Integrated Input-Output and Systems Analysis Modelling: The case of Tunisia. Part 2 - A systems model with IO multipliers

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Method Article

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Abstract

This work extends a simple open source energy systems model of the Tunisian electricity sector, used for research purposes. The extension includes addition of job creation multipliers from an Input-Output analysis. Test scenarios are then developed, to assess future emissions and job creation trajectories associated with the introduction of energy efficiency and renewable energy programs. The results indicate that increased economic efficiency associated with significant (but limited) injections of energy efficiency and renewable energy reduce gas imports, reduce emissions and increase local jobs. The analysis is cursory and initial. Its objective is to enhance open modelling that can be developed and co-created for deeper policy analysis.

1. Introduction

This is the second part of a two-part methodological paper on integrating an energy systems model, with an Input-Output (IO) model for Tunisia. In the first paper, we describe a simple IO model that examines direct and indirect job changes from various energy efficiency (EE) and power supply options in the Tunisian system. In this part we integrate it with an energy investments model created with OSeMOSYS (Open Source energy Modelling System). The focus of this paper is indicated in pink in Figure 1. Elements highlighted in white are included in part one of this paper.

To move from the static IO model and integrate it with OSeMOSYS we need to:

- Transform the job gains and job loss numbers obtained from the Input-Output analysis into coefficients to be fed to OSeMOSYS. This is most conveniently[1] done, by adding them in the form of 'emission factors'.
- Those factors should be added to the appropriate technologies in the system, to avoid double counting. A typical representation is by using a Reference Energy System (RES).
- Thereafter we develop scenarios, to prove the method and analyse the types of insights obtained. The first is taken as reference and thereafter policy scenarios are compared to it.

1.1 Background

In 2012, the Wuppertal Institute modelled scenarios of development of the electricity sector of Tunisia, including changes in demand and investments in supply infrastructure [1]. The study utilises a suite of models. The investment scenarios are modelled with a simulation framework (PlaNet). Investments are not optimised according to e.g. least-system-cost criteria. Only the intra-annual operation of electricity supply technologies and network is optimised.

The first long-term energy investments optimisation model of Tunisia was published by Dhakouani et al. in 2017 [2]. The model is created in OSeMOSYS and represents the electricity sector. It presents an initial approach to account for jobs created by technological shifts. It quantifies the number of jobs created when installing new electricity generation capacity in Tunisia, as proportional to the installed capacity. It embeds in OSeMOSYS job creation coefficients in number of jobs per unit of installed capacity. The coefficients are derived from literature [3], [4]. It then imposes a job creation target, according to government plans [5], [6]. The target causes the choice of investments to meet future electricity demands to shift towards renewable technologies, because these have higher coefficients than thermal power plants. However, the coefficients are assumed exogenously and not derived from a structured study of the entire Tunisian economy. Furthermore, they do not consider job losses related to technological changes. The model is further developed and used for analysing the impact of planned decrease of system reliability (through peak clipping) on the penetration of variable renewables [7]. More energy-economy modelling efforts have recently started, in the North African context. Y. Radi created an energy-economy model for Egypt, by linking an energy investment model in OSeMOSYS to an IO model [8]. In this application, the results of the energy investment model are fed into the IO model to assess economy and job impacts of energy investments. Other similar models have been published in the MENA region. Saadeh et al. initiated a similar effort as in Tunisia for the case of Jordan [9]. They published an open access dataset for replicating and extending an electricity system model in OSeMOSYS or a similar bottom-up energy modelling tool. Taliotis et al. created a detailed model of the electricity system of Cyprus [10]. They used the model to assess the potential of natural gas for energy security and fast ramping generation [11] and the integration of renewable energy [12]. All these efforts share the objective of creating open source and replicable energy investment models. The models are all meant to be built upon in a modular way to extend the sectoral coverage of the analyses, increase the data granularity and add insights on macroeconomic impacts. This paper implements the same idea and uses the same modelling tools. It adds to knowledge by consolidating a methodology for open energy-economy modelling and showing an application. The methodology may serve to complement all above modelling efforts and support the creation of a community of practice for energy-economy modelling in the MENA region.

The rest of the paper includes a description of the electricity sector and policies in Tunisia, the job gains and losses figures obtained from the IO analysis (part one of this paper), the assumptions of the electricity model, the scenarios, the results and finally the policy implications, limitations and recommendations for future work.

[1] An emission factor relates the activity of technology to an emission of a pollutant or material. In this case, rather than an emission it will be used to track jobs lost, or jobs created.

2. Methods And Tools

This section describes the electricity component of the model used in this analysis. Primary data is provided by the Tunisian Company of Electricity and Gas (STEG), complemented with other sources and checked against the International Energy Agency's world energy balances [13].

2.1. Structure of the Tunisian electricity system

The Tunisian power system is dominated by gas supply with increasing, albeit still low, levels of renewable energy technology (RET). The need for gas is met almost equally with imported gas (mainly from Algeria) and domestic gas resources. The use of electricity interconnections with neighbouring countries is limited [14]. Domestic resources of coal are scarce and not exploited. Domestic resources of oil are not anymore exploited either. The country has been struggling with a status of energy deficit in the past decade, mostly due to improvement of living conditions, increased final energy consumption and decline of domestic production. The deployment of renewables has been hampered by policies subsidising the final consumption of electricity [2].

The country's strategies for the energy sector aim to achieve the Intended Nationally Determined Contributions submitted to UNFCCC in 2015 [15]. Main points in the mitigation goals are the increase of renewable penetration in electricity supply and the reduction of primary energy use through energy efficiency measures. The National Appropriate Mitigation Actions turn the above in feasible goals for the country [16]. The Tunisian Solar Plan (PST) further concretises the renewable targets and is the reference strategy for the development of renewables and energy efficiency measures in the country [4].

Unemployment in Tunisia has been increasing since 2014. The government has set objectives to create jobs and the energy efficiency and renewable sectors have a potential to create new jobs [17]. At the same time, the impacts on the economy of reduced use of gas need to be evaluated carefully. While reducing use of imported gas could have positive effects, reducing use of local gas and operation of local gas-fired power plants could cause loss of jobs.

Key features of the existing power system are summarised below and provided by STEG, when not indicated otherwise.

- In 2017, 73 PJ of electricity was generated according to the IEA [13], almost entirely from gas-fired power plants and using around 160 PJ of gas to produce that in the process. Imports of electricity accounted for only around 2 PJ in the same year and were balanced out by exports.
- Of the gas used in the entire economy, national production accounted for just under 40%. Imported gas just over 60%. The latter may fuel natural gas expansion.

- Transmission and distribution losses amounted to 18% in 2017 and are expected to reduce to 11% by 2022.
- Currently, there is 245MW of wind power, 30MW solar and 62MW of hydro in the power system. The remainder of the country's ca 5 GW of installed capacity comprises gas fired power plants.

2.2. Model structure

Including the IO job multipliers allows for a very initial (and limited) level of integration between an IO and energy systems model. Below, we suggest further steps that might be considered to increase integration.

To do so, the aforementioned average job-gains and job-losses are added to the OSeMOSYS model and represented as 'emissions'. CO_2 emissions are also represented. By doing this, different configurations of the energy system are associated with a simple estimate of jobs lost and gained in a semi-dynamic fashion.

For job losses and gains, we do this specifically for: Combined Cycle Gas Power Plants, Open Cycle Gas Power Plants, Solar PV, Concentrating Solar Power, Wind onshore and offshore, Residential Energy Efficiency, Commercial Energy Efficiency and Industrial Energy Efficiency programmes, and Electricity import. This is a limited and cursory set of potential interventions. It is also a limited set of potential interactions between elements of the IO and systems model. Further, many elements of this analysis are static, but the ambition is to develop a clear and simple 'first step'.

Similarly, CO_2 emissions are tracked for the key fuel used for bulk power generation, namely natural gas. For simplicity, it is assumed that the bulk of the natural gas extracted (nationally) and imported for the power sector is used and burned in the power sector. Accordingly, gas heading for the power sector, and resulting emissions are tracked.

In the Reference Energy System (RES) in Figure 2, boxes indicate groups of technology. Lines indicate flows. Coloured lines represent energy flows and trace energy movement from supply to power station operation to transmission and distributions to demand; lines in black track job-losses or gains as a function of the operation of the technology and CO_2 emissions.

Elements of the real system were simplified for the purpose of this study to keep the representation intuitive, yet realistic. Coal and nuclear power plants are disregarded, as not officially accounted for in present strategies. Current gas fired power plants are included in the model separately and here grouped by type for sake of representation. Future gas fired power plants are represented as aggregated capacity, instead.

The model period covers the years from 2015 (for calibration with the IO model) to 2040.

Every year is divided in 108 parts, i.e. in 7 seasons, 2 day-types (workday and weekend) and 8 parts of the day, in the attempt to capture as much as possible the variations of the demand and of the availability of renewable sources. The global discount rate used in the model is 8%, equivalent to the one considered in the IO model. Table 1 summarises other overall characteristics of the study.

Table 1. Overall characteristics of the model.

Time period	2015-2040
Time resolution	108 parts in one year: 7 seasons * 2 day-types (weekday and weekend) * 8 parts in one day
Global discount rate	8%
Depreciation method	Straight-line

2.3. Job gains and losses as 'emission factors'

As mentioned, the link between the IO model developed in part one of this paper and the energy investment model lies in the coefficients representing job gains and job losses. These coefficients are added to OSeMOSYS in the form of 'emission coefficients' for the aforementioned reasons. The methodology was previously developed and based on efforts applied in various peer reviewed studies[4–7]. Here a description of the main features of the link between the energy and the IO model is given:

- Emission factors are entered as a function of the activity of the selected technology.
- In the previous part of the paper, job impacts related to investments in energy efficiency measures and in new electricity generating capacity are computed. They vary over time, with changes during the construction or implementation and running of the energy efficiency, gas or renewable energy project. In OSeMOSYS, they are introduced as averages and as emission factors. To do so, we divide the total job-gains or job-losses by the number of years of the economic life of the power plant or energy efficiency measure operates.
- In the static IO analysis, we made the important assumption that we will decompose when using OSeMOSYS. This decomposition is done as OSeMOSYS is dynamic. Specifically this is around imports of natural gas:
    - In the static analysis, it was assumed that an intervention would change the amount of gas-powered electricity generation. This was entered as exogenous assumption and can now be endogenised. Job-gains for domestic gas extraction as well as the building of new power plants are accounted for.
    - For energy efficiency, this allows OSeMOSYS to endogenously calculate changes in the need to build and import gas, as lower electricity use will require less generation.
    - For renewables investment, this allows OSeMOSYS to determine the level of gas fired generation displaced, and with that the proportion of imported gas used.

The job-loss and job-gain numbers calculated in part one of this paper are reported in Table 2, as thousands jobs per PJ and per year. They are computed for the whole national economy and they include both direct and indirect effects. This overcomes a limitation highlighted in Dhakouani et al. [2]. They are disaggregated by potential technology investments. The values refer to the first year of the time domain (2015). Those followed by a downward facing arrow decrease during the time domain of the study, due to the assumption of decreasing capital costs.

Table 2. Job-gains and job-losses per energy system element.

Technology*	**Job creation coefficient (1000 jobs / PJ - year)**	**Job loss coefficient (1000 jobs / PJ - year)**
450 MW new CC	0.32	0.58
300 MW new GT	0.40	0.82
Onshore wind	0.58	0.43
Offshore wind	1.20	0.87
Wind autoproduction	0.67	0.51
Solar PV utility scale	0.64↓	0.46↓
CSP (concentrating solar power)	1.30 ↓	1.02↓
Solar autoproduction	0.71↓	0.51↓
Energy Efficiency – Residential	0.41	0.26
Energy Efficiency – Commercial	0.37	0.21
Energy Efficiency - Industrial	0.52	0.24
Electricity import	0	0.71

While taking this approach is an advance as it allows a first analysis of its type for Tunisia, it has important limitations. While the limitations are not addressed in this work, the model(s), data and approach are deliberately developed to allow for advances and changes to be facilitated and easily made in future work.

The data in the table, derived from Part One of this paper, are subject to a range of assumptions. Those include costs, payback and local content. None of those are precise and they are also a function of policy. If targeted, for example, local content in the measures might be higher than those assumed.

The results are also impacted by assumptions made in the economy analysis. The economic analysis is based on the IO Table of Tunisia. In the table, the electricity sector is aggregated together with the gas and water sectors. Similarly, one average value for wages across sectors was used, in the absence of more aggregated information.

As job-gains and job-losses are entered as 'emission factors' in OSeMOSYS to allow for the integration, they represent average per-unit effects of the power plants and energy efficiency interventions. Those per unit averages are used in calculations when the intervention is actively producing or saving electricity use. Ideally, they would be split further. They should indicate the job impacts as a function of the capacity of the intervention as well as during production. This is because, especially in the case of very high RET (not examined here), there will be the need to increase investment in conventional power plants simply to provide extra reserves. Reserve capacity may operate for very limited periods during the year. Their investment will change economic flows in the system and impact jobs.

In future work, it is recommended that an extra equation is added to OSeMOSYS to allow for job gains and losses as a function of capacity, not just activity. That will allow for the representation of money flows (and job impacts) as a function relating to capital repayment and fixed operating and maintenance costs that are independent of the power plant's load factor.

2.4. Demand projections

The electricity demand projection is assumed according to projections by STEG and is reported in Table 3. It excludes the 'auto-production', i.e. the estimated self-production by de-centralised rooftop PV and wind. The assumed self-production by the latter two, in terms of projected installed capacity, is given in Figure 3. The demand projection includes, on the contrary, impacts of energy efficiency measures. The load profile is calculated from half-hourly electricity load data from STEG, for year 2017. It can however be customised for every year.

Table 3. Electricity demand growth assumed for Tunisia.

Year	2015	2019	2020	2025	2030	2035	2040
Demand (PJ)	56.4	71.3	66.8	86.9	106.2	124.4	142.4

2.5. Performance characteristics of power plants

Power plant techno-economic characteristics data is provided by the electricity and gas utility STEG for almost all power plant types. When not available through STEG, it is derived from literature as follows. The capital cost for Concentrating Solar Power (CSP) is derived from IRENA, assuming the technology of choice will be parabolic trough with a storage capacity of 4 to 8 hours, taking a lower end cost for 2018 [18] and assuming a trend of cost decrease by STEG. The capacity factor of CSP is assumed to be constant and suggested by STEG. Biomass power plants are assumed to be fed with agricultural waste and their characteristics are assumed as the averages for power plants in Europe as given by IRENA [18]. For offshore wind turbines, the capital cost for a 250 MW park to be built off the Sicilian coast by an independent developer (Copenhagen Offshore Partners) is assumed as representative and taken from online news [19]. Other data is derived from that of onshore wind turbines and a capacity factor constantly 7% higher than the one of onshore wind turbines is assumed. For energy efficiency measures, the capital costs are assumed by the authors, hypothesising a payback time of 5, 4 and 6 years (respectively, for commercial, industrial and residential measures) and an avoided electricity cost equal to the average electricity tariff in Tunisia as obtained from RES4MED [20]. All these are assumptions, developed by the authors in the absence of more precise data, and need to be tested and updated by analysts in the openly available model.

All key techno-economic assumptions are summarised in Table 4. For batteries, it must be noted that costs are all given per unit of energy stored. Where a downward facing arrow is provided next to the cost figure, it means that the given cost refers to the start of the modelling period and it is assumed to decrease through the years, according to trajectories developed by STEG.

Table 4. Techno-economic characteristics of power plants.

	Capital Cost MUSD/GW	VOM MUSD/PJ	FOM MUSD/GW	Efficiency %	Max CF %	Availability %	Lifetime Years
New CCGT	950	0.39	8.52	54%	100%	85%	30
Existing CCGT	-	0.40	8.99	48%	100%	86.3%	30
New OCGT	642	0.65	10.8	36%	100%	88.5%	30
Small OCGT	-	-	20	28.7%	100%	89.2%	30
Hydro	-	-	14.4	-	9.5%	100%	100
Pumped Storage	808	-	20	-	-	-	50
Solar PV farm	800↓	-	20↓	-	15% (average)	98%	25
Solar PV rooftop	880↓	-	22↓	-	15% (average)	98%	25
Concentrating Solar Power (CSP)	4700↓	1.39	141↓	-	45% (constant)	98%	30
Biomass	1250	1.39	62.5	30%	85% (constant)	100%	
Batteries utility scale	83333↓ in MUSD/PJ	0.83 in MUSD/PJ	2500↓ in MUSD/PJ	90%	100%	100%	15
Steam Turbine	-	-	21	32.7%	100%	81.7	40
Wind onshore	1300	2.22	39	-	28.3% (average)	98%	25
Wind offshore	2964	2.22	88.9	-	35.3% (average)	98%	25
Commercial EE	2186	-	-	-	-	-	10
Industrial EE	2448	-	-	-	-	-	10
Residential EE	2623	-	-	-	-	-	10

2.6. Fuel prices

The current and projected price of natural gas is provided by STEG and it has been updated to take into account the decrease in international prices resulting from the COVID-19 pandemic. It is given in Figure 4.

2.7. Test scenarios

Scenario development is undertaken in order to help unpack the insights potentially deriving from this methodological approach. For this purpose, we allow the cost optimisation to deviate from the strategies and decisions of the electricity utility and of the government. The latter are analysed in the case study paper linked to this publication. Here, we are first interested in historic trends to form a reference: what would happen if historic trends were continued - i.e. the future was frozen to limit potential decisions? This helps to create a basis against which policies, programmes and projects can be evaluated. We can then take other scenarios and compare the changes in costs, jobs and CO_2 emissions to this scenario. It helps us to understand if any changes we make result in costs or benefits - and what the relation between the two are.

We use the Open Source energy Modelling System (OSeMOSYS) as it calculates dynamic changes to the system - but ensures that the system configuration is thermodynamically consistent (recall that this was a limitation in a standard IO model). In OSeMOSYS we determine levels of substitution and interactions that happen as RET replaces gas and EE changes electricity supply requirements. To do so we make assumptions about the relative roles that RET and EE might play in the economy. These are assumptions, based on studies and targets by STEG and the National Agency for Energy Management (ANME). Note that these can be adjusted as new information becomes available.

In summary we assume:

- Deployment of wind, solar and biomass aiming to reach 30% share of renewables in electricity generation, based on the Tunisian Solar Plan [4]. Here we assume the capacity of each technology is at least equal to what was planned in the Tunisian Solar Plan by 2030, but we allow it to be higher if cost-optimal.
- Potential energy efficiency deployment is allowed to penetrate, reducing electricity demand by 30% in 2030. This is an extrapolation of the INDC objective of reaching 30% reduction of primary energy demand in 2030 compared to reference. We assume a mix of energy efficiency measures in industrial, commercial and residential sector as follows:
    - 11% by aggressive measures in the industrial sector
    - 8% by aggressive measures in the commercial sector
    - 10% by aggressive measures in the residential sector

Assumptions reflect commitments as well as results of studies on energy efficiency potentials. For instance, the NAMA of Tunisia highlights high potential for energy efficiency in the cement sector, the highest emitting industrial sector in Tunisia [16]; GIZ and ANME highlight potential in the buildings sector, for instance through roof insulation and energy-saving lamps [17].

Higher levels of RET penetration and EE reductions are possible. However, they will require structural adjustments that will incur non-trivial non-marginal changes to the system.

Based on these considerations we define four scenarios. The scenarios are limited as we are interested in tractability and exploring selected insight. In summary, those are:

- '**Frozen Future**' **(FF)**, which continues historic trends. Besides the already committed investments in renewable technologies scheduled until 2025, it invests only in gas to meet new demands.
- '**Energy Efficiency**' **(EE)**, that allows for the maximum energy efficiency penetration described above, totalling approximately a 30% reduction in demand by 2030, compared to baseline projections. For comparative purposes, all other aspects are kept as in the Frozen Future scenario.
- '**Renewable Energy Technology (RET)**', that allows for investments in variable RET, aiming for RET to reach 30% of the total electricity generation by 2030 (including hydro) and potentially overshoot the target. For comparative purposes, all other aspects are kept constant. Investments in hydro power are not allowed and investments in biomass are allowed just up to the extent discussed in the Tunisian Solar Plan, since no higher potential is yet proven or discussed locally.
- '**Clean Growth' (CG)**, combining the assumptions of the EE and RET scenarios.

3. Results

In this section generation, capacity, GHG emission and job-loss/gain results are reported.

3.1. Generation

In all scenarios we see a reduction in gas-fired power generation compared to the Frozen Future. As we assume that there will not be an increase in domestic gas production, all new production is fuelled by imports.

In Figure 6, 7 and 8, we see aggressive inroads made by energy efficiency, renewables and both of those in CG. However, of interest is that gas remains important - and the dominant fuel source. In the case of increased RET levels it plays an important role, balancing RET variability to provide predictable demand-following electricity supply.

3.2. Capacity

Capacity is shown in Figures 9 to 12. Gas capacity needs to grow to meet growing demand - in the FF scenario. The capacity increases by about two and a half times. In the EE scenario, the gas capacity growth drops significantly - and only doubles by the end of the period. In the RET scenario, the capacity less than doubles. On the other side, given that RET options have a low load factor, there are disproportionately large increases in renewables (the load factor is low, as the sun does not shine, nor the wind blow, all the time). Allowing concurrent energy efficiency investment at the same time as RET reduces the large gas capacity requirement - as seen in the CG Scenario.

3.3. Job creation and GHG emissions

In Figure 13 and 14, we compare emissions and job gains, respectively. Emissions are described in absolute terms, while job creation is relative to the FF scenario.

In all cases emissions are reduced compared to the FF scenario. Both RET and EE are chosen in the model indicating economic gains, and the model chooses to combine them in the CG scenario. Not surprisingly, therefore, there is an increase in jobs in all three scenarios compared to the FF, as imported gas is replaced by renewable and energy efficiency options. Renewable and energy efficiency options result as having higher employment rate (per unit of activity) than gas, according to the assumptions and methodology of this study. However, in absolute terms almost all scenarios apart from the CG scenario result in job-losses. This happens due to gas being by large the dominant source of electricity supply in those scenarios.

If the economy did not have a growing power sector to supply the energy it needs, there would be massive economic loss. Energy and electricity in particular is needed for economic development. Expanding the power system based on natural gas (to large extent imported) results in losses - as money is lost from the economy. Nonetheless, we note in Figure 14 relative increase in jobs associated with moving to energy efficiency and RET.

4. Discussion

We presented a simple and open source methodology to obtain an estimate of job loss and creation effects due to dynamic replacements in electricity supply options. The latter are calculated on the basis of thermodynamically sound constraints and least cost criteria, filling gaps of traditional Input-Output analyses.

This methodology and its application to test scenarios may provide key indications for policy design. Picking the example presented above for validation, the first indication is that moving to a cleaner and more economically efficient system with higher growth requires high capital outlays. Though once levelised they result in a lower cost system, changes in financial flows will result.

Additionally, if high RET and energy efficiency futures are embarked on, it is clear that there will be job losses, but importantly also job gains. This will imply a need for vocational training to identify and ensure high local participation. Those will include construction jobs with a specific focus on energy efficiency by sector as well as those required for fitting rooftop PV or solar farms etc. Therein should be a special focus on the sustainability of that job-demand to ensure that expectations of the workforce are calibrated - and mapped with the local capacity for training such.

The test scenarios used in this study show that the extent of capital investment required for a least-cost and low-carbon transition depends on cost trajectories for those technologies still expected to have developments, especially RET. The number of jobs gained versus the jobs lost seems to depend highly on the local content of the investments in new technology and infrastructure, but also on their techno-economic characteristics (capital costs and capacity factors, especially). The outcomes of technology-specific studies for the context of Tunisia, especially related to solar, wind and biomass, could be used to refine the assumptions in this study and obtain more thorough insights on potential job creation under a range of likely futures.

5. Limitations

All elements of this analysis can be **u**biquitously **R**etrieved, **R**e-used, **R**econstructed, **R**epeated this allows for **I**nteroperability and **A**uditability (u4RIA) [21]. This paper applies an u4RIA approach in order to ensure FAIR (findability, accessibility, interoperability, reusability) scientific and sustainable development principles are applied [22].

However, part of that data is limited and there is scope to increase its granularity and account for locally specific costs. Including this analysis, or elements of it in continuous processes such as local teaching and research programs will be important. This because, although the models are open and available, there is up to now no process for systematic update or continuous development in place.

In terms of the integration component of the analysis, there is clear scope for development. Some key limitations include that:

- Changes in electricity demand will occur with changes in the economic activities that results in the job losses or gains.
- In this representation, we do not track changes in economic activity (such as GDP).
- In this representation, we link job losses and job gains to the level of activity of technologies rather than to their capacity. This may bias results in case where significant investments are made in technologies used for backup and peak-load generation.

Finally, where the share of variable RET in electricity supply is expected to grow significantly, the reliability of supply may decrease. The feasibility of the electricity supply mix resulting from OSeMOSYS (including probability of lost load or unmet demand) needs to be assessed with appropriate tools. This can be done by analysing the results here obtained (available generating capacity and reserve capacity) with operation and dispatch modelling tools.

6. Recommendations

Stemming from this analysis are several clear recommendations. They focus on the IO model, the OSeMOSYS model, model integration and the modelling process.

In terms of the IO model, it is suggested that there is at least an annual update. This would focus both on updating the data used as well as improving its granularity. A specific shortfall in the raw data used, was that the electricity data is integrated with gas. Further, more detailed investigation of financial flows for a more detailed array of investments should be investigated, informed by the macro results described here. Finally, for local ownership it could be important to use locally developed Input-Output tables.

In terms of OSeMOSYS, it would be useful to develop more detailed information on the energy efficiency potential by sector.

In terms of integration, extending the scope of both the IO and OSeMOSYS model to explore other energy forms will help capture a more comprehensive picture vis a via RET and other energy efficiency. Inclusion of changes in demand as a function of interventions is an important next step. This will help investigate whether or not the lower cost energy system might result in a rebound in demand. In turn, that would allow analysis of future needs and other indirect effects. Key questions would be: Would emissions increase? Would this create new opportunities for higher RET and EE deployment? Further, the IO used is static, but the economic structure will change over time, together with technology development in the energy sector. Mapping cost, performance and economic interactions with those will fill a gap systematic of this and other studies of its type.

Abbreviations

EE Energy Efficiency

IO Input-Output

PST Tunisian Solar Plan (Plan Solaire Tunisien)

RET Renewable Energy Technology

Declarations

Data availability

The data supporting this analysis is openly available under license CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/) and annexed to this publication.

Author contributions

Mark Howells: conceptualisation, methodology, data curation, visualisation, investigation, original draft preparation; Thameur Necebi: methodology, data curation; John Skip Laitner: methodology, investigation; Francesco Gardumi: methodology, data curation, visualisation, investigation, writing, review and editing; Franziska Bock: data curation, review, editing.

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Conflicts of interest

The authors declare no conflict of interest.

References

[1] S. Lechtenböhmer, A. Durand, M. Fischedick, A. Nebel, O. Soukup, and S. Wane, "Etude Stratégique du Mix Energétique pour la Production d'Electricité en Tunisie: Rapport Final," Wuppertal Institut für Klima, Umwelt, Energie GmbH, Wuppertal, Germany, Apr. 2012. Accessed: Apr. 02, 2020. [Online]. Available: https://epub.wupperinst.org/frontdoor/deliver/index/docId/4785/file/4785_Mix_Energetique_Tunisie.pdf.

[2] A. Dhakouani, F. Gardumi, E. Znouda, C. Bouden, and M. Howells, "Long-term optimisation model of the Tunisian power system," *Energy*, vol. 141, pp. 550–562, Dec. 2017, doi: 10.1016/j.energy.2017.09.093.

[3] République Tunisienne Ministère de l'Industrie, de l'Energie et des Mines, "Strategie nationale de maîtrise de l'energie: objectifs, moyens et enjeux," Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Jun. 2014. Accessed: Apr. 03, 2020. [Online]. Available: https://www.giz.de/en/downloads/giz2014-fr-strategie-energie-tunisie.pdf.

[4] Agence Nationale pur la Maitrise de l'Energie, "Plan Solaire Tunisien: Programmation, conditions et moyens de la mise en oevre," Tunis, Tunisia, Apr. 2012. Accessed: Apr. 01, 2020. [Online]. Available: http://www.anme.nat.tn/fileadmin/user1/doc/DEP/Rapport_final__PST.pdf.

[5] E. Llera, S. Scarpellini, A. Aranda, and I. Zabalza, "Forecasting job creation from renewable energy deployment through a value-chain approach," *Renew. Sustain. Energy Rev.*, vol. 21, pp. 262–271, May 2013, doi: 10.1016/j.rser.2012.12.053.

[6] M. Wei, S. Patadia, and D. M. Kammen, "Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?," *Energy Policy*, vol. 38, no. 2, pp. 919–931, 2010.

[7] A. Dhakouani, E. Znouda, and C. Bouden, "Impacts of energy efficiency policies on the integration of renewable energy," *Energy Policy*, vol. 133, p. 110922, 2019.

[8] Y. Y. Rady, "An Integrated Energy Economic Interaction Model with Application to Egypt," PhD Thesis, American University in Cairo, Cairo, Egypt, 2019.

[9] O. Saadeh, Z. Dalala, T. Niet, E. P. Ramos, and M. Howells, "Technoeconomic data adopted for the development of a long-term electricity supply model for the Hashmite Kingdome of Jordan," *Data Brief*, vol. 30, p. 105391, Jun. 2020, doi: 10.1016/j.dib.2020.105391.

[10] C. Taliotis, E. Taibi, M. Howells, H. Rogner, M. Bazilian, and M. Welsch, "Technoeconomic assumptions adopted for the development of a long-term electricity supply model for Cyprus," *Data Brief*, vol. 14, pp. 730–737, Oct. 2017, doi: 10.1016/j.dib.2017.08.019.

[11] C. Taliotis, H. Rogner, S. Ressl, M. Howells, and F. Gardumi, "Natural gas in Cyprus: The need for consolidated planning," *Energy Policy*, vol. 107, pp. 197–209, Aug. 2017, doi: 10.1016/j.enpol.2017.04.047.

[12] C. Taliotis, E. Taibi, M. Howells, H. Rogner, M. Bazilian, and M. Welsch, "Renewable energy technology integration for the island of Cyprus: A cost-optimization approach," *Energy*, vol. 137, pp. 31–41, Oct. 2017, doi: 10.1016/j.energy.2017.07.015.

[13] International Energy Agency, "IEA Countries and Regions: Tunisia." https://www.iea.org/countries/Tunisia (accessed Apr. 01, 2020).

[14] International Energy Agency, *World Energy Balances 2019*. Paris, France: International Energy Agency, 2019.

[15] Ministry of Environment and Sustainable Development, "Intended Nationally Determined Contribution - Tunisia," Republic of Tunisia, Tunis, Tunisia, Aug. 2015. Accessed: Aug. 21, 2020. [Online]. Available: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Tunisia%20First/INDC-Tunisia-English%20Version.pdf.

[16] "National Appropriate Mitigation Action (NAMA) Database." http://www.nama-database.org/index.php/Tunisia (accessed Apr. 01, 2020).

[17] GIZ and ANME, "Renewable energy and energy efficiency in Tunisia – employment, qualification and economic effects," Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2012. Accessed: Apr. 07, 2020. [Online]. Available: https://energypedia.info/images/8/85/EN_Renewable_energy_and_energy_efficiency_in_Tunisia_GIZ_2012.pdf.

[18] IRENA, *Renewable Power Generation Costs in 2019*. Bonn, Germany, 2020.

[19] Tuniscope, “Un parc éolien flottant entre la Sicile et la Tunisie,” *TS Tuniscope*, Jun. 19, 2020. https://www.tuniscope.com/article/205908/tech/high-tech/eolien-102212 (accessed Nov. 10, 2020).

[20] L. Detoc, “RES4MED Country Profiles: Tunisia,” RES4MED, Nov. 2016. Accessed: Apr. 02, 2020. [Online]. Available: https://www.res4med.org/wp-content/uploads/2017/11/Country-Profile-Tunisia-Report_05.12.2016.pdf.

[21] M. Howells *et al.*, “Energy system analytics and good governance-U4RIA goals of Energy Modelling for Policy Support,” 2021.

[22] S. Collins *et al.*, “Turning FAIR into reality: Final Report and Action Plan from the European Commission Expert Group on FAIR Data,” European Commission, Directorate-General for Research and Innovation, Brussels, Belgium, 2018. Accessed: Jan. 04, 2021. [Online]. Available: https://ec.europa.eu/info/sites/info/files/turning_fair_into_reality_0.pdf'.

Figures

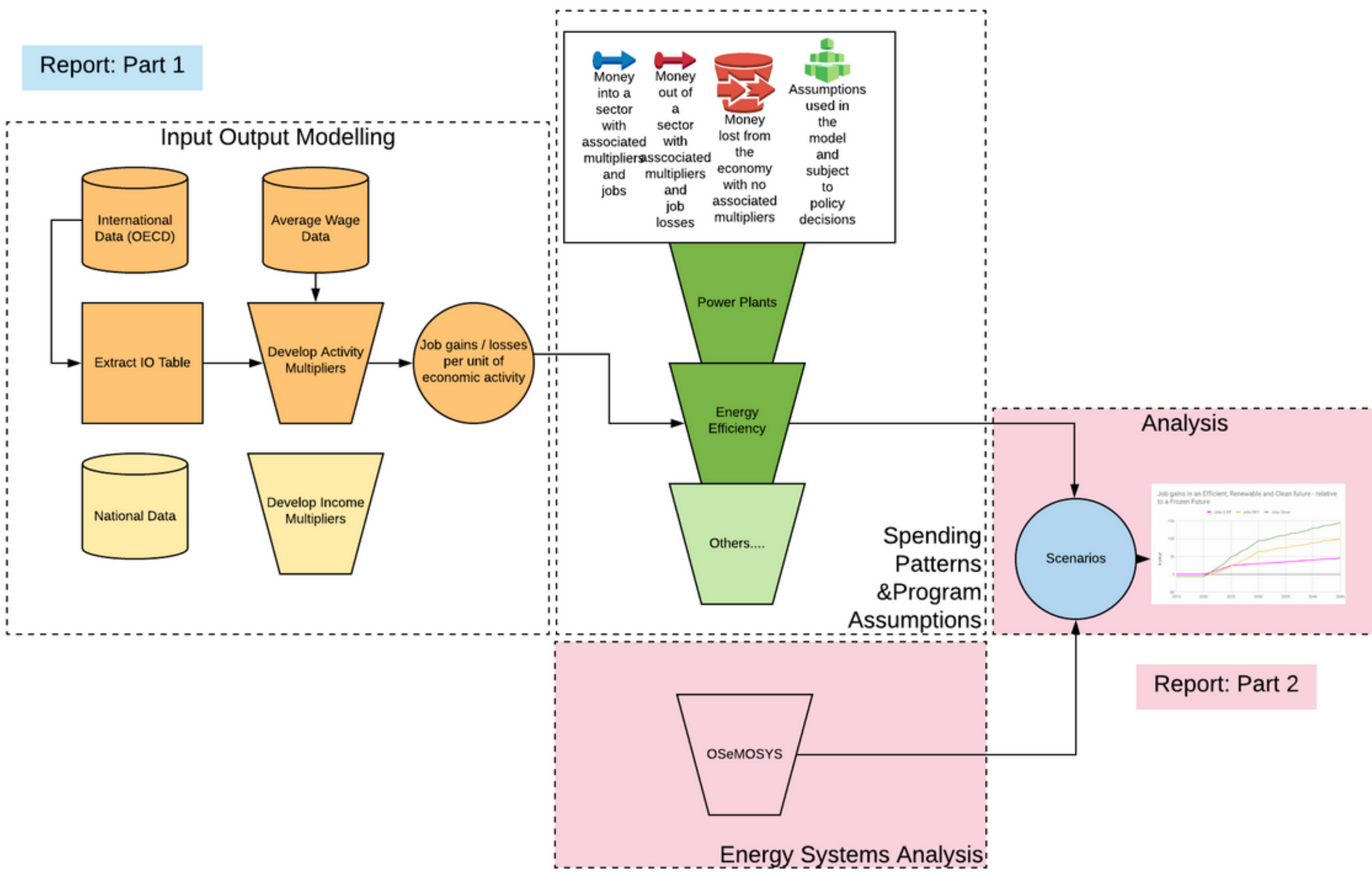

Figure 1

Integration of a simple Input-Output model with OSeMOSYS. The highlighted area indicates the scope of this paper.

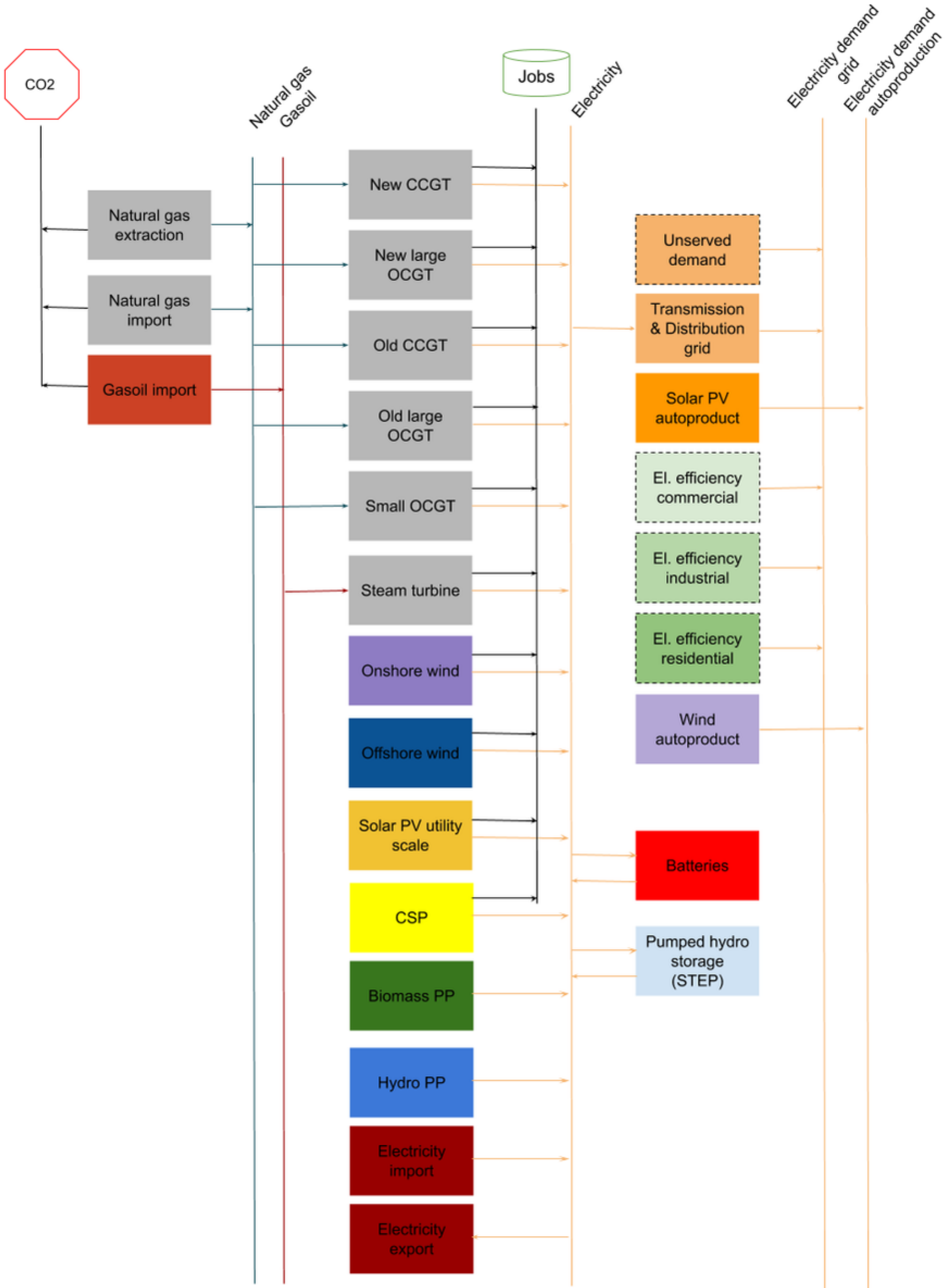

Figure 2

Simplified Reference Energy System for the Tunisian electricity-IO model.

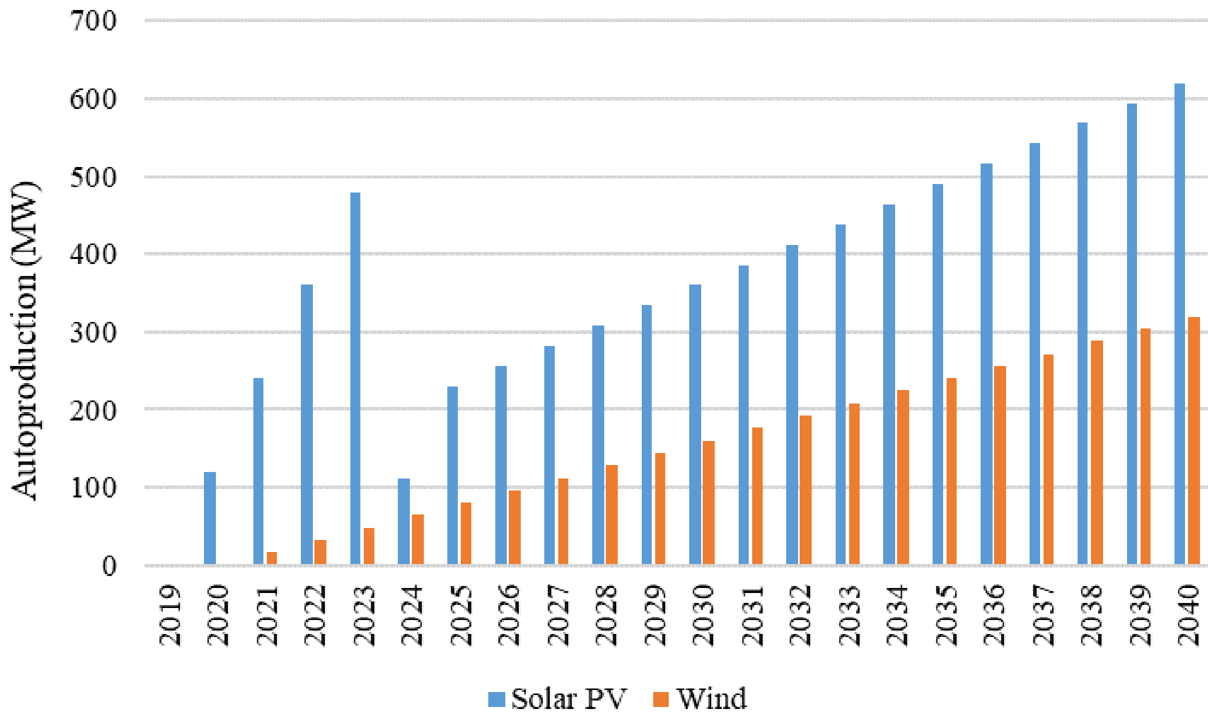

Figure 3

Assumptions of cumulative capacity of solar and wind autoproduction (STEG).

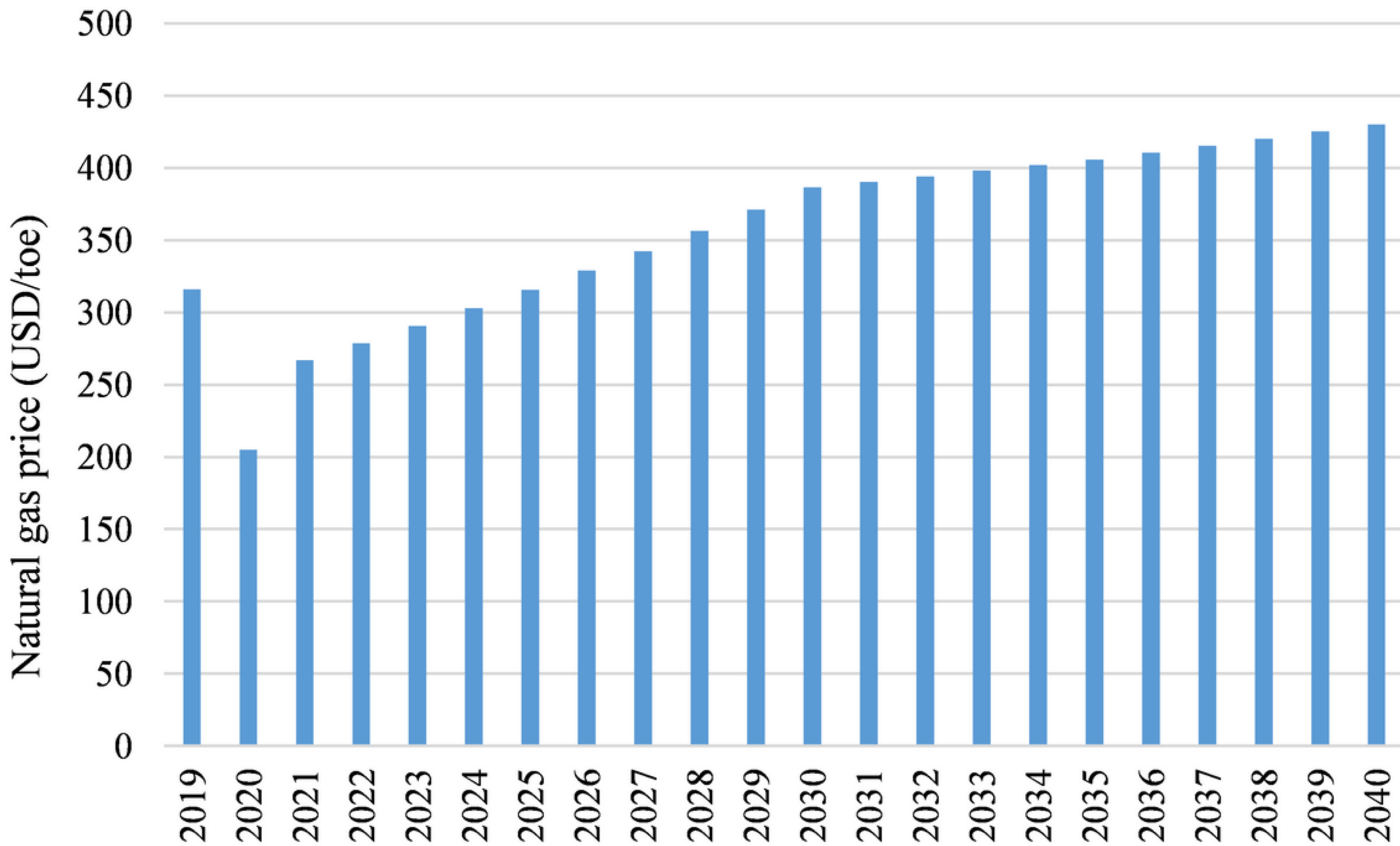

Figure 4

Assumed natural gas price trajectory.

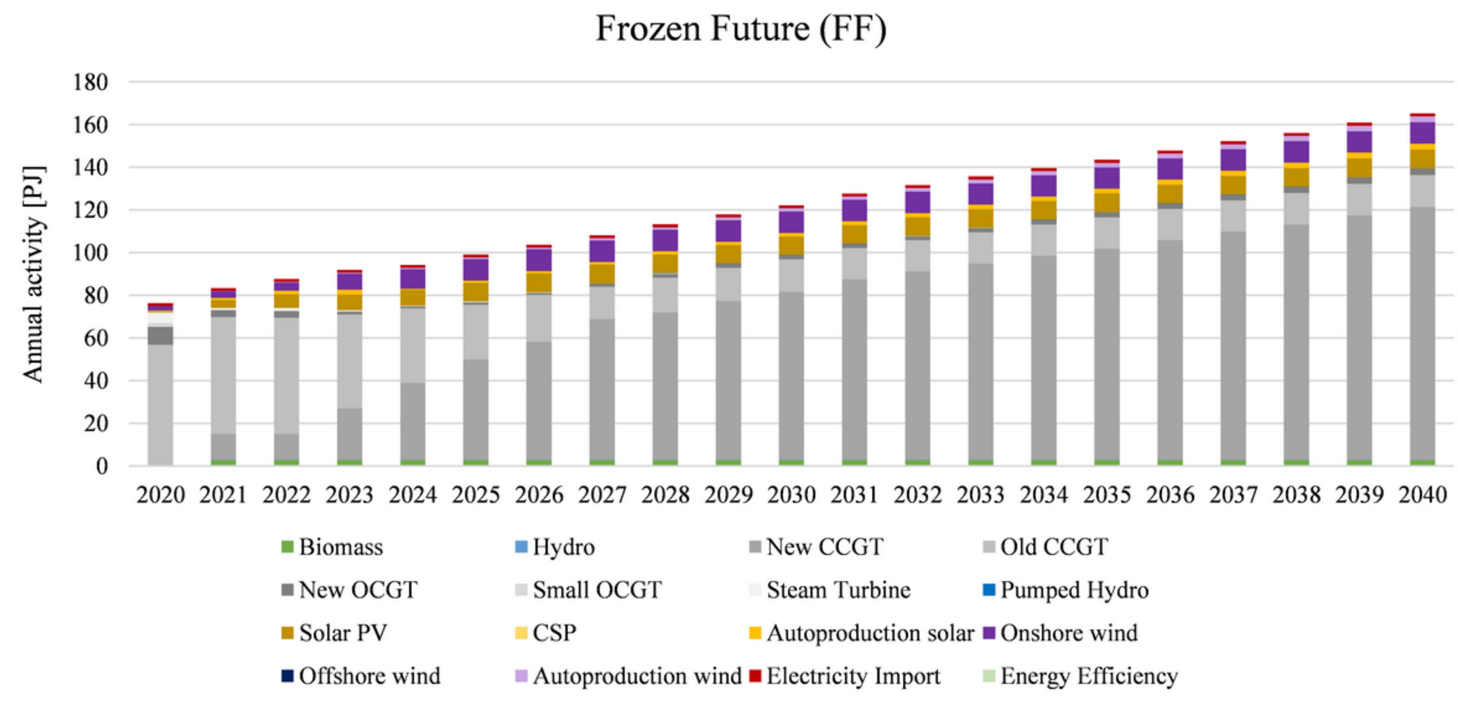

Figure 5

Electricity supply in the Frozen Future scenario.

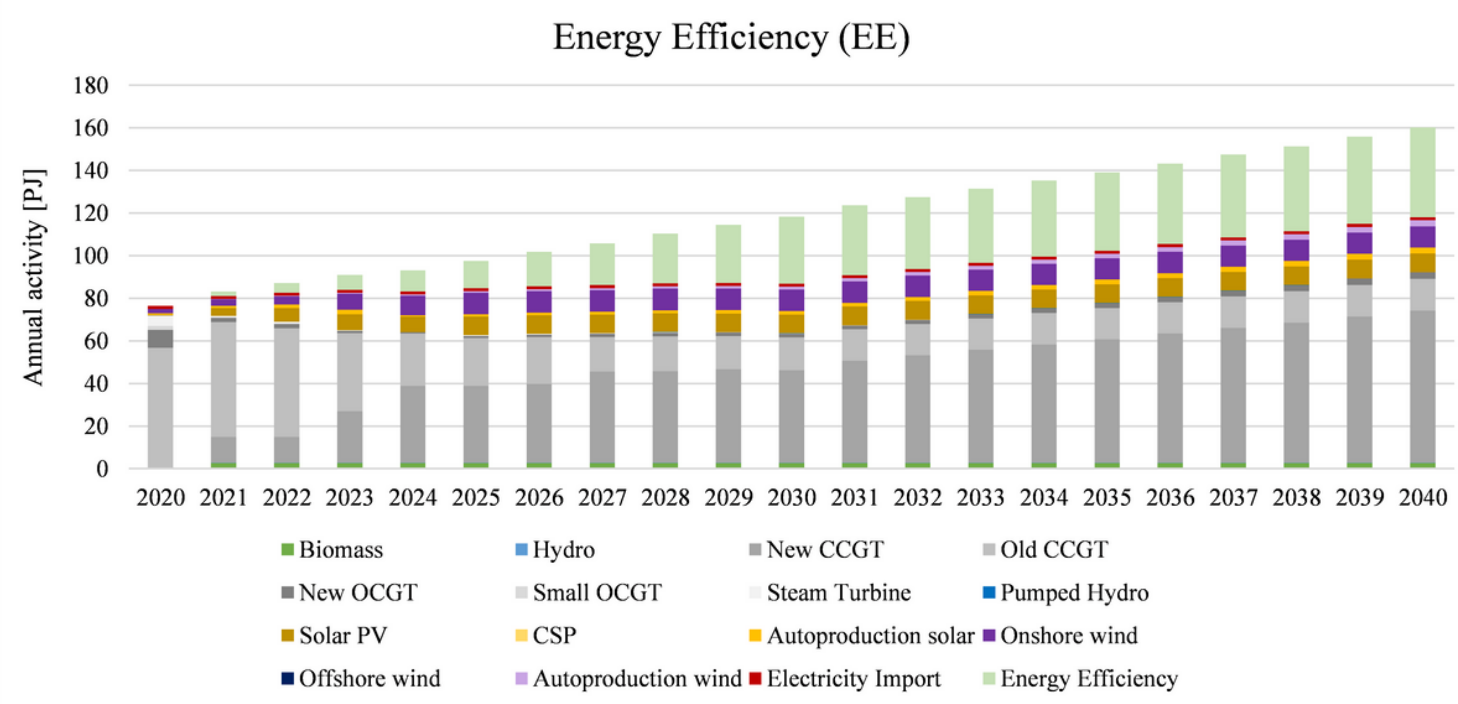

Figure 6

Electricity supply in the Energy Efficiency scenario.

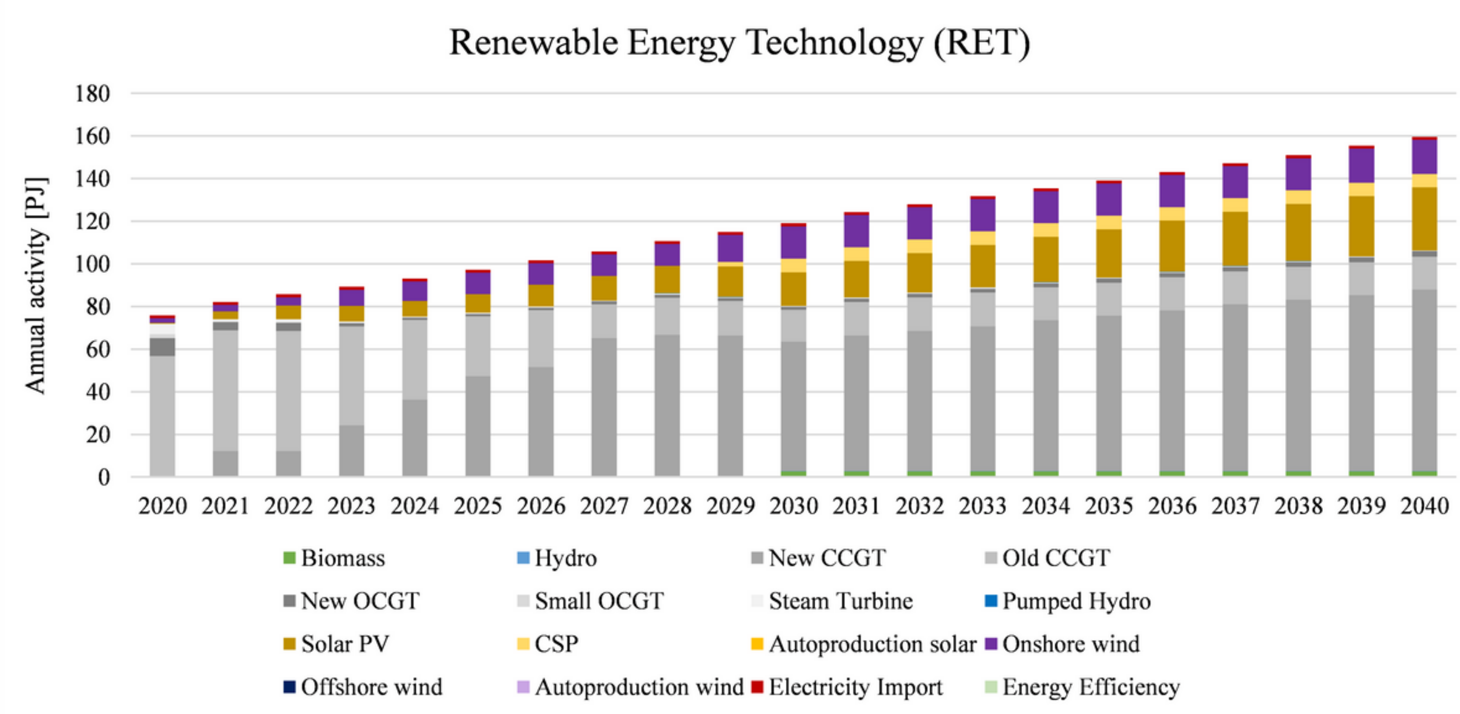

Figure 7

Electricity supply in the Renewable Energy Technology scenario.

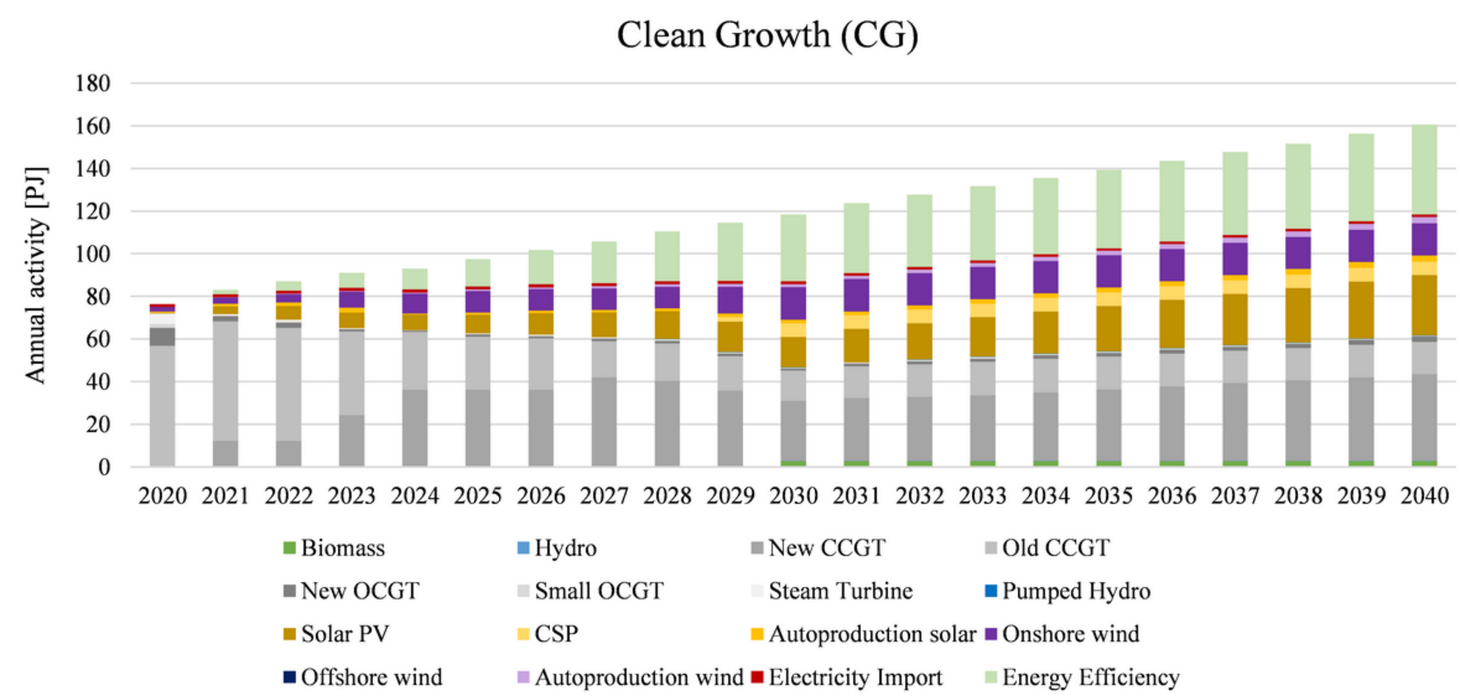

Figure 8

Electricity supply in the Clean Growth scenario.

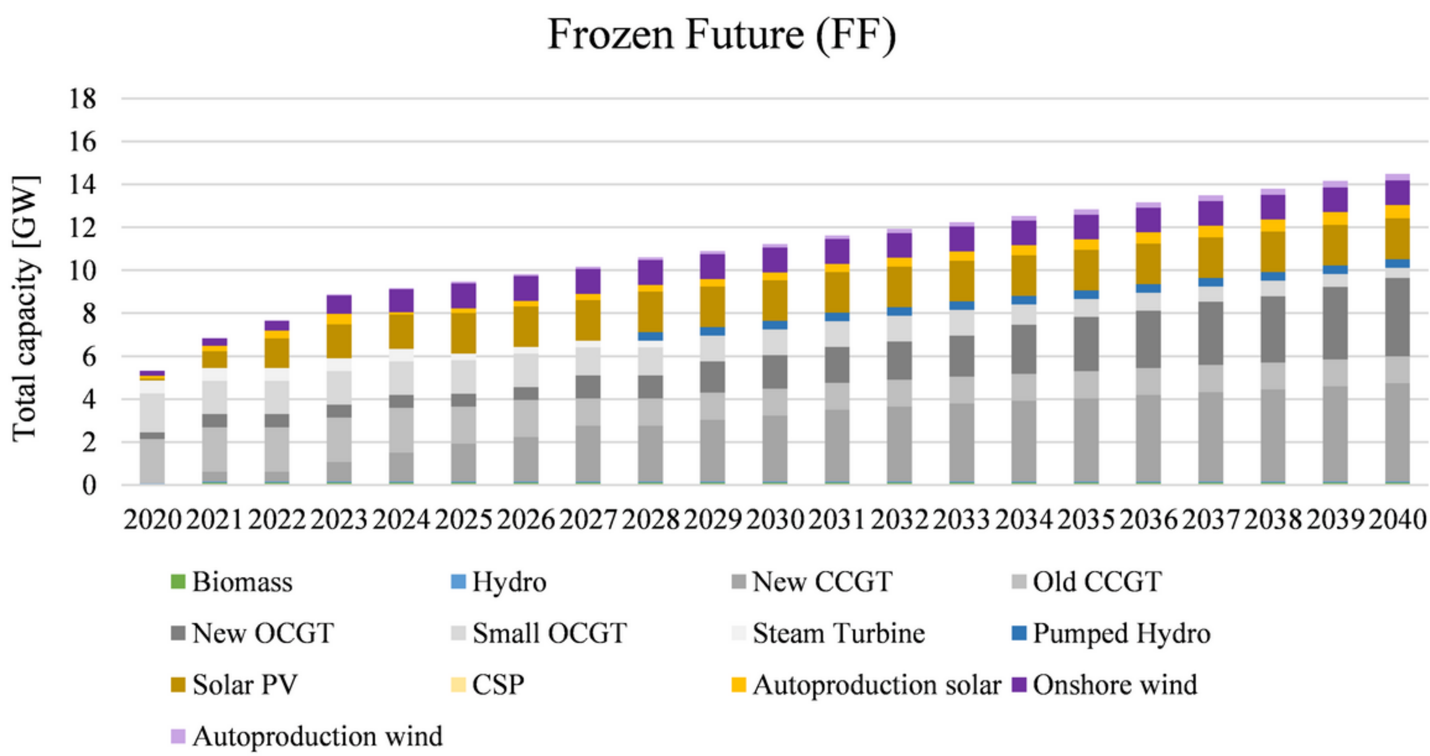

Figure 9

Total capacity (existing + installed) in the Frozen Future scenario.

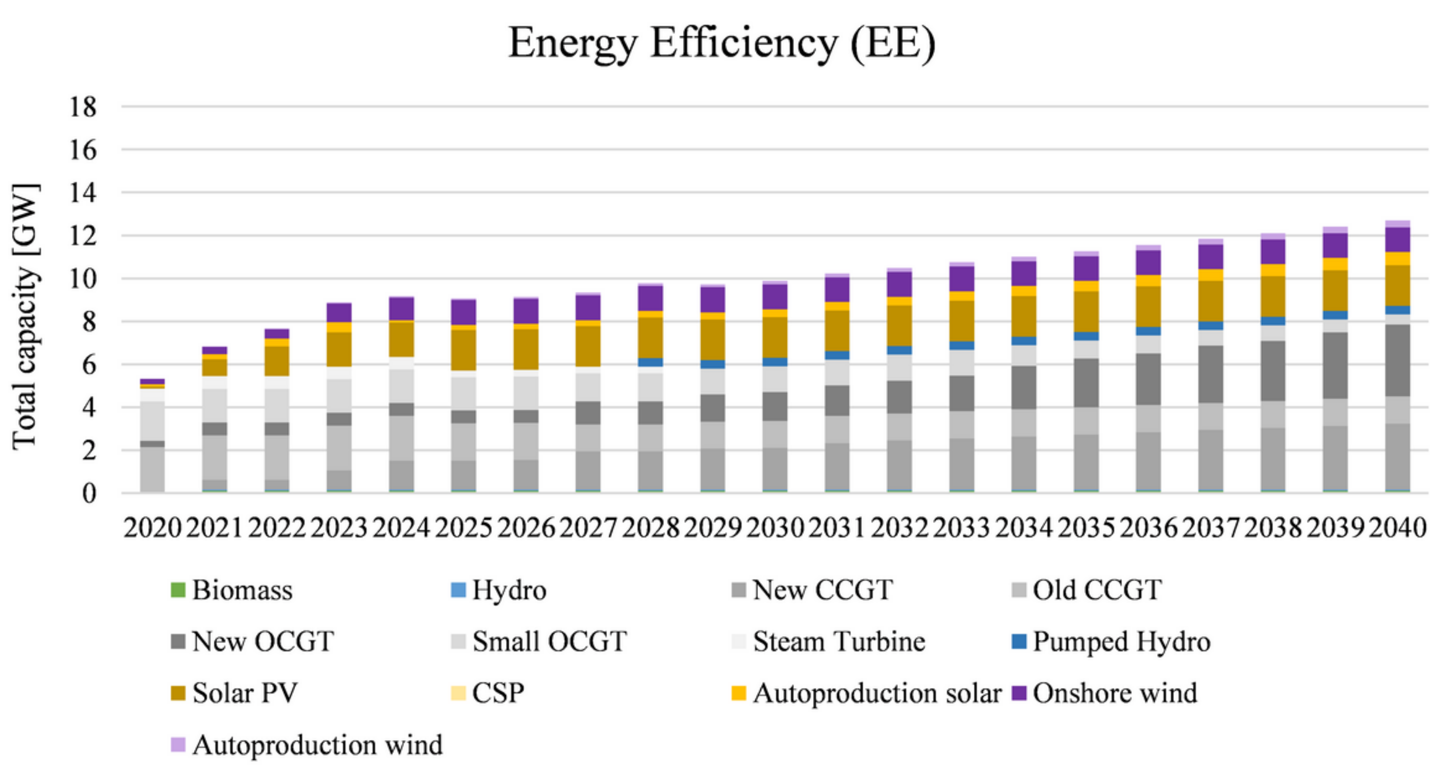

Figure 10

Total capacity (existing + installed) in the Energy Efficiency scenario.

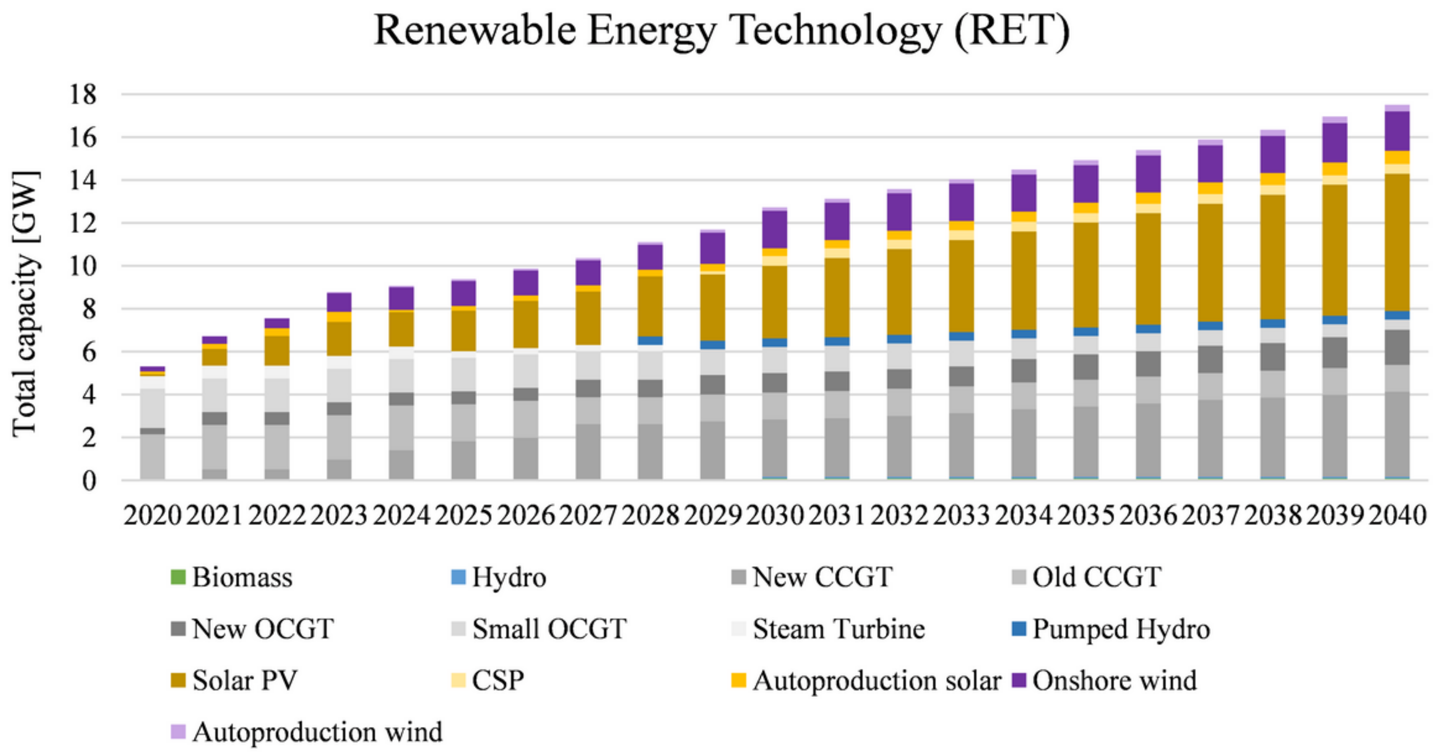

Figure 11

Total capacity (existing + installed) in the Frozen Future scenario.

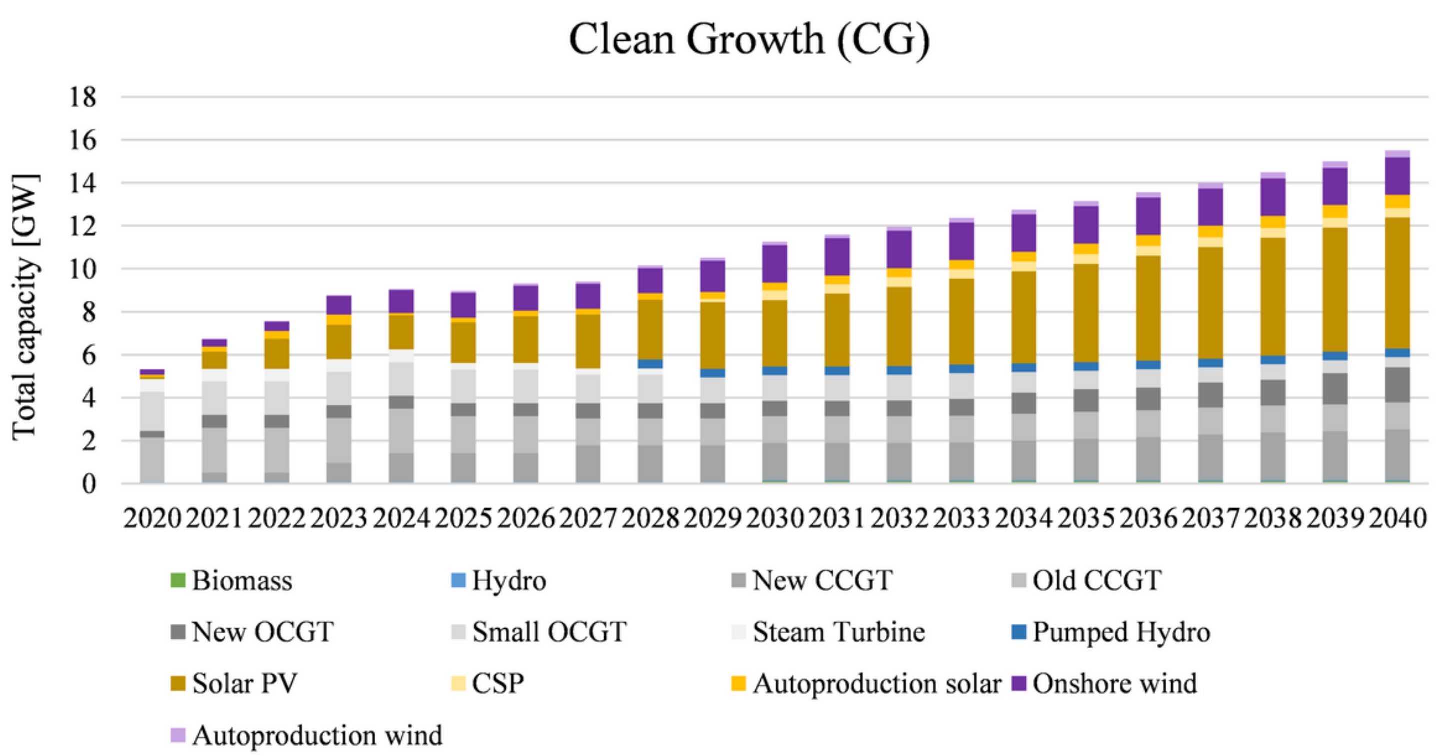

Figure 12

Total capacity (existing + installed) in the Clean Growth scenario.

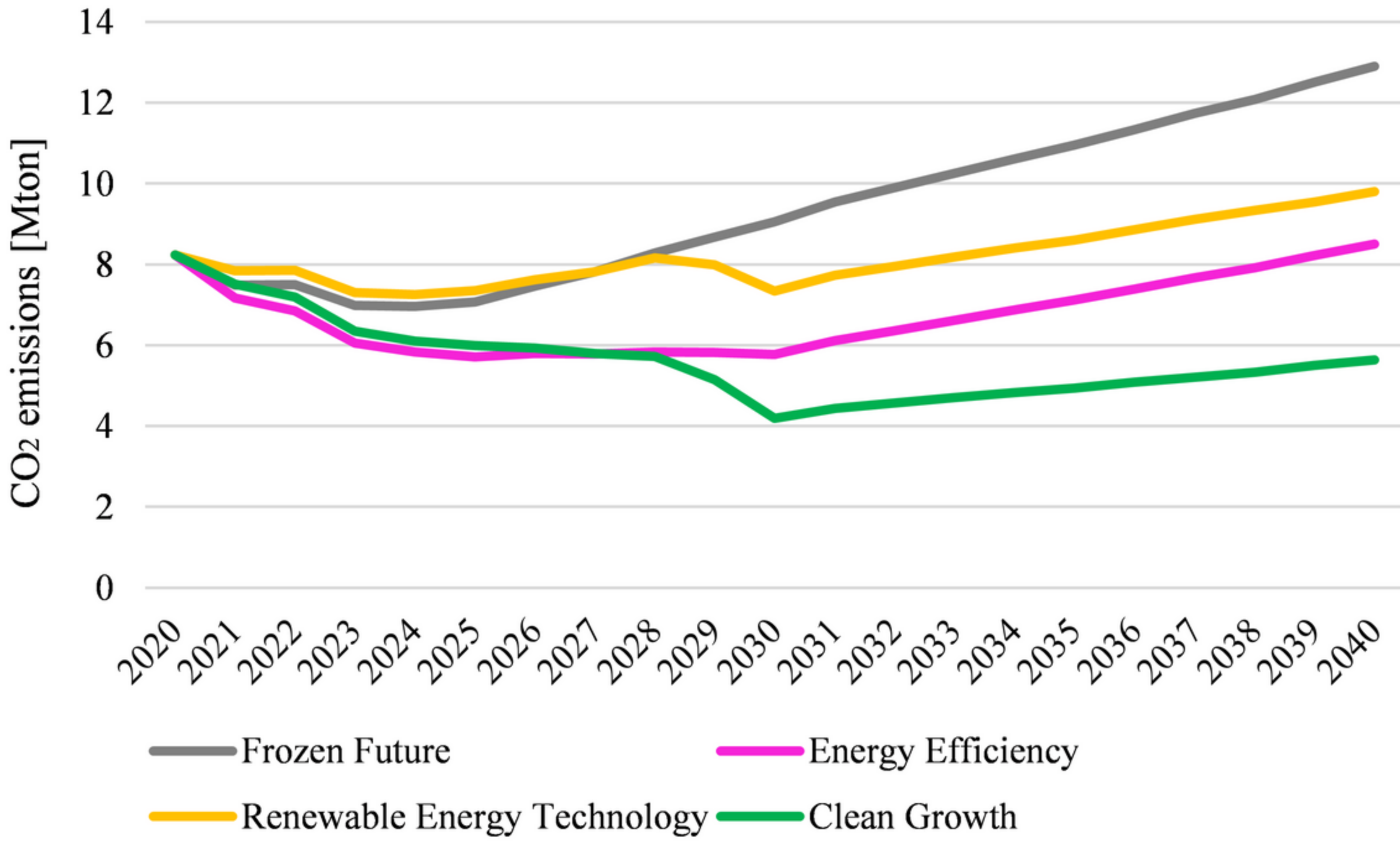

Figure 13

Comparison of CO2 emissions in the scenarios.

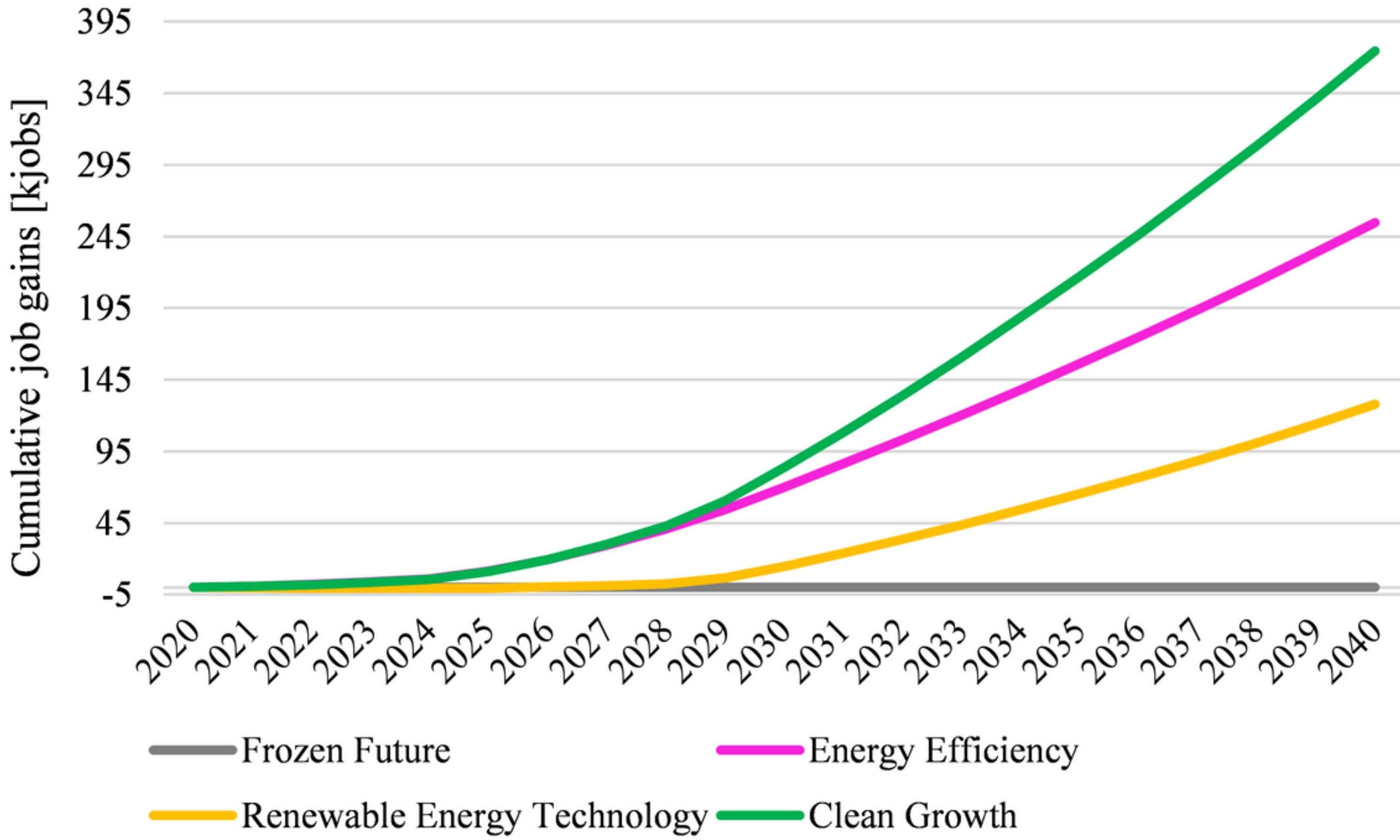

Figure 14

Cumulative job gains in the EE, RET and CG scenarios, relative to the FF scenario.