GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Impact of the Spanish electricity system transition on water resources using energy modelling and life cycle assessment

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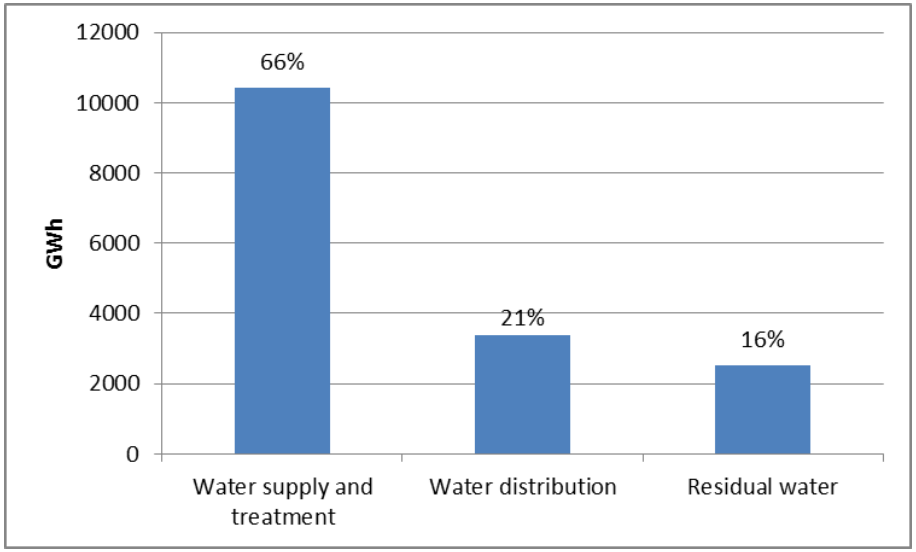
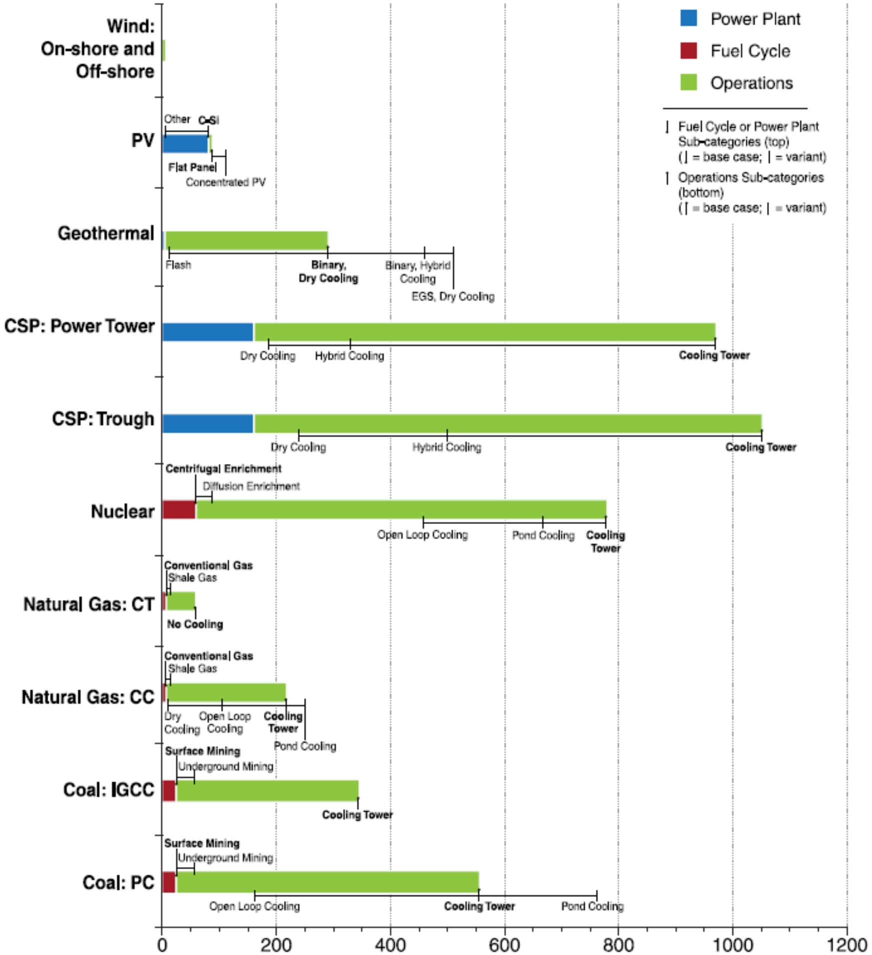
INTRODUCTION
The Nexus Energy-Water

ENERGY FOR WATER & WATER FOR ENERGY



Electricity consumption (GWh)

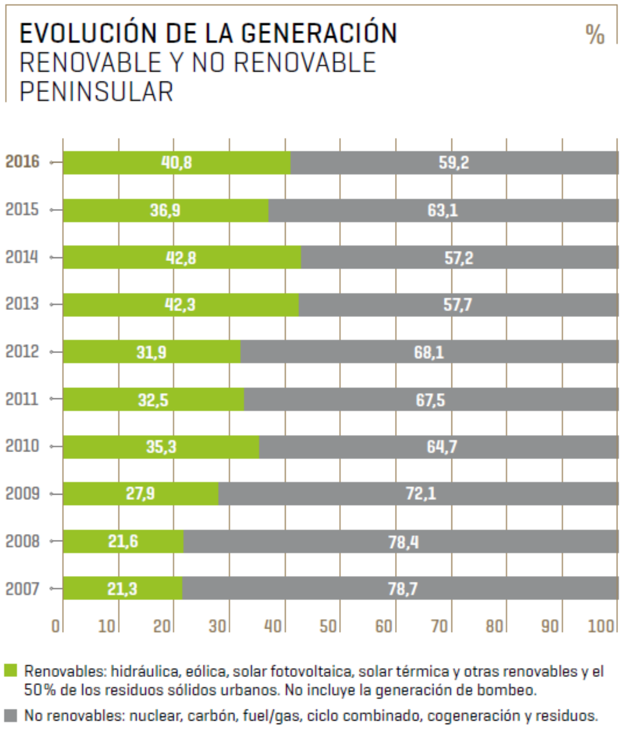
Source: Aldaya and Llamas, 2013

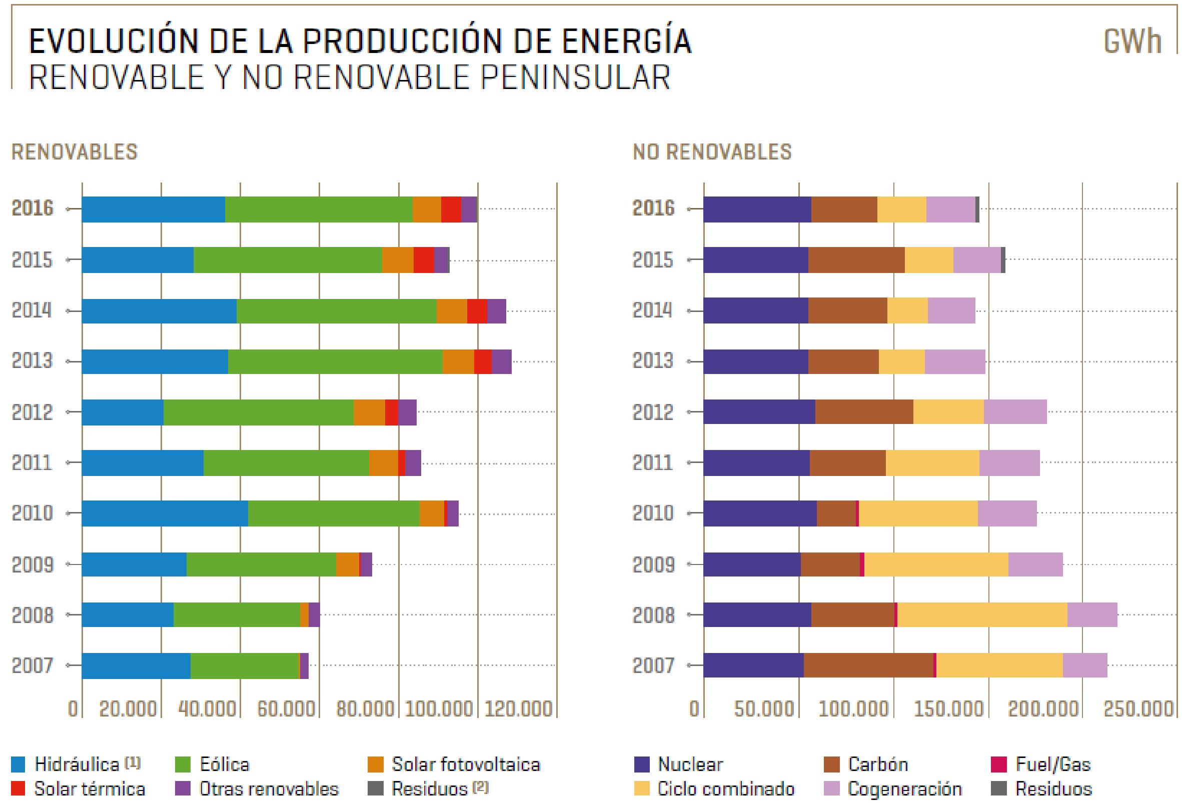


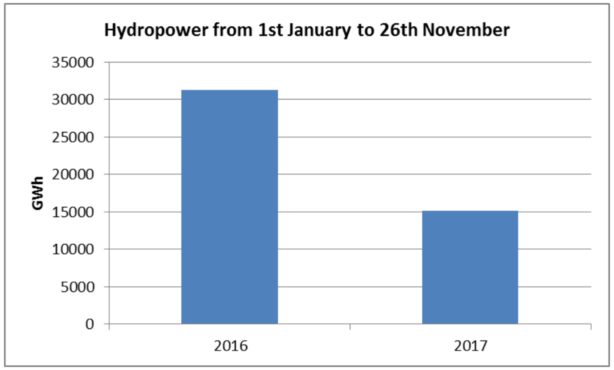
Life cycle water consumption (gal/MWh)

Source: Meldrum *et al.*, 2013

INTRODUCTION
The role of hydropower in Spain







-51,5%

Hydro, 15% of total gross production in 2010, 2013 and 2016

METHODOLOGY

Life Cycle Assessment (LCA)

To assess the potential environmental impacts and resources used throughout a product's life cycle from raw material acquisition, via production and use phases, to waste management

UNE-EN-ISO 14040-44
Functional unit: 1 kWh
Ecoinvent v3.1 database (adjusted)

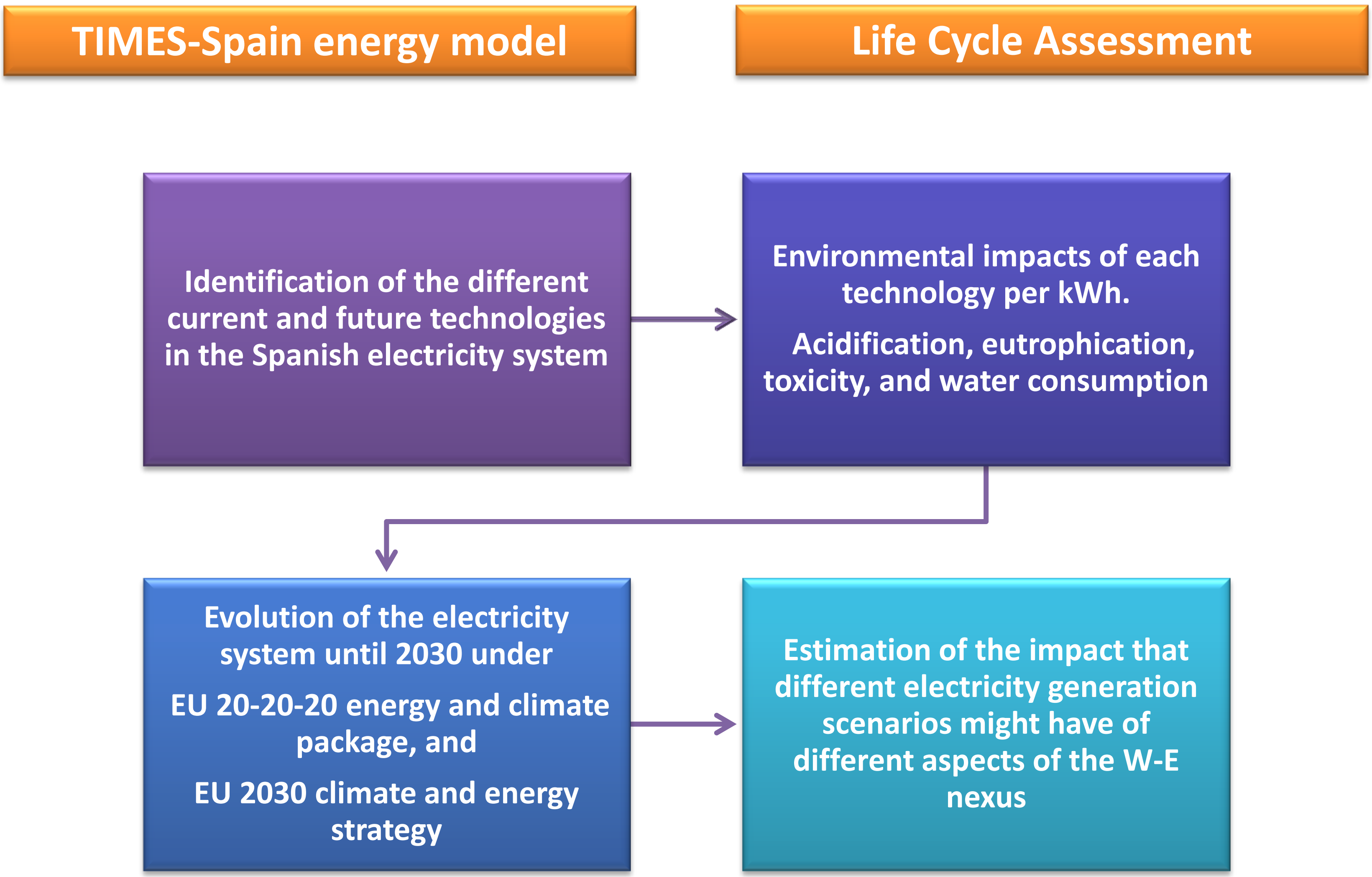
Impacts	Acidification	Eutrophication of freshwater bodies	Ecotoxicity of fresh water bodies	Water consumption
Assessment method	Accumulated exceedance (Seppälä *et al.*, 2006; Posch *et al.*, 2008)	ReCiPe (Struijs *et al.*, 2008)	USEtox method (Rosenbaum *et al.*, 2008)	Swiss Ecoscarcity model (Frischknecht *et al.*, 2007)
Units	moles of H+	kg of P equivalent	CTU (comparative toxic units)	Litre water equivalent

METHODOLOGY

TIMES-Spain energy model

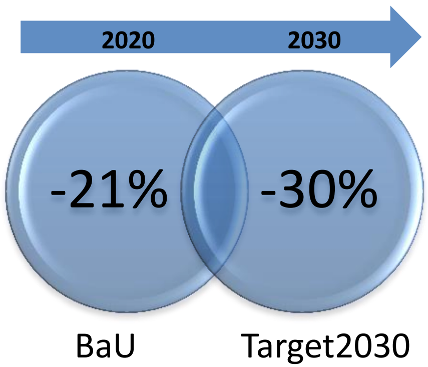
- Optimisation model -> optimum energy system at minimum cost and maximum social welfare and sustainability
- Covering the whole energy system
- Technology rich
- 1 region
- Time horizon 2050
- Interconnections with France and Portugal for electricity exchange

METHODOLOGY

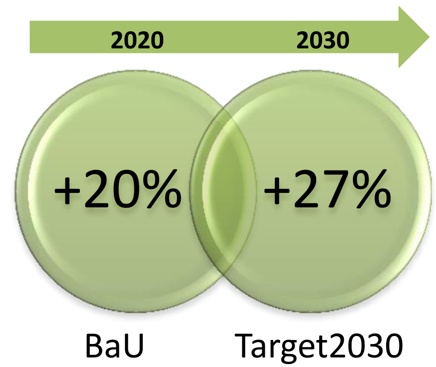


METHODOLOGY
Scenarios

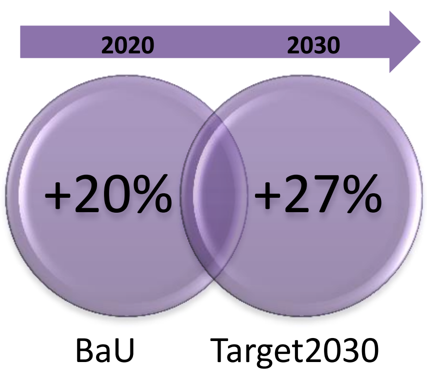
GHG emissions



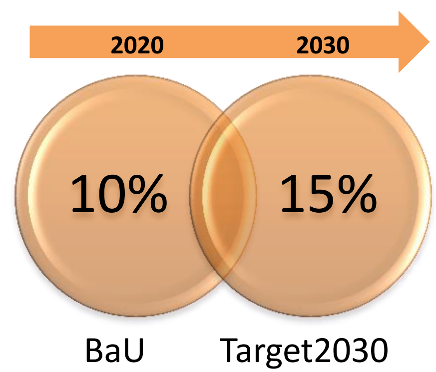
Renewable energy share



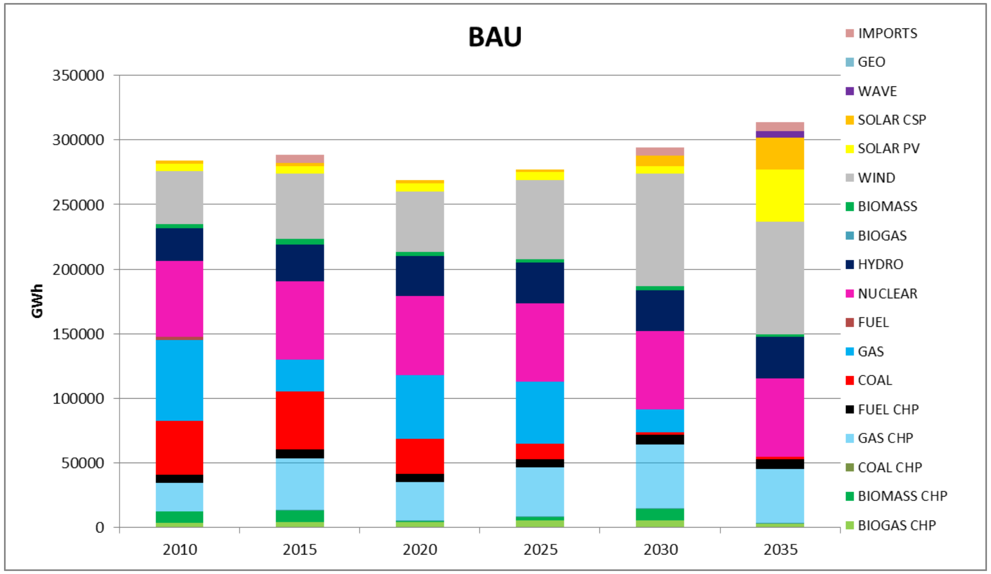
Efficiency

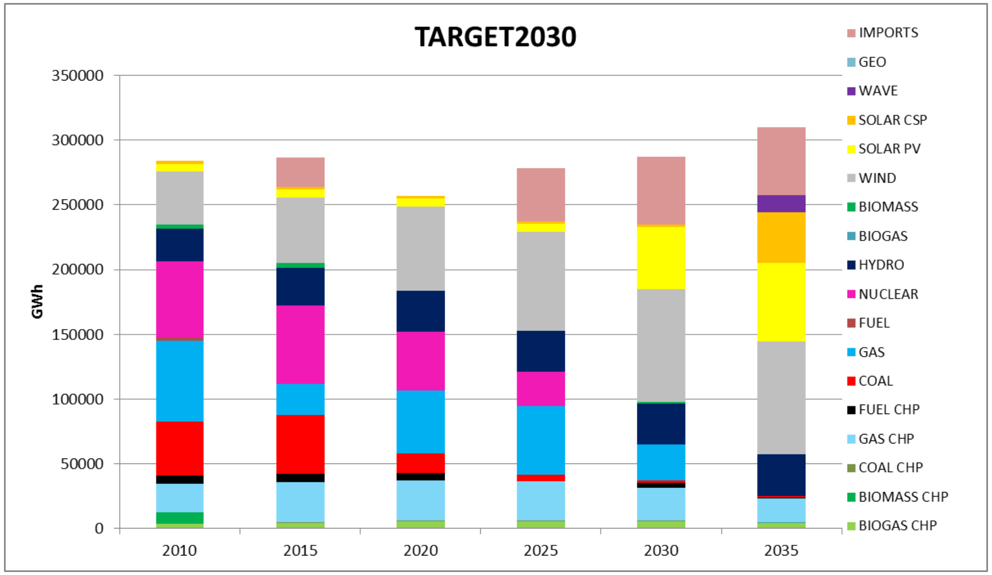


Electricity interconnection



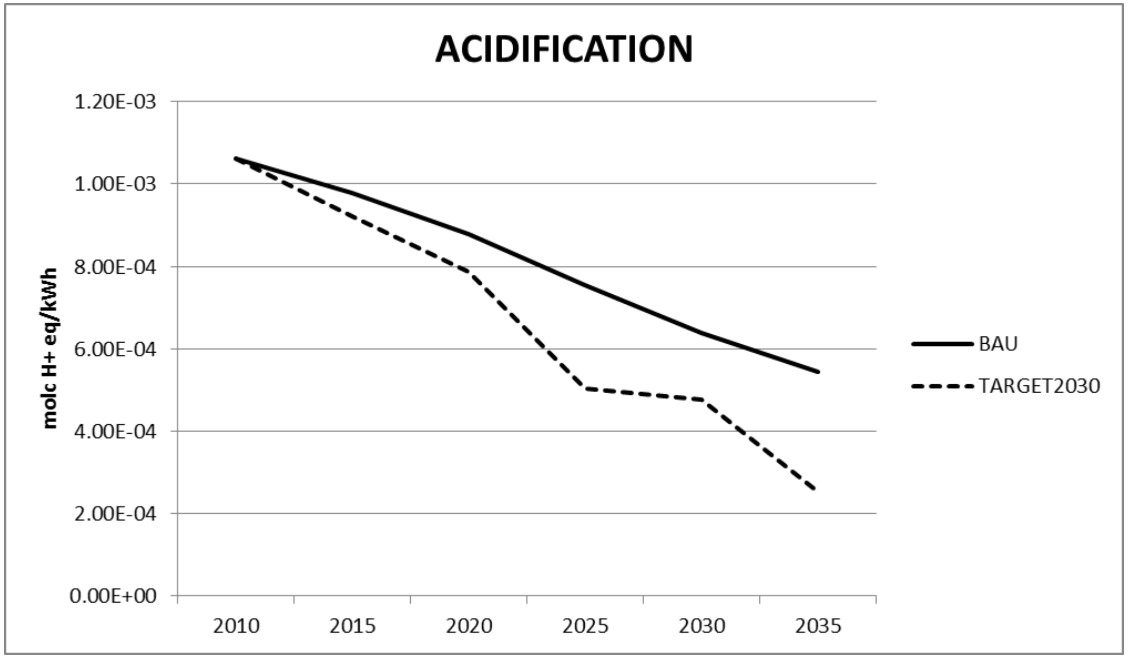
RESULTS
Electricity production





RESULTS
Acidification

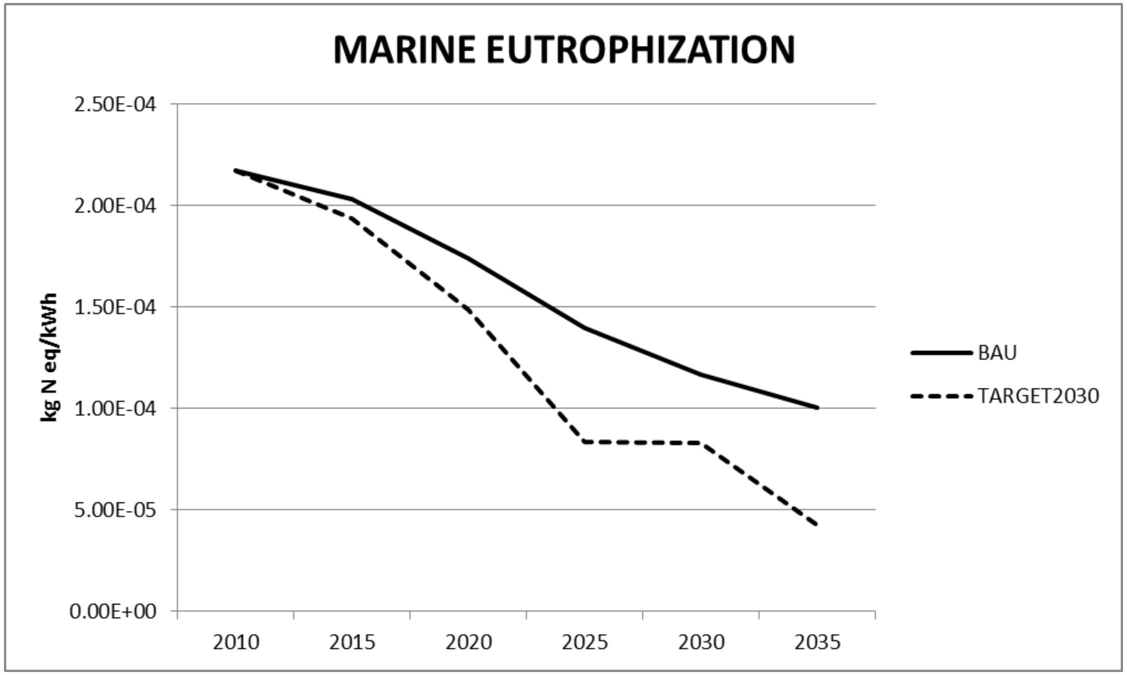
Potential increase in water and soil acidity caused by sulphur and nitrogen oxide emissions



	ACIDIFICATION
	molc H+ eq
BIOGAS	1.31E-03
BIOGAS CHP	3.77E-04
NATURAL GAS CHP	1.70E-03
NATURAL GAS CC CHP	1.19E-03
BIOMASS CHP	9.26E-04
COAL	2.57E-03
LIGNITE	1.57E-03
CSP CURRENT TECH	5.97E-04
CSP FUTURE TECH WITH GAS	6.90E-04
CSP FUTURE TECH WITHOUT GAS	7.08E-05
NATURAL GAS COMBINED CYCLE	9.67E-04
MINIHYDRO	1.74E-05
HYDRO DAM	2.19E-05
NUCLEAR	1.11E-04
WAVES	2.13E-05
OIL	7.46E-03
PV CURRENT TECH MIX	5.73E-04
PV ROOF CURRENT TECH	7.99E-04
PV ROOF FUTURE TECH	2.71E-04
PV PLANT CURRENT TECH	5.43E-04
PV PLANT FUTURE TECH	3.09E-04
WIND CURRENT	1.28E-04
WIND MEDIUM TERM	1.09E-04
WIND FUTURE	1.00E-04
IMPORTS 2015	1.39E-04
IMPORTS 2020	1.42E-04
IMPORTS 2025	1.53E-04
IMPORTS 2030	1.57E-04
IMPORTS 2035	1.57E-04

RESULTS
Marine eutrophication

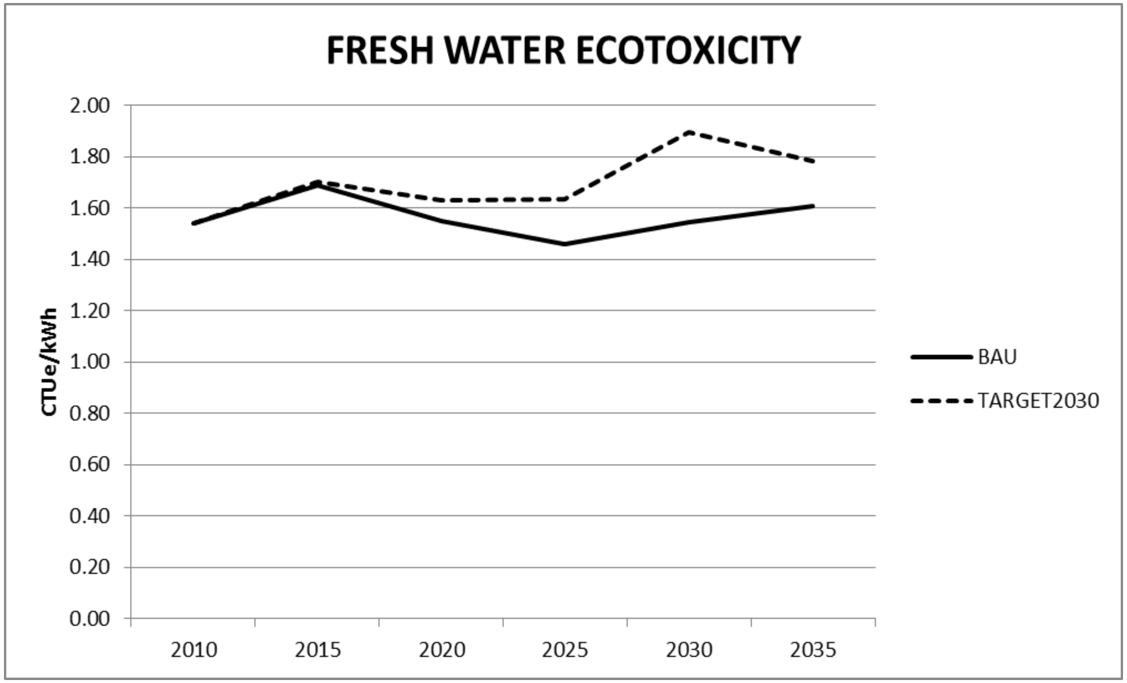
Increased of some limiting nutrients that trigger the growth of algae. As consequence, the light does not reach many other plants affecting to the whole ecosystem. The dead organic matter remains on the bottom of the water body, which decreases the available oxygen



	MARINE EUTROPHICATION
	kg N eq
BIOGAS	2.20E-04
BIOGAS CHP	6.34E-05
NATURAL GAS CHP	2.78E-04
NATURAL GAS CC CHP	1.71E-04
BIOMASS CHP	1.94E-04
COAL	6.30E-04
LIGNITE	9.48E-04
CSP CURRENT TECH	1.03E-04
CSP FUTURE TECH WITH GAS	1.19E-04
CSP FUTURE TECH WITHOUT GAS	1.18E-05
NATURAL GAS COMBINED CYCLE	1.38E-04
MINIHYDRO	5.44E-06
HYDRO DAM	6.45E-06
NUCLEAR	2.13E-05
WAVES	7.84E-06
OIL	1.66E-03
PV CURRENT TECH MIX	8.08E-05
PV ROOF CURRENT TECH	1.08E-04
PV ROOF FUTURE TECH	3.86E-05
PV PLANT CURRENT TECH	7.71E-05
PV PLANT FUTURE TECH	4.16E-05
WIND CURRENT	2.42E-05
WIND MEDIUM TERM	2.05E-05
WIND FUTURE	1.89E-05
IMPORTS 2015	2.75E-05
IMPORTS 2020	2.77E-05
IMPORTS 2025	2.98E-05
IMPORTS 2030	3.02E-05
IMPORTS 2035	3.03E-05

RESULTS
Ecotoxicity of fresh water bodies

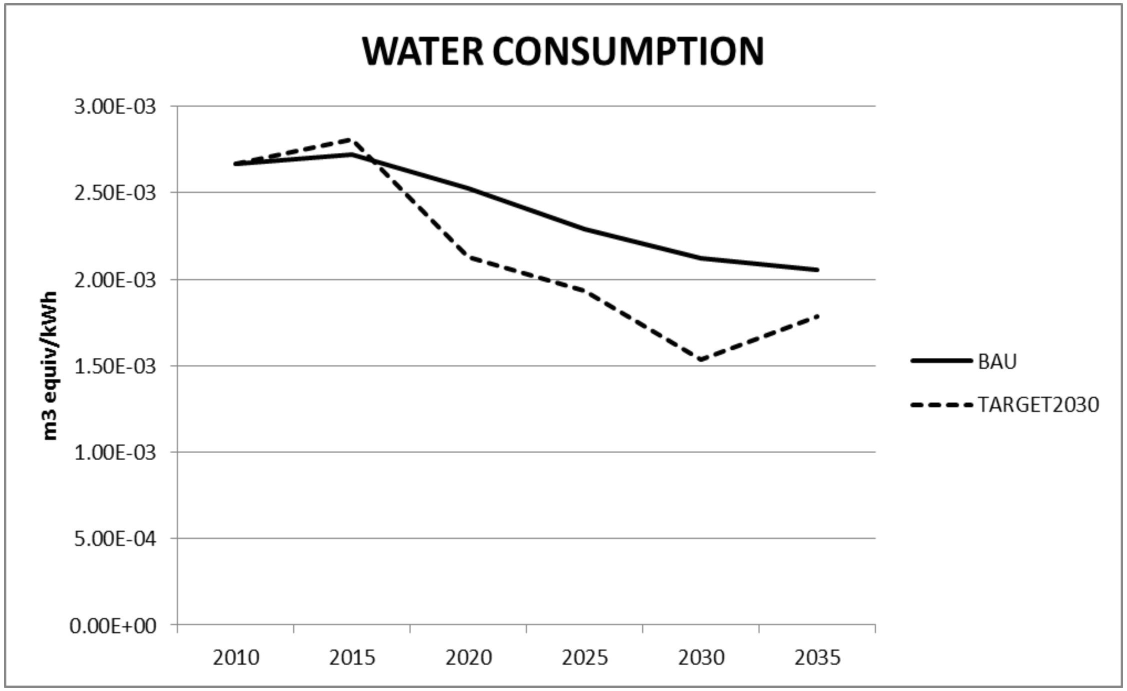
When released to the environment, some polluting substances that reach fresh water have the potential to damage humans or ecosystems.



	FRESH WATER ECOTOXICITY
	CTUe
BIOGAS	1.78E+00
BIOGAS CHP	5.12E-01
NATURAL GAS CHP	6.50E-01
NATURAL GAS CC CHP	3.77E-01
BIOMASS CHP	5.10E-01
COAL	3.42E+00
LIGNITE	1.89E+01
CSP CURRENT TECH	4.28E-01
CSP FUTURE TECH WITH GAS	4.81E-01
CSP FUTURE TECH WITHOUT GAS	9.66E-02
NATURAL GAS COMBINED CYCLE	3.06E-01
MINIHYDRO	2.70E-02
HYDRO DAM	2.99E-02
NUCLEAR	4.32E-01
WAVES	2.08E-03
OIL	6.74E-01
PV CURRENT TECH MIX	4.27E+00
PV ROOF CURRENT TECH	1.09E+01
PV ROOF FUTURE TECH	1.68E+00
PV PLANT CURRENT TECH	3.36E+00
PV PLANT FUTURE TECH	4.58E+00
WIND CURRENT	3.97E+00
WIND MEDIUM TERM	3.37E+00
WIND FUTURE	3.10E+00
IMPORTS 2015	5.76E-01
IMPORTS 2020	8.92E-01
IMPORTS 2025	1.13E+00
IMPORTS 2030	1.26E+00
IMPORTS 2035	1.27E+00

RESULTS
Water consumption

Water consumption in relation to water availability



	WATER CONSUMPTION
	l water eq
BIOGAS	4.08E-01
BIOGAS CHP	1.17E-01
NATURAL GAS CHP	4.75E+00
NATURAL GAS CC CHP	1.57E+00
BIOMASS CHP	3.21E+00
COAL	3.79E+00
LIGNITE	1.11E+01
CSP CURRENT TECH	8.19E+00
CSP FUTURE TECH WITH GAS	3.88E+00
CSP FUTURE TECH WITHOUT GAS	4.93E+00
NATURAL GAS COMBINED CYCLE	1.46E+00
MINIHYDRO	1.07E-02
HYDRO DAM	1.74E-02
NUCLEAR	4.93E+00
WAVES	0.00E+00
OIL	3.51E+00
PV CURRENT TECH MIX	3.17E+00
PV ROOF CURRENT TECH	4.22E+00
PV ROOF FUTURE TECH	1.51E+00
PV PLANT CURRENT TECH	3.02E+00
PV PLANT FUTURE TECH	1.31E+00
WIND CURRENT	1.68E-01
WIND MEDIUM TERM	1.43E-01
WIND FUTURE	1.31E-01
IMPORTS 2015	4.09E+00
IMPORTS 2020	3.68E+00
IMPORTS 2025	3.40E+00
IMPORTS 2030	3.28E+00
IMPORTS 2035	3.28E+00

CONCLUSIONS

Other impacts different than Climate Change should be taken into consideration when analysing energy and electricity systems impacts

Not only operation but all the fuel cycle should be considered in the impact analysis

The reduction in electricity production with coal and the renewable technologies penetration lead to lower acidification and eutrophication impacts

Fresh water ecotoxicity decreases in the first periods to increase from 2025 with the massive penetration of solar PV technologies

Impact on water consumption is also reduced until 2030 when it starts increasing mainly due to CSP penetration

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THANKS FOR YOUR ATTENTION

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Willaarts, B.A; De la Rúa, C; Cabal, H; Garrido, A; Lechon, Y (2016). **El Nexo Agua-Tierra-Energía en España**. Fundación Canal Isabel II. Book (in Spanish) available at:

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