Economic Analysis of Clean Energy Options for Kuwait

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Abstract

An economic assessment was performed of the potential for clean energy options to contribute to the power and desalination needs in the State of Kuwait over the next 20 to 40 years. The paper summarizes two analyses that were performed for the Kuwait Institute for Scientific Research to develop a strategy promoting renewable energy and evaluating alternative technologies including nuclear energy.

The analyses were performed using a power and water model for Kuwait that was constructed using the International Energy Agency - Energy Technology Systems Analysis Programme (IEA-ETSAP) TIMES modeling framework. Data provided by the Ministry of Electricity and Water (MEW) and the Kuwait Petroleum Company (KPC) characterizes the projected demand for power and water; the existing and planned power generation and water desalination plants, including the expected retirement of existing plants; and future fossil fuel prices and availability. New power generation options – including renewable energy (RE), nuclear, combined cycle gas turbines (CCGT) and reheat steam power plants (RHSPP) – were compared in this least-cost optimization framework.

The model results indicate that by 2030 the cost-effective RE share is 11% of electricity generation in the Reference case and 8% the case with the nuclear option. The RE technologies alone provide a 2030 net-back value compared to the Reference case of US$2.35 billion, while in the nuclear case they increase the 2030 net-back value by an additional US$1.5 billion. Increasing the RE share, as a government policy, to 10%, 15% and 20%, decreases the 2030 netback benefit by US$1.0, $3.6 and $8.3 billion respectively.

Sensitivity runs based on scenarios that assume higher RE costs or lower availability, lower demand growth, lower oil and gas prices, higher nuclear plant investment costs, and RE capacity credit were analyzed. The analysis provides a compelling economic basis for initiating a renewable energy program in the State of Kuwait. However, these forecasted benefits will only materialize to the extent the projected RE investments are achieved if they begin in earnest soon.

The analysis identifies a cost-effective share of renwable energy use in Kuwait as about 11% of electricity generation in 2030. The investment in renewable energy provides the State of Kuwait with a net-back value of US$2.35 billion, due to the fuel savings that is generated by using renewables.

1. Introduction

In Kuwait, the daily consumption per capita of electric power is 14,000 kWh, and of desalinated water is 600 L. These are among the highest in the world, and the total consumption of each has almost doubled every 10 years (Darwish and Darwish, 2008). While 10% of the energy produced in Kuwait was being consumed locally in 1980, this percentage increased to 20% in 2005 and is expected to reach 40% by 2015 (Alotaibi, 2011).

Several studies have been observed in the related scientific literature on the evaluation and promotion of clean energy technologies targeted to the GCC countries (Flamos, 2012, Flamos et al., 2012). A-Hamid and Hamdy (2003) deal with the economics of off-shore and on-shore wind energy systems in Qatar, while Al-Badi et. al. (2009) assess the renewable energy resources potential in Oman and identify the barriers to their significant utilization. Al-Karaghouli et. al. (2009) study the solar and wind opportunities for water desalination in the Arab regions while Alnatheer (2005, 2006) evaluates the potential contribution of renewable energy to electricity supply in Saudi Arabia and assesses the environmental benefits of energy efficiency and renewable energy in the country's electric sector. Doukas et. al (2006) and Patlitzianas & Flamos (2012) have investigated renewable energy sources and the rationale use of energy development in the countries of GCC. Collaboration and knowledge transfer from EU countries is considered of great importance for the smooth integration of clean energy technologies in GCC countries. In this framework, Flamos et. al. (2010) describe the role of the EU-GCC Clean Energy Network that has been established to promote smooth cooperation between the EU and the GCC key energy players for the challenging objective to engage GCC countries in a more sustainable development path. More specifically, Alotaibi (2011) assesses the energy situation in Kuwait and its historical, current, and future conditions with a focus on the power plant sector, which is the major consumer of energy in the country. The author makes an attempt to briefly describe the most realistic and efficient electricity production solutions available and to discuss other alternative resources such as nuclear, solar, and wind energy. Al-Nassar et. al. (2005) have investigated the potential wind power generation in the State of Kuwait while Darwish (2001) discusses and clarifies the annual reports published by the Ministry of Electricity and Water of Kuwait, showing the efforts made to satisfy the continuous increasing demands of power and desalted water, status of the operating plants, projects under construction, and future planning. The author further introduces a method to allocate fuel energy consumption between desalinated water and electric power production and discusses future forecasting for power and water needs, turbine unit size choice, and how to reduce power and desalinated water consumption. To a similar direction Darwish and Darwish (2008) propose several conservation methods to reduce water consumption and its related energy consumption. Establishing energy conservation programs among different sectors as well as more efficient forms of energy would restrict the accelerated depletion of Kuwait's conventional fuel resources. In this framework, this paper summarizes the main results of 2 studies performed for the Kuwait Institute for Scientific Research to develop a strategy for evaluating and promoting clean energy technologies including renewables and nuclear energy.

The first study presented in this paper (Lightbridge Corporation, 2010) evaluated the economic feasibility of developing and deploying a civil nuclear power program as one element of a strategy to meet future electricity generation and fresh water needs over the coming decades while the second (Lightbridge Corporation, 2011) evaluated the economic feasibility of renewable energy (RE) to contribute to the power and desalination needs of the country.   Both studies were performed using a detailed, bottom-up power and water model for Kuwait that was constructed using the International Energy Agency - Energy Technology Systems Analysis Programme (IEA-ETSAP) TIMES modeling framework.[1] Data provided by the Ministry of Electricity and Water (MEW) and the Kuwait Petroleum Company (KPC) characterizes the projected demand for power and water; the existing and planned power generation and water desalination plants on the system, including the expected retirement of existing plants; and future fossil fuel prices and availability. New power generation options, including renewables, nuclear, reheat steam power plants and combined cycle gas turbines, were compared in a least-cost optimization model of the Kuwait power and water system that is described in Section 2. The technology cost and performance parameters used in the study are described in section 3, and Section 4 summarizes the study design. Section 5 contains a discussion of the key economic results of the study, and Section 6 provides conclusions.

2. Model Description

A TIMES model of the Kuwait electricity generation and water desalination system was developed with the data and support from MEW and KPC. In particular, reports and spreadsheet analyses performed at MEW (Wood, 2009a; Wood, 2009b) were an important reference and source of data. The model was named the Kuwait Power and Water (KPW) model. A simplified Reference Energy System (RES) diagram for the KPW model is shown in Figure 1, and a full description of the KPW model can be found in (Lightbridge Corporation, 2011).

The TIMES KPW model minimizes the total cost of the energy system over the planning horizon while meeting the specified demand for electricity and fresh water. All cost elements are appropriately discounted to a selected year, and for each year of the planning horizon, the total energy system cost is comprised of:

- Capital costs incurred building and/or dismantling power plants;
- Fixed and variable annual operating and maintenance (O&M) costs associated with each power plant, and other annual costs occurring during the construction and dismantling of power plants;
- Costs incurred for domestic resources and imports consumed for the production of electricity and/or clean water;
- Revenues from exports (at assumed prices);
- Delivery costs where appropriate; and
- Taxes and subsidies (where applicable) associated with commodity flows and process activities or investments.

Electricity and water are provided for sixteen (16) time slices that represent subdivisions of the year over four (4) seasons and four (4) apportionments of the day that allow the model to properly capture the shape of the demand, especially peak requirements.

[1] TIMES is an integrated energy system least-cost optimization model. See http://www.iea-etsap.org/web/index.asp.

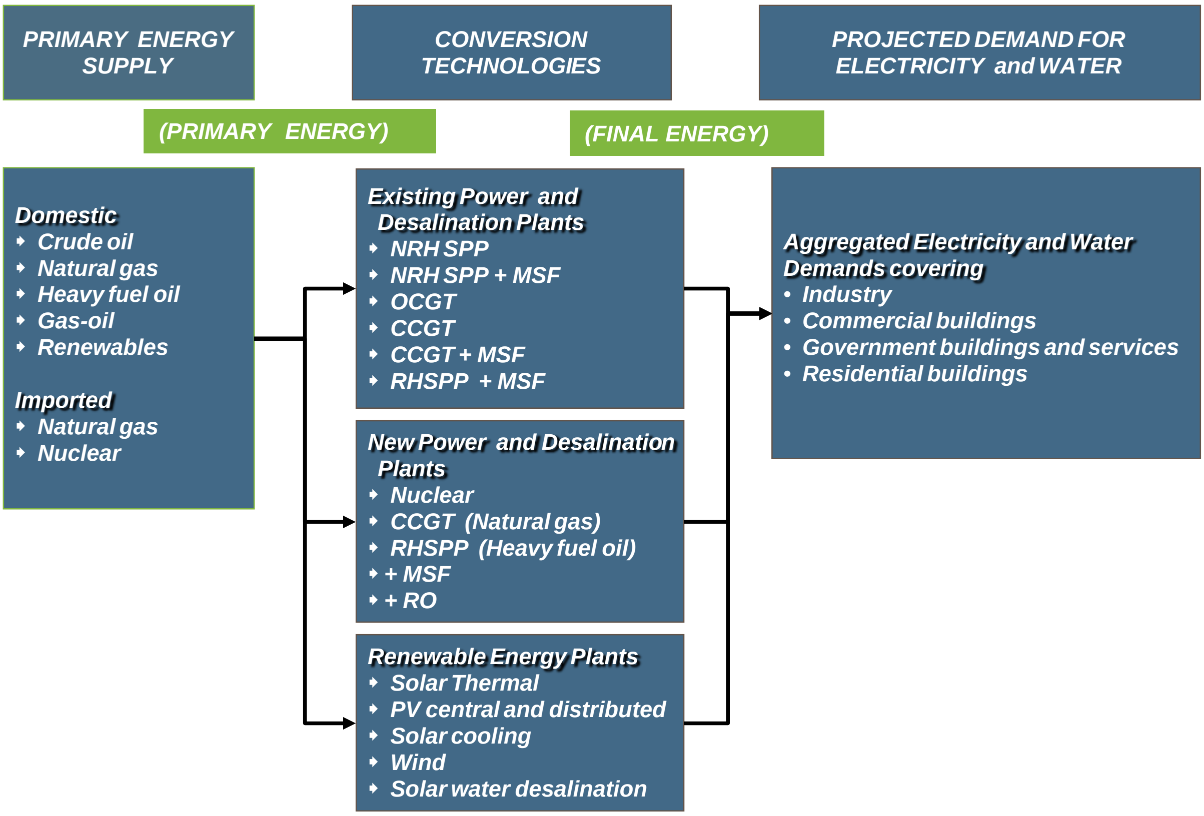

Figure 1: Simplified RES of the Kuwait Power and Water Model

3. Technology Data Assumptions

The RE technologies highlighted in this study consist of wind, solar PV and concentrating solar thermal power options. The cost and performance characterizations used in this analysis were developed through a combination of literature review (DOE-EIA, 2010; IEA/NEA, 2010) and consultations by KISR with RE technology experts and the modeling team. The most important RE technology parameters are summarized in Table 1 and the complete set of RE technology characteristics is provided in (Lightbridge Corporation, 2011).

The investment cost ("Inv. Cost") columns show the overnight capital costs in 2008 US$'s for 2015 and 2030[2]. The decrease in investment cost from 2015 to 2030 is due to the anticipated technology learning driven by projections of anticipated global installed capacity. The cost reduction is thus an exogenous input and is fixed for all the modeled scenarios. The "O&M" column shows the fixed operations and maintenance costs in 2008 US$ also for 2015 and 2030. The reduction is also from anticipated technology learning. The "Annual Availability" column shows the capacity factor [electricity generation/(installed capacity x hours in a year)]. The "Capacity Credit" column shows the percentage of the installed capacity (MW) that is counted as firm and can be expected to contribute to the system demand during peaking. The "Start Year" shows the earliest year the technology can be expected to come online in Kuwait. The "Inv. Limit" column shows the maximum build rate or new capacity upper limit in MW per annum for each technology for 2015 and 2030. The last column shows the cumulative limit on total installed capacity for Kuwait.

[2] In all cases, values for years between 2015 and 2030 are linearly interpolated.

The cost and performance parameters for new Gen III nuclear power plants were developed based on a comprehensive literature review (DOE-EIA, 2010; IEA/NEA, 2010; Wood, 2009a, Keystone, 2007; Lazard, 2009; MIT, 2009; NEI, 2009; NEA, 2009; Schneider, 2009; UBS, 2009; WNA, 2010)and are shown in Table 2. For the nuclear plants, the investment cost also includes the cost of establishing a Nuclear Energy Program Implementation Office (NEPIO), a nuclear regulatory framework, decommissioning and other institutional support capacity. The nuclear operating and maintenance costs also include the annual cost of regulatory fees.

The cost and performance parameters for a new Reheat Steam Power Plant (RHSPP), Combined Cycle Gas Turbine (CCGT), Multi-Stage Flash (MSF) and Reverse Osmosis (RO) technologies were developed from Kuwait sources (Wood, 2009b).

4. Study Definition and Resulting Energy Sector Configuration

The starting point for this study is a Reference scenario, which represents a least-cost evolution of the Kuwait power and water system without nuclear power or renewables. Next, a Nuclear scenario was developed which allows nuclear power plants to be built from 2020 onwards. Then both the Reference and the Nuclear scenarios were run with the addition of the RE technologies to the portfolio of future power plant options to see what is the cost-effective share of renewables under each situation.

4.1 Key Assumptions

The key assumptions defining the Reference scenario include the following. The electricity and water demand projection used are the “MEW Reference” projections, which are considered a medium growth scenario. The evolution of oil and gas prices follows the KPC “Reference” assumptions for 2010, and the availability of domestic natural gas for energy production follows the “KPC maintenance” assumptions, which correspond to a maximum production of 2.7 billion standard cubic feet per day (BSCFD). The discount rate for conventional technologies is set to 7.5%, and no nuclear plants are permitted to be built. An annual maximum build rate of 30 Million Imperial Gallons (MIG) was imposed for RO desalination plants, and no air pollution constraints or CO_2 taxes are imposed. Finally, a minimum utilization constraint was placed on fossil plants to better represent the dispatch priorities of MEW. The levels are 60% for existing plants, 50% for new plants, and 10% for peaking plants.

Table 1: Renewable Energy Technology Parameters

Technology	Inv. Cost 2015 $/kW	Inv. Cost 2030 $/kW	O&M 2015-2030 $/kW/yr.	Annual Avail. %	Capacity Credit %	Start Year	Inv. Limit 2015-2030 MW/yr.	Cumulative Upper Limit MW
Tower w storage	5,044	3,783	73 – 44	37%	50%	2015	50-200	NA
Trough	3,929	3,056	58 – 44	23%	20%	2015	100-300	NA
Trough w storage	7,639	5,941	323 – 251	37%	50%	2015	100-300	NA
Trough hybrid	4,273	3,487	249 – 194	23%	100%	2015	100-300	NA
Fresnel	3,570	2,677	58 – 44	23%	20%	2015	50-200	NA
Fresnel w storage	7,280	5,563	58- 44	37%	50%	2015	50-200	NA
Fresnel hybrid	3,950	3,147	58 – 44	23%	100%	2015	50-200	NA
Stirling engine	4,656	3,492	58 – 44	23%	20%	2015	100-300	NA
PV centralized	2,178	1,188	15 -6	17%	20%	2012	100-300	1558
PV rooftop (commercial & residential)	3,713	1,485	17 – 10	17%	20%	2012	60-300	3115
Wind (onshore)	1,601	1,358	61 – 30	28%	20%	2012	100-300	NA

Table 2: Characteristics of New Nuclear and Conventional Power Plant Options

Power Plant Name	Plant Type	PV Investment Cost ($/kW)	Fixed O&M Cost ($/kW-yr.)	Fuel plus O&M Cost ($/GJ)	Variable O&M ($/TIG)	Efficiency	Start	Lifetime
Generic CCGT	CCGT	1100	34.0			0.55	2015	25
Generic CCGT/MSF	CCGT/MSF	1400	34.0			0.39	2011	25
Generic-RHS	RHSPP/MSF	2350	14.8			0.32	2019	40
Generic-GT	OCGT	750	40.0			0.34	2019	25
Generic-RO	RO	8666[3]			0.68	8.70[4]	2015	25
Generic-NUC	Nuclear	5246[5]		6.43		0.327	2020	50

[3] The unit for investment cost of Reverse-Osmosis plants is in $ per thousand Imperial Gallons (TIG) per day.

[4] The efficiency for RO plants is expressed in TIG per GJ.

[5] This includes IDC at the reference discount rate of 7.5% and 7-year construction period and 2-year pre-construction period, regulatory set-up costs, and discounted decommissioning costs for a 2-unit 2800 MW plant.

4.2 Reference Scenario

The resulting Reference scenario includes the following: Initial new electricity-generation and water-desalination capacity growth comes from planned CCGT/MSF plants. Long-term growth is met by the combination of CCGT and RO plants. Crude oil use for power generation is phased out and replaced by imported LNG starting in 2016, which reaches about 580 BSCF per year in 2030. Sulfur dioxide and particulate emissions are largely unchanged, but CO_2 emissions almost double by 2030, and annual energy system expenditures reach US$24 billion by 2030.

4.3 Nuclear Scenario

The primary difference between the Nuclear and the Reference scenarios is that it allows nuclear plants to be built from 2020 onwards at a rate of up to 1.4 GW per annum, and it imposes a maximum limit of 50% share of electricity generation from nuclear.

The primary results of the Nuclear scenario include the following. Nuclear replaces CCGT capacity and reaches 9.8 GW in 2030 to become the dominant base-load technology. CCGT plants provide mostly intermediate generation, while the development of desalination capacity is similar to that in the Reference case. Natural gas imports peak at 270 BSCF per year in 2020 and decline to less than 140 BSCF per year in 2030 as more nuclear deploys. Gas imports in 2030 are one quarter of the level in the Reference scenario. Annual energy system expenditures are just over US$20 billion in 2030, compared to US$24 billion in the Reference case, so annual savings in 2030 are approximately $4 billion. Air pollutants decline to 60% of 2008 values because of a decline in heavy fuel oil use, with the CO_2 emissions peaking in 2020 at 60 million tons per year before declining to below 2008 levels by 2030. The cumulative savings (net-back value) between 2020 and 2030 is US$21.4 billion, and the cumulative net-back value grows to US$105.6 billion by 2050, which would continue for the remaining thirty years of life for the nuclear plants.

4.4 Adding Renewables

Both the Reference and the Nuclear scenarios were run with the addition of the RE technologies to the portfolio of future power plant options to determine the cost-effective share of renewables. The main RE Policy scenarios are described in Table 3 and consisted of a mandatory target in 2030 for RE generation as a percentage of total electricity generation. Three RE Target levels were examined: 10%, 15% and 20% of total generation by 2030 (ramping up from 2015).

In doing the preliminary RE policy runs, the minimum utilization constraint that was placed on fossil plants (60% Existing, 50% New, and 10% Peaking) was found to be overly constraining the system. Because the fossil technologies were already operating at their minimum level due to the introduction of nuclear, the RE technologies had no choice but to force out the nuclear plants to achieve the higher policy targets. To allow the model to better explore the optimal configuration of the Kuwait power and water system containing both nuclear and RE technologies, the minimum utilization constraint for the existing and new plants was relaxed to 20%. These runs have the suffix _ff (for flexible fossil operation) appended to their name.

Table 3: Policy Scenario Definitions

Scenario Name	Scenario Description

Ref_RE	Reference with RE technologies
Nuc_RE	Nuclear with RE technologies
Ref_RE_10, 15 or 20	Reference with 10%, 15% or 20% RE target in 2030
Nuc_RE_10, 15 or 20	Nuclear with 10%, 15% or 20% RE target in 2030
<root>_ff	Flexible fossil operation

5. Economic Analysis Results

The KPW model provides a wide variety of output results, but those summarized in this paper describe the evolution in capacity on the Kuwait power and water sector, and the net-back value. The net-back value is calculated as the reduction in energy-system cost components between any alternative scenario and the Reference case. The components of the total energy system cost include the annualized investment recovery costs, the annual fuel costs, and the annual operating and maintenance costs. The annualized investment-recovery cost is the annual cost for debt repayment and return on equity. The difference in these annualized costs is the most accurate way to calculate the net-back value. A positive netback, means that annualized oil/gas revenues minus annualized costs of the power/water system is higher in the alternative case (e.g. Nuclear or RE) compared to the Reference case, which means that the alternative case has economic benefits for Kuwait. The bigger the netback; the larger the economic benefits.

5.1 Cost-effective RE implementation

Within the study, several quantitative data have been mapped showing the effects on different procedures (Electricity Production, Installed Capacity, etc.) and scenarios (Reference, Ref_RE, Nuclear, Nu_RE) of introducing RE technologies. Figure 2 shows the impact of introducing RE technologies into the generation mix in both the Reference and Nuclear cases. The cost-effective RE uptake in 2030 is 11% of total generation in the Reference case and 7.5% of total generation in the Nuclear case.

Figure 3 shows the amount of RE capacity as a share of total generating capacity reaches 22% in the Reference case and 16% in the Nuclear case by 2030. Note that in the RE cases the total installed capacity reaches about 35 GW compared to about 30 GW in the non-RE cases due to intermittent nature and lower availability of the RE technologies.

Figure 4 shows the impact of taking into account the “capacity credit” or contribution of the RE technologies to the peak demand. This “firm” capacity of RE technologies is considerably less than installed capacity, and the total system “firm” capacity returns to the 30 GW level.

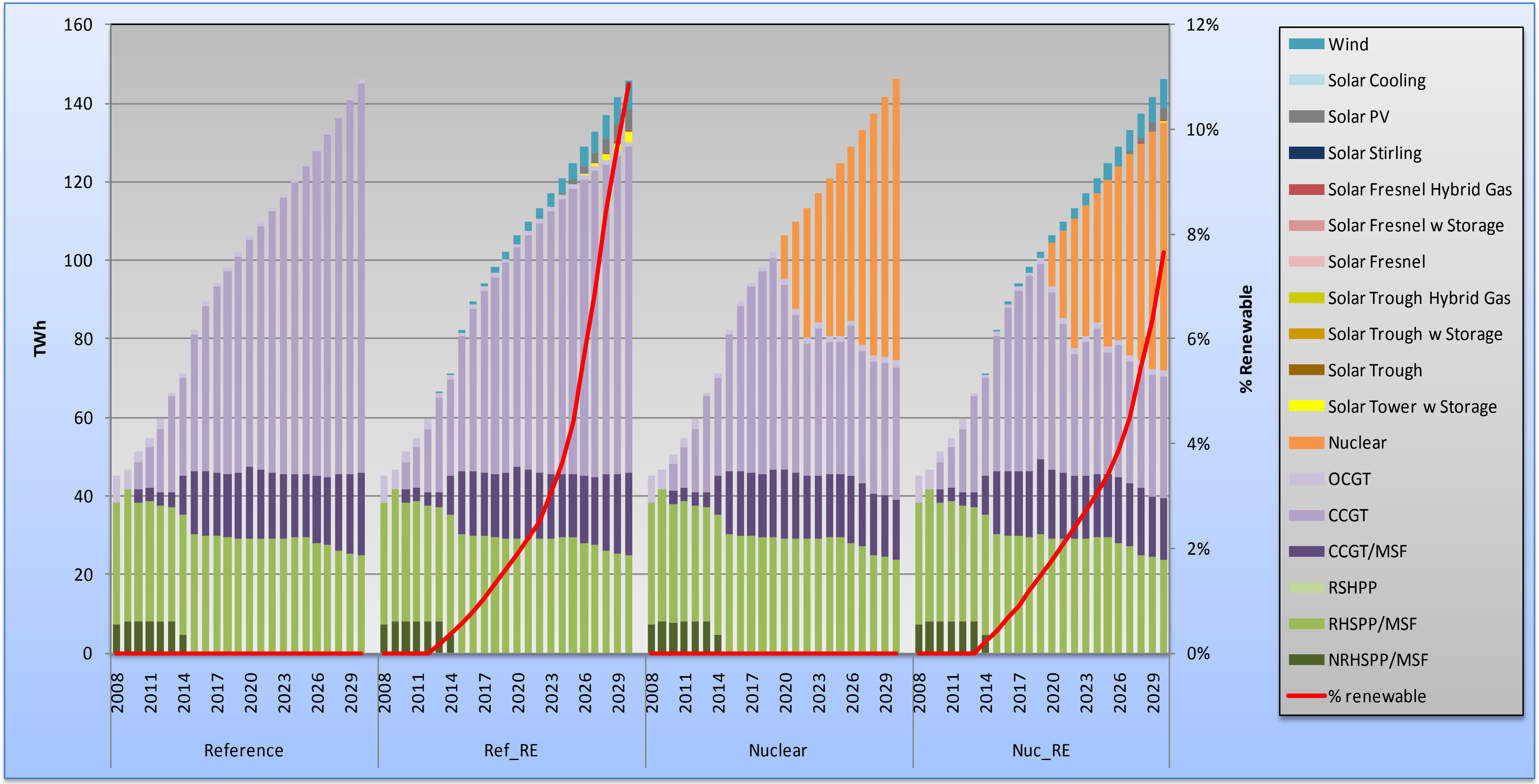

Figure 2: Introduction of RE Technologies to Reference and Nuclear Case: *Electricity Production*

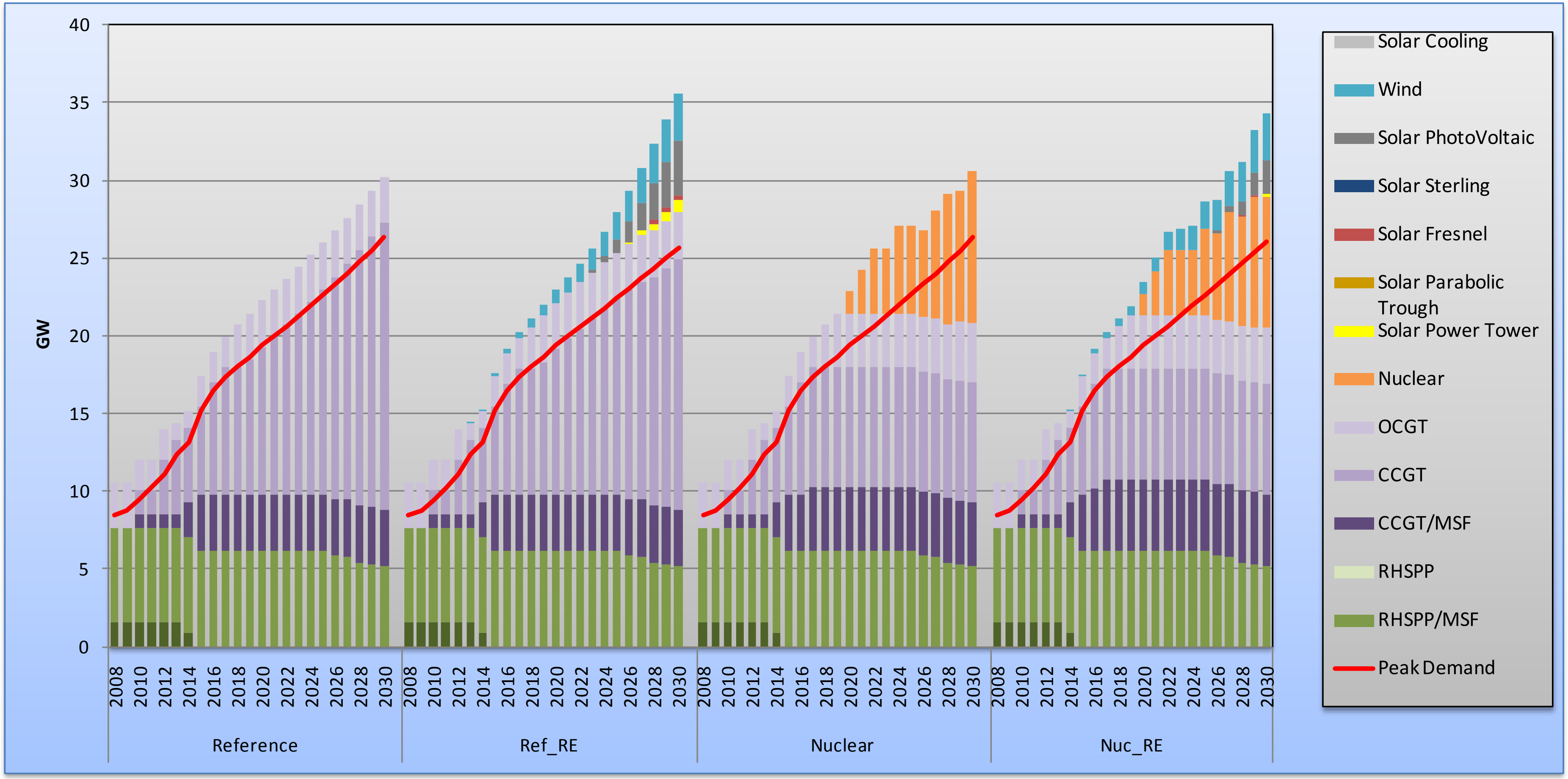

Figure 3: Introduction of RE Technologies to Reference Case and Nuclear Case: *Installed Capacity*

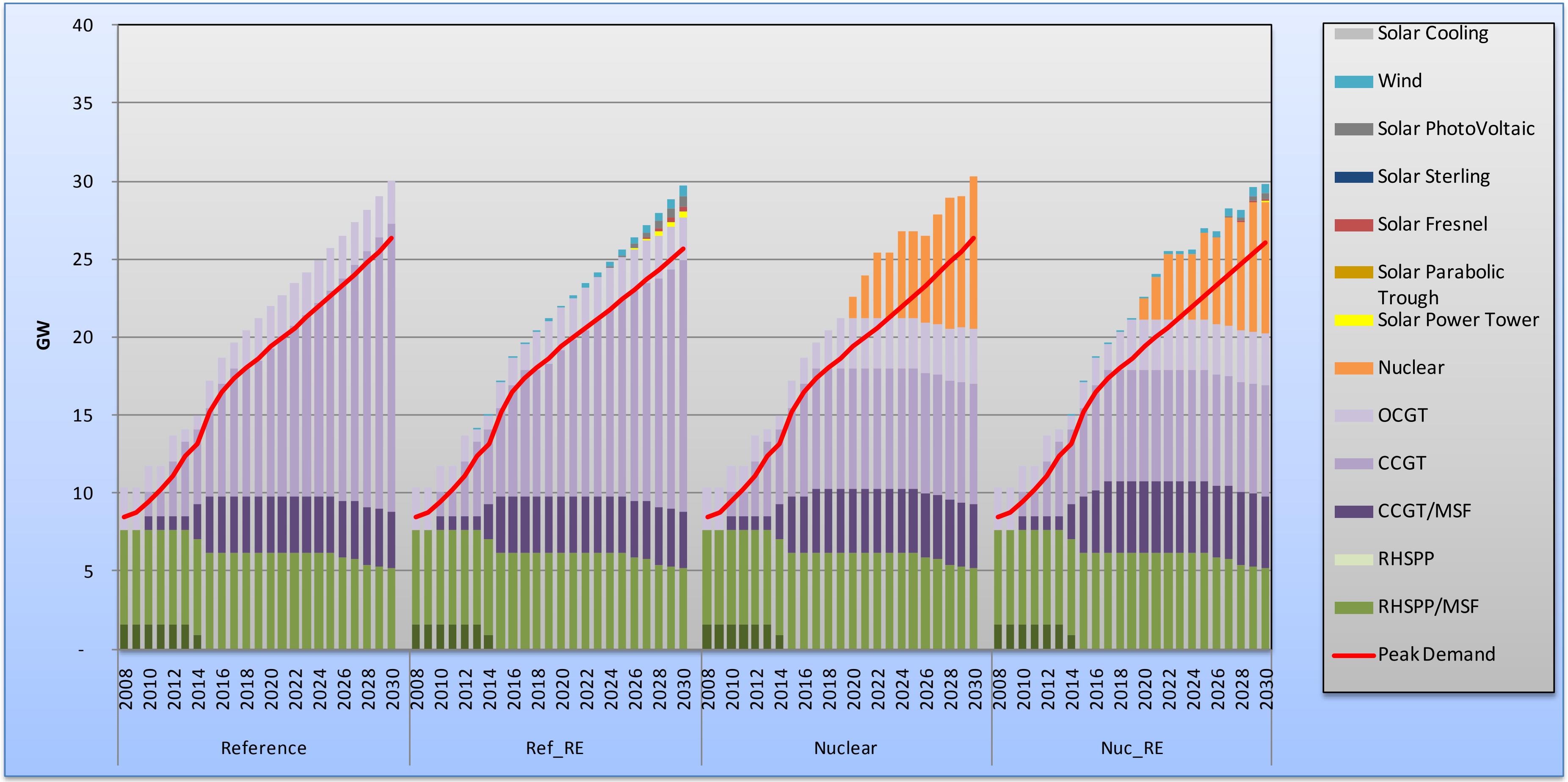

Figure 4: Introduction of RE Technologies to Reference Case and Nuclear Case: *Firm Capacity*

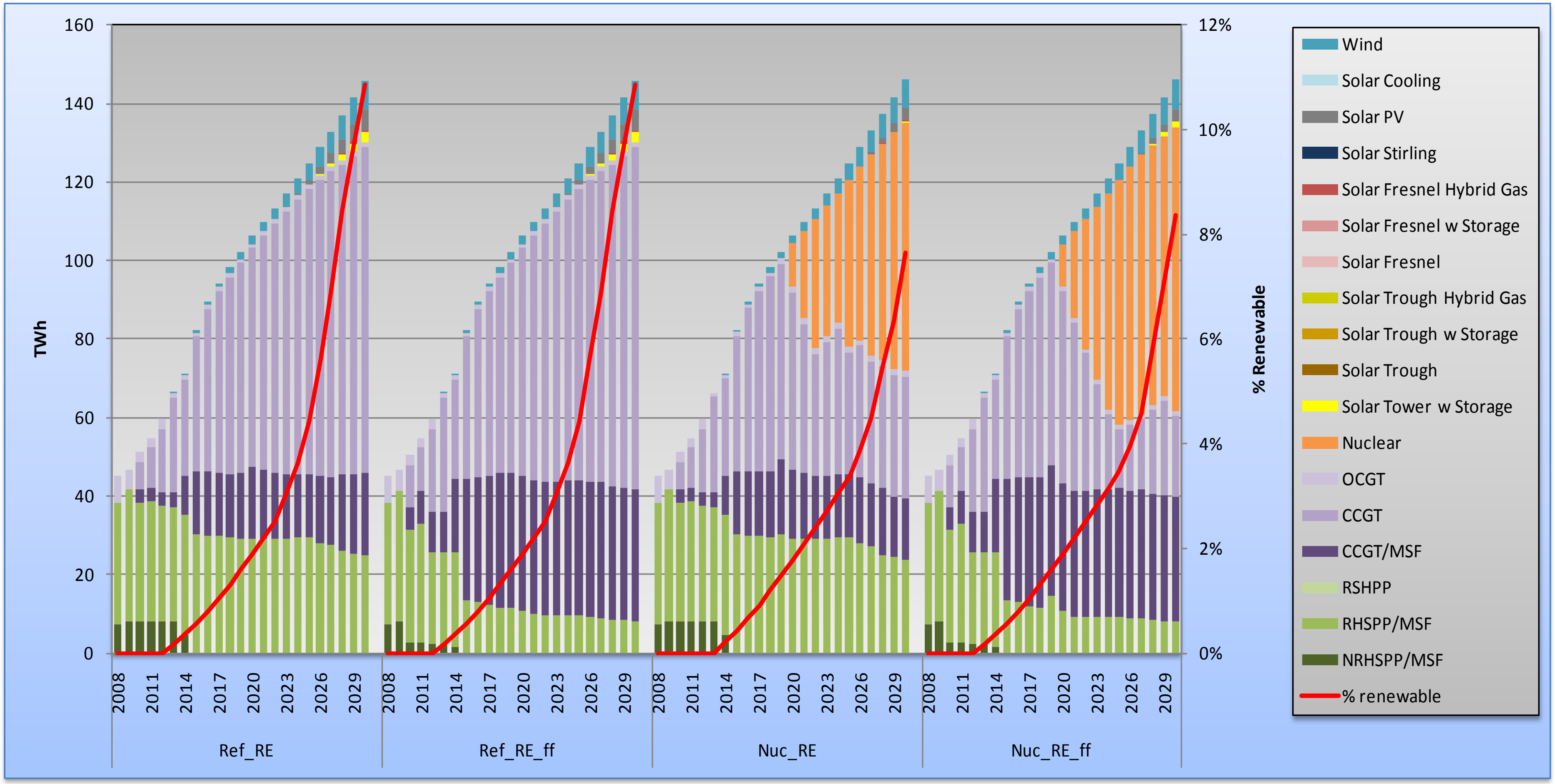

Figure 5: Electricity Generation with Relaxed Operation Constraints on Fossil Plants

5.2 Relaxation of Operation Constraints on Fossil Plants

Within the study, the relaxation of several operation constraints of fossil plants has been observed. Figure 5 shows the impact of relaxing the minimum utilization constraint on the existing and new fossil power plants. In the Reference case, the RHSPP/MSF plants are replaced by CCGT/MSF and there is a very slight increase in the RE share. However, in the Nuclear case, in addition to the RHSPP/MSF plants being replaced by CCGT/MSF, both the Nuclear and RE technologies replace some CCGT plants, and the cost-effective RE share of electricity generation increases from 7% to 8%.

Figure 6 shows the impact of these scenarios on the system netback value. More relaxed operation of the fossil plants results in a US$12.9 billion increase in the 2030 netback value in the Reference case due to the reduction in heavy fuel oil based generation. In the Nuclear case with more relaxed operation of fossil plants, the netback value increases by US$3.6 billion relative to the base Nuclear case (US$25 billion minus US$21.4 billion). Adding the RE Technologies to the Nuclear case further increases the 2030 netback value by another US$1.5 billion (to US$26.56 billion total). Clearly these results point to a need to review the role of these older, less efficient, fossil-based generating facilities.

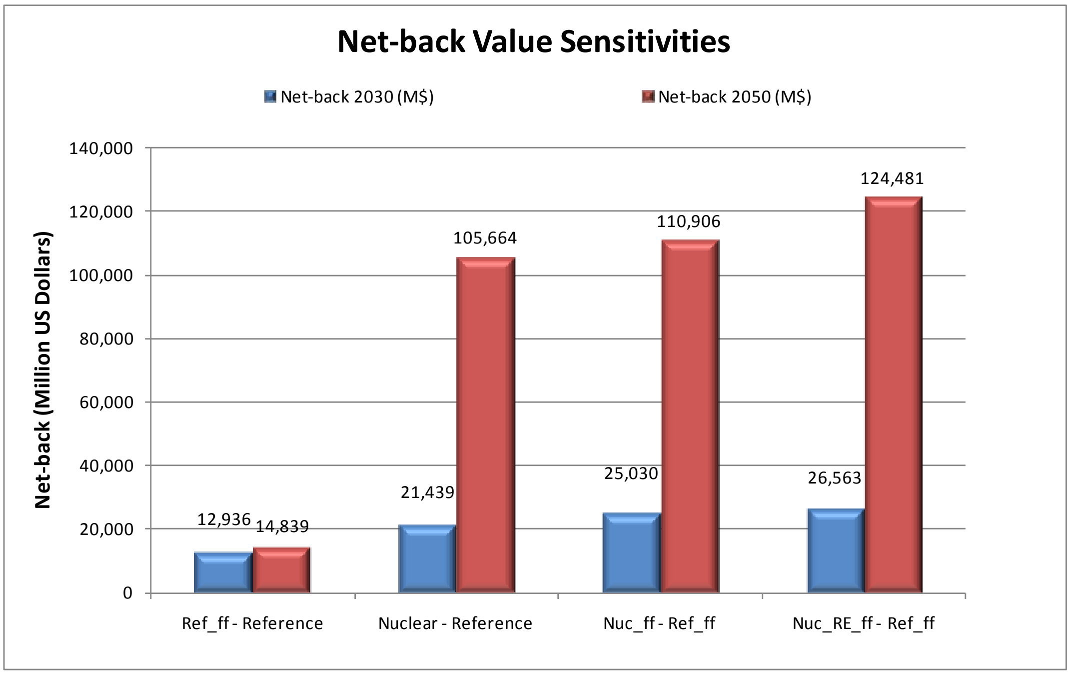

Figure 6 Net-back Value Comparisons for relaxed fossil fuel operation

5.3 Renewable Electricity Generation Target Scenarios

A range of RE target scenarios were examined to quantify the costs and benefits of policies that might impose RE targets, and to identify the most cost-effective mix of RE technologies for Kuwait under such policy targets. Three 2030 RE target levels were tested, namely a 10%, 15% and 20% with and without nuclear. The RE target scenarios were constructed by imposing a lower constraint on the share of electricity from RE technologies, ramping up from zero in 2015 to the target value in 2030. The target was set on the share of electricity generated upstream of the transmission and distribution grid. Distributed technologies (e.g. Rooftop PV and solar cooling devices) were given extra credit to account for the lower transmission and distribution losses, and for gas co-fired hybrid technologies, only the solar electricity is given credit towards the RE target.

Figure 7 shows that the increased RE power generation displaces mostly CCGT plant output.

Figure 8 shows that to achieve the higher RE generation targets, the system needs to add more intermittent RE capacity. For the base and 10% RE target cases, 6 nuclear units are to be installed by 2030, but for the 15% and 20% RE target cases, only 5 nuclear units are to be built by 2030.

Analysis of the breakdown of the RE technologies shows that each RE technology has a different maximum build rate limit, and as these limits are reached the next most cost effective technology comes into the mix. In the cost-effective RE scenario (Nuc_RE_ff) the predominant RE technology is wind. At the 10% target, in addition to the wind there is a higher penetration of PV and Solar Tower technologies. At 15% there is some penetration by Fresnel technologies, and at 20% there is some penetration of Solar Trough technology.

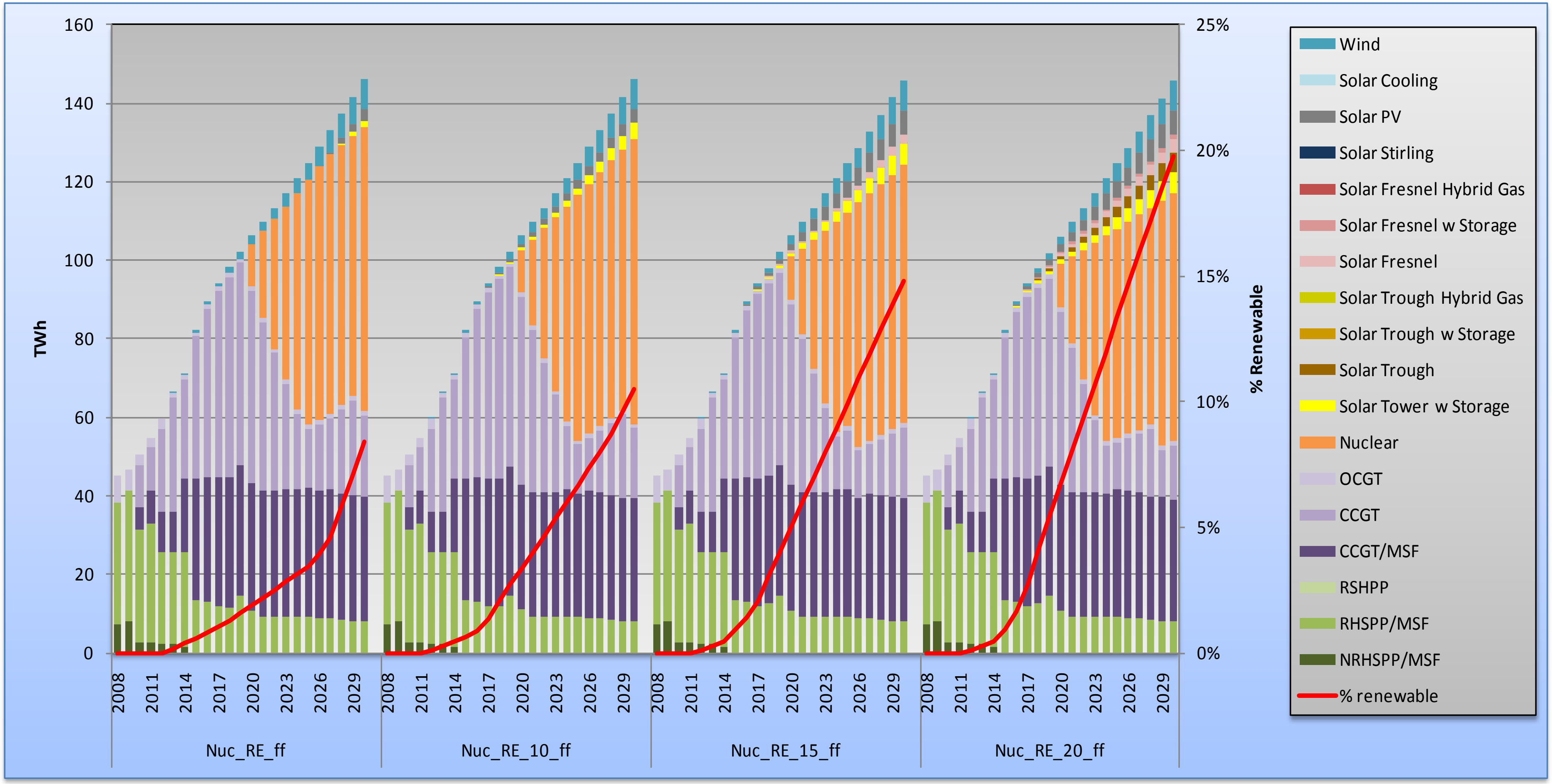

Figure 7: RE Targets of 10%, 15% and 20% of Electricity Production by 2030 with Nuclear

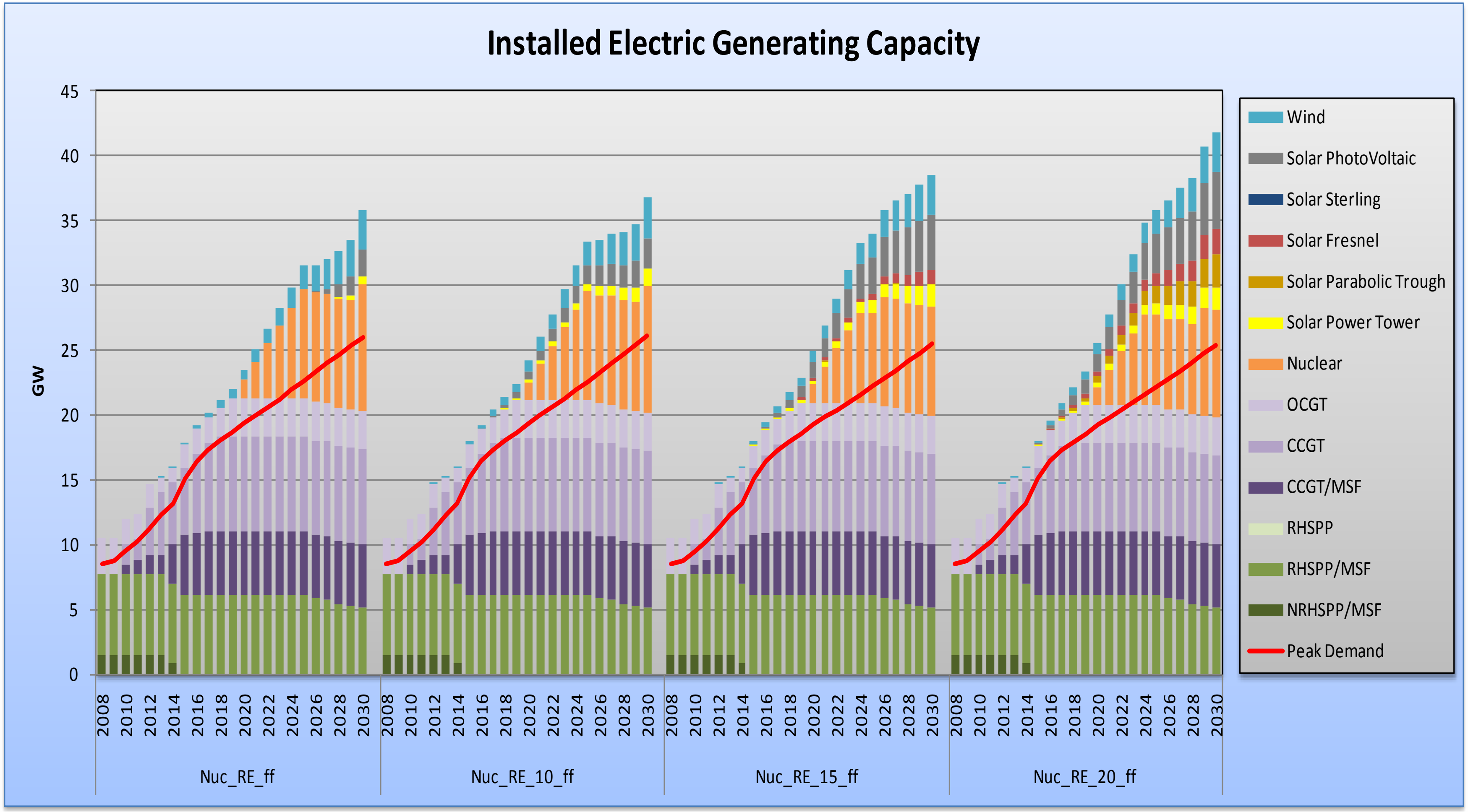

Figure 8: Installed Capacity for the Three Target Levels

6. Netback Comparison

Another observation worth mentioning concerns Netback Comparison. Figure 9 shows what happens to the netback value as the various RE targets are imposed. Increasing the RE share from 8% in the "Nuc_RE_ff" case to 10%, 15% and 20%, decreases the 2030 netback benefit by US$1.0, 3.6 and 8.3 billion, respectively. This represents the economic loss arising from turning to the more expensive generation alternatives, though the incentives needed to grow a strong RE industrial base in Kuwait are not included. Therefore, these costs should be compared to the non-energy system benefits that an indigenous RE industrial base might bring to Kuwait.

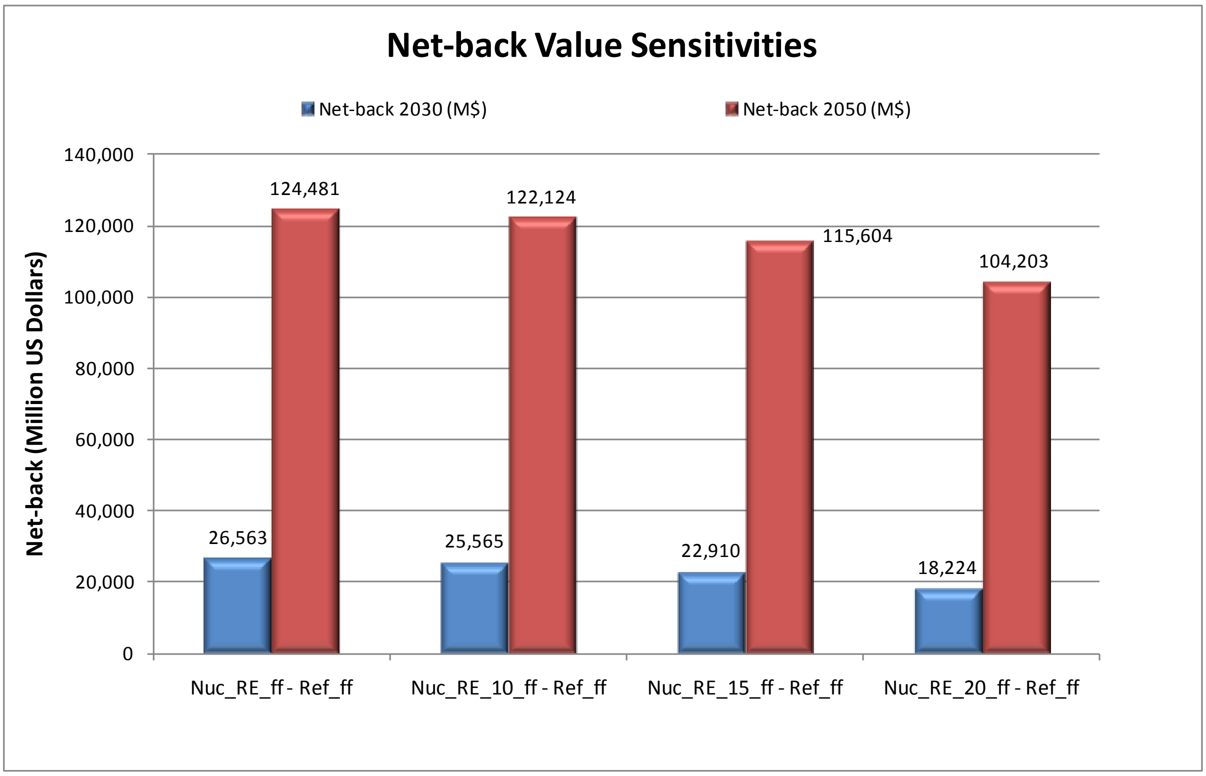

Figure 9: Netback on RE Target Cases: The Cost of Having RE Targets

Figure 10 shows the different electricity generation mix obtained in the Reference case with relaxed operation of fossil plants without RE technologies, with only cost-effective RE technologies and with a 20% RE target. The latter case is then compared to the 20% RE target in the Nuclear case with relaxed operation of fossil plants. The comparison at 20% shows that there is not a significant difference in the RE mix with and without nuclear in the system. Without nuclear, there is some additional solar gas hybrid penetration because of its dispatchability and higher capacity factor.

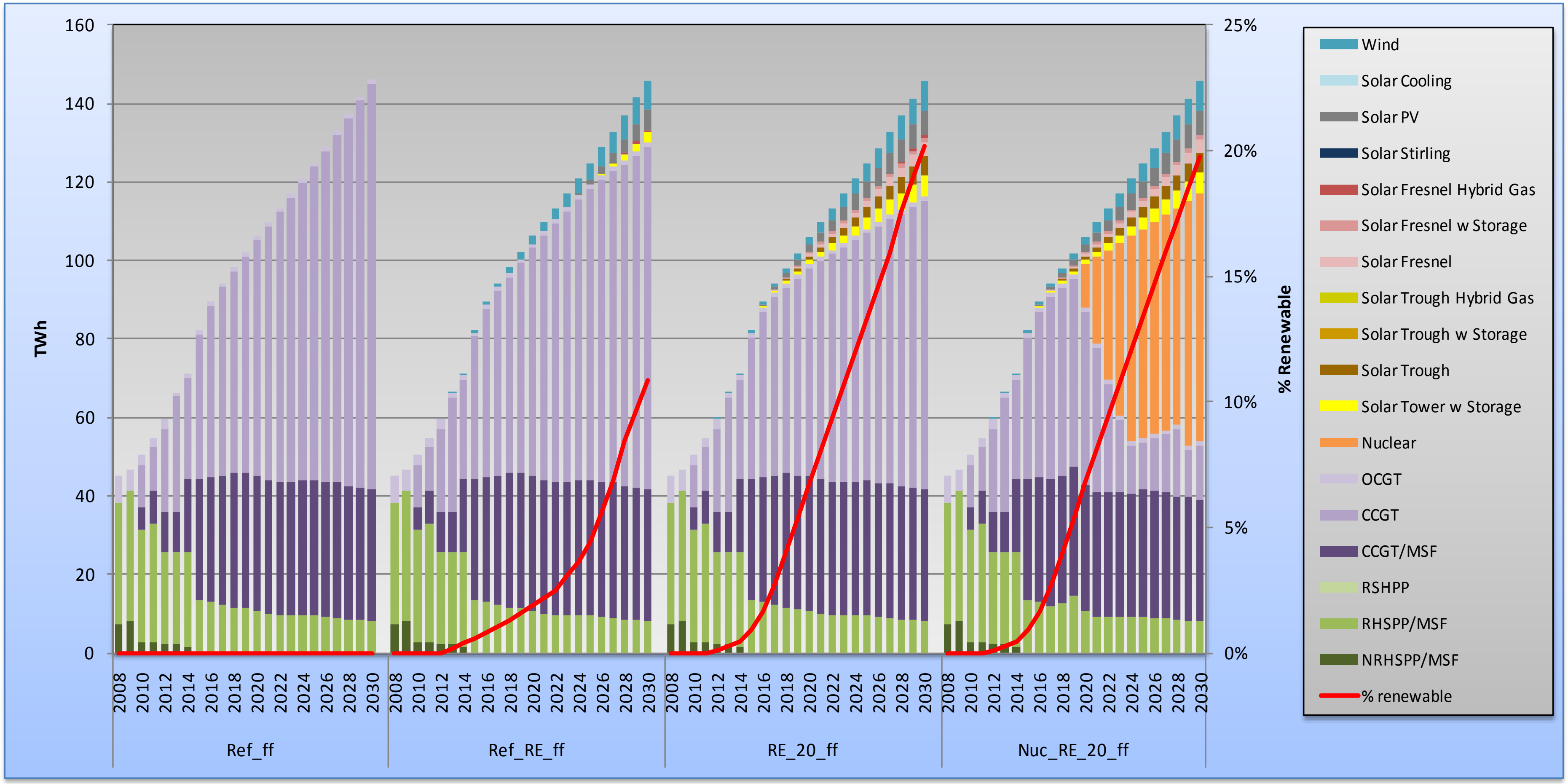

Figure 10: Electricity Production without and with nuclear for 20% RE Target by 2030

Figure 11 shows that adding RE technologies to the *Ref_ff* case increases the 2030 netback value by US$2.35 billion, while increasing the RE share to the 20% target (*Ref_20_ff* case) decreases the 2030 netback value by US$2.5 billion because the RE technologies displace some of the slightly more cost-effective CCGT plants. Furthermore, in the Nuclear case, the 20% RE target decreases the 2030 net-back by US$8.3 billion because the RE technologies have to displace some of the cost-effective nuclear electricity as the fossil plants are already turned down to their 20% minimum operating constraint.

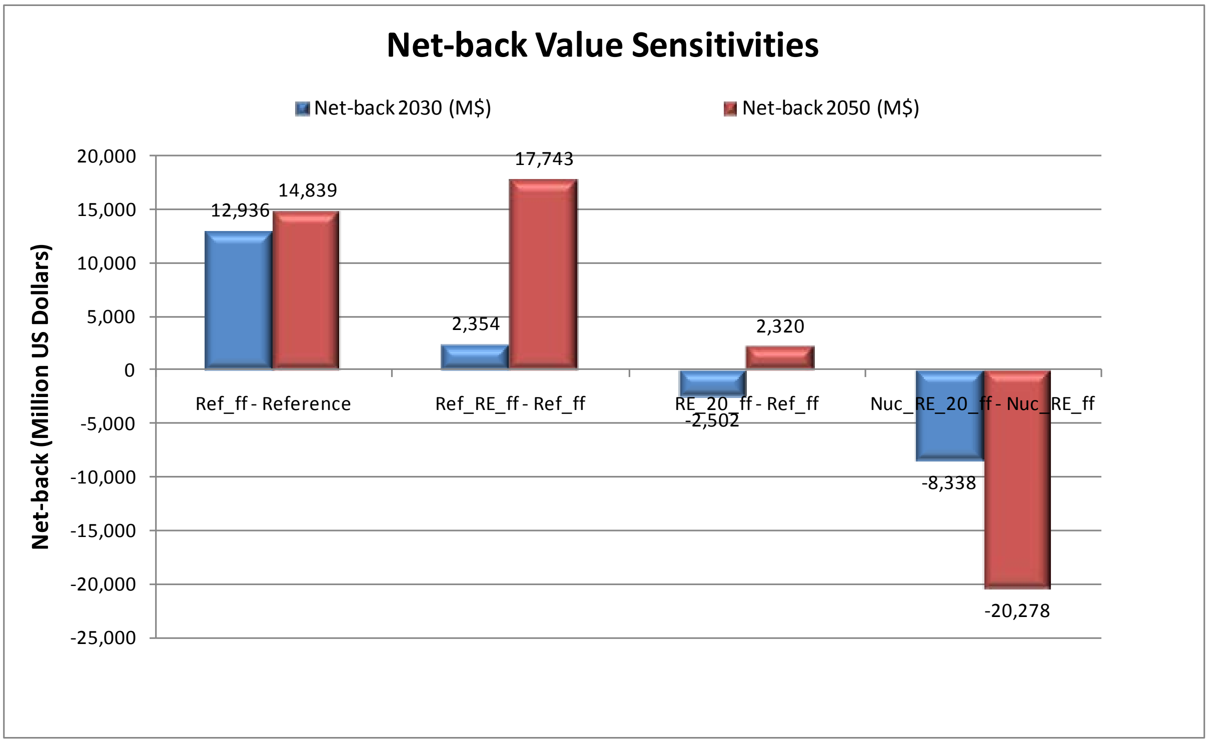

Figure 11: Net-back Values of 20% RE Target without and with Nuclear

In these four cases, overall fossil fuel consumption decreases as RE generation increases, and decreases even further with the introduction of nuclear. In particular, natural gas imports drop by 6%, 14% and 50% respectively relative to the *Ref_ff* case.

CO_2 emissions follow the same pattern as fossil fuel consumption and decrease with more RE electricity generation, and decrease even further with the introduction of nuclear, reaching 48%. There is no significant difference with the other emissions, as the SO_2, NOx and particulate emissions come mainly from heavy fuel oil combustion, which is similar in all scenarios at the minimum level allowed by the model constraints.

There is no significant difference observed in water desalination capacity and production between the various scenarios. This is mainly because the system is investing in as many RO plants as it is permitted, and the remainder of the water demand is being met by MSF plants. The growth in RO plants is being driven by the economics of water production. Therefore, the addition of RE technologies to the power generation mix does not affect the water generation mix.

7. Sensitivity cases

Table 4 describes the sensitivity cases that were run with the KPW model, and Table 5 summarizes the results of these scenarios according to the following metrics:

- Change in 2030 netback value compared to the *Nuc_RE_ff* case;
- Percentage generation of electricity from renewable technologies in 2030;
- Installed renewable energy capacity in 2030;
- Land area occupied by renewable technologies (excluding roof-tops PV);
- Installed nuclear capacity in 2030;
- Change in cumulative natural gas imports (up to 2030), and
- Change in cumulative CO2 emissions (up to 2030).

The largest loss of netback is under the low gas price scenario, at around $16 billion for the 2030 value. The next largest loss of netback is under the high cost and delayed nuclear program at around $11 billion for the 2030 value. The 20% RE target costs around $8.3 billion in netback compared to not having a target. This cost goes up to just over $10 billion with a land constraint but drops to just under $6 billion if most cost effective Solar Tower technology is allowed to come in faster. Lower than anticipated investment cost reductions in RE technologies due to technology learning decreases the share of cost effective RE and the netback benefit. It also increases the cost of achieving RE targets. The lower wind availability results in $1.3 less netback by 2030.

Installed RE capacity ranges from 4.4 GW in the combined low wind – low RE reliability case to 13.7 GW in the 20% RE target case. Nuclear capacity in 2030 stays at 9.8 GW except in RE target cases of 15% and above, low gas, high nuclear costs where there is one less unit built and in the low demand case 2 less units built. Gas import reductions range from 35% to 51%. Cumulative CO_2 emissions savings range from 40% to 52%.

Table 4 Sensitivity Case Definitions

Number	Sensitivity Name	Changing Parameter	Reference Value	Sensitivity Value
1	High RE Cost	All RE Investment Cost	Reductions from Expert	70% of Expert Reductions on all RE
2	Very High RE Cost	All RE Investment Cost	Reductions from Expert	50% of Expert Reductions on all RE
3	High PV Peak	PV Peak Firm Capacity	20%	50%
4	High Storage Peak	Storage Firm Capacity	50%	80%
5	Low Wind Availability	Wind Availability	28%	20%
6	Low RE Reliability	Wind Availability, PV Firm Capacity, Storage Firm Capacity	28%, 20%, 50%	20%, 0%, 25%
7	High Cost and Delayed Nuclear	Nuclear Investment Cost and Start Year	Reference, 2020	High (30% increase), 2022
8	Low Demand	Demand Projection for Electricity and Water	Reference	Low (DA1 14% reduction)
9	Low Gas Price CO2	Gas Price and CO2 tax	Ref ($/Mbtu): 14, no CO2 tax	WEO_Low($/Mbtu): 9 CO2 Tax: $30/ton
10	Solar Thermal Limit	Limit on all solar thermal rather than individual techs	2030 individual: 200-300 MW/year	2030 sum: 900 MW/year
11	Land Constraint	Available Land Area for Power Generation Capacity	No land Constraint. At 20% RE target 18,000 ha is used	Land limit set to 70% (13,500 ha)

Table 5: System Metrics for Target and Sensitivity Cases

Group #	Sensitivity Name	Change in 2030 Netback Value	% RE of 2030 Electric Generation	2030 RE Capacity	RE Land Area ex. Roof-tops & wind	2030 Nuclear Capacity	Change in Cum. Gas Imports*	Change in Cum. CO_2 Emissions*
		Million US$	%	GW	‘000 ha	GW	%	%
	Nuc_RE_ff	-	8%	5.7	6.2	9.8	-44%	-48%
	10% RE Target	-998	10%	6.8	9.05	9.8	-47%	-49%
	15% RE Target	-3,653	15%	10.2	11.52	8.4	-49%	-49%
	20% RE Target	-8,339	20%	13.7	18.07	8.4	-50%	-52%
1	**High RE Cost**	-834	6%	4.5	3.5	8.4	-43%	-43%
2	**Very High RE Cost**	-1,177	5%	3.0	0.0	8.4	-43%	-41%
3	**High PV Peak**	162	9%	5.9	6.8	9.8	-44%	-45%
4	**High Storage Peak**	-95	9%	6.0	6.7	9.8	-44%	-45%
5	**Low Wind Availability**	-1,363	5%	4.5	6.2	9.8	-41%	-45%
6	**Low RE Reliability**	-1,344	5%	4.4	5.8	9.8	-38%	-40%
7	**High Cost and Delayed Nuclear**	-11,331	9%	6.4	6.2	8.4	-35%	-45%
8	**Low Demand (compared to *Ref_ff_LowDemand*)**	-2,897	11%	6.4	6.2	7.0	-51%	-48%
9	**Low Gas Price w CO2 tax (compared to *Ref_ff_LowGasCO2tax*)**	-16,272	6%	4.6	4.6	8.4	-38%	-44%
10	**Solar Thermal Limit (@ 20% RE Target)**	-5,949	20%	11.6	16.6	8.4	-50%	-52%
11	**Land Constraint (@ 20% RE Target)**	-10,176	20%	12.5	13.5	8.4	-50%	-52%

* Changes in Gas imports and CO_2 emissions are relative to *Ref_ff* unless specified otherwise

8. Conclusions

The study presented quantified the economic benefits of electricity generation by renewable sources in the State of Kuwait in a Reference case as well as under a Nuclear deployment scenario. The analysis shows that renewable technologies provide complimentary fuel saving and emission reductions to both the Reference and the Nuclear scenarios. The cost-effective 2030 renewable electricity share is 11% without nuclear and 8% with nuclear, given the projected costs for renewable energy and nuclear technologies. Cost-effective renewable technologies increase the Net-back value of the Reference scenario by US$2.35 billion and the nuclear case by US$1.5 billion. Increasing the RE share (with nuclear) to 10%, 15% and 20%, decreases the 2030 netback benefit by US$1.0, 3.6 and 8.3 billion respectively. At the 10% RE Target there is no reduction in the 2030 installed Nuclear capacity. But at the 15% and 20% RE Targets there is one less Nuclear unit built by 2030.

Renewable energy technologies diversify the nation's generation portfolio away from fossil fuels. The magnitude of the role RE can play depends on how much cost reduction projections materialize. Although incorporating costly renewable resources into the generation portfolio mix might increase the expected costs, fuel price risk is lower and will offset by increased export of petroleum and less consumption of natural gas. Adding a fixed cost source of electricity to the generation portfolio coupled with the value of enhancing security of supply, allows for decreased risk and variability of the total power production costs.

The breath of sensitivity analysis performed resulted in a comprehensive picture of the options and implications of nuclear and renewable energy inclusion in the Kuwait energy mix. However, the economic model results do not explicitly consider factors such as energy security, generation portfolio diversification, regional grid integration and the need for technical and institutional infrastructure development. These issues should be more fully addressed as part of a roadmap to guide the development of a national infrastructure for renewable energy in the power sector.

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