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An integrated life cycle sustainability assessment of electricity generation in Turkey

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HIGHLIGHTS

- First integrated life cycle sustainability assessment of the electricity sector in Turkey.
- 11 environmental, three economic and six social sustainability indicators estimated.
- Multi-criteria decision analysis carried out to identify most sustainable options.
- Hydro is the most sustainable option for Turkey, followed by geothermal and wind.
- This work demonstrates how tensions among sustainability aspects can be reconciled.

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ABSTRACT

This paper presents for the first time an integrated life cycle sustainability assessment of the electricity sector in Turkey, considering environmental, economic and social aspects. Twenty life cycle sustainability indicators (11 environmental, three economic and six social) are used to evaluate the current electricity options. Geothermal power is the best option for six environmental impacts but it has the highest capital costs. Small reservoir and run-of-river power has the lowest global warming potential while large reservoir is best for the depletion of elements and fossil resources, and acidification. It also has the lowest levelised costs, worker injuries and fatalities but provides the lowest life cycle employment opportunities. Gas power has the lowest capital costs but it provides the lowest direct employment and has the highest levelised costs and ozone layer depletion. Given these trade-offs, a multi-criteria decision analysis has been carried out to identify the most sustainable options assuming different stakeholder preferences. For all the preferences considered, hydropower is the most sustainable option for Turkey, followed by geothermal and wind electricity. This work demonstrates the importance for energy policy of an integrated life cycle sustainability assessment and how tensions between different aspects can be reconciled to identify win-win solutions.

1. Introduction

Sustainable development is becoming increasingly important for many nations. The publication of 'Our Common Future' (WCED, 1987), gave the most widely used definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It is now widely recognised and accepted that sustainable development involves balancing environmental, economic and social issues (Perdan, 2011). Taking a life cycle approach to sustainable development ensures that sustainability aspects are taken into account over the whole life cycle of a system being considered (Perdan, 2011; UNEP/SETAC, 2011). Life cycle sustainability assessment (LCSA) is ideally suited for evaluating the environmental, economic and social sustainability (UNEP/SETAC, 2011). LCSA integrates environmental life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA) to help estimate the level of sustainability of a product, sector or an economy (Guinée et al., 2011; Zamagni et al., 2013).

The electricity sector is important for sustainable development of a region or a country as it affects various environmental, economic and social issues across the supply chain. As indicated in Table 1, these issues have been studied on a life cycle basis for different countries, including Australia, Germany, Mexico, Nigeria, Singapore and the UK. The studies varied with respect to the methodology used for the assessment as well as the electricity technologies and sustainability indicators considered. Life cycle assessment (LCA) has been the most widely used methodology for

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Table 1
Recent studies on life cycle sustainability assessment of electricity technologies in different countries.

Authors	Scope	Country	Technologies considered	Sustainability issues (number)
Hirschberg et al. (2004)	Sustainability of electricity supply technologies	Germany	Coal, oil, natural gas, nuclear, hydro, wind, solar	Economic (7): Financial requirements and resources Environmental (5): Climate change, emissions to air, waste, land use, severe accidents Social (6): Employment, proliferation, human health, local disturbances, risk aversion, critical waste confinement time
May and Brennan (2006)	Sustainability assessment of electricity	Australia	Coal, natural gas	Economic (5): Wealth generation, capital requirements Environmental (12): Climate change, resource depletion, acidification, eutrophication, photochemical smog, human toxicity, ecotoxicity, solid wastes, particulates, water consumption Social (4): Employees, health and safety
Kannan et al. (2007)	Life cycle energy, emissions and costs of power	Singapore	Coal, gas, oil, solar	Economic (3): Total levelised costs Environmental (2): Climate change, energy use
Genoud and Lesourd (2009)	Characterization of sustainable development indicators for various power generation technologies	Not specified	Coal, natural gas, oil, nuclear, hydro, solar, wind, geothermal	Economic (5): Efficiency, renewability, production capacity upon demand, possibility of growth, cost Environmental (10): CO_2, NO_x, SO_2, VOCs, Cd, CH_4 emissions, particles, biochemical oxygen demand, radioactivity, noise pollution Social (6): Notion of public good, land area requirement, energy payback, employment, supply risk, use of local energy resources
Evans et al. (2009)	Assessment of sustainability indicators for renewable energy technologies	Not specified	Solar PV, wind, hydro, geothermal	Techno-economic (3): Levelised costs, efficiency of energy conversion, availability, technical limitations Environmental (3): Climate change, water consumption, land use Social (8): Toxin release, noise, bird strike risk, visual amenity, effect on agriculture and seismic activity, odour, river damage
Gujba et al. (2010)	Sustainability assessment of energy systems	Nigeria	Coal, natural gas, oil, hydro, biomass, solar, wind	Economic (3): Levelised costs, capital costs, total annualised costs Environmental (10): Climate change, ecotoxicity, ozone layer depletion, acidification, eutrophication, photochemical smog, human toxicity, resource depletion
Jeswani et al. (2011)	Assessing options for electricity generation from biomass	UK	Coal, direct-fired biomass, gasified biomass	Environmental (5): Climate change, acidification, eutrophication, photochemical smog, human toxicity Economic (2): Capital costs, total annualised costs
Stamford and Azapagic (2012)	Sustainability assessment of electricity	UK	Nuclear, coal, natural gas, offshore wind, solar	Techno-economic (13): Operability, technological lock-in, immediacy, levelised costs, cost variability, financial incentives Environmental (11): Climate change, recyclability, ecotoxicity, ozone layer depletion, acidification, eutrophication, photochemical smog, land use Social (19): Provision of employment, human health impacts, large accident risk, local community impacts, human rights and corruption, energy security, nuclear proliferation, intergenerational equity
Maxim (2014)	Sustainability assessment of electricity generation technologies	Not specified	Coal, natural gas, piston engine, combined heat and power (CHP), fuel cell, hydro (large and small), wind (onshore and offshore), solar, geothermal, biomass, nuclear	Techno-economic (4): Ability to respond to demand, efficiency, capacity factor, levelised costs Environmental (2): Land use, external costs (environmental) Social (4): External costs (human health), job creation, social acceptability, external supply risk
Santoyo-Castelazo and Azapagic (2014)	Sustainability assessment of electricity	Mexico	Nuclear, coal, natural gas, oil, hydro, geothermal, wind	Economic (3): Levelised costs, capital costs, total annualised costs Environmental (10): Climate change, ecotoxicity, ozone layer depletion, acidification, eutrophication, photochemical smog, human toxicity, resource depletion Social (4): Energy security, public acceptability, health and safety, intergenerational issues