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Article

Harnessing the Sun and Wind for Economic Development? An Economy-Wide Assessment for Egypt

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Abstract: While the recent political transition in Egypt has delayed much-needed policy reforms, our paper suggests that under certain conditions, fostering the national renewable energy strategy may be a promising way of giving an ailing economy an urgently needed impetus. Based on the literature and results of a renewable-energy focused computable general equilibrium model, we recommend that Egypt supports the generation of wind power. While some energy may be exported to generate foreign exchange, a substantial part of the newly produced energy should be sold domestically to ease existing supply constraints and to avoid Dutch disease effects. In addition, and in order to maximize the benefits of renewable energy sources, the renewable energy strategy should be accompanied by a (further) reduction of energy subsidies. Finally, lessons from other countries suggest that sound institutions; appropriate, clear and lasting regulations; careful technology transfer; and cross-ministerial coordination are important for success.

Keywords: renewable energy; economic development; income distribution; computable general equilibrium (CGE) analysis; Egypt

1. Introduction

The global debate on renewable energies often revolves around reducing carbon dioxide (CO_2) emissions as one option to mitigate climate change. The power sector constitutes 41% of global CO_2 emissions [1], and the world is not on track to realize the 2020 interim CO_2 emission reduction targets [2]. The energy-related global carbon emissions are largely driven by the increasing volume derived from within developing countries, including many Arab countries [1,3]. Limiting the increase of carbon emissions from energy generation in these countries is therefore indispensable for achieving the ambitious targets [4,5]. However, because economic development requires energy, especially at earlier stages, balancing the rising demand for energy with a need to limit CO_2 emissions is one of the key climate change mitigation challenges [6,7]. Together with the increase in energy efficiency, which has huge potential to mitigate carbon emissions, the rapid diffusion of renewable energy technologies (RET) is thus considered the second most important mitigation option [8].

In addition to reducing CO_2 emissions, the development of renewable energies may also have positive effects on countries' economic development. The early and broad diffusion of RET would not only slow down the increase of global carbon emission but also allow economies to "leapfrog" over the use of conventional energy resources like oil, coal, or gas toward production technologies reliant on more climate-friendly power [9,10]. Diversifying electricity generation through RET may be particularly important in light of potentially rising future energy costs and geopolitical risks related to mineral resources (energy security). In addition, renewable energies may create jobs and thus foster economic development. Several studies to date have been comparing job creation effects of RET deployment with conventional power generation (see [11]). The general picture shows that, on a per-megawatt basis, there are more jobs being created in solar and wind technology deployment than in conventional power technology. Finally, there may be other associated socioeconomic benefits, including the protection of resources, the reduction of air pollution, and improved health outcomes.

One of the main criticisms of renewable energies is that they are often not cost competitive and thus have to be subsidized. However, production costs for windmills and solar panels have decreased (in part because of subsidies) and—depending on location and the relevant opportunity costs for conventional energy—energy production from renewables can be profitable [12]. As a result, several emerging economies are stepping up efforts in RET deployment [13]. China, for example, has been strengthening its renewables policies and targets since 2012; other countries, including several Arab countries, have developed renewable energy strategies and show considerable potential toward achieving them [14]. However, for renewable development to work, challenges such as the lack of transparency, political uncertainty, and regional economic disparities, need to be resolved in order to attract and retain investors [14].

Egypt is one of the Arab countries that laid out ambitious plans for developing RET. In fact, one of the reasons for developing RET is the hope that it will help promote economic growth and job creation. This is particularly important since recent political events have slowed down economic growth prospects and increased unemployment and poverty [15,16]. Poverty has increased by nearly 50% in the past 15 years from a low of 16.7% (9.9 million people) in 1996 to 21.6% in 2009 and 25.2% (21 million) in 2011 [17]. Moreover, although poverty remained highest in rural areas, the period 2009–2011 saw the fastest rate of increase in urban areas, where poverty grew by nearly 40%.

The objective of this paper is to assess how exactly RET can support economic development in Egypt and thus also provide lessons for other countries. In order to provide answers to these questions, the remainder of the paper is structured as follows. Section 2 examines the status quo of energy in Egypt as well as the potential and plans for renewables. Section 3 discusses the data and model. Section 4 presents the key results and Section 5 concludes.

2. Energy in Egypt: Status Quo, Potential and Plans for Renewables

2.1. Status Quo

Energy production and use has been growing rapidly in Egypt over the past years. Oil and natural gas are the most important natural resources in Egypt's natural assets [15]. Gas production reached 2.17 trillion cubic feet (tcf) in 2011. Despite this strong growth in gas production, the existing capacity is still insufficient to meet export and domestic demand.

The oil sector presents a similar picture. Even though Egypt continuously discovers more reserves—which increased from 3.7 billion barrels in 2010 to 4.4 billion barrels in 2012—it produced only 815,000 barrels per day (2011), which shows decline. At the same time, domestic oil consumption has grown to about the same amount as oil production in 2011 [18].

Egypt's current installed capacity for electricity generation consists of 88% fossil-fuel-based technologies and 12% renewable energy technologies, of which 83% is hydropower [19]. Since all major hydropower sites have been developed there is little potential to expand electricity production from hydropower [20]. In places where 99% of households have access to the electricity system, the peak load growth rate averaged 7.5% per year from 2005 to 2010 [20,21]. In order to satisfy demand increase, the power sector expanded its installed capacity to roughly 25,000 megawatts by the end of 2010. Those efforts were insufficient to fully meet high and rising demand, however, and have led to widespread electricity shortages across the country [20]. Natural gas has traditionally comprised nearly 100% of conventional supply but dropped to roughly 80% in 2010 because of the insufficient supply of gas [20]. Heavy fuel oil has been burned to compensate for the gas shortage in the power sector.

2.2. Potential for Renewables

Due to the limited availability of fossil fuels in the power sector and the increasing cost of electricity supply, the government's interest in the diversification of the energy mix has been evolving rapidly over the past few years. Egypt has solar irradiation and appropriate wind conditions—the prerequisites to producing electricity from renewable sources. The country has large deserts that are sparsely populated and thus, in principle, both solar and wind technologies have potential for widespread application. The annual direct normal solar irradiance ranges from 2000 kilowatt hours per square meter (kWh/m^2) to 3200 kWh/m^2 across the country, with a steady daily profile of approximately 9–11 h of sunlight [20]. Wind conditions are also favorable in the Gulf of Suez reaching wind speeds of 7–8 meters per second. The lower cost of wind technologies compared to solar power, due to relatively high wind speed potentials, especially in the western part of the Gulf of Suez [13], favor the adoption and proliferation of wind technologies in Egypt's energy mix.

Moreover, from an economic point of view, renewable technologies in Egypt are competitive with conventional technologies in both the MENA region and Europe (see Figure 1).

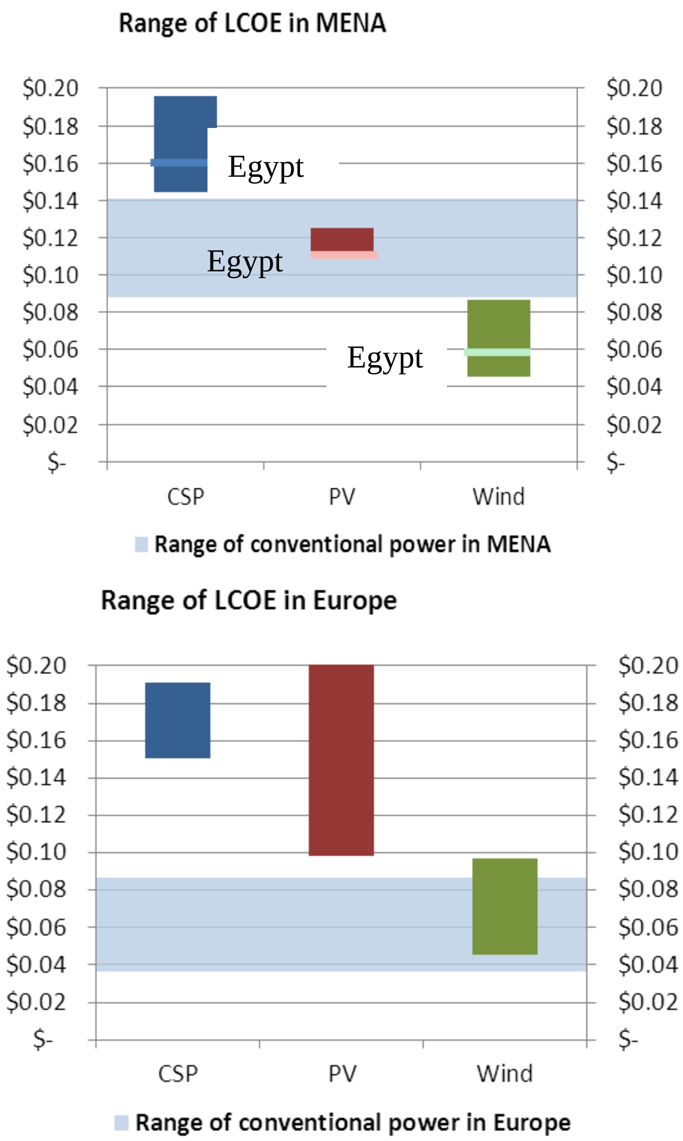

Figure 1. Range of levelized cost of electricity for different technologies in MENA and Europe (€/kWh). Note: LCOE = levelized cost of electricity; CSP = concentrating solar power; and PV = photovoltaic; Source: Authors' calculations based on Desertec Industrial Initiative [22]. The LCOE calculation takes into account country specific solar irradiation and wind speed figures affecting the LCOE on country level.

The estimated LCOE of Egyptian power generation from existing power plants (including hydro, natural gas, and fuel oil) is at US$0.11/kWh. Those of onshore wind energy generation are at US$0.06/kWh, utility scale solar photovoltaic (PV) at US$0.11/kWh, and concentrated solar power (CSP) costs US$0.16/kWh. The LCOE has been calculated also for other MENA countries taking into account respective solar irradiation and average wind speed. This illustrates that wind technology specifically is competitive with conventional power generation technologies in Egypt. The figures we use [22] are in that range and also confirm that wind technology is competitive with conventional power, unlike PV and CSP.

2.3. Egypt's Renewable Energy Strategy

In response to the existing opportunities and challenges due to energy shortages in the energy sector, the Egyptian Supreme Council of Energy has approved a strategy that aims to increase the share of renewable energy to 20% of electricity overall by 2020, with 12% coming from solar and wind technologies and 8% from hydropower [12,23]. Specifically, Egypt's wind target is set at roughly 7200 megawatts by 2020 and is clearly prioritized due to its lower cost compared to solar technologies [12]. Solar development targets are less pronounced and not as ambitious with a solar PV target at 220 megawatts by 2020 and 1100 megawatts of CSP. Egypt announced a further 2027 target of 2800 MW of CSP and 700 MW of PV [24]. The lower solar PV target is also due to the fact that solar technology is more expensive relative to wind technology.

Achieving these targets will require swift mid-term development of solar and wind power plants. In order to meet this requirement, the current installed capacity of wind electricity generation needs to grow by 13 times, PV by 15 times, and CSP by 55 times [19].

The process by which to achieve these targets is in two parts [24,25]. First, a competitive bidding process for projects shall be organized, leading to long-term power purchase agreements (PPA) of 20 to 25 years. Second, there shall be feed-in tariffs (FiT) determined based on the results of the bidding process. The FiT intend to support small and medium developers with capacities of up to 50 MW. The NREA has also increased efforts to incentivize private sector engagement in the emerging renewable energy sector. Proposed measures include favorable permits and land-use agreements for renewable energy project developers, custom-duty exemptions, local content awards in tendering processes, and power generation licenses from the national utility company.

Solar and wind technologies in Egypt are not only expected to contribute to fuel savings and CO_2 reductions but also to meet the increasing electricity demand in the country (annual growth rate of peak load averaged between 2005 and 2010 at 7.5% per annum; [20]) and may cover part of the electricity demand in Europe, as proposed, for example, by the Desertec vision [26].

In the following sections, we will investigate how these proposed renewable energy plans and the Egyptian power sector's shift toward renewable energy technologies will impact the country's overall economic development and welfare situation.

3. Modeling the Economy-Wide Effects of Investing in Renewable Energy

Recent studies assessed energy demand and supply for MENA countries till 2030 by using energy-economic models with an annual time resolution [27] or "characteristic" time periods (time slices) over the year to represent supply and demand matches over the year [28], or by leaving out intermittence in their energy module in order to reduce complexity [29]. Given that those studies are interested in macroeconomic and countrywide effects, they do not take into account country specific power demand patterns (supply and demand of power per hour of the day). By following the approach of annual time resolution, it is not possible account for the different technology characteristics (dispatch time and power storage infrastructure requirements) as well as precise power grid investments for the necessary grid expansion. Grid costs are included as an additional investment premium for each technology. This paper uses the power technology expansion figures from the national renewable energy policy targets because we explicitly want to assess the economy-wide effects of Egypt's Renewable Energy Strategy. Thus, we are confined to using the given power technology investment figures from the Government of Egypt.

3.1. The Database: A Renewable-Energy-Focused Social Accounting Matrix

The basis for our assessment of renewable energy investments in Egypt is a social accounting matrix (SAM) we developed. The SAM represents the structure of the Egyptian economy and importantly describes the linkages between various renewable energy sectors, other sectors of the economy, institutions, and other countries (through trade) [30]. The SAM is based on the latest published supply and use tables compiled by the Central Agency for Public Mobilization and Statistics (CAPMAS) for 2008/09 and is complemented with data from the Household Income, Expenditure, and Consumption Survey for the same year [31] as well as data on the economically active population in 2007 [32]. The SAM includes production, intermediate use, final demands, sectoral capital earnings, and sectoral expenditures on wages and salaries, as well as the distribution of factor income to households and the redistribution of income between the private and public sector. Key aspects of the Egyptian economy in 2008 will be discussed below.

The input–output data compiled by CAPMAS [33] do not include statistics on renewable electricity supply technologies; rather the electricity sector in the benchmark data is an aggregate of existing renewable and conventional technologies. We therefore calculated the input requirements for the renewable electricity technologies based on additional data sources, allowing us to disaggregate the aggregate electricity sector into renewable and conventional subcomponents, as in Desertec Industrial Initiative [22] and Calzadilla *et al.* [34]. We conduct our disaggregation using data from an industry survey conducted by Dii that describes cost and technological characteristics of PV, CSP, and wind electricity generation technologies (see Tables 1 and 2). The different inputs; capital, land, and labor for each technology have been assessed on a component level in order to specify the linkage of each input to other sectors in the economy.

Table 1. Production cost estimates for renewable equipment manufacturing (EUR/kW).

	PV	CSP	WIND
Minerals and mineral products		464	
Rubber, plastic products		579	
Metals and metal products	150	678	289
Electronic equipment	810	355	
Machinery and other equipment	260	919	459
Vehicles and transport equipment			224
Construction	90	583	79
Other transport		215	15
Business services	150	997	134
Total	1460	4790	1200

Note: PV stands for photovoltaic power; CSP for concentrated solar power; and WIND for wind power. Source: [22].

Table 2. Production cost estimates for renewable electricity generation (EUR/kW).

	PV	CSP	WIND
Electronic equipment	7.5		
Machinery and other equipment	4.2	21.7	10.8
Water		3.8	
Business services	0.7	8.1	3.2
Insurance	5.0	26.6	3.2
Labor remuneration	21.0	32.6	3.6
Capital rental	102.2	335.3	84.0
Land rental	1.6	0.2	3.2
Total	142.2	428.3	108.0

Note: PV stands for photovoltaic power; CSP for concentrated solar power; and WIND for wind power. Source: [22].

To generate cost shares for renewable equipment manufacturing, we calculated the weighted cost for each technology from the input–output data using the technology components for each technology in Table 1 as weights. The technology of equipment manufacturing and the electricity generation phase of the technology, and the consumption of further capital are two separate groups of vectors. This allows us to compile input cost shares for each technology and to separate the aggregate electricity generation sector into conventional and renewable subsectors. The input cost shares for all electricity-generating technologies are given in Table 3.

Table 3. Benchmark cost shares for renewable equipment manufacturing, all other manufacturing, and electricity generation.

	Equipment manufacturing				Electricity generation			
	PV	CSP	WIND	Other manu.	PV	CSP	WIND	Conventional
Intermediates	0.65	0.56	0.65	0.69	0.12	0.14	0.16	0.55
Energy								0.10
Primary education	0.05	0.06	0.05	0.03	0.09	0.05	0.02	0.09
Secondary education	0.02	0.02	0.02	0.01	0.04	0.02	0.01	0.04
Tertiary education	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Capital	0.28	0.35	0.27	0.25	0.72	0.78	0.78	0.21
Land	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Note: PV stands for photovoltaic power, CSP for concentrated solar power, and WIND for wind power. Source: Authors' calculations based on [22,33].

Overall, the key differences between renewable and conventional electricity technologies are that the renewable energy technologies are more capital intensive and less energy intensive than the conventional electricity generating technology. Renewable energy technologies are also somewhat less labor intensive and require significantly less intermediate inputs. Moreover, our data suggest that the renewable equipment manufacturing sectors, especially CSP, have a higher proportion of value added compared to the broader manufacturing sector. Yet, most of the value added that will be generated in the renewable sectors is capital income on foreign direct investment that will be repatriated to foreign owners of the capital stock.

3.2. The Model: A Dynamic Computable General Equilibrium Model

To assess the potential impacts of alternative renewable investment schemes for Egypt, we build a multi-sector dynamic computable general equilibrium (DCGE) model following the standard DCGE model described in Diao and Thurlow (2012) [35]. In the following, we will describe the most important features of the model as they relate to Egypt and our specific modifications and simulations. The full set of equations and a description of variables and parameters can be found in Appendix A.

The Egyptian economy is modeled as a competitive economy with flexible prices and market conditions. Agents represented in the model are consumers, who maximize utility; producers, who maximize profits; and the government. Egypt is connected with the rest of the world via bilateral trade flows, remittances, and other transfers.

To reflect the fact that investments in windmills and solar panels take place over a longer period of time, the analytical framework is recursively dynamic—which means that the evolution of the economy over time is described by a sequence of single-period static equilibriums connected through capital accumulation, changes in factor supply, and sector specific technical progress. The economic structure, including energy production from renewables, is fully specified and covers production, investment, and final consumption by consumers and the government. Policy instruments are taxes, subsidies, or quantity constraints in factor markets, product markets, and international trade. The model results show relative changes to a reference scenario that also needs to be defined.

Producers of renewable energy and those of other goods and services (including one agricultural sector, 23 industrial sectors, and two service sectors) are price takers in output and input markets and maximize profits using constant returns to scale technologies. For all sectors, except renewable energy producers, the production function consists of a constant-elasticity-of-substitution (CES) aggregate of capital and labor (and land in agriculture and renewables) nested within a Leontief aggregate of all other inputs (that is, intermediate demand is determined by fixed technology coefficients, or Leontief demand:

$$X_i = \Lambda_i \left(\sum_f \alpha_{if} \cdot V_{if}^{-\rho_i} \right)^{-1/\rho_i} \quad (1)$$

where X is the quantity of output of sector *i*, Λ is the total factor productivity (TFP), *V* is the quantity of demand for each factor *f* (labor, capital, land), and α is a share parameter of factor *f* used for the production of commodity *i*. For renewable energy production, we assume a Leontief technology, where the entire domestic capital–labor–land nest is combined with foreign direct investment (FDI), which is determined exogenously by foreign investors.

We model separate domestic manufacturing sectors that produce capital equipment for renewable energy generation (for example, wind turbine blades, nacelles, solar panel and inverter manufacturers). Producers of renewable energy will choose to purchase outputs from these manufacturing sectors, rather than purchasing imported renewable energy capital goods. Profit maximization implies that factor payments equal average production revenues. Labor, capital, and land are fixed, implying full employment and intersectoral mobility, except for capital and land, which are assumed to be immobile across sectors. New capital from past investment is allocated to sectors according to profit rate differentials under a "putty–clay" specification. This means that once capital stocks have been invested it is difficult to transfer them to other uses. The same holds true for land in agriculture and in renewable electricity sectors. This means that as renewable electricity sectors expand, they generate additional demand for labor, which then affects economy-wide wages and production in other sectors by increasing labor competition. Based on the 2008/09 Household Income, Expenditure and Consumption Survey (HIECS), labor markets are segmented across three skill groups: (1) low-skilled workers with primary education; (2) semi-skilled workers with secondary education; and (3) skilled workers who have completed tertiary schooling.

Factor incomes are distributed to households using fixed income shares on households' initial factor endowments. Incomes are then saved (based on marginal propensities to save) or spent on consumption (according to marginal budget shares). Household savings and foreign capital inflows are collected in a national savings pool and used to finance investment demand (meaning a savings-driven investment closure). Finally, prices equilibrate product markets so that demand for each commodity equals supply. The model therefore links production patterns to household factor incomes through changes in factor employment and returns.

Households maximize a Cobb-Douglas utility function so that budget shares are constant. Households are disaggregated across rural/urban and by per capita expenditure quintiles, giving a total of 10 representative households in the full DCGE model. Households pay taxes to the government based on fixed direct and indirect tax rates. Tax revenues finance exogenous recurrent spending and transfers to households, resulting in an endogenous fiscal deficit. Finally, the model includes a simple consumption-side microsimulation module where each respondent in HIECS is linked to their corresponding representative household in the DCGE model. Changes in commodity prices and each household group's consumption spending are passed down from the DCGE model to the survey respondents, where their total per capita consumption and poverty measures are recalculated.

International trade is captured by allowing production and consumption to shift imperfectly between domestic and foreign markets, depending on the relative prices of imports, exports, and domestic goods (inclusive of relevant sales, trade taxes, and subsidies). This specification captures differences in domestic and foreign products and allows for observed two-way trade. However, Egypt is still considered a small economy, such that world prices are fixed and the real exchange rate (that is, price index of tradable to nontradable goods) adjusts to maintain a fixed current account balance.

Renewable electricity expansion is assumed to be driven entirely by foreign direct investment, and all profits generated in the renewable sectors are remitted abroad. The decision to invest is thus resolved exogenously by foreign investors FDI in renewable electricity and in manufacturing sectors will expand the capital stock for renewables. This expansion in resources will cause growth rate in renewables to increase in all renewable energy scenarios. Renewable energy producers must, however, compete with other sectors for intermediate inputs and labor resources. In the DCGE model, we assume full employment, which means that total labor supplies are fixed and increasing labor demand raises workers' wages, thereby leading to a reallocation of workers from the non-renewables to the renewables sectors. Ultimately, the trade-offs from renewables production will generally be smaller than the gains from new investments in the renewables industry. As a result, national GDP growth rates will increase in most renewable energy scenarios. Moreover, we assume that all renewable electricity is exported.

We initially create the renewable electricity and renewable equipment manufacturing sectors representing their current capacities (see next section) then smoothly increase renewable energy production over the period 2008–2020, reflecting the likely gradual expansion of the industry. The wind target in Egypt is set to 7200 megawatts by 2020 and is clearly prioritized for its lower cost compared to solar technologies [12]. Solar development targets are less pronounced and not that ambitious with a solar PV target at 220 megawatts by 2020 and 1100 megawatts of concentrated solar power.

The Egypt DCGE model is first run forward using the 2008–2020 period, assuming no expansion in renewable electricity production. This produces a reference scenario against which to assess Egypt's renewables strategy. For this, we first calibrate the Egypt DCGE model to track observed trends in key demographic and macroeconomic indicators. Population growth and growth of unskilled, medium-skilled, and high-skilled labor are all set at 2% per year during 2008–2020. We exclude an expansion of agricultural land to capture rising population density in rural areas. In order to achieve recently observed growth rates in GDP, total factor productivity growth is set to 0.5% for agriculture and 1.6% for industry per year during the simulation period. Thus, the baseline scenario also captures the recent poor performance of the Egyptian economy. Then in the renewables simulations we expand the size of the renewable electricity and renewable equipment subsectors to produce the above mentioned target values.

When interpreting these results, it is important to keep several well-known weaknesses of DCGE models in mind. While none of the following limitations of the model presented in this paper is likely to alter the key messages, it is important to highlight them. First, like any other model, the DCGE is very data intensive. While it is a major strength of this type of model to reconcile data from different sources, such as balance of payments data, national accounts and household surveys, it is also perhaps their major weakness. Second, the assumption of full employment and flexible wages in Egypt can be justified by the fact that producing renewable energy equipment and operating renewable energy plants require specific skills, which unemployed people may not have. Thus hiring people to support renewable energy driven growth will have to be done from the existing workforce.

4. Potential Impacts of Investing in Renewable Energy Projects

4.1. Renewables in the Economy-Wide Context

Table 4 shows the structure of the Egyptian economy in 2008, which is the initial starting point for the model. Given our focus on renewable energy, employment generation, and poverty reduction, we are interested in how Egypt's renewable energy strategy affects the income earned by each household as well as how it is earned. The SAM provides the information needed to answer both questions. The former is what is referred to as the *functional* distribution of income—the returns to factors—and the latter is the *size* distribution of income—how the factor returns are distributed (and redistributed) among households (and the government and the rest of the world).

Table 4. Structure of Egypt's economy, 2008.

Sectors		**Share of total (%)**				**Export intensity (%)**	**Import penetration (%)**
		GDP	**Employment**	**Exports**	**Imports**		
1-26	Total	100.00	100.00	100.00	100.00	16.59	20.14
1	**Agriculture**	**13.41**	**31.82**	**2.70**	**8.00**	**4.00**	**13.70**
2-24	**Industry**	**36.95**	**22.05**	**63.63**	**82.20**	**22.00**	**31.76**
2	Mining	15.83	0.16	19.40	6.40	31.90	16.00
3-18	Manufacturing	14.92	11.01	39.70	72.80	23.62	41.71
3	Food processing	3.61	2.07	4.10	6.00	10.30	18.00
4-18	Other manufacturing	11.31	8.94	35.60	66.80	27.62	47.37
4-6	**Renewable equipment manufacturing**	**0.18**	**0.05**	**0.70**	**0.60**		**36.21**
4	PV equipment	0.01	0.00	0.00	0.00		49.50
5	CSP equipment	0.03	0.01	0.10	0.10		30.30
6	Wind equipment	0.15	0.04	0.60	0.50		36.70
12	Petroleum and petroleum processing	2.05	0.79	14.90	4.40	45.70	24.40
19-23	Utilities	1.71	1.27	2.40	2.60	12.44	15.96
19-22	Electricity	1.33	0.94	2.30	0.60	15.10	5.29
19-21	**Renewable electricity**	**0.04**	**0.00**	**2.20**	**0.00**	**100.00**	
19	PV electricity	0.00	0.00	0.10	0.00	100.00	
20	CSP electricity	0.01	0.00	0.30	0.00	100.00	
21	Wind electricity	0.04	0.00	1.80	0.00	100.00	
22	Conventional electricity	1.29	0.93	0.10	0.60	0.80	5.30
23	Water	0.38	0.34	0.10	2.00	1.90	39.50
24	Construction	4.50	9.60	1.50	0.40	3.90	1.40
25-26	**Services**	**49.64**	**46.13**	**33.50**	**9.30**	**0.07**	**5.10**
25	Private services	18.35	22.07	31.10	2.20	29.40	3.40
26	Government services	31.29	24.07	2.40	7.10	1.70	6.00

Note: Sector summaries in bold type. Source: Results from the Egypt DCGE model.

Agriculture generates only 13% of Egypt's gross domestic product but more than 30% of total employment. Most farmers are smallholders with low education levels; more than 17% of total low-skilled labor income is generated in agriculture. However, Egypt as a whole relies on imported food, which accounts for 14% of total imports and 18% of all processed food in the country.

The Egyptian economy is dominated by mining (including oil, petroleum, and petroleum processing) and private services (including tourism and Suez Canal services). Mining does not, however, generate much employment, and most nonfarm workers in the country are employed in private and public services and construction. Incomes in many of these nonfarm sectors are only slightly higher than those in agriculture, due in part to low education levels and shortage of skilled labor in the country. Indeed, 85% of skilled-labor income is generated in the public sector. Energy is a small sector and renewable energy is still in its infancy, making up only a tiny share of total value added and employment in 2008.

4.2. Renewable Energy Scenarios

We assess the Egyptian renewable energy strategy in several scenarios (Table 5). All scenarios incorporate Egypt's investment and production plans for renewable electricity production by 2020, both for specific technologies (labeled PV, CSP, and WIND) or for the combined investment into all technologies (labeled COMB). For combined scenarios, this involves a permanent 34% increase in FDI inflow to the renewable energy sector. This increase is equivalent to just under 1% of baseline GDP and 5% of baseline investment but total investment in renewables reaches 10% of total investment in 2020.

In all scenarios, we assume that all renewable electricity is exported while additional domestic demand for electricity is satisfied by domestic and import supply of conventional electricity, which is a perfect substitute to renewable sources. COMB1 (and PV, CSP, and WIND) examines a scenario without climate policy, where renewable electricity can only be exported at prices of conventional electricity. Given low fossil fuels prices, this requires substantial subsidies to CSP technology and to a less extent to PV technology (Table 5). COMB2 assumes that climate change mitigation policies raise conventional electricity prices to a level that covers CSP production costs. Finally, COMB3 assumes that, additionally, the Egyptian government reduces fuel subsidies by 10% as a complimentary measure to renewables policy. Consequent changes in the domestic budget balance, which follows from climate change mitigation policy and fuel policy balance, are accommodated through adjustments in investment, thus implying a redistribution of income from fuel consumers to investors.

Table 5. Scenarios for renewable energy development in Egypt by 2020.

Scenario	Capacity build-up, MW	Total FDI/baseline investment, %	Reference electricity price	Subsidy rate, %
COMB1	585–8420	4.80	fuel unit cost	PV: 18.8%; CSP 75.1%
PV	15–220	0.85	fuel unit cost	18.80%
CSP	20–1100	2.22	fuel unit cost	75.10%
WIND	550–7200	3.23	fuel unit cost	-
COMB2	585–8420	4.80	converges to CSO unit cost	-
COMB3	585–8420	4.80		fuel excise subsidy: −10%

Source: Authors' compilation.

4.3. Impacts on Economic Growth and Employment

The renewables simulations reflect the case, where FDI and land are allocated to the renewables sectors according to Egypt's renewable energy strategy. This implies that the electricity generating capacity of PV will increase from 15 megawatts in 2008 to 220 megawatts in 2020 and that of CSP and WIND from 20 to 1100 megawatts and from 550 to 7200 megawatts, respectively. We assume that the solar and wind parks will be located on brown field sites or other sites, where there is no other valuable land use—meaning that renewable energy parks will not displace any agricultural land being cultivated.

In the scenario without climate policy (COMB1), the Egyptian economy adopts low fossil fuel prices that require substantial subsidies to the renewable electricity sector, especially CSP electricity production, in order for them to be competitive with conventional energy. Our results show that total subsidies for PV and CSP increase gradually to up to 2.5% of GDP. Compared to the baseline scenario without renewable investment, the transition to a decarbonized power sector in Egypt leads to real income gains in the renewable energy sector as a result of FDI inflow to the renewable energy sector. However, these real income gains are dampened by a decrease in domestic fixed investment (see Table 6) and real income losses in other sectors and the overall impact of the renewable energy strategy on growth across the Egyptian economy for that scenario would be quite low; overall growth would be just 0.01 percentage points above baseline growth (see Table 6). The reduction of domestic fixed investment is mostly felt in the construction sector, where the growth rate is one percentage point lower than in the baseline and largely results from the subsidies to CSP technology (see column 4 in Table 7), while the impact of subsidies to PV technology is quite low, given PV's small share in the renewable energy investment plan.

Table 6. Core macroeconomic assumptions and results, 2008–2020.

	Initial, 2008	**Baseline scenario**	**Investment in renewable energy sectors**					
			COMB1	**PV**	**CSP**	**WIND**	**COMB2**	**COMB3**
			Average annual growth rate, 2008–2020 (%)					
Population	80 millions	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Total GDP	100.00	4.15	4.16	4.15	3.96	4.34	4.48	4.55
Fixed investment	19.01	4.44	3.30	4.42	3.20	4.53	4.47	4.79
Labor	24.93	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Primary	9.17	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Secondary	4.55	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Tertiary	11.21	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Domestic capital stock	73.79	2.95	2.87	2.95	2.87	2.96	2.96	3.03
Renewables FDI supply	0.20	0.00	34.21	3.35	23.86	27.18	34.21	34.21
Total land supply	1.08	0.00	0.15	0.00	0.00	0.14	0.15	0.15

Table 6. *Cont.*

	Initial, 2008	Baseline scenario	Investment in renewable energy sectors					
			COMB1	PV	CSP	WIND	COMB2	COMB3
			Final-year value, 2020					
Electricity generating capacity, MW								
PV	15	15	220	220			220	220
CSP	20	20	1100		1100		1100	1100
Wind	550	550	7200			7200	7200	7200
Real exchange rate	100.00	100.60	100.20	100.60	101.20	99.70	99.00	99.00
Nominal exchange rate	100.00	100.40	99.90	100.40	100.60	99.70	99.20	99.20
Domestic prices	100.00	99.80	99.60	99.80	99.40	100.00	100.10	100.10
Renewables FDI supply	244.1 millions EUR	244.13	4627.47	102.22	1864.26	2660.99	4627.47	4627.47

Source: Results from the Egypt DCGE model.

Our findings suggest that, in the case of Egypt, the massive scaling up of renewable energy may negatively affect other sectors in two key ways. First, the expansion of PV and especially CSP technologies and the accompanying rise in subsidy payments to these sectors imply that an increasing amount of investment is drawn from the overall macroeconomic investment budget. Thus demand for investment goods is reduced, and this is mostly felt in the construction sector. Second, export sectors are negatively affected through Dutch disease effects, if all renewable energy is exported (see Table 7). This is because in our simulations the renewable energy sector eventually accounts for almost 25% of total merchandise export earnings by 2020. Since we assume that the current account balance is fixed in foreign currency, the increase in exports causes the real exchange rate to appreciate relative to the baseline scenario (see Table 6). This reduces the competitiveness of traditional export sectors, such as textiles, chemicals, electrical and nonelectrical machinery, and private services (tourism and Suez Canal services); exports and production of these sectors therefore declines.

Table 7. Sector growth results, 2008–2020.

	GDP share 2008 (%)	Baseline growth (%)	Deviation from baseline scenario growth rate (%-point)					
			Investment in renewable energy sectors					
			COMB1	PV	CSP	WIND	COMB2	COMB3
GDP	**100.00**	**4.18**	**0.01**	**0.00**	**−0.19**	**0.19**	**0.22**	**0.29**
Agriculture	**13.41**	**2.87**	**−0.04**	**0.00**	**−0.02**	**−0.01**	**−0.02**	**0.04**
Industry	**36.95**	**4.62**	**0.69**	**0.02**	**0.20**	**0.48**	**0.84**	**0.88**
Mining	15.83	4.82	−0.09	0.00	−0.08	−0.01	−0.01	0.05
Manufacturing	14.92	4.51	1.61	0.03	0.70	0.92	1.62	1.59
Food processing	3.61	4.18	−0.04	0.00	−0.03	−0.02	−0.03	0.03
Non-food manufacturing	11.31	4.61	2.08	0.05	0.92	1.20	2.09	2.04
Renewable equipment manufacturing	0.18	1.54	34.92	3.39	24.85	27.40	34.85	34.82
PV manufacturing	0.01	1.54	31.26	31.28	0.06	−0.08	31.15	31.12
CSP manufacturing	0.03	1.53	50.05	0.00	50.15	−0.07	49.93	49.89

Table 7. *Cont.*

	GDP share 2008 (%)	Baseline growth (%)	Deviation from baseline scenario growth rate (%-point)					
			Investment in renewable energy sectors					
			COMB1	PV	CSP	WIND	COMB2	COMB3
Wind manufacturing	0.15	1.54	29.76	0.00	0.07	29.68	29.72	29.70
Textiles	2.22	4.62	−0.05	0.00	−0.01	−0.04	−0.07	0.00
Wood	1.20	4.61	−0.07	0.00	−0.04	−0.03	−0.06	0.02
Paper and printing	0.41	4.62	0.02	0.00	0.03	0.00	−0.01	0.04
Chemicals	1.33	4.67	−0.03	0.00	0.02	−0.05	−0.07	−0.06
Rubber and plastics	0.22	4.70	0.17	0.01	0.06	0.11	0.16	0.23
Petroleum and petroleum processing	2.05	4.77	−0.11	0.00	−0.08	−0.03	−0.06	−0.57
Non-metallic products	0.86	4.63	0.02	0.00	−0.03	0.04	0.11	0.08
Basic metals	0.88	4.69	0.38	0.01	0.05	0.32	0.39	0.26
Fabricated metal products	0.86	4.48	0.17	0.00	−0.10	0.26	0.34	0.44
Non-electrical machinery	0.26	4.70	−0.22	0.00	−0.09	−0.13	−0.19	−0.12
Electrical machinery	0.55	4.67	−0.16	0.00	−0.06	−0.10	−0.15	−0.07
Transport equipment	0.30	4.59	−0.04	−0.01	−0.11	0.06	0.01	0.11
Utilities	1.71	4.19	3.30	0.09	1.39	2.05	3.24	3.08
Electricity	1.33	4.16	4.00	0.12	1.71	2.52	3.97	3.86
Renewable electricity	0.04	1.61	34.32	3.70	23.05	27.77	34.21	34.18
PV electricity	0.00	1.56	31.30	31.28	0.04	−0.03	31.15	31.12
CSP electricity	0.01	1.59	50.09	0.00	50.12	−0.02	49.93	49.89
Wind electricity	0.04	1.62	29.80	0.00	0.01	29.79	29.72	29.70
Conventional	1.29	4.24	0.22	0.00	0.08	0.14	0.23	0.08
Water	0.38	4.30	0.47	0.00	0.22	0.26	0.29	−0.11
Construction	4.50	4.45	−0.95	−0.02	−1.02	0.06	0.10	0.39
Services	**49.64**	**4.18**	**−0.03**	**0.00**	**0.00**	**−0.02**	**−0.03**	**0.02**
Private services	18.35	4.41	−0.04	0.00	0.00	−0.04	−0.06	0.00
Public services	31.29	4.04	−0.01	0.00	0.00	−0.01	−0.01	0.03

Notes: Sector summaries and averages in bold type. Source: Results from the Egypt DCGE model.

In the isolated PV and CSP scenarios, the demand effects clearly dominate. For example, the number of workers employed in construction falls by 438,000 and 6000 workers in the CSP and PV scenarios, respectively (see Table 8). By contrast, the number of workers used in construction increases by 21,000 in the WIND scenario, because the expansion of wind energy does not require additional subsidies and therefore does not lead to a crowding-out of domestic fixed investment. Moreover, workers are reallocated from trade-oriented agriculture and private services to the renewable energy sectors as a result of the real appreciation. In the COMB1 scenario, which replicates Egypt's renewable energy strategy, both effects are at work and lead to a restructuring of the economy toward manufacturing and services while the construction sector contracts.

Table 8. Employment results, 2008–2020 (000 workers).

	Employment, 2008	Baseline employment, 2020	Deviation from baseline scenario, final employment						Employment generation/additional 100 MW electricity		
			Investment in renewable energy sectors								
			COMB1	PV	CSP	WIND	COMB2	COMB3	PV	CSP	WIND
Total workers	21,677	26,422	0	0	0	0	0	0			
Agriculture	**6897**	**8145**	**53**	**−1**	**115**	**−58**	**−103**	**−117**	**−452**	**10,615**	**−878**
Industry	**4780**	**6013**	**−159**	**3**	**−304**	**135**	**226**	**260**	**1238**	**−28,150**	**2030**
Mining	**35**	46	0	0	1	−1	−1	−1	−10	48	−9
Manufacturing	2387	2998	233	8	122	103	172	141	3845	11,297	1547
Food processing	449	517	4	0	10	−5	−8	−10	−49	900	−74
Other manufacturing	1939	2481	229	8	112	108	181	151	3893	10,396	1621
Renewable equipment manufacturing	**11**	**11**	**185**	**8**	**74**	**103**	**183**	**182**	3767	6814	1549
PV manufacturing	1	1	8	8	0	0	7	7	3771	1	0
CSP manufacturing	1	1	71	0	73	0	70	69	0	6793	−1
Wind manufacturing	9	9	106	0	0	103	106	105	−3	20	1550
Textiles	430	550	3	0	10	−7	−13	−13	−80	971	−109
Wood	232	296	0	0	4	−3	−6	−6	−49	341	−50
Paper and printing	79	101	2	0	3	−1	−1	−1	3	264	−8
Chemicals	257	331	4	0	9	−5	−7	−10	−25	840	−75
Rubber and plastics	43	55	3	0	2	1	2	2	51	196	17
Petroleum and petroleum processing	170	222	−4	0	0	−4	−6	−23	−71	−26	−54
Non-metallic products	166	212	5	0	3	1	4	1	11	311	21
Basic metals	171	221	24	1	8	15	19	12	285	771	233
Fabricated metal products	166	206	11	0	−1	11	15	16	111	−105	172
Non-electrical machinery	50	65	−2	0	0	−2	−3	−3	−38	−14	−31
Electrical machinery	107	137	−3	0	1	−4	−6	−5	−29	83	−54
Transport equipment	58	74	0	0	−1	1	0	0	−43	−50	12
Utilities	276	342	24	1	12	12	18	6	269	1103	178
Electricity	203	250	17	0	8	8	14	7	225	741	124
Renewable energy production	**0**	**0**	**5**	**0**	**2**	**3**	**4**	**4**	143	184	39
PV electricity	0	0	0	0	0	0	0	0	143	0	0
CSP electricity	0	0	2	0	2	0	2	2	0	184	0
Wind electricity	0	0	3	0	0	3	2	2	0	1	39
Conventional energy	203	250	12	0	6	6	10	3	82	556	85
Water	73	92	8	0	4	4	4	−1	44	362	54

Table 8. *Cont.*

	Employment, 2008	Baseline employment, 2020	Deviation from baseline scenario, final employment						Employment generation/additional 100 MW electricity		
			Investment in renewable energy sectors								
			COMB1	PV	CSP	WIND	COMB2	COMB3	PV	CSP	WIND
Construction	2081	2627	−417	−6	−438	21	37	114	−2867	−40,598	314
Services	**10,000**	**12,263**	**97**	**−2**	**187**	**−82**	**−132**	**−152**	**−994**	**17,269**	**−1240**
Private services	4783	5986	41	−1	112	−65	−107	−115	−727	10,363	−984
Government services	5217	6277	56	−1	75	−17	−25	−37	−267	6907	−256

Notes: Sector summaries and averages in bold type. Source: Results from the Egypt DCGE model.

Scenarios COMB2 and COMB3 assume that prices for fossil fuels rise swiftly and steadily because of limits on CO_2 emissions, thereby leading to a convergence of renewable and conventional electricity production costs. The reduced need to subsidize solar power implies that the Dutch disease effect dominates, reducing the competitiveness of traditional export sectors, such as textiles, chemicals, electrical and non-electrical machinery, and private services (tourism and Suez Canal services), and these sectors decline. Agricultural production and food processing decrease despite rising domestic income since the appreciation of the real exchange rate also reduces the competitiveness of domestic import-competing sectors. Ultimately, the trade-offs from renewable energy production are smaller than the gains from new investments in the renewable energy sector. As a result, national GDP growth rates increase in all renewable energy scenarios, though these increases vary depending on the volume of investment and whether the renewable energy strategy is somehow flanked by additional measures.

Scenario COMB3 assumes that the renewable energy strategy is supported by a 10% reduction of fuel subsidies. Lower fuel subsidies have no direct impact on the renewable energy sectors, but exhibit significant indirect effects: by raising input costs to almost all sectors, they lead to a higher real appreciation. Moreover, lower government subsidies imply a reduction of the public deficit and an increase in investment, both of which lead to higher growth in the COMB3 scenario compared to COMB1 and COMB2.

Generally, the more profitable the renewable electricity production technology is, the larger its impact on national economic growth. Thus, the scenario with the largest positive gains in total GDP is WIND, which is the most profitable renewable electricity technology (see Table 2).

Table 8 reports impacts on employment. The number of jobs created in the renewable energy sector varies greatly across scenarios. The last three columns show the labor requirements to build up and operate a 100 megawatt solar or wind park. Generally, CSP is the most labor-intensive technology followed by PV and WIND. For all technologies, the number of workers used to produce renewable electricity is much smaller than the number of workers used to build up a renewable energy park. For example, one individual operation and maintenance worker in electricity production is needed for every 26 equipment manufacturing workers in the PV sector. The labor intensity of renewable electricity production is higher. Finally, CSP generation is also highly labor-intensive. In fact, the large amount of capital required to produce CSP equipment makes it the most labor-intensive option overall.

Low investments in PV and low labor-intensity mean that only 7700 manufacturing jobs are created in the PV scenario. Conversely, CSP equipment manufacturing employs 74,000 additional workers to produce renewable equipment in the CSP scenario. Wind equipment manufacturing is less labor-intensive than CSP and PV, however; the significant investment pays off and generates the most jobs.

Renewable electricity generation creates relatively few jobs, with almost all employment effects from renewable investment coming from equipment manufacturing. Moreover, unlike those in equipment manufacturing, jobs in electricity plants are largely reserved for semi-skilled and skilled workers; most of these workers must be sourced from other manufacturing subsectors as the renewable electricity sector grows. Lower skilled laborers mainly come from agriculture and services. Enhancing a renewable electricity industry in Egypt will therefore create new job opportunities for some sectors but will also impose significant adjustment costs on others, especially those in export agriculture and services.

4.4. Impacts on Household Incomes and Poverty

Investments in renewables increase national GDP and factor returns, causing household incomes to rise. Although this is true in all renewables scenarios, there are significant differences in the distributional impacts across household groups. Table 9 reports changes in households' equivalent variation, which is a welfare measure that controls for changes in prices. All rural quintiles benefit from the expansion of renewable energy production in Egypt. What is more, lower-income households actually see the most benefit because they receive a larger share of their income from labor, which has become relatively scarce as a result of the renewables expansion.

Table 9. Household per capita equivalent variation results, 2008–2020.

	Per-capita consumption, 2008 (LE)	Baseline growth (%)	Deviation from baseline scenario growth rate (%-point)					
			COMB1	**PV**	**CSP**	**WIND**	**COMB2**	**COMB3**
Rural	2879.2							
Quintile 1	2207.5	2.02	0.03	0.00	−0.11	0.14	0.27	0.32
Quintile 2	2443.1	2.51	0.06	0.00	−0.12	0.18	0.33	0.39
Quintile 3	2648.4	2.53	0.00	0.00	−0.12	0.12	0.23	0.27
Quintile 4	2925.3	2.73	−0.03	0.00	−0.13	0.10	0.18	0.21
Quintile 5	3591.0	2.77	−0.04	0.00	−0.12	0.08	0.14	0.17
Urban	4715.3							
Quintile 1	2778.9	2.13	−0.04	0.00	−0.12	0.08	0.14	0.17
Quintile 2	3144.2	2.47	−0.04	0.00	−0.11	0.07	0.12	0.14
Quintile 3	3701.6	2.59	−0.05	0.00	−0.12	0.07	0.14	0.16
Quintile 4	4496.1	2.69	−0.04	0.00	−0.12	0.08	0.14	0.16
Quintile 5	8356.4	2.76	−0.06	0.00	−0.11	0.05	0.10	0.11

Source: Results from the Egypt DCGE model.

Urban households also benefit from an increase in the economy-wide returns to labor and capital and from the higher overall level of economic growth in the country. It is typically the middle of the urban income distribution that benefits the most, owing to the fact that these quintiles rely more heavily on labor wages for their incomes. Moreover, these households are typically endowed with semi-skilled and high-skilled labor, which is used fairly intensively in the renewable equipment manufacturing sectors (for example, as operators and technicians).

Figure 2 shows the national distributional effects of the renewables strategy on households' equivalent variation. PV receives only a tiny share of the total investment volume of Egypt's renewable strategy and therefore generates very little additional value added in the economy, so its effects on household welfare are small. CSP and WIND are far more beneficial for households. Moreover, the welfare gains are evenly distributed across lower expenditure quintiles. Clearly, only if the renewables strategy is combined with a reduction of fuel subsidies will the strategy lead to significant improvements in income distribution. Lower-income households benefit the most from the expansion of overall activity in COMB3.

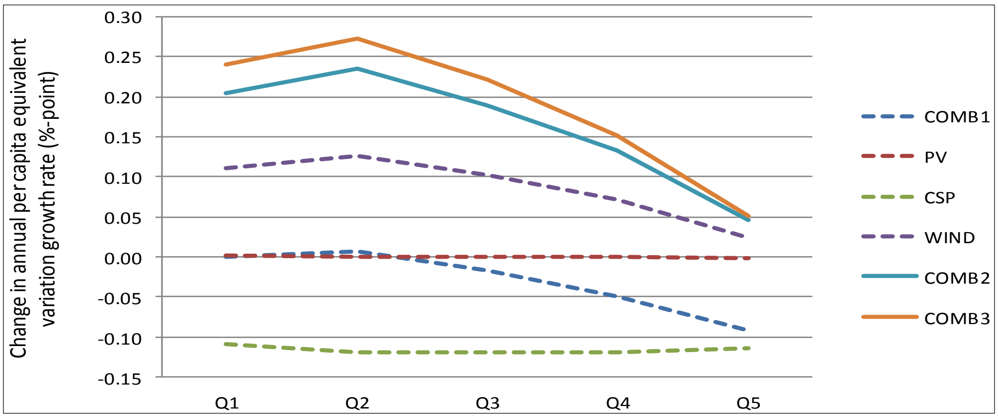

Figure 2. Change in per capita equivalent variation from baseline scenario by quintile, 2010–2020. Notes: Equivalent variation is a measure of household welfare that controls for changes in commodity prices. Source: Results from the Egypt DCGE model.

Table 10 reports changes in national and regional poverty rates for the various renewable scenarios. The headcount rate—which measures the share of the population below the poverty line—declines most under the renewable energy cum fuel sector liberalization scenario (COMB3). There is almost no poverty reduction, however, in the unilateral Egyptian renewables strategy (COMB1). Yet, if undertaken within a global climate protection system (COMB2) and combined with a reduction of fuel subsidies (COMB3), prices for conventional electricity and higher public investment in Egypt will benefit poor households, which earn most of their income from the provision of low-skilled labor to construction and the production of consumer nondurables, including food and agricultural products.

Table 10. Poverty results, 2008–2020.

	Poverty rate, 2008 (%)	**Baseline poverty, 2020 (%)**	**Deviation from final baseline scenario poverty rate (%age point)**					
			COMB1	**PV**	**CSP**	**WIND**	**COMB2**	**COMB3**
Headcount (P0)	21.8	12.2	0.0	0.0	0.3	−0.3	−0.5	−0.7
Rural	29.9	17.1	−0.1	0.0	0.3	−0.5	−0.9	−1.1
Urban	10.4	5.3	0.1	0.0	0.2	−0.1	−0.1	−0.2
Gap (P1)	4.5	2.3	0.0	0.0	0.1	−0.1	−0.2	−0.2
Rural	6.2	3.2	0.0	0.0	0.1	−0.1	−0.3	−0.3
Urban	2.0	1.0	0.0	0.0	0.0	0.0	−0.1	−0.1
Squared gap (P2)	1.4	0.7	0.0	0.0	0.0	−0.1	−0.1	−0.1
Rural	2.0	0.9	0.0	0.0	0.1	0.0	−0.1	−0.1
Urban	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0

Source: Results from the Egypt DCGE and microsimulation model.

5. Conclusions

Investments in renewable energy can be beneficial for economic growth, employment, and the poor. However, the quantity and quality of those benefits depend on the natural conditions, opportunity costs of conventional energy, structure of the economy, institutional capacity to implement energy sector reform, and other factors.

One of the countries that have significant potential for renewable energy production and ambitious plans for expansion is Egypt. While the recent political transition has put many initiatives on hold, the authors suggest that, under certain conditions, fostering the renewable energy strategy may be a promising way to provide an urgently needed impetus for the ailing economy. More specifically, the evidence-based results of our research lend themselves to the following recommendations.

- Egypt should focus on the generation of wind power. Not only is wind power the sole renewable energy source competitive without subsidies, but it is also among the most favorable for economic growth, employment, and poverty reduction.
- An export-led renewable energy strategy can offset some of the positive effects through Dutch disease. Results suggest that if all renewable energy planned under the Egyptian strategy is exported, these may compose up to 20% of all exports by 2020. Given the related appreciation of the real exchange rate and potential loss of jobs in other export sectors, it is advisable to consume a significant amount of additional energy domestically.
- The implementation of the renewables strategy should be accompanied by a reduction of energy subsidies. Energy subsidies distort markets and render most of the renewable energies uncompetitive; they also contribute to Egypt's high budget deficit. Reducing energy subsidies would not only lower the deficit but also support the development of renewable energies.
- While investments in renewable energy have positive growth and employment effects, their impact on the poor has been rather modest to date. Thus, if poverty reduction is the main policy goal, other policies that support broader-based growth and targeted social safety nets are more appropriate.

Finally, it is important to stress that the implementation of a renewable energy strategy can be very challenging and complex. For example, windmills and solar panels designed for a European climate may not function well in Egypt's desert region, where temperatures are higher and the volume of sand is a concern. If these potential caveats are carefully assessed, however, sun and wind have the potential to support economic development. Sound institutions, appropriate and lasting regulations, careful technology transfer, and cross-ministerial coordination are the keys to success.

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Author Contributions

All authors contributed equally to this work. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Appendix

Appendix A1: DCGE Model Variables and Parameters.

	Index subscripts		
i	Sectors and products	*h*	Households
f	Factors	*t*	Time periods
	Endogenous variables (* denotes fixed by closure)		
AR	Average economywide capital rental rate	PM	Import price
C	Household consumption quantity	PP	Producer price
CPI	Consumer price index *	PS	Supply price (without transaction costs)
D	Domestic production supplied to local market	PT	Total domestic supply price (all regions)
E	Export quantity	PV	Value-added price
ER	Nominal exchange rate	Q	Composite commodity supply (with imports)
FB	Recurrent fiscal balance	R	Government tax revenues
FS	Foreign savings (capital inflows) *	SK	Sectoral allocation of new capital
G	Government consumption quantity *	SP	Sectoral profit share
I	Total investment spending	SR	Sectoral return on capital
L	Transaction cost demand quantity	T	Total domestic supply quantity (all regions)
M	Import quantity	V	Factor demand
P	Market price	VS	Total factor supply *
PD	Domestic price (with transaction costs)	X	Gross output (by region)
PE	Export price	Y	Total household income
PK	Capital price	Z	Wage distortion term
	Exogenous variables		
cd	Marketing margin on domestic products	Γ	Export function shift parameter
ce	Marketing margin on exports	Λ	Production function shift parameter
cm	Marketing margin on imports	Φ	Region aggregation function shift parameter
d	Economywide capital depreciation rate	Ω	Import function shift parameter
gg	Government consumption growth rate	α	Production function share parameter
gp	Total factor productivity growth rate	β	Household marginal budget share
gv	Total factor supply growth rate	γ	Non-income-related consumption quantity
hw	Household foreign transfer receipts	δ	Factor income distribution shares

io	Input coefficient matrix	ε	Investment demand value shares
pwe	World export price	θ	Import substitution elasticity transformation
pwm	World import price	κ	Consumer price index weights
rw	Government foreign transfer receipts	μ	Import function share parameter
s	Marginal savings rates	ν	Region substitution elasticity transformation
tc	Commodity sales tax rate	ρ	Factor substitution elasticity transformation
te	Export tax rate	τ	Export function share parameter
tf	Factor tax rate (e.g., corporate tax)	φ	Export substitution elasticity transformation
tm	Import tariff rate	ψ	Region aggregation function share parameter
ty	Direct income tax rate	ω	New investment mobility parameter

Appendix A2. DCGE Model Equations.

$$PM_{it} = ER_t(1 + tm_i)pwm_i + \sum_{i'} P_{i't}cm_{i'i} \quad (A1)$$

$$PE_{it} = ER_t(1 - te_i)pwe_i + \sum_{i'} P_{i't}ce_{i'i} \quad (A2)$$

$$(1 - tc_i)P_{it}Q_{it} = PD_{it}D_{it} + PM_{it}M_{it} \quad (A3)$$

$$PD_{it} = PS_{it} + \sum_{i'} P_{i't}cd_{i'i} \quad (A4)$$

$$PT_{it}T_{it} = PS_{it}D_{it} + PE_{it}E_{it} \quad (A5)$$

$$PP_{irt} = PV_{irt} + \sum_{i'} P_{i't}io_{i'ir} \quad (A6)$$

$$X_{irt} = \Lambda_{irt}\left(\sum_f \alpha_{irf}V_{irft}^{-\rho_{ir}}\right)^{-1/\rho_{ir}} \quad (A7)$$

$$V_{irft} = \Lambda_{irt}^{-\frac{\rho_i}{1+\rho_{ir}}}X_{irt}\left(\alpha_{if}\frac{PV_{irt}}{Z_{irft}W_{ft}}\right)^{1/(1+\rho_{ir})} \quad (A8)$$

$$T_{it} = \Phi_{it}\left(\sum_r \psi_{if}X_{irt}^{-\nu_i}\right)^{-1/\nu_i} \quad (A9)$$

$$X_{irt} = \Phi_{it}^{-\frac{\nu_i}{1+\nu_i}}T_{it}\left(\psi_{if}\frac{PT_{it}}{PP_{irt}}\right)^{1/(1+\nu_i)} \quad (A10)$$

$$T_{it} = \Gamma_i\left[\tau_i D_{it}^{\varphi_i} + (1 + \tau_i)E_{it}^{\varphi_i}\right]^{1/\varphi_i} \quad (A11)$$

$$\frac{D_{it}}{E_{it}} = \left(\frac{\tau_i}{1 - \tau_i} \cdot \frac{PD_{it}}{PE_{it}}\right)^{1/(\varphi_i - 1)} \quad (A12)$$

$$Q_{it} = \Omega_i\left[\mu_i D_{it}^{-\theta_i} + (1 + \mu_i)M_{it}^{-\theta_i}\right]^{-1/\theta_i} \quad (A13)$$

$$\frac{D_{it}}{M_{it}} = \left(\frac{\mu_i}{1 - \mu_i} \cdot \frac{PM_{it}}{PD_{it}}\right)^{1/(1+\theta_i)} \quad (A14)$$

$$L_{it} = \sum_{i'}(cd_{ii'}D_{i't} + ce_{ii'}E_{i't} + cm_{ii'}M_{i't}) \quad (A15)$$

$$Y_{ht} = \sum_{irf} \delta_{hf}(1 - tf_f)Z_{irft}W_{ft}V_{irft} + hw_h ER_t \quad (A16)$$

$$C_{hi} = \beta_{hi}\left[(1 - s_h - ty_h)Y_{ht} - \sum_{i'} P_{i'}\gamma_{hi'}\right]P_i^{-1} + \gamma_{hi} \quad (A17)$$

$$R_t = \sum_i (tc_i P_{it} Q_{it} + tm_i pwm_i M_{it} + te_i pwe_i E_{it}) + \sum_h ty_h Y_{ht} + \sum_{irf} tf_f Z_{irft} W_{ft} V_{irft} \quad \text{(A18)}$$

$$R_t + ER_t rw = \sum_i P_{it} G_{it} + FB_t \quad \text{(A19)}$$

$$I_t = \sum_h s_h Y_{ht} + FB_t + ER_t FS \quad \text{(A20)}$$

$$I_t \varepsilon_i = P_{it} N_{it} \quad \text{(A21)}$$

$$\sum_{ir} V_{irft} = VS_{ft} \quad \text{(A22)}$$

$$Q_{it} = \sum_h C_{iht} + N_{it} + G_{it} + \sum_{i'} io_{i'i} X_{it} + L_{it} \quad \text{(A23)}$$

$$\overline{FS} + \sum_h hw_h + rw = \sum_i pwm_i M_{it} - \sum_i pwe_i E_{it} \quad \text{(A24)}$$

$$CPI = \sum_i P_{it} \kappa_i \quad \text{(A25)}$$

$$VS_{ft+1} = VS_{ft}(1 + gv_{ft}) \quad \text{where } f \neq k \quad \text{(A26)}$$

$$\Lambda_{it+1} = \Lambda_{it}(1 + gp_{it}) \quad \text{(A27)}$$

$$G_{it+1} = G_{it}(1 + gg_{it}) \quad \text{(A28)}$$

$$V_{irkt+1} = (1-d)V_{irkt} + SK_{irkt}\frac{I_t}{PK_t} \quad \text{where } PK_t = \sum_i P_{it}\varepsilon_i \quad \text{(A29)}$$

$$SK_{irkt} = SP_{irkt} + \omega SP_{irkt}\left(\frac{SR_{irkt} - AR_t}{AR_t}\right) \quad \text{(A30)}$$

$$SP_{irkt} = Z_{irkt} W_{kt} V_{irkt}\left(\sum_{i'r'k'} Z_{i'r'k't} W_{k't} V_{i'r'k't}\right)^{-1} \quad \text{(A31)}$$

$$AR_t = \left(\sum_{irk} Z_{irkt} W_{kt} V_{irkt}\right)\left(\sum_{irk} V_{irkt}\right)^{-1} \quad \text{(A32)}$$

$$SR_{irkt} = \frac{Z_{irkt} W_{kt}}{AR_t} \quad \text{(A33)}$$

Source: [35].

Appendix B. Macro SAM for Egypt 2008/2009 (billions £E)

	Activities	Commodities	Factors	Households	Government	Rest of the world	Savings-Investment	Direct taxes	Import tariffs	Indirect taxes	Total
Activities		1820.8									1820.8
Commodities	751.5			821.4	98.0	299.8	200.0				2170.6
Factors	1069.4										1069.4
Households			1067.5		42.0	42.3					1151.7
Government						3.4		141.3	14.1	−30.9	127.9
Rest of the world		366.6	1.9								368.5
Savings-Investment				189.0	−12.0	23.0					200.0
Direct taxes				141.3							141.3
Import tariffs		14.1									14.1
Indirect taxes		−30.9									−30.9
Total	1820.8	2170.6	1069.4	1151.7	127.9	368.5	200.0	141.3	14.1	−30.9	

Source: Results from the Egypt DCGE model.

References and Notes

1. International Energy Agency. *CO_2 Emissions from Fuel Combustion: Highlights 2012*; Organisation for Economic Co-operation and Development, International Energy Agency: Paris, France, 2012.
2. International Energy Agency. *Energy Technology Perspectives 2012: Pathways to a Clean Energy System*; Organisation for Economic Co-operation and Development, International Energy Agency: Paris, France, 2012.
3. This led to the occurrence, for the first time in history, of developing countries surpassing transition and industrialized countries in aggregate CO_2 emissions from the energy sector [1]. The net installations (that is, annual new power capacity installations without repowering) have been slightly larger for renewable energy technologies (RET) compared to conventional technology at the end of 2012.
4. Intergovernmental Panel on Climate Change. *Special Report on Renewable Energy Sources and Climate Change Mitigation*; Intergovernmental Panel on Climate Change: Cambridge, UK, 2011.
5. The global energy supply has not become significantly cleaner in the last two decades, as evidenced by the fact that the amount of CO_2 emitted for each unit of energy supplied has decreased by less than 1 percent since 1990. Coal-fired power generation rose by nearly 6 percent between 2010 and 2012 globally and continues to grow faster than non-fossil energy sources on an absolute basis.
6. Chow, J.; Kopp, R.J.; Portney, P.R. Energy Resources and Global Development. *Science* **2003**, *203*, 1528–1531.
7. Jakob, M.; Haller, M.; Marschinski, R. Will History Repeat Itself? Economic Convergence and Convergence in Energy Use Patterns. *Energy Econ.* **2012**, *34*, 95–104.
8. Global Energy Assessment. *Towards a Sustainable Future*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2012.
9. Popp, D.; Hascic, I.; Medhi, N. Technology and the Diffusion of Renewable Energy. *Energy Econ.* **2011**, *33*, 648–662.
10. Watson, J.; Sauter, R. Sustainable Innovation through Leapfrogging: A Review of Evidence. *Int. J. Technol. Glob.* **2011**, *5*, 170–189.
11. Rutovitz, J.; Atherton, A. Energy Sector Jobs to 2030: A Global Analysis. 2009. Available online: http://www.greenpeace.org/brasil/PageFiles/3751/energy-sector-jobs-to-2030.pdf (accessed on 12 June 2014).
12. REN21. *Renewables 2013 Global Status Report*; Renewable Energy Policy Network for the 21st Century (REN21) Secretariat: Paris, France, 2013. Available online: http://www.ren21.net/Portals/0/documents/Resources/GSR/2013/GSR2013_lowres.pdf (accessed on 5 June 2014).
13. International Energy Agency. *Tracking Clean Energy Progress 2013: IEA Input to the Clean Energy Ministerial*; Organisation for Economic Co-operation and Development, International Energy Agency: Paris, France, 2013.

14. Organisation for Economic Co-operation and Development. *Optimising Investment Incentives for Renewable Energy Projects in MENA: A Stocktaking Report*. MENA-OECD Task Force on Energy and Infrastructure, Working Paper; Organisation for Economic Co-operation and Development: Paris, France, 2012.
15. African Development Bank. *African Economic Outlook: Egypt*; African Development Bank: Tunis, Tunisia, 2013.
16. Breisinger, C.; Al-Riffai, P.; Ecker, O.; Abuismail, R.; Waite, J.; Abdelwahab, N.; Zohery, A.; El-Laithy, H.; Armanious, D. *Tackling Egypt's Rising Food Insecurity in Times of Transition*; Joint Country Policy Note; World Food Programme, Country Office Arab Republic of Egypt, and International Food Policy Research Institute: Washington, DC, USA, 2013.
17. A large share of poor and nonpoor people clusters around the poverty line, which can partially explain the rapid rate of increase of people moving into poverty in recent years.
18. US Energy Information Administration. *Egypt: Overview*; US Energy Information Administration: Washington, DC, USA, 2013.
19. Regional Center for Renewable Energy and Energy Efficiency. *Egypt Renewable Energy Country Profile*; Regional Center for Renewable Energy and Energy Efficiency: Cairo, Egypt, 2012.
20. African Development Bank. *Clean Energy Development in Egypt*; African Development Bank: Tunis, Tunisia, 2012.
21. Ibrahim, A. Renewable Energy Sources in the Egyptian Electricity Market: A Review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 2016–2030.
22. Desertec Industrial Initiative. *Economic Impacts of Desert Power*; Desertec Industrial Initiative: Munich, Germany, 2013.
23. The development of wind technology was initiated in 1996 when the New & Renewable Energy Authority (NREA) was formed. A series of large-scale grid-connected wind projects have been implemented with a total installed capacity of about 550 megawatts in 2010 [20].
24. Vidican, G. *Building Domestic Capabilities in Renewable Energy. A Case Study of Egypt*; Deutsches Institut für Entwicklungspolitik: Bonn, Germany, 2012.
25. Amer, H. Renewable Energy Strategy for 2020 and Regulatory Framework. Egyptian Electric Regulatory and Consumer Protection Agency. In Proceedings of the Global Workshop on Grid Connected Renewable Energy, Washington, DC, USA, 31 August–4 September 2009.
26. The Desertec vision aims to generate sustainable power from the sites where renewable sources of energy are most abundant and export it to regions like Europe with high electricity demand. This also contributes to combatting climate change, ensuring a reliable energy supply, and promoting security and development. Available online: http://www.desertec.org (accessed on 10 May 2014).
27. Fragkos, P.; Kouvaritakis, N.; Capros, P. *Prospects for Energy Supply and Demand in the Southern Mediterranean*; MEDPRO Technical Report No. 22 (interim version); CEPS: Brussels, Belgium, 2012.
28. Haller, M.; Ludig, S.; Bauer, N. Decarbonization scenarios for the EU and MENA power system: Considering spatial distribution and short term dynamics of renewable generation. *Energy Policy* **2012**, *47*, 282–290.

29. Massetti, E.; Ricci, E.C. An assessment of the optimal timing and size of investments in concentrated solar power. *Energy Econ.* **2013**, *38*, 186–203.
30. An aggregated macro-SAM can be found in Appendix B. For the detailed SAM, please contact the authors.
31. Central Agency for Public Mobilization and Statistics. Household Income, Expenditure and Consumption Survey, HIECS (2008/2009). Version 1.0 of the Licensed Data Files, Provided by the Economic Research Forum. Available online: http//www.erfdataportal.com/index.php/catalog (accessed on 20 November 2013).
32. International Labour Organisation. Key Indicators of the Labour Market (KILM 8). International Labour Organisation. Available online: http//www.ilo.org/empelm/what/WCMS_114240/lang--en/index.htm (accessed on 12 February 2014).
33. Central Agency of Public Mobilization and Statistics. *Supply and Use Tables for 2008/2009*; Central Agency of Public Mobilization and Statistics: Cairo, Egypt, 2013.
34. Calzadilla, A.; Wiebelt, M.; Blohmke, J.; Klepper, G. *Desert Power 2050: Regional and Sectoral Impacts of Renewable Electricity Production in Europe, the Middle East, and North Africa*; Kiel Working Paper 1891; Kiel Institute for the World Economy: Kiel, Germany, 2013.
35. Diao, X.; Thurlow, J. A Recursive Dynamic Computable General Equilibrium Model. In *Strategies and Priorities for African Agriculture: Economy-wide Perspectives from Country Studies*; Diao, X., Thurlow, J., Benin, S., Fan, S., Eds.; International Food Policy Research Institute: Washington, DC, USA, 2012.