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Short Communication

Life-cycle consequences of internalising socio-environmental externalities of power generation

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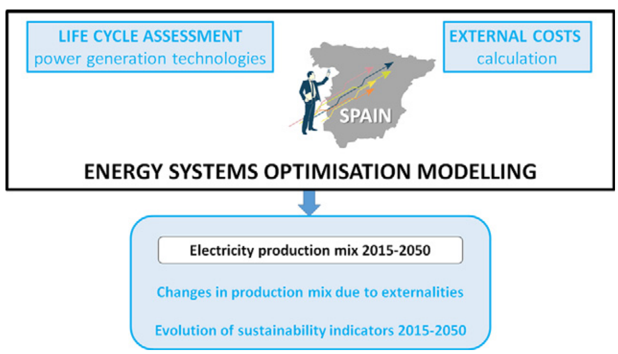
HIGHLIGHTS

- Calculation of external costs of power generation technologies in Spain.
- Integration of externalities and life-cycle indicators into an energy systems model.
- Internalisation of externalities hastens the decarbonisation of the electricity mix.
- Internalisation of externalities effectively leads to a decrease in climate change.
- Internalisation of externalities effectively leads to reduced human health impact.

GRAPHICAL ABSTRACT



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ABSTRACT

Current national energy sectors are generally unsustainable. Within this context, energy policy-makers face the need to move from economy- to sustainability-oriented schemes. Beyond the integration of the sustainability concept into energy policies through the implementation of techno-economic, environmental and/or social restrictions, other approaches propose the use of externalities –based on life-cycle emissions– to deeply take into account sustainability in the design of the future energy system. In this sense, this work evaluates the consequences of internalising socio-environmental externalities associated with power generation. Besides the calculation of external costs of power generation technologies and their implementation in an energy systems optimisation model for Spain, the life-cycle consequences of this internalisation are explored. This involves the prospective analysis of the evolution of the sustainability indicators on which the externalities are founded, i.e. climate change and human health. For the first time, this is done by endogenously integrating the life-cycle indicators into the energy systems optimisation model. The results show that the internalisation of externalities highly influences the evolution of the electricity production mix as well as the corresponding life-cycle profile, hastening the decarbonisation of the power generation system and thus leading to a significant decrease in life-cycle impacts. This effect is observed both when internalising only climate change externalities and when internalising additionally human health external costs.

1. Introduction and motivation

National energy sectors are currently unsustainable in most of the countries. For instance, at the global level, electricity production from fossil fuels still represents around 67% (IEA, 2016). Despite the growing

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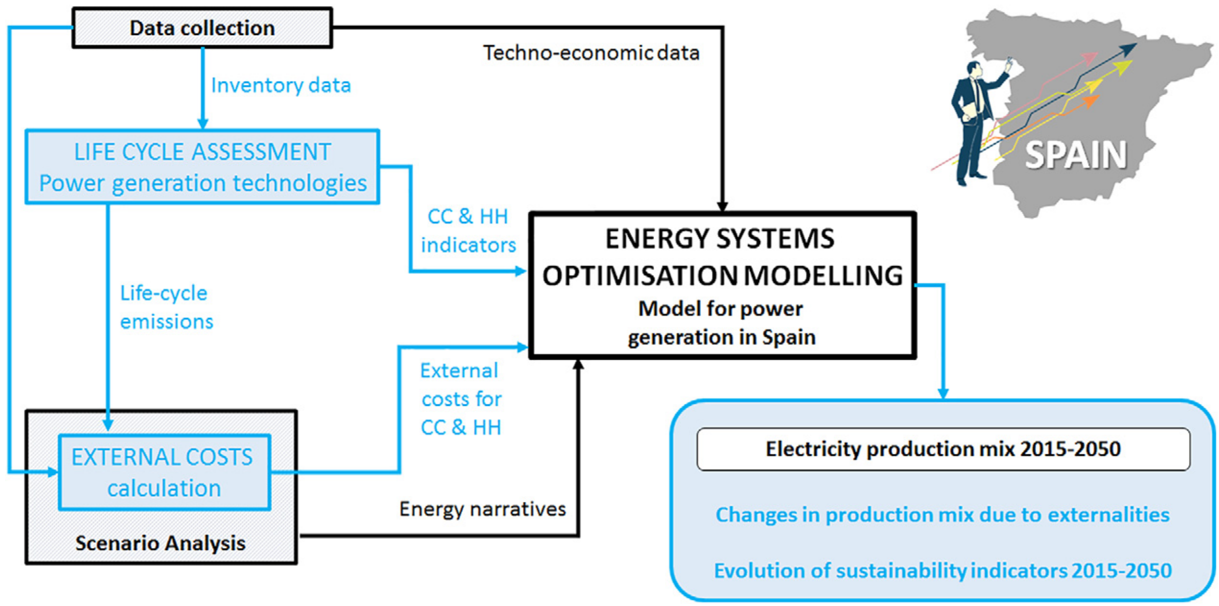

Fig. 1. Methodological approach to enhanced energy systems optimisation modelling through endogenous integration of external costs and life-cycle sustainability indicators. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

role of renewable energy technologies, their emergence rate is low when compared to previous energy transitions (Sovacool, 2016). In this respect, new technologies do not yet arise as the perfect solution for the future, nor are fossil-based power generation technologies a vestige of the past. Within this context, energy policy-makers face the challenging need to move from economy- to sustainability-oriented policies actually responding to societal concerns.

Table 1

Climate change-related external costs of power generation technologies in Spain [BWR: boiling water reactor; NGCC: natural gas combined cycle; PV: photovoltaics; PWR: pressurised water reactor; RoR: run-of-river; SOFC: solid oxide fuel cells].

Power generation technology	External cost due to climate change (€$_{2013}$/MWh)							
	2015	2020	2025	2030	2035	2040	2045	2050
Existing coal thermal	26.7	28.9	32.2	34.4	36.6	49.9	65.5	76.6
Existing NGCC	12.5	13.5	15.1	16.1	17.1	23.4	30.6	35.8
Existing cogeneration	14.1	15.3	17.0	18.2	19.4	26.4	34.6	40.5
Existing oil combustion engine	23.6	25.6	28.5	30.5	32.5	44.2	58.0	67.8
Existing nuclear BWR	0.18	0.19	0.21	0.23	0.24	0.33	0.43	0.51
Existing nuclear PWR	0.18	0.20	0.22	0.24	0.25	0.35	0.45	0.53
Existing hydropower – dam	0.13	0.14	0.16	0.17	0.18	0.24	0.32	0.37
Existing hydropower – RoR	0.09	0.10	0.11	0.12	0.12	0.17	0.22	0.26
Existing wind onshore	0.27	0.29	0.33	0.35	0.37	0.51	0.66	0.78
Existing solar PV	1.14	1.24	1.38	1.48	1.57	2.14	2.81	3.29
Existing biomass power	2.29	2.47	2.73	2.90	3.14	4.26	5.61	6.55
Existing waste-to-energy power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Existing biogas power	2.62	2.84	3.15	3.37	3.60	4.90	6.44	7.53
New NGCC	11.8	12.8	14.2	15.2	16.2	22.1	28.9	33.8
New cogeneration	12.2	13.2	14.7	15.7	16.8	22.9	30.0	35.0
New NGCC with CO_2 capture	6.48	7.02	7.82	8.35	8.91	12.1	15.9	18.6
New wind onshore	0.18	0.20	0.22	0.23	0.25	0.34	0.44	0.52
New wind offshore	0.38	0.42	0.46	0.49	0.53	0.72	0.94	1.10
New solar PV – plant	0.68	0.73	0.82	0.87	0.93	1.27	1.66	1.95
New solar PV – roof	0.55	0.60	0.67	0.71	0.76	1.04	1.36	1.59
New solar thermal (with storage)	1.03	1.12	1.25	1.33	1.42	1.93	2.54	2.97
New solar thermal (without storage)	0.86	0.93	1.04	1.11	1.19	1.62	2.12	2.48
New biomass power	0.09	0.09	0.10	0.10	0.12	0.16	0.21	0.24
New waste-to-energy power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New biogas power	2.01	2.17	2.41	2.56	2.76	3.75	4.93	5.76
New geothermal power	0.10	0.11	0.12	0.13	0.13	0.18	0.24	0.28
New wave power	0.64	0.69	0.77	0.82	0.87	1.19	1.56	1.83
New SOFC	10.3	11.1	12.4	13.3	14.1	19.3	25.3	29.6

Table 2

Human health-related external costs of power generation technologies in Spain [BWR: boiling water reactor; NGCC: natural gas combined cycle; PV: photovoltaics; PWR: pressurised water reactor; RoR: run-of-river; SOFC: solid oxide fuel cells].

Power generation technology	External cost due to human health impact (€$_{2013}$/MWh)							
	2015	2020	2025	2030	2035	2040	2045	2050
Existing coal thermal	68.6	74.7	81.3	88.4	92.2	96.2	100.4	104.7
Existing NGCC	2.01	2.19	2.38	2.59	2.71	2.82	2.95	3.07
Existing cogeneration	5.09	5.54	6.03	6.56	6.84	7.14	7.45	7.77
Existing oil combustion engine	35.6	38.7	42.1	45.8	47.8	49.8	52.0	54.2
Existing nuclear BWR	2.57	2.79	3.04	3.31	3.45	3.60	3.75	3.92
Existing nuclear PWR	2.63	2.87	3.12	3.39	3.54	3.69	3.85	4.02
Existing hydropower – dam	0.41	0.44	0.48	0.52	0.55	0.57	0.60	0.62
Existing hydropower – RoR	0.32	0.35	0.38	0.41	0.43	0.45	0.47	0.49
Existing wind onshore	2.04	2.22	2.42	2.63	2.74	2.86	2.99	3.11
Existing solar PV	3.30	3.59	3.91	4.25	4.44	4.63	4.83	5.04
Existing biomass power	4.49	4.89	5.32	5.79	6.04	6.30	6.57	6.85
Existing waste-to-energy power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Existing biogas power	4.34	4.73	5.14	5.59	5.84	6.09	6.35	6.63
New NGCC	0.93	1.01	1.10	1.19	1.24	1.30	1.35	1.41
New cogeneration	1.73	1.88	2.05	2.23	2.33	2.43	2.53	2.64
New NGCC with CO_2 capture	2.21	2.40	2.61	2.84	2.97	3.09	3.23	3.37
New wind onshore	0.72	0.79	0.86	0.93	0.97	1.01	1.06	1.10
New wind offshore	1.98	2.16	2.35	2.55	2.66	2.78	2.90	3.02
New solar PV – plant	1.54	1.68	1.82	1.99	2.07	2.16	2.25	2.35
New solar PV – roof	1.04	1.13	1.23	1.34	1.40	1.46	1.52	1.58
New solar thermal (with storage)	1.84	2.00	2.17	2.37	2.47	2.58	2.69	2.80
New solar thermal (without storage)	1.27	1.38	1.50	1.63	1.70	1.78	1.86	1.94
New biomass power	2.25	2.45	2.67	2.90	3.03	3.16	3.30	3.44
New waste-to-energy power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New biogas power	4.77	5.18	5.64	6.14	6.40	6.68	6.97	7.27
New geothermal power	0.19	0.21	0.23	0.25	0.26	0.27	0.28	0.29
New wave power	3.76	4.09	4.44	4.84	5.04	5.26	5.49	5.73
New SOFC	3.03	3.30	3.59	3.90	4.07	4.25	4.43	4.62