47.5% MD - Electric motors	
		47.5% MTH.200.C - Electric heaters	
		5% Light – Electric lights	
6. Oil and gas extraction	Oil & Oil Products	Industry static diesel engines	
U	Natural Gas	Industrial heat/furnace - MTH.200.C	
	Electricity	47.5% MD - Electric motors	
	-	47.5% MTH.200.C - Electric heaters	
		47.5% Light - Electric lights	

7. Oil refineries	Oil & Oil Products	50% Industrial heat/furnace - MTH.200.C	
		50% Industrial heat/furnace - HTH.600.C	
	Natural Gas	50% Industrial heat/furnace - MTH.200.C	
		50% Industrial heat/furnace - HTH.600.C	
	Electricity	47.5% MD - Electric motors	
		23.75% MTH.200.C - Electric heaters	
		23.75% HTH.600.C - Electric heaters	
		5% Light - Electric lights	
8. Own use in electricity,	Oil & Oil Products	Industrial heat/furnace - MTH.100.C	
CHP and heat plants			
	Natural Gas	Industrial heat/furnace - MTH.100.C	
	Electricty	47.5% MD - Electric motors	
		47.5% MTH.100.C - Electric heaters	
		5% Light - Electric lights	
	Combustible Renewables	Industrial heat/furnace - MTH.100.C	
9. Patent fuel plants	Coal & Coal Products	Industrial heat/furnace - MTH.200.C	
	Electricity	47.5% MD - Electric motors	
		47.5% MTH.200.C - Electric heaters	
		5% Light – Electric lights	
10. Pumped storage plants Electricity		MD - Electric motors	
11. Non-specified (energy		Disaggregated in other economic	
own use)		subsectors according to the main report	
Tabl	o 6. Mapping of the "Engrand	um uno" aconomia acotom	

Table 6: Mapping of the "Energy own use" economic sector

#### III. Electricity breakdown - Residential & Commercial and public services

In order to disaggregate the electricity used in the Residential & Commercial and public services sectors, a point of departure is taken in the Spanish SECH-SPAHOUSEC project (IDAE 2011). As showcased in Figure 1, this study provides a breakdown of electricity use in 2010 for the Spanish Residential sector.

From these values, a first split of the consumption for 2010 is obtained, with 5 main categories:

- Heating
- Cooling (air conditioning)
- Domestic motors
- Lighting
- Domestic appliances

However, the share of cooling seems to be underestimated in the SECH-SPAHOUSEC, and bottom-up studies ascribe a larger part of electricity to cooling in 2010 (García López and Sendra 2017). The share of cooling in 2010 is accordingly adjusted, raising from 2.3% in the first estimation to 9.3%. The share of the other categories are diminished according to their relative weight in the total.

	CONSUMO FINAL			
	ELECTRICO	COMBUSTIBLES	TOTAL	
USOS FINALES	TJ	TJ	TJ	
CALEFACCIÓN	15.907	272.667	288.574	
AGUA CALIENTE SANITARIA	16.129	100.114	116.243	
COCINA	20.063	25.588	45.651	
REFRIGERACIÓN	5.042	107	5.148	
ILUMINACIÓN	25.366		25.366	
ELECTRODOMÉSTICOS	133.470		133.470	
Frigoríficos	40.834		40.834	
Congeladores	8.083		8.083	
Lavadoras	15.812		15.812	
Lavavajillas	8.083		8.083	
Secadoras	4.469		4.469	
Horno	11.022	1	11.022	
τν	16.263	1	16.263	
Ordenadores	9.906		9.906	
Stand-by	14.292		14.292	
Otro Equipamiento	4.707	j I	4.707	
CONSUMO TOTAL	215.978	398.475	614.453	

#### Desagregación según Consumo Térmico y Eléctrico

Figure 1: Electricity use breakdown in the Spanish Residential sector – 2010 (IDAE 2011), page 59

Once the breakdown is carried out for 2010, time series are built for the period 1960-2013. Two main steps are implemented:

- Firstly, the share of cooling is assumed to raise linearly from 0% in 1960 to 10% in 2013.
- Secondly, the electric uses shares are constructed by using the same pattern as was calculated for the UK in a former study (Brockway et al. 2014).

The same breakdown calculated for the Residential sector is used for the Commercial and public services sector.

#### **IV. Efficiencies calculations**

#### i. Smoothing LTH efficiency

As mentioned in the main report, efficiency time series for LTH have been smoothed similarly to what was done in other studies (Brockway et al. 2014). Figure 2 showcases the smoothing carried out.



Figure 2: Time series (2000-2013) for LTH first law efficiencies

### ii. Outdoor temperature – indoor LTH heating

As described in the main report, only the winter temperatures of the coldest winter regions are taken into consideration when calculating the outdoor temperature for LTH, since these are the regions in which most of the winter heating occurs and consequently the representative regions.

The regions taken into consideration are: Galicia, Castilla y León, Asturias, Cantabria, Navarra, País Vasco, Aragón, Cataluña, Madrid, Castilla-la-Mancha, and Extremadura.

For each of these regions, monthly average temperatures for each meteorological station available were downloaded from the AEMET website<sup>2</sup>, and the average winter temperature for each region was calculated by taking the winter mean (December-January-February) of the underlying meteorological stations. Then the outdoor temperature for winter in Spain is calculated as the mean of these regions winter temperatures.

It is to be noted that the AEMET does not provide yearly temperatures but only mean temperatures over large periods, therefore the winter temperature computed is a mean that remains the same over the exergy analysis carried out.

## iii. Outdoor temperature – MTH and HTH

The method for MTH and HTH outdoor temperature is the same as mentioned before, with the difference that all Spanish regions are taken into consideration and that the yearly mean is computed including the 12 months of the year.

### iv. BOF and EAF steel efficiency calculations

Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) steel production first law efficiencies are based on UK data. The energy intensity of the total steel production (GJ/ton) in the UK is

<sup>2</sup> http://www.aemet.es/es/portada

taken from the ISSB<sup>3</sup>. One main methodological improvement here is that instead of using the aggregated energy intensity, the BOF and EAF energy intensities are calculated separately. To do so, we use as a point of departure data from (Griffin, Hammond, and Norman 2013) which provides average energy intensities of both BOF and EAF processes within the UK in 2007. Their values are slightly adapted in order to be consistent with the ISSB aggregated energy intensity data, and then are used as a point of departure for BOF and EAF energy intensity time series construction. Basically, the same improvement rate as observed in the ISSB data is applied to both BOF and EAF in order to construct time series, with a point of departure on the 2007 data adapted from (Griffin, Hammond, and Norman 2013).

One issue with this method is that the noise from UK data is kept when building Spanish time series. In order to remove it and to kept only the general trend, efficiencies are finally smoothed.



Figure 3: UK BOF energy intensities (1960-2013), smoothed and non-smoothed

A 10 years delay is subsequently applied to both BOF and EAF energy intensities for the Spanish context.

Finally, the first law efficiency is calculated as mentioned in the main report, namely:

$$\eta = \frac{Theoretical minimum energy/ton}{Actual energy/ton}$$

where the theoretical minimum is taken as 8.6 GJ/ton for BOF and as 1.3 GJ/ton for EAF (Fruehan et al. 2000).

#### v. Ammonia efficiency calculation

Ammonia first law efficiency are based on US efficiencies according to (Brockway et al. 2014). This data was adapted using the Spanish ammonia production energy intensity found in (Worrell et al.

<sup>3</sup> http://www.issb.co.uk/

1994) for 1988 (28 GJ/ton). This value is used as a point of departure for building the Spanish ammonia first law efficiency time series in three steps:

- Firstly, the time series is constructed by applying the same improvement rates as for the US during the whole period 1960-2013 according to the previous study (Brockway et al. 2014)
- Secondly, it is found that as the ammonia production process is particularly efficient in Spain and that the first approach gives an energy intensity that is close to the theoretical minimum in the most recent years (22 GJ/ton vs against a theoretical minimum of 19.4 GJ/ton according to (Rafiqul et al. 2005)). Consequently, it is decided to constrain the ammonia production energy intensity above 21 GJ/ton. A best fit decaying exponential function with a limit at 21 GJ/ton is subsequently used in order to build the Spanish energy intensity time series
- Thirdly, the first law efficiency is derived from the equation

 $\eta = \frac{Theoretical minimum energy/ton}{Actual energy/ton}$ 

where the theoretical minimum is taken from (Rafiqul et al. 2005). Figure 4 showcases the first law efficiencies with the constrained limit at 21 GJ/ton and without.



Ammonia first law efficiency

Figure 4: Ammonia first law efficiency - constrained vs unconstrained

#### vi. Mechanical drive smoothing

As mentioned in the main report, most of the mechanical drive efficiencies are adapted from UK calculations by applying a 10 years delay. This brings the same kind of consistency issue as discussed above: the noise coming from the data and from events specific to the UK are transferred to the Spanish time series. In order to get rid of these yearly fluctuations, the time series are smoothed, as showcased in Figure 5 in the specific case of petrol cars.



Figure 5: Petrol cars efficiencies

## References

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