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Life cycle sustainability assessment of electricity generation in Pakistan: Policy regime for a sustainable energy mix

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ABSTRACT

Electricity crisis has become a key issue in Pakistan mainly due to a tenacious and spreading gap between demand and supply. Moreover, the current production is causing severe environmental and energy security issues due to reliance on thermal sources. Stakeholders are hindered to address these issues due to a significant knowledge gap causing discrepancies in power policies. A comprehensive approach over the sustainability dimensions is missing due to non-adoption of life cycle thinking. This study adopts an integrated approach of life cycle sustainability assessment of the electricity sector in Pakistan for proposing policy guidelines and implementation framework to optimize the future energy mixes. In total, 20 sustainability indicators have been assessed covering life cycle of seven electricity generation sources, currently in use. These sources have been ranked by equally weighting the sustainability dimensions and respective indicators. Hydropower is found as the most sustainable option having lowest environmental and economic impacts. While due to worst economic and social impacts, oil is found to be the least sustainable option for the country. While establishing tradeoffs between different electricity generation sources, this study presents an unbiased view and highlights the worth of life cycle approach in sustainability assessment for improving the energy policies.

1. Introduction

Sustainable development (SD) is a dynamic process aimed at balancing the current and future competing needs (Azapagic et al., 2004). It has evolved from environmental and economic domains to embrace the societal, technological, institutional and political necessities of the world (Meyar-Naimi and Vaez-Zadeh, 2013; Štreimikienė et al., 2016). Because of the growing concerns over unsustainable practices, necessary processes and methods have been developed and used to assess, manage and improve sustainability. Since sustainable development has an overarching mandate, one of the widely adopted approaches for achieving it is life cycle thinking which enhances the sustainability in different sectors and industries (Ness et al., 2007). Various life cycle techniques such as Life Cycle Assessment (LCA), Life Cycle Costing (LCC), Social Life Cycle Assessment (S-LCA) and Life Cycle Sustainability Assessment (LCSA) have been developed to cover various dimensions of sustainable development (Rovere La et al., 2010; UNEP, 2012).

Various sectors and industries including manufacturing, infrastructure, construction, urban development, agriculture, mining and mineral extraction, education, and most importantly, electricity production are governed by sustainable development (Aboushady and El-Sawy, 2013; Santoyo-Castelazo and Azapagic, 2014). Energy in the form of electricity production has central importance in the overall growth of a nation along with other industries. A sustainable mean of electricity production can improve economy, quality of life and social wellbeing of a country (Maxim, 2014). With an initial focus on environmental issues, the electricity production is now being studied to enhance economic, social and technological aspects in the developed as well as developing regions. Research on sustainable electricity production varies with respect to many features such as depth of study, technological level, temporal and geographical distribution, and tools used for assessment and integration of different sustainability dimensions (Santoyo-Castelazo and Azapagic, 2014).

Table 1 summarizes a total of 161 indicators that are used in 29 different studies of separate regions throughout the world to study the sustainable electricity production. The reviewed studies, published during years 2002–2017, reflect the accumulated knowledge of last 15 years. The synthesized indicators are grouped into 11 sustainability issues covering the three generalized groups of sustainability; environment, techno-economy and socio-politics. Though there are some indicators that can be placed in more than one sustainability issues,

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Table 1
Sustainability issues and indicators for electricity generation.

Sr No.	Sustainability Issue	Indicators	Country/Region	Reference
Environment				
1	Emission to air, water and soil	GWP; Ozone depletion; Acidification; Eutrophication; Photochemical oxidant creation; Freshwater, Marine and Terrestrial ecotoxicity; NMVOC, Particulate matter and Mercury emissions; Ecotoxicity; Air pollution; Hydrocarbons accidental spills; Emissions of several pollutants; Radioactivity (impact of radon); TOPP; Water quality; Winter smog; Ecological impact of zinc; Smog; Threatened species; Ionizing radiation (Total = 23)	UK, Germany, Australia, Singapore, Austria, Spain, Portugal, Mexico, India, Indonesia, Mauritius, Turkey, US, Poland, Iran and Lithuania	Gagnon et al. (2002); Góralczyk (2003); Hirschberg et al. (2004); May and Brennan (2006); Kannan et al. (2007); Chatzimouratidis and Pilavachi (2009); Evans et al. (2009);
2	Resource consumption	Water consumption; Uranium energy depletion; Exergy destruction; Use of abiotic resources (elements and fossil fuels) (Total = 5)	UK, Germany, Australia, Singapore, Austria, Spain, Portugal, Mexico, India, Indonesia, Mauritius, Turkey, US and Poland	
3	Land use and quality	Land occupation; Change in unprotected ecosystem area; Greenfield land use; Biodiversity; Land contaminations; Percentage effective land use; Urban land occupation; Natural land transformation; Land use competition (Total = 9)	UK, Germany, Spain, India, US and Iran	Genoud and Lesourd (2009); Kowalski et al. (2009)
4	Waste related issues	Recyclability of input materials; Chemical, Hazardous solid, Non-hazard solid and Total waste; Treatment of waste; Critical waste confinement time; Waste repository (Total = 8)	UK, Germany, Australia, Spain and Lithuania	Schenler et al. (2009)
5	Others	Energy payback ratio; Compliance with local natural conditions (Total = 2)	Iran and Lithuania	Albo et al. (2010)
Techno-Economic				
1	Financial	Economic dispatchability; Capital, O & M, Fuel, Annualized, Marginal, Decommissioning, External, and Total levelized costs; Financing risk; Fuel price sensitivity; Financial incentives and assistance; Value added; Capital inclusive value added; Cost benefit index (CBI); Payback period; Profitability index (Total = 17)	UK, Germany, Australia, Singapore, Austria, Mexico, Turkey, US, Iran and Lithuania	Carrera and Mack (2010) Gujba et al. (2010) Rovere et al. (2010)
2	Operability	Capacity and Availability factor; Technical dispatchability; Technological lock-in; Time to plant start-up from start of construction; Flexibility; Availability and technological limitations; Efficiency of energy generations; Renewability; Electrical generation potential; Per capita generation; Equivalent inertia; Auxiliary consumption; Technological competitiveness, Reliability, Innovativeness and Advantage; Durability of technology; Dependency to foreign electrical and Mechanical technology; Maturity in engineering and management activities; Lifetime of global fuel reserves at current extraction rates (Total = 22)	UK, Germany, Austria, US, Iran and Lithuania	Dorini et al. (2011) Stamford and Azapagic (2011) Stamford and Azapagic (2012) Meyar-Naimi and Vaez-Zadeh (2013)
Socio-Political				
1	Employment	Direct, Indirect and Total employment (direct + indirect); Average job income level; Job seasonality; Qualified manpower (Total = 6)	UK, Germany, Australia, Austria, Turkey, US, Mexico, Iran	Garcia et al. (2014) Maxim (2014) Santoyo-Castelazo and Azapagic (2014)
2	Health and safety	Worker fatalities; Human toxicity potential; Worker human health impacts and Total human health impacts from radiation; Fatalities due to large accidents; Mortality; Maximum credible number of fatalities per accident; Worker injuries; Toxin release; Carcinogenic and Non-carcinogenic; Respiratory effects (Total = 12)	UK, Germany, Australia, Spain, Mexico, India, Indonesia, Mauritius, Turkey, US and Iran	Brizmohun et al. (2015)
3	Security and reliability of energy resources	Geo-political factors; Amount of imported fossil fuel potentially avoided; Diversity of fuel supply mix; Fuel storage capabilities; Proliferation; Diversity of technologies; Potential and effects of terrorism; Security and reliability of energy provision; Technology's autonomy (dependence on resource provision); (Total = 10)	UK, Germany, Austria, EU, Mexico, Turkey, Iran and Lithuania	Hanafi and Riman (2015) Klein and Whalley (2015)
4	Political and institutional stability and legitimacy	Fuel autonomy; Percentage of imported inputs; Private participation in total system; Political conflict, participation and stability and legitimacy; Governance; Immunity to terrorism and obstructionism; Compliance with international obligations; Legal regulation of activities; Support of government institutions political organizations; Influence on sustainable development of energy (Total = 12)	Germany, EU, Mexico, Iran and Lithuania	Shah and Unnikrishnan, (2015) Atilgan and Azapagic (2016)
5	Quality of life and local community impact	Proportion of staff hired from local community; Spending on local suppliers; Direct investment in local community; Involvement of countries in the life cycle with known corruption problems; Volume of radioactive waste to be stored; Volume of liquid CO2 to be stored; Noise; Visual amenity; Adaptability; Perceived risk normal operation and Accountability; Landscape; Displacement (of people and animals); River damage; Odor;	UK, Germany, Austria, EU, Mexico, Iran and Lithuania	Li et al. (2016) Štreimikienė et al. (2016) Rodríguez-Serrano et al. (2017)

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