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Solar driven net zero emission electricity supply with negligible carbon cost: Israel as a case study for Sun Belt countries

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A B S T R A C T

A high temporal and spatial resolution energy transition study was performed using a linear optimization based energy system transition model. The study uses Israel's electricity sector dataset, which has important characteristics typical for several Sun Belt countries. It has 7 scenarios aimed at assessing the impacts of various policy factors, such as carbon cost and coupling to the water sector. Under the present renewable electricity technology cost projections, a carbon cost only speeds up the transitions into renewable electricity. However, a No Carbon Cost scenario also achieves comparable results by 2050 (with only 2% fossil). The levelized cost of electricity in 2050 was shown to be less than that of 2015 in all scenarios except under the Current Policy. The Current Policy scenario will significantly increase the cost of electricity in the post-2020 period even when a carbon cost is ignored. The observed emission reduction comes after 2030 but there are still significant emissions by 2050. This shows that Israel's present energy policy carries multiple risks to the nation. Alternatively, Sun Belt countries, such as Israel, can speed the transition of the electricity sector without the need to implement carbon cost, only by promoting solar photovoltaics and supporting batteries.

1. Introduction

Transitioning to a net zero greenhouse gas (GHG) emission energy system by 2100 is the only option to avoid a global temperature increase of 2 °C compared to the preindustrial level. The 2015 United Nations Climate Change Conference, COP21, outcome has produced an agreement to reduce carbon emissions of 196 participating countries [1]. The agreement gives countries the responsibility to set their own nationally determined target. However, even though the target of the Paris Agreement is based on science, the lack of expected ambitious goals in several (Intended) Nationally Determined Commitments ((I)NDC) of countries shows a significant difference with the science based target [2]. According to a study by Rogelj et al. [3], if climate action continues at the same rate of reduction as seen in the present INDC submitted by countries, the temperature will be higher than the target set in the Paris Agreement, which aims for a global temperature increase well below 2 °C, with an effort to limit it to 1.5 °C. It is impossible to achieve the targets of the Paris Agreement without achieving a net zero emission energy system well before the year 2100. As a result, some studies have shown the need for an aggressive investment in Renewable Energy (RE) technology in some countries [4], such as India, China and USA. While others studied the global [5] need to increase RE to meet the aspired target. This requires an improved policy [6]. This paper presents case studies that will clarify the gap in policymaking as well as the associated risk together with the alternative solution.

Currently, researchers and investors see RE as a comparably low risk area, leaving the risk mostly to policy changes of any kind. Consequently, RE technologies are set to continue its remarkable growth. The projected massive PV capacity growth is expected to result in cost reduction [7], which improves its cost competitiveness [8] and the ability to revolutionize the energy system [9]. Agreement on the promising future of PV technology is common even if the magnitude of cost reduction seen at global level [10] differs from the one expected at a particular location on the globe [11]. Possible cost reduction for PV and wind energy [12] as well as batteries [13] are also reported. These are one of the many reasons that improves RE technology competitiveness [14] and world RE perspective [15]. Perspectives on the RE technology role in the future global energy outlook [16] and the levelized cost of its electricity [17] are also improving year to year. Several researchers

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Abbreviations

A-CAES	Adiabatic Compressed Air Energy Storage
CCGT	Combined cycle gas turbine
CSP	Concentrated Solar thermal Power Plant
CHP	Combined heat power plant
DES	Desalination
CO_{2eq}	CO_2-equivalent
COP 21	The 21st Conference of Parties
GT	Gas turbine
GHG	Greenhouse gases
HHB	Hot heat burner
IEC	Israel Electric Corporation
(I)NDC	(intended) nationally determined commitments
LCOE	Levelized cost of electricity
OCGT	Open cycle gas turbine
PHS	pumped hydro storage
PtG	Power-to-Gas
PV	Photovoltaic
RE	Renewable electricity
ST	Steam turbine
TES	Thermal energy storage
UNFCC	United Nations Framework for Climate Change
WS	Water Security

report economic and technical feasibility of 100% RE powered electric systems by mid-century for various parts of the world, e.g. global [18], Finland [19], Northeast Asia [20], Denmark [21], Australia [22], Macedonia [23], Israel [24], Portugal [25], India [26], etcetera. Researchers also reported paths to decarbonized energy systems for all energy sectors with wind-solar-water based energy resources [27], and using broader RE technologies including geothermal and biomass [28]. A survey by REN21 [6] found that several experts agree that by 2050 100% RE system is technically and economically feasible. However, the same survey shows that these experts are pessimistic about its achievement by 2050 due to various reasons [6]. One of the causes of the pessimism is the lack of ambitious policy goals set by countries, as many are taking a cautious step as compared to the required aggressive measures to reduce GHG emissions. However, the study [6] indicated that progress in the past decade suggests that with sufficient political will and proper policy, 100% RE by mid-century is still possible. This may suggest that the bottleneck is mainly social than technical capacity. In order to change the possibility to reality, nations should be provided with evidence that clarify the long-term opportunity of investing in RE technologies. The foregoing discussion shows that RE has the potential to provide cheaper electricity, which has also clearly shown by studies reporting lower levelized cost of electricity by 2050 as compared to the cost in the years preceding it [18]. These studies show that the main driver for the reduction in levelized cost of electricity is the anticipated continual decrease in cost of PV technologies and batteries. Such findings indicate that present policies that does not commit to fast transition may have significant deficiencies and as a result carry some form of risks to the nations, particularly for Sun Belt countries that have good solar resources. Thus, it is important to study various transition policy scenarios in order to identify the gaps and potential policy solutions. Creating a detailed transition path involving various scenarios for a large geographic area covering several countries requires significant resources and time. However, the required policy lessons can be obtained by performing detailed scenario studies of particular country energy system transitions. This research will, therefore, examine policy gaps by modelling and analysing various electricity system transition scenarios by using Israel as a representative for Sun Belt countries. Israel is chosen because it presents a good scenario that is common to several countries. It also provides the opportunity to model the system with better certainty because of the absence of existing or planned electricity trade with neighbouring countries. The three most important reasons that make Israel a good representative for Sun Belt countries are the following:

First, fossil fuel is the central part of Israel's energy politics. According to data from the Central Bureau of Statistics of the government of Israel [29], in the year 2013 over 99% of the annual energy need of Israel was supplied by fossil fuel sources such as coal, natural gas and oil, with the remaining small fraction coming from solar energy in the form of electricity and heat. Until mid-2000s primary energy supply was met by shipped coal and crude oil [30]. However, the recent discovery of offshore natural gas (NG) and its subsequent production from 2004 onwards [30], and a temporary pipeline-import from Egypt (which was started in 2008 and halted in 2012) has reduced its heavy dependence on coal and oil imports. Because of discoveries of even larger gas-fields, the production of NG is expected to increase [30]. Currently, NG is used for 40% of Israel's electricity generation. This share is expected to rise in the coming years based on present policies. In general, Israel's energy system is good representative of other countries relying on fossil fuel. Certainly, due to the use of fossil hydrocarbons for energy production, greenhouse gases as well as other pollutants are released to the environment. Studies show that Israel's GHG emissions by 2030 will be double its 2005 emission level [31] if no reduction effort is made. Israel has started a late effort to reduce its GHG emissions [32]. The nation commits itself to reduce its emissions by 20% below the business as usual by 2020, while finally achieving a 26% reduction of GHG per capita emissions below the 2005 level by 2030 [33]. If this effort is continued, in the long term, Israel should go from the present nearly 100% fossil hydrocarbon based energy economy to a net zero emission economy. This makes its circumstance one of the most demanding transitions to be achieved with slower steps, which presents Israel as a good representative for policies of many countries around the world [2]. This study is by no-means a criticism of the policy path taken by Israel, which is significant as compared to its no consideration policy until 2009. However, when economic projections of renewables show a promising future, it is important to evaluate that the targeted goal really reflects the required ambition.

Second, Israel is an energy island that has reliably self-sufficient energy supply. Electricity generation is entirely domestic with transmission connection only to the Gaza and West Bank regions, to which Israel has energy supply commitments [30]. Due to the geopolitical situation, there is no land-based trade of fossil fuels. Consequently, energy security is a conspicuous agenda. However, with a self-sufficient energy system typical of several countries on small-geographic region, it serves as a good candidate to analyse the energy transition policy gap of several other countries in greater detail. This is because it presents the best opportunity to perform high spatial and temporal resolution modelling of the power grid in transition models.

Third, Israel has excellent solar resources that is typical for many Sun Belt countries [34]. As a small and densely populated country that has an expanding population and economy, Israel faces pressing challenges from land and water scarcity. Arid zones cover about 45% of the country [33]. Consequently, water stress may