NATIONAL ENERGY TRANSITION STRATEGIES TO HARNESS LOCAL RENEWABLE ENERGIES BASED ON CRITERION WEIGHTS

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Overview

Recent scientific and novel research on climate change have reported that world leaders have at most twelve years to implement radical policies to safeguard planet earth from the snares of global warming[1][2]. Evidence and facts from reliable historical data shows that the use of fossil fuels as sources of energy are key drivers of the ever-increasing greenhouse gas emissions. Not only are fossil fuels (FFs) environmentally unfriendly, they are also non-renewable and unsustainable. Policymakers are battling with the problem of fulfilling the energy needs of consumers without polluting the environment and a swift switch to use of renewables is practically a feasible option. The dominance of FFs as depicted in trends in historical energy demand for the United States of America (USA) and Canada has left greater quantities of local renewable and sustainable energies in these countries untapped. Based on the strong causal relationships between energy supply and economic growth and development, the use of FFs as key sources of supply suggests that these energies are deeply rooted in the economies of both countries and realistic transition pathways are needed to guage USA and Canada in their quest to a green and sustainable world without disrupting the smooth flow of the economic system. Though a number of climate-saving transition pathways have been proposed, there is little evidence of models that dwell on local renewable energies as key drivers of change. Here, we use criterion weights to propose a basket of national energy transition pathways that focus primarily on the use local renewables for USA and Canada. Contrary to well-adopted subjective criterion weight models, our weighting model is devoid of the subjective judgements of modellers. Further, the model can be implemented for medium-term, long-term and very long-term renewable energy transition pathway modelling; and we also estimate the dollar values of costs, benefits and net present value of each transition path per country.

Methods

We note that the number and volume of renewable energies available to USA and Canada and used in the study varies per countries and include variables such as geothermal, solar, wind and biomass. Though two countries are used we report results for the USA case due to limited space. Medium-term, long-term and very long-term timelines in this study are defined as three-five years, five-ten years and more than ten years respectively[3]. The span of data timeline used also varies per country but generally covers monthly and/or yearly renewable energy supply from 1971 to 2017.

A total renewable energy supply, S, equation is estimated as:

$$S_{jt} = R_{1t} + R_{2t} + \ldots\ldots + R_{kt} \quad (1);$$

where j is country, R is source, and t is time.

Due to unavailability of data for sum renewable energy variables such as solar and wind [for January 1973 to December 1983 in the case of USA], such renewables were summed for various times (t) and represented on quarterly basis [for variables with monthly data]. In order to propose future transition pathways, we learn from historical transitions and leverage on a number of wedges to derive optimal paths. Based on the determinants of supply in equation (1), we estimate the weights of the determinants based on criterion weight models proposed by Saaty[4], Takeda, Cogger and Yu[5], and Cogger and Yu[6]. The eigenvalue of a determinant, herein also referred to as weight, for a particular year t is estimated in a way that:

$$w^{R_{1t}} * S_{jt} = R_{1t} \quad (2); \text{ and}$$

$$w^{R_{1t}} + w^{R_{2t}} + \ldots\ldots + w^{R_{kt}} = 1 \quad (3)$$

In order to reflect a realistic model and real country scenario, we set thresholds for all renewable energies based on proven resources or reserves of all local renewable energies in the two countries considered for this study. Based on the blocks of weights generated from equations (2) and (3), a target or an objective [such as increasing local renewable energy production by say five-fold by 2050 with 2013-2016 as base period] is set for each country and use machine learning algorithms to estimate potential pathways (PPWs) to achieve such targets; and narrow the PPWs to find an optimal path. The optimal transition path is considered as one where the potential discounted benefits outweight the corresponding discounted costs. A basket of factors, including but not limited to, (i) drilling, plant, overhead and transmission, for cost; (ii) subsidies, green environment and expected revenue, for benefits, and (iii)

other wedges [i.e., exogenous variables such as lead time, life time, utilization, anticipated load, available technology, etc.]; were considered in choosing the optimal cost-benefit transition path. We use out-of-sample tests techniques to show how accurate the proposed path is to that of the realized path, and present other efficient paths the country could have used.

Results

With eigenvalues between 0.6727 [minimum] and 0.9814 [maximum] for the 1977-2016 period, the empirical results show that biomass has been contributing more than three-fifths of total non-hydro renewables [i.e., sum of geothermal, solar, wind and biomass] in the past four decades for the USA. Despite such gargantuan share, renewable energy from biomass is loosing and will continue to loose its weight to solar, wind and geothermal sources (SWGs) as technologies to harness these three renewable energies are advancing at astronomical rates. Moreover, the resource capacity and proven reserves of SWGs are vast relative to that from biomass and there has been massive rise in user (i.e., consumers) preference for SWGs. This explains the sharp rise in criterion weights [i.e., increase of ~2-fold ($0.0186 < w < 0.02895$), more than 4-million-fold ($\sim 0.0000001 < w < 0.0530$) and more than 21-million-fold ($0.0000001 < w < 0.24532$) for geothermal, solar and wind respectively] for the four-decade dataset used for the model set. Depending on the base-year period selected, the weight for (i) geothermal could be increased to a maximum of ~2-fold in the medium-term, ~2-fold in the long-term, and ~3-fold in the very long-term; (ii) solar could be increased to a maximum of ~500-fold in the medium-term, ~3892-fold in the long-term, and nearly 2-million-fold in the very long-term; and (iii) wind could be increased to a maximum of ~730-fold in the medium-term, ~1060-fold in the long-term, and nearly 1-million-fold in the very long-term towards total renewable energy supply. Based on the abundant untapped resources of SWGs, favourable renewable energy policies, rising least-cost technologies and continual acceptance and demand from the general public, the optimal transition pathways suggest the USA can more than fulfil her estimated ~109 quadrillion British thermal unit energy demand in 2050 [extracted from Energy Information Administration's Annual Energy Outlook 2018 – AEO2018] with supply from solar, wind and geothermal [arranged from highest to least net discounted benefits]. Thus, the results suggest that the USA is capable of going a 100% renewable national energy mix by 2050 and even export surpluses to neighboring countries.

Conclusions

The world is on a brink of entering into an irrecoverable and unsustainable climate path and a radical shift to a renewable energy-dominated natinal energy mix is key to evading the snares of global warming. Unless well-guided, a sharp shift from fossil fuel-dominated national energy mix to renewables could interrupt the smooth flow of the economic system which may breed unintended consequences. Here, we propose transition pathways based on criterion weights that minimize the costs and maximize the benefits from swithching to renewables and with the core aim of harnessing local renewable energies for USA and Canada. We find that the USA can supply all of her energy demands in 2050 with 100% renewables with priorities [ranked based on least net discounted costs] in solar, wind and geothermal. We also show that depending on the reference year, the priority order path could vary for a given policy time horizon and case country.

References

1. Xu, Y.; Ramanathan, V.; Victor, D. G. Global warming will happen faster than we think. *Nature* **2018**, *564*, 30–32, doi:10.1038/d41586-018-07586-5.
2. Guan, D.; Mahindra, A.; Whiteman, G.; Peters, G. Emissions are still rising: ramp up the cuts. *Nature* **2018**, *564*, 27–30, doi:10.1038/d41586-018-07585-6.
3. Jie, M.; Oppong, A.; Acheampong, K. N.; Abruquah, L. A. Forecasting Renewable Energy Consumption under zero assumptions. *Sustain.* **2018**, *10*, 1–10, doi:10.3390/su10030576.
4. Saaty, R. W. The analytic hierarchy process-what it is and how it is used. *Math. Model.* **1987**, *9*, 161–176, doi:10.1016/0270-0255(87)90473-8.
5. Takeda, E.; Cogger, K. O.; Yu, P. L. Estimating criterion weights using eigenvectors: A comparative study. *Eur. J. Oper. Res.* **1987**, *29*, 360–369, doi:10.1016/0377-2217(87)90249-9.
6. Cogger, K. O.; Yu, P. L. Eigenweight vectors and least-distance approximation for revealed preference in pairwise weight ratios. *J. Optim. Theory Appl.* **1985**, *46*, 483–491, doi:10.1007/BF00939153.