Evaluating the sustainability of future energy mixes

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Summary

For effective mitigation of greenhouse-gas emissions and their ensuing climate disruption, the worldwide consumption of fossil fuels for energy production must be curtailed deeply and urgently. Yet historical evidence shows that energy efficiency typically fails to reduce energy consumption while maintaining economic growth, and large-scale renewable resources, excluding hydroelectric power, are difficult to harness economically at large scales. Moreover, in many East Asian and European countries with large demand and high population densities, there is limited land for energy production. In this thesis I look at the problem of fossil-fuel replacement by nuclear and renewables, focusing on three relevant case studies (South Korea, Japan and Australia). I first calculate the maximum limits of renewable-energy sources in South Korea, revealing that geophysical constraints mean that renewable energy could only supply < 35% of electricity consumption. I then compared the current electricity mix with six alternative scenarios using multi-criteria decision-making analysis (MCDMA); the factors included electricity cost, greenhouse-gas emissions, land transformation, water consumption, heated-water discharge, air pollution, radioactive waste, solid waste and safety issues. The relative MCDMA rank ranges from 0 (most sustainable) and 3 (least sustainable). This evaluation showed that a high-penetration nuclear-power scenario yielded the fewest negative environmental, economic and social impacts for South Korea (score = 0.26 out of 3), whereas maximising renewable energy led to the second-worst impacts (1.81) (Chapter II). I then applied MCDMA with *a priori* socio-economic weightings to evaluate the sustainability impacts of a nuclear-free pathway and three other pathways (15 to ~ 35% nuclear share) proposed by the Japanese government after the Fukushima-Daiichi nuclear meltdowns. Despite some sensitivity to the selected criterion weights, the result confirmed that a nuclear-free pathway for Japan was consistently the worst option to pursue (2.49 out of 3), with the 35% nuclear power scenario yielding the lowest negative impacts score (0.74) (Chapter III). To understand the influence of uncertainty on these metrics, I compared four energy scenarios (a governmental plan, the Greenpeace scenario, and two other nuclear-centred scenarios) using probabilistic simulations based on external costs. This approach supported the conclusion that, despite inherent uncertainty, the nuclear-centred scenarios would yield the lowest total cost per unit of final energy consumption by 2050 (\$14.4 GJ^{-1}), whereas the Greenpeace scenario results in the highest costs (\$25.4 GJ^{-1}). These results imply that large-scale expansion of nuclear power will be the most sustainable pathway for countries with insufficient renewable energy resources, like South Korea and Japan (Chapter IV). I then modelled the optimal future electricity mixes for Australia, a nation that has abundant renewable energy reserves, and does not (yet) permit the development of nuclear energy for electricity generation. Using a 'genetic' optimisation algorithm modified by different socio-politic perspectives, I determined that although a renewables-only pathway might be able to supply Australia's electricity consumption to 2050, the inclusion of nuclear power (at > 40% of total electricity consumption) would yield more optimal economic and environmental benefits (Chapter V). In Chapter VI, I modelled the potential for, and barriers to, a global nuclear-dominated energy system (i.e., > 50% of worldwide final energy consumption). This showed that although some countries do not have appropriate economic, political or technological capacity for high nuclear shares in their electricity generation, nuclear power would reduce total capital investment and result in a lower land-transformation burden than a renewables-only scenario. Finally in Chapter VII, I summarise the approaches and results I developed in the thesis, and I present a pathway for future research in national-scale sustainably energy systems.

Statement of Originality (Thesis Declaration)

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