PUBLIC UTILITIES COMMISSION BELIZE

FINAL DETERMINATION

AND

ORDER

BELIZE ELECTRICITY LIMITED LEAST COST EXPANSION PLAN

MARCH 12, 2024

PUBLIC UTILITIES COMMISSION

DETERMINATION BY THE PUBLIC UTILITIES COMMISSION IN THE MATTER OF THE LEAST COST EXPANSION PLAN FOR BELIZE AS SUBMITTED BY BELIZE ELECTRICITY LIMITED

I. INTRODUCTION

A. Goals and Objectives of Least Cost Planning

1. Electricity plays a critical input for economic, social, and political development of a country and as such, the Public Utilities Commission (the "Commission") holds the view that it is of utmost importance that Belize has adequate and reliable electricity supply to meet demand.

   The Least Cost Expansion Plan ("LCEP") is a vital step in the process of planning resource efficiency. For this reason, the Commission has, on various occasions, called upon Belize Electricity Limited ("BEL") to develop a LCEP that would provide a realistic guide as to how the growing demand for electricity can be met in the long-term and at a minimum cost.

   Least-cost planning is a way of analyzing the growth and operation of utilities that considers a wide variety of both supply and demand factors so the optimal way of providing electric service to the public can be determined. A path is chosen that will ensure reliable service for the customers, economic stability and a reasonable return on investment for the utility, environmental protection, equity among ratepayers, and the lowest costs to the utility and the consumer. A least-cost plan balances three interests (reliability, profitability, and affordability) while keeping a sharp eye on the risks and uncertainties associated with each component of the plan. Moreover, through periodic review and reassessment, least-cost planning detects changes in the economics of providing electric service and allows corrections to be made. These changes allow the utility to cope with unexpected changes in fuel costs, variations in demand, advances in technology, or other changes affecting the utility's economics. This flexibility of least-cost planning allows utilities to respond to the ups and downs of the national and regional economies and minimizes the social impacts that the operations and costs of utilities can have on an economy, especially a depressed one. Finally, least-cost planning often reveals opportunities to save fuel and thereby reduces the environmental impacts of utilities' operations[1].

   The Commission considers that any LCEP submitted by BEL should ensure that it provides for sufficient, reliable, sustainable and a rapid development of the electricity sector. Additionally, the LCEP had to achieve the following:

   - Conform to national, regional, and local development objectives and more specifically adherence to National Energy Plan for Belize ("NEP-2023");
   - Provide for the diversification of power generation resources over time and increase the share of clean energy in the total mix over time;
   - Ensure that supply is closely aligned to projected demand in a cost-effective manner;
   - Maximize the use of renewable energy within Belize's energy mix;

[1] Least-Cost Utility Planning Handbook for Public Utility Commissioners, Volume 1 published by the National Association of Regulatory Utility commissioners (NARUC).

- Enhance regional cooperation and trade in electricity, including investment in transmission network development, to further improve security of supply;
- Minimize the short term and long-term economic cost of delivering electricity services or their equivalent;
- Minimize the environmental impacts of electricity supply and use;
- Minimize foreign exchange costs;
- A reasonable cost for consumers.

Prior to the current submission by BEL, and as far as the Commission is aware, the last Least Cost Planning Study was completed by OLADE on behalf of BEL in 2019. That study can be viewed at https://biblioteca.olade.org/opac-tmpl/Documentos/old0427.pdf.

B. Statutory Authority

1. Belize Electricity Limited ("BEL") has a legal obligation to furnish information to the Public Utilities Commission (the "Commission") under Section 11 of the Electricity (the "Act). The utility provider also has an obligation under Sections 49 and 50 the Public Utilities Commission Act (the "PUC Act") to furnish information. Where BEL fails to file any request for information, the PUC Act prescribes a fine, subject to summary conviction pursuant to Section 45.

2. This Commission holds the view that it is charged with the legal authority to request least-cost planning from these enabling legislations.

3. Additionally, the Commission has a statutory right under Section 7 of the PUC Act, to engage experts or persons having technical or special knowledge necessary for the purpose of assisting the Commission to carry out its functions under the PUC Act.

C. Request for and Submission of the LCEP

1. By way of letter dated December 18, 2019, and relying on Section 11 of the Act, Mr. John Avery, the Chairman of the Commission at the time, wrote to BEL and requested that the company files a Least Cost Generation Plan ("LCGP"). Given the timing of this request, the Commission might have anticipated that BEL would file the recent plan that had been prepared by OLADE.

2. This LCGP, according to Avery, should have been for a minimum planning horizon of ten (10) years, and consistent with BEL's established planning philosophy. For the purpose of this Final Determination, the term "Least Cost Generation Plan" will be eventually substituted for the terms "Least Cost Expansion Plan" or ("LCEP") and Integrated Resource Plan or ("IRP") and these words may therefore be used interchangeably throughout this Determination).

3. A deadline of January 3, 2020 was set for BEL to make its submission and the letter specified that the Plan should include the following:

   (a) Demand and Load Forecasts (Low, Expected, High Forecasts Scenarios);
   (b) Characteristics and projected electricity supply and associated costs for each source of supply;
   (c) Dispatch Simulation to satisfy Demand/Load scenarios utilizing incumbent supplies and any proposed additional supplies, along with projected costs associated with dispatch strategy and strategies;
   (d) Any other relevant information that BEL may wish to provide.

In the Final Decision of the 2020 Full Tariff Review Proceedings for BEL, the previous Commission emphasized the importance of the Plan.

In the Annual Tariff Review Proceedings of April 2022, the current Commission noted, with concern, that the LCGP was still not submitted.

4. On 23 September 2022, BEL notified the Commission that Siemens had concluded the new LCEP study and that BEL's own decision will be informed by the result of the study. BEL indicated, at that time, that the LCEP Study was filed with the understanding that the formal proposals for implementation coming from BEL will be submitted in October of the same year.

5. On February 9, 2023, the CEO of BEL, Mr. John Mencias, gave a detailed presentation on the salient features of the Business Plan for BEL and committed, at that time, to submit BEL's LCEP shortly thereafter.

6. The Commission eventually received BEL's formal filing on 21 March 2023, when it was informed, by way of a letter, that BEL intends to adopt, as its own without modification, the Siemens LCEP that had already been filed six months prior.

7. One month later, on 23 April 2023, the Chairman of BEL, Mr. Andrew Marshalleck, submitted a comprehensive set of documents to the PUC, including a document entitled **Belize Electricity Limited Integrated Resource Plan**, which the Commission was invited to adopt/approve.

8. By way of letter dated September 19, 2023, BEL subsequently sought the PUC's approval to procure short-term generation capacity. Since this application came after an earlier filing of the LCEP by BEL, this latter filing was combined with the former for the purposes of these proceedings and is referred to as "the Subsequent Filing."

9. Most regrettably, it has taken almost four years for an LCEP to be developed and filed by BEL.

D. The Policy Environment

1. At the 26th Conference of the Parties in Glasgow ("COP 26") the Government of Belize ("GOB") committed to two consequential actions in its Nationally Determined Contributions ("NDC's"). By 2030, Belize envisions a transformative shift in its electricity system, characterized by a substantial reduction in fossil-fuel dependency, an electric grid that is future-proofed and the comprehensive integration of renewable energy sources. Specifically, GOB has committed to following:

- *Implementation of feasible Hydroelectric, Solar PV, Wind Electric, and Biomass projects, ensuring that gross generation from renewable sources constitutes no less than 75% of total supply by 2030;*
- *Implementation of energy efficiency measures, targeting a minimum of 10% lower energy intensity compared to business-as-usual levels by 2030;*
- *Establishment of a robust regulatory environment for Distributed Energy Resources (DERs) by 2023, fostering the decentralized and efficient use of renewable energy; and*
- *Undertake a fundamental overhaul of the electric grid to eliminate bottlenecks in transfer capacity and address constraints. This upgrading aims to seamlessly integrate utility-scale variable renewables (VREs), promote the widespread adoption of Distributed Energy Resources (DERs), prepare for the electrification of transport, and create opportunities for renewable energy projects within interconnected systems. The investments in grid modernization are strategically directed to significantly enhance flexibility, reinforce resiliency, and improve efficiency—primarily by reducing transmission losses—with the overarching objective of ensuring that system losses do not exceed 10% by 2030.*

2. In respect of Energy Efficiency ("EE"), the aim of GOB is that, on a per capita basis, citizens of Belize will maintain the same standard of living while, at the same time, reduce overall consumption of energy by 10 percent.

3. Regarding the regulatory environment for DERs, the Commission is actively involved in rulemaking to meet this commitment in 2024.

4. By 2050, the GOB commits to attain carbon neutrality. This commitment is exceedingly ambitious and will require widespread changes in the transport and industrial end-use segments. This is so particularly because of the following:

   - *Energy use in Transport accounts for at least 45% of total primary energy and drives the demand for substantial imports of liquid fossil-fuels.*
   - *Energy use in Industry accounts for about 35% of total primary energy. Almost half of industry energy inputs are fossil fuels, mainly for process heat applications.*
   - *Electricity use in Commercial and Residential processes accounts for about 20% of total primary energy.*

   The full report on Belize's NDC's is available on the UNFCCC's website at https://unfccc.int/sites/default/files/NDC/2022-06/Belize%20Updated%20NDC.pdf

5. Throughout 2023, the GOB sought to proactively update the country's National Energy Policy ("NEP-2023"). The full NEP-2023 report is available at https://www.mpuele.gov.bz/wp-content/uploads/2023/11/Belize-National-Energy-Policy-2023.pdf.

   Based on NEP-2023, the key policy goals influencing this Planning Determination are:

   - *Reduce cost of energy services;*
   - *Increase indigenous energy sources;*
   - *Increase access to energy services;*
   - *Improve contribution to the NDC's, which now has improved by raising the ambition for energy intensity from 10% to 25%;*
   - *Enhance energy sector governance; and*
   - *Strengthen energy management capabilities.*

6. GOB has also disseminated a Reference Portfolio ("GRP"), having notable similarities with the Siemens LCEP. The Government's Reference Portfolio signals a heightened prioritization of energy security, which is to be achieved through diversified energy sources (see Table 1). The GRP compares closely to the Siemens Reference Portfolio, which is the baseline candidate portfolio used in its analysis that led to the Belize-centric Portfolio recommendations in Table 4.

Table 1: GOB's Reference Portfolio

Comparison of Expansion Plans		
	GOB Reference Portfolio	**SIEMENS Reference Portfolio**
Battery Storage	40 MW	40 MW
Solar PV	160 MW /w 0.2h storage	200 MW
GE LM2500 Upgrade		8 MW
Gas-fired RICE	40 MW	45 MW
Wind Electric		45 MW
Regional Interconnections	200 MW	

7. The GRP contemplates changes to the industry structure, seeking to foster a dynamic and efficient electricity subsector that promotes competition, discourages monopolistic practices, and embraces technological advancements.

   Specifically, the GRP calls for the following:

   - *Establishing an independent system operator ("ISO");*
   - *Creating the enabling environment for distributed energy resource; and*
   - *Directing that BEL shall focus on modernizing the electricity grid to support the energy transition, enhance resiliency and drive efficiency improvements.*

8. At 28th Conference of the Parties in Dubai ("COP 28"), GOB advocated for three consequential actions for the globe to stay within the 1.5^{o} c of warming target set in the Paris Agreement.

   These actions build on the COP 26 commitments and seek to accelerate the energy transition to 2030, as follows:

   - *Phase out of fossil fuels in the electricity sub-sector by 2030;*
   - *Triple renewable energy capacity to 2030; and*
   - *Double energy efficiency improvements every year until 2030.*

E. Summary of the Commission's Process

1. In June 2023 and pursuant to its statutory rights under Section 7 of the PUC Act, the Commission engaged the services of PSR Energy Consulting and Analytics of Rio de Janeiro, Brazil ("PSR") to review the LCEP. PSR's report is exhibited as Appendix A to this Determination.

2. In September 2023, the Commission, through the assistance of the World Bank, similarly engaged the services of Agostinho Miguel Garcia, Principal Consultant, Sun Business Development, Portugal (the "Consultant"). This Consultant conducted a simulated load study, contemplating the introduction of solar plants into BEL's grid. The Consultant's Report is exhibited as Appendix B hereto.

3. Between October 13 and November 24, 2023, the Commission also held publicly advertised consultation in an effort to generate commentary on BEL's LCEP filing from the general public, affected and interested parties, and other stakeholders. At the close of the consultation period, the Commission did not receive any comments regarding the LCEP and as such, the Commission's analysis and Determination is based on the advice of the experts engaged.

4. The summary of the comments received from the experts are including in the body of this Determination.

II. BEL's ASSESSMENT OF OPTIONS AND RECOMMENDATIONS

A. Load Forecast

1. The projected need for an increase in resources presented in the LCEP is supported by a forecast of future energy demand requirements for the 20-year planning horizon, by load centres as shown in Table 2 below.

2. Siemens projects that peak demand in 2042 would amount to 155.3 MW during the wet season and 153.92 during the dry season.

3. As the Commission has often noted in previous decisions, documentation about assumptions, sensitivity, demographics, usage patterns etc were not readily available to assess the forecast done by Siemens.

Table 2: Load Forecast for 20-year planning horizon

	Belize		Ladyville		San Ignacio		Belmopan		Corozal		Orange Walk		San Pedro		Dangriga		Independence		Punta Gorda		Caye Caulker		Total	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
2022	17.51	14.86	17.05	14.49	8.96	9.57	11.46	10.09	5.95	6.66	10.31	10.15	13.33	10.87	7.15	6.94	9.01	7.75	2.45	2.49	2.24	1.90	105.43	95.76
2023	18.10	15.47	17.64	15.10	9.31	10.00	11.86	10.52	6.19	6.97	10.67	10.58	13.78	11.35	7.38	7.19	9.31	8.07	2.54	2.59	2.32	1.99	109.11	99.83
2024	18.68	16.09	18.22	15.71	9.67	10.44	12.26	10.95	6.44	7.27	11.04	11.01	14.24	11.84	7.61	7.45	9.62	8.40	2.63	2.69	2.40	2.07	112.78	103.93
2025	19.23	16.68	18.77	16.28	10.00	10.86	12.63	11.36	6.67	7.56	11.38	11.42	14.66	12.30	7.82	7.70	9.90	8.71	2.71	2.79	2.47	2.15	116.24	107.80
2026	19.65	17.12	19.19	16.71	10.25	11.16	12.92	11.67	6.84	7.78	11.64	11.72	14.98	12.64	7.98	7.88	10.11	8.94	2.77	2.86	2.53	2.22	118.86	110.68
2027	20.03	17.54	19.57	17.13	10.48	11.47	13.17	11.96	7.00	7.99	11.88	12.02	15.27	12.96	8.13	8.06	10.31	9.15	2.83	2.93	2.58	2.27	121.23	113.49
2028	20.41	17.96	19.95	17.55	10.70	11.78	13.43	12.26	7.15	8.21	12.11	12.31	15.56	13.28	8.27	8.24	10.50	9.37	2.89	3.01	2.63	2.33	123.60	116.30
2029	20.79	18.38	20.32	17.97	10.93	12.08	13.69	12.55	7.31	8.43	12.35	12.61	15.85	13.59	8.42	8.42	10.70	9.59	2.94	3.08	2.68	2.38	125.97	119.10
2030	21.16	18.80	20.70	18.39	11.16	12.39	13.94	12.85	7.46	8.65	12.58	12.91	16.14	13.91	8.56	8.60	10.89	9.81	3.00	3.15	2.73	2.44	128.32	121.88
2031	21.54	19.21	21.07	18.81	11.38	12.69	14.20	13.14	7.62	8.86	12.82	13.20	16.43	14.22	8.71	8.77	11.08	10.03	3.06	3.23	2.78	2.50	130.66	124.66
2032	21.91	19.63	21.44	19.22	11.60	12.99	14.45	13.43	7.77	9.08	13.05	13.50	16.71	14.53	8.85	8.95	11.27	10.24	3.11	3.30	2.82	2.55	133.00	127.42
2033	22.28	20.04	21.81	19.63	11.83	13.29	14.70	13.72	7.93	9.29	13.28	13.79	17.00	14.84	8.99	9.13	11.46	10.46	3.17	3.37	2.87	2.61	135.31	130.17
2034	22.65	20.45	22.18	20.04	12.05	13.59	14.95	14.01	8.08	9.50	13.51	14.08	17.28	15.15	9.13	9.30	11.65	10.67	3.22	3.44	2.92	2.66	137.62	132.90
2035	23.01	20.86	22.54	20.45	12.27	13.89	15.20	14.30	8.23	9.71	13.73	14.37	17.56	15.45	9.28	9.48	11.84	10.88	3.28	3.51	2.97	2.72	139.90	135.62
2036	23.38	21.26	22.90	20.85	12.48	14.18	15.44	14.58	8.38	9.92	13.96	14.65	17.84	15.76	9.41	9.65	12.02	11.09	3.33	3.59	3.02	2.77	142.17	138.31
2037	23.73	21.66	23.26	21.26	12.70	14.48	15.69	14.86	8.53	10.13	14.18	14.94	18.11	16.06	9.55	9.82	12.21	11.30	3.39	3.66	3.06	2.82	144.42	140.98
2038	24.09	22.06	23.62	21.65	12.91	14.77	15.93	15.14	8.67	10.34	14.40	15.22	18.39	16.35	9.69	9.99	12.39	11.50	3.44	3.73	3.11	2.88	146.65	143.62
2039	24.44	22.45	23.97	22.05	13.12	15.05	16.17	15.42	8.82	10.54	14.62	15.50	18.66	16.65	9.83	10.16	12.57	11.71	3.49	3.79	3.16	2.93	148.85	146.24
2040	24.79	22.84	24.32	22.43	13.33	15.34	16.40	15.69	8.96	10.74	14.84	15.77	18.93	16.94	9.96	10.33	12.75	11.91	3.55	3.86	3.20	2.98	151.03	148.83
2041	25.14	23.22	24.66	22.82	13.54	15.62	16.64	15.96	9.10	10.94	15.05	16.05	19.19	17.22	10.09	10.49	12.93	12.11	3.60	3.93	3.25	3.03	153.18	151.39
2042	25.47	23.60	25.00	23.20	13.74	15.89	16.87	16.23	9.24	11.14	15.26	16.32	19.45	17.51	10.22	10.65	13.10	12.30	3.65	4.00	3.29	3.08	155.30	153.92

4. Regarding this Load Forecast, PSR observed that "*Future load is projected with overly simplistic methods (a fixed growth rate). There is room for improvements in the methodology, at least for the initial years of the horizon, when there is more knowledge of the economic growth rate of the country and single-point sources of demand may be known (ex. large hotel installation, industry, or any other possibility of a significant load growth)*."

5. PSR's observation appears to have been with some merit, as BEL's September 19, 2023 submission provided additional details for the period 2024-2026, which differed significantly from the Load Forecast in Table 2.

6. In its Subsequent Filing (*see forecast of Peak Demand in **Table 3***), BEL indicated that "*Based on*

the latest trends, peak demand is projected to grow to 130 MW in 2024 and by 10 MW for each year thereafter up to 2026."

7. In fact, in October 2023, actual demand peaked at 127 MW and therefore the Commission has no doubt that the Load Forecast, as shown in Table 2, is inaccurate and unreliable.

Table 3: Schedule of Firm Capacity Additions (and Subtractions) 2024 - 2026

Units of MW	1st Half Year	2nd Half Year	1st Half 2024	2nd Half 2024	1st Half 2025	2nd Half 2025	1st Half 2026	2nd Half 2026
Peak Demand (Grid)	**125.0**	**115.0**	**130.0**	**120.0**	**140.0**	**130.0**	**150.0**	**140.0**
In-Country Capacity (Grid)	**113.5**	**93.5**	**130.0**	**110.0**	**140.0**	**132.5**	**162.5**	**152.5**
***ADD:* BEL GT Upgrade**			*12.0*	*12.0*	*12.0*	*12.0*	*12.0*	*12.0*
***ADD:* CCK Power Station**			*4.5*	*4.5*	*4.5*	*4.5*	*4.5*	*4.5*
ADD:* BEL BESS (Battery) *#1					*10.0*	*10.0*	*10.0*	*10.0*
ADD:* BEL BESS (Battery) *#2						*10.0*	*10.0*	*10.0*
ADD:* BEL BESS (Battery) *#3							*10.0*	*10.0*
ADD:* BEL BESS (Battery) *#4								*10.0*
***ADD:* NGC Rice**						*25.0*	*25.0*	*25.0*
SUBTRACT: Bapcol Fossil Fuel						*-22.5*	*-22.5*	*-22.5*
In-Country Reserve Margin (Grid)	**-11.5**	**-21.5**	**0.0**	**-10.0**	**0.0**	**2.5**	**12.5**	**12.5**

8. At best, then, the Siemens' Expansion Plan, which is predicated on its Load Forecast, is effectively a plan to enable BEL to meet projected energy requirements only up to 2027. The Commission FINDS that based on BEL's Subsequent Filing, the Siemens Load Forecast is in fact unrealistic as a basis for long term planning.

9. The practical impact of this very understated Load Forecast is quite far-reaching. PSR points out that "*The consequence of underestimating low demand growth in future years may be less critical for generation assets, because the LCEP is mostly based on "modular" solar and wind installations and more critical for the transmission expansion, which could anticipate reinforcements, upgrades of voltage levels and retirements of obsolete equipment*."

10. Given that the Load Forecast is critical to the soundness of the LCEP, any error in the Load Forecast will have serious effects on the entire plan. As such, the Commission notes, with concern, that the Load Forecast is not sufficiently accurate and reliable.

B. Supply Side Options – Generating Facilities

1. The LCEP provides for additional generation sources recommended as part of Siemens' Belize Centric Strategy up to the year 2042. For ease of reference, BEL's submission, in summary form, is reproduced as Table 4 below:

Table 4: Additional General Sources up to 2042 (Belize Centric Strategy)

Rice Gas

Total MW	In Service year	POI (Location)	Note
22.50	2024	Dangriga	Build 115 kV line to Dangriga

Solar

Total MW	In Service year	POI (Location)	Note
20.00	2024	Orange Walk	Model @ 80% Pmax during peak daytime
20.00	2026	Ladyville (Includes Belize Solar)	Model @ 80% Pmax during peak daytime
20.00	2034	La Democracia	Model @ 80% Pmax during peak daytime
20.00	2036	West	Model @ 80% Pmax during peak daytime
20.00	2038	La Democracia	Model @ 80% Pmax during peak daytime
20.00	2040	La Democracia	Model @ 80% Pmax during peak daytime
20.00	2042	West	Model @ 80% Pmax during peak daytime

Storage

Total MW	In Service year	POI (Location)	Note
10.00	2023	San Pedro	Model 5 MW at night -10 day
10.00	2023	Ladyville	Model 5 MW at night -10 day
10.00	2023	Independence	Model 5 MW at night -10 day
10.00	2023	Orange Walk	Model 5 MW at night -10 day

Wind Belize Coastal

Total MW	In Service year	POI (Location)	Note
20.00	2029	San Pedro	Model @ 80% Pmax day or night
20.00	2031	Corozal	Model @ 80% Pmax day or night

2. In its April 02, 2023 submission, BEL proposes to bring on the following additional generation sources for the BEL described Phase 1 of the LCEP as shown in Table 5:

Table 5: Additional General Sources

Generation Technology	Capacity (MW)	Location	In-Service Year
Gas Turbine (GT) Upgrade	12	West Lake	2023
Utility Scale Solar	7	Chan Chen	2024
Utility Scale Solar	10	Maskall	2025
RICE (Natural Gas)	22.5	Dangriga	2025
Utility Scale Solar	20	Ladyville	2026
Utility Scale Solar	20	TBD	2027

3. In BEL's April 02, 2023 submission, the company also identified additional major capital projects that it proposes to undertake, as recommended by the LCEP (see Table 6):

Table 6: Major Capital Projects being undertaken over 2023 - 2027

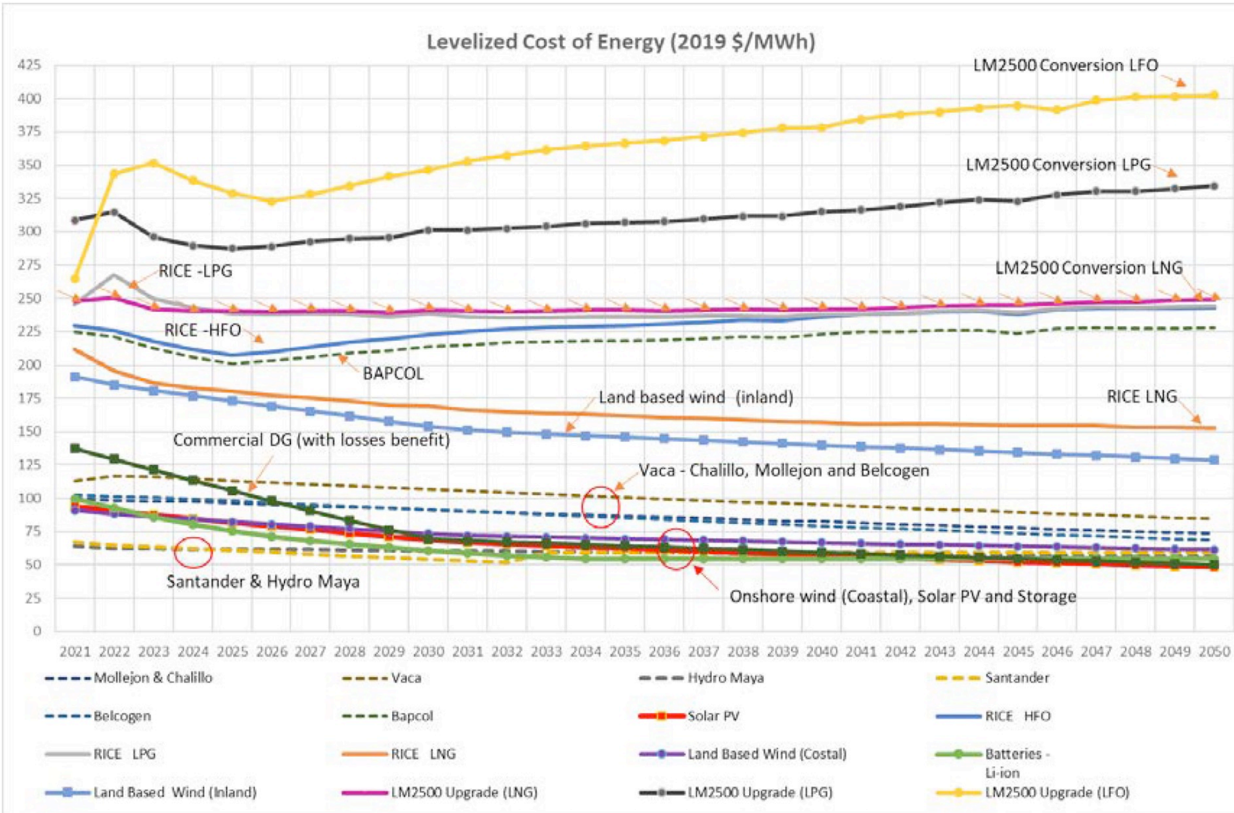
Project	Cost	Description
Battery Energy Storage Solution	$100M	Investment for engineering, procurement, and construction of 40MW battery storage to meet capacity requirements and energy shifting.
Smart Grid (Country-wide Rollout AMI)	$39.23M	For full-scale deployment of AMI meters and the buildout of BEL's smart-grid strategy. Smart meters will enable BEL to access customer metering information remotely, identify anomalies and analyse trends
Gas Turbine Repowering	$38M	Recommended by LCEPTo upgrade BEL's Gas Turbine Facility at Mile 8 George Price Highway. Investment would increase capacity from 19MW to 30.9MW and allow for dual fuel operations (diesel and natural gas)
Maskall to North Ambergris Caye 69 kV submarine interconnection	$37M	Recommended by LCEP
115kV Transmission line Democracia to Dangriga	$29.8M	Recommended by LCEP
North Ladyville to Belize II 115 kV Transmission Line	$19.2M	Recommended by LCEP
Customized Electricity Service (CES)	$16.2M	To support universal access to affordable, reliable, and safe electricity to customers that requires a non-standard connection via a cost sharing agreement between BEL and the customer
Construction of New Operations Facility (JSR)	$15M	For the construction of a new modern warehouse facility to improve inventory management and achieve cost saving benefits
New Belize II 115/22 kV substation 2	$12.78M	Recommended by LCEP
Rural Electrification	$11M	To support universal access to affordable, reliable, and safe electricity to customers in rural areas
EU Project Implementation (Electrification of 5 villages using Microgrid)	$10M	With EU support, to facilitate the electrification of five villages using microgrid
Solar PV Rooftop Rental Pilot	$9.45M	To diversify the BEL's line of services to include Solar PV which will allow customers in remote areas to be connected to the grid and support BEL's strategy of incorporating distributed generation. This investment will also increase clean in-country production and stabilize cost of power.

The full LCEP as produced by Siemens is available on the PUC's website at www.puc.bz/bel-least-cost-expansion-plan-april-2023/

4. Siemens considered distributed generation ("DG") as a favourable supply option for large commercial and industrial customers and expected current costs reductions for self-supply to continue. As such, in contemplating DG, Siemens suggests that "*over time 50% of the current Commercial 2 customers will switch to self -supply and the speed of conversion will increase as the savings become larger ..... Customers are assumed to self-supply 100% of its load, injecting to BEL during the day and extracting at night. The figure also shows the savings with the proposed rate and in this case the savings achieved by the conversion to self-supply occur later, by 2026.*"

5. BEL did not provide any worksheets used by Siemens to detail standards of performance and costs for the supply-side options considered. The graph below at Table 7 is a visualization of what supply options were assessed:

Table 7: All Resources LCOE



6. PSR was concerned that the assessment was too narrow, resulting in the exclusion of more economic alternatives and noted that "*Biomass conversion technologies interlock with Belize economic development goals, e.g. sugarcane, waste, etc. and, again, were not considered as expansion option.*"

7. PSR Inc proposed a range of conventional and non-conventional generation technologies available and noted that "*The LCEP concentrates on installing solar and wind resources + natural gas-fired RICE. Other options for the system, such as the installation of synchronous condensers, modernize hydropower to make it more flexible, or the provision of synthetic inertia by solar and wind power, appear to be disregarded. The concern here is that economical options may have been overlooked.*"

8. Table 8 shows the proposed energy supply options proposed by Siemens as compared to those proposed by PSR. Of significance is that PSR did not consider fossil-fuel fired generation sources to be viable options and therefore screened them out quite early in the study process.

Table 8: Energy Supply Options Applicable to Belize

Energy Supply Options applicable to Belize		
	SIEMENS	PSR, Inc.
Battery Storage	√	√
Synchronous Condensers		√
Synthetic Inertia		√
Flexibility Improvements		√
Solar PV	√	√
Wind Electric	√	√
Hydroelectric		√
Biomass		√
GE LM2500 Upgrade	√	
Gas-fired RICE	√	
Regional Interconnections	√	√

9. PSR Inc. disagreed with Siemens' core assumption that there must be gas-fired Reciprocating Internal Combustion Engine ("RICE") in the electricity matrix and expressed concern that "*…the RICE plant will be responsible for a large emission of greenhouse amount gases, which will make the decarbonization effort of the country more difficult. The selection of RICE as a resource capable of providing both capacity and ancillary services is understood, but it should be challenged by the very ideal of the LCEP, which is to find the combination of resources that provides the least cost.*"

10. The Commission had shared similar concerns in its Decision regarding the Subsequent Filing for approval of the purchase of a 21 MW Plant that BEL intended to install on a temporary basis in San Pedro, Ambergris Caye. The full decision can be viewed at the Commission's website at https://www.puc.bz/wp-content/uploads/2023/12/PUC-Final-Decision-Short-Term-Plant-Purchase-BEL-12-2023-1.pdf.

11. By BEL adopting the fossil fuel-fired options preemptively selected by Siemens, the PUC raises concerns for GOB's its commitments made under the United Nations Framework Convention on Climate Change ("UNFCCC").

12. Regional Interconnection were also contemplated by Siemens, but these options were ultimately screened out early in their study process. The Siemens Report states:

> *13.1.3 Expansion of the interconnection with Mexico: a new 115 kV line Xul-Ha – Chan- Chen – Camalote that is expected to double the capacity of energy transfer between Belize and Mexico and required the expansion of the Xul-Ha 230/115 kV transformer capacity (one new transformer).*
>
> *13.2 Two candidate points for interconnection between Guatemala and Belize:*
>
> *13.2.3 An interconnection via Melchor de Mencos: This interconnection is facilitated by a new 230 kV line Peten – ITSA – Ixpanpajul – Melchor de Mencos.*
>
> *An interconnection via Modesto Mendez 230 kV: There is a new 230 kV line Yalchacti –Modesto Mendez (125km) to reinforce this area and Modesto Mendez is approximately 48 km from Punta Gorda. This interconnection would be limited by 69 kV unless the path is upgraded to La Democracia.*

13. The Commission's expectation is that there is an evaluation of the impact of all the various generation sources on the load forecast. The mix that is best able to maintain adequate reliability, ensure financial viability for the utility, provide for flexibility, and fulfills policy and regulatory objectives would result is the least-cost plan up to 2042.

14. Given the findings regarding the Load Forecast, the Commission holds the view that Table 4 (***as it relates to solar and storage only***), must be translated into a commitment for meeting peak load up of 155 MW by 2027, given current realities.

C. Demand-side Options – Conservation programmes

1. Siemens make a general recommendation in respect of its energy efficiency ("EE") and Demand Response strategy, stating that "*Belize initiates Energy Efficiency / Demand Response programs that via energy audits, rebate programs and improvements of codes and standards result in a reduction of the consumption under that is currently forecasted*.

2. The NEP-2023 commits to reducing energy intensity across sectors by… "*a. Increase public transport use; b. Reducing public transport costs; c. Adapt CARICOM EE Building Code; d. Increase EE education; e. Modernize energy management*" and projects that "*Successful implementation of these policies is expected to reduce the country's energy intensity by 25%*,"

3. The Commission expected to see targeted savings per year for the duration of the LCEP to meet GOB's goal in NEP-2023, which will require BEL to design and promote programs that will yield such savings over the 20-year horizon as anticipated by GOB. BEL has not shown how it intends to collaborate with the Government to achieve the 25% reduction in energy intensity compared to business as usual.

D. Transmission and Distribution

1. Siemens approach for the expansion of the transmission network were stated as follows:

   "*The classical approach to address this is to build new transmission lines, ideally following a different path than the reinforced lines, creating a backup supply in what is called a loop service. However, BEL has a unique opportunity to leapfrog the industry and move its design to one that leverages the use of non-wires-alternatives to provide reliability and resiliency.*
   In this approach, as shown below, we used the resources identified in the capacity expansion plan to provide local support to the load and reduce the dependence on imported power via transmission during emergencies.

   There are few instances where new facilities are recommended for a) addressing construction issues with the existing transmission and at the same time allowing better integration of the new generation (e.g., Dangriga 115 kV), b) short new lines are proposed for reliability of supply (e.g., Belmopan 115 kV) or c) new lines and substations will prove a second supply to the load congested areas and included undergrounding to increase resiliency (Belize City). Additionally, there are multiple expansions to the transformation capacity at the substations to supply the increased load and recommendations are being made to improve the configuration so that a failure on one line does not unduly affect more than the interconnecting substations (e.g., BAPCOL tap)."

2. PSRs view on Siemens' approach to meeting future load growth in terms of reliability and cost efficiency are that:

   2.1 "*A stronger, integrated, and planned transmission network for the future demand may be preferable in the long term, in terms of present value of total investment and operation cost, than a succession of intermediate upgrades as load increases in the system, leading to a myriad of voltage levels that could be unified to a higher amount for the accommodation of the future loads, especially if there is a considerable growth due to the electrification of transport.*"
   2.2 *"The transmission expansion plan should address and propose solutions to the problems related to the high penetration of RES, like the decrease in inertia and power active reserve."*
   2.3 *"The assumption of working with four main regions that is understandable from the point of view of system reliability and resilience. Nevertheless, considering the heterogenous spatial distribution of generation resources and demand, the target of supply self-sufficiency of each region may lead to much higher costs related to heavy investments in generation and BESS assets distributed in the regions and smaller investments on transmission reinforcement."*
   2.4 *"Another consequence of a weaker transmission reinforcement is that it will not enable synergies of the various generation sources, such as solar, wind, biomass, and hydropower in the country, sometimes referred as "portfolio effect".*
   2.5 *"An integrated approach to energy and electricity planning is desirable. An example is the growing share of electricity in the energy matrix, which increases the need for supply reliability going forward. In turn, increased reliability could be achieved by different means, such as evolving the national transmission network topology to a mesh pattern or harmonizing the different voltage levels in the country. These options should be investigated as well.*"

3. In the Commission's view, the expansion of the transmission and distribution Systems are tied directly to the Load Forecast. The demand projections not only enable optimum planning for when,

how much and what type of generation technologies must be added onto the grid, but it also impacts where BEL will expand its network in that:

3.1 if there are insufficient transmission lines to transport the electricity generated from plants sites to areas of high demand, the deployment of renewable energy projects may be limited;

3.2 if an area has limited transmission capacity, it limits the import of electricity from neighboring areas with surplus, inexpensive generation when local generation is insufficient or resorting to expensive local generation. This restriction can lead to higher electricity prices and reduced reliability for consumers;

3.3 if generation capacity is constrained due to transmission limitations, grid operators may be forced to curtail renewable energy generation or rely on more expensive and less efficient backup generation sources to maintain system reliability. These measures can increase operational costs and compromise the economic viability of renewable energy projects;

3.4 the planning and implementation of transmission projects can be time-consuming and costly, resulting in delays in the rollout of supply-side resources. These delays can hinder the integration of new generation technologies and impede efforts to modernize the grid.

4. Given this, the supposition must be that BEL's plan for the transmission and distribution system is likewise only designed to accommodate a demand up to 2027, and therefore inadequate.

5. The design of transmission networks is crucial to ensure that they can effectively accommodate current and future electricity demand while also supporting the integration of new supply-side resources. Underinvestment in transmission assets can indeed lead to premature obsolescence and hinder the efficient operation of the electricity system. A proper load forecast and an associated long-term network plan will need to be developed and filed by BEL.

6. Notwithstanding these deficiencies, the Commission is largely in agreement with the recommendations made by Siemens, that call for the following:

a) Implement Mesh topologies across the Transmission Network;
b) Elimination of Chan Chen as well as the Belmopan and BAPCOL taps;
c) Ring buses at BelCoGen, La Democracia, Dangriga and BAPCOL substation;
d) Expansions to the installed transformer capacity at bulk supply points, over the planning horizon, to supply the increased load;
e) New lines and substations will provide a second supply to the load-congested areas (Belize City and San Pedro).

In relation to e) above, BEL shall comply with Section 52 of the Electricity Act which requires the PUC's consent prior to the construction of new transmission lines.

E. Resource Adequacy Analysis (RAA)

1. Siemens describes its approach for the dispatch of generation resources in 2042 (see Tables 9, 10 and 11) as follows:

"**14.5.4 Generation Dispatch**

One dispatch was modeled for daytime conditions minimizing the thermal generation in country and results in *an export to Mexico of 17 MW and two dispatches for nighttime conditions as indicated earlier…*

The tables below show the dispatch of the units in service for the Base Strategy which is the most demanding from a transmission point of view and was used for the assessment of performance. The Belize Centric strategy requires the same investments in transmission, which are largely driven by load growth and the available dispatchable resources (RICE and Battery energy storage) which are the same as for the Base Strategy."

Table 9: Generation Day Peak Dispatch Base Strategy

Generator	Type	PGen (MW)	QGen (MVAr)	PMax (MW)
Vientos del Caribe 1	Wind	12.0	-0.3	15.0
Vientos del Caribe 2	Wind	8.0	-0.2	10.0
Vientos del Caribe 3	Wind	8.0	-0.2	10.0
Ladyville Battery	Storage	-10.0	1.2	10.0
Ladyville PV	Solar	16.0	0.4	20.0
West PV 1	Solar	16.0	-6.6	20.0
West PV 2	Solar	16.0	-6.6	20.0
La Democracia PV 1	Solar	16.0	2.2	20.0
La Democracia PV 2	Solar	16.0	-2.2	20.0
Hydro Maya	Hydro	1.3	1.9	2.5
Independence Battery	Storage	-10.0	4.8	10.0
Chalillo	Hydro	1.8	2.0	3.5
Mollejon	Hydro	4.2	-2.0	8.4
Maskall PV	Solar	16.0	-1.6	20.0
Mexico (CFE)	Mexico	-17.0	4.5	100.0
Chan Chen PV	Solar	16.0	-6.6	20.0
Orange Walk PV	Solar	16.0	2.2	20.0
San Pedro Battery	Storage	-10.0	4.8	10.0
Orange Walk Battery	Storage	-10.0	1.2	10.0
Total Utility Generation MW/MVAr		**106.3**	**-1.1**	
Total Load Served		**100.7**	**27.2**	
Total Losses MW		**5.6**		
Total Losses %		**5.3%**		

Table 10: Generation Night Peak Max Security Dispatch Base Strategy

Generator	Type	PGen (MW)	QGen (MVAr)	PMax (MW)
Vientos del Caribe 1	Wind	12.0	0.7	15.0
Vientos del Caribe 2	Wind	8.0	0.5	10.0
Vientos del Caribe 3	Wind	8.0	0.5	10.0
LM 2500 Gas Turbine[20]	Gas	6.2	1.3	30.9
Ladyville Battery	Storage	5.0	4.1	10.0
Hydro Maya	Hydro	2.3	0.3	2.5
Independence Battery	Storage	5.0	1.7	10.0
Independence RICE 1/3	Gas	1.2	1.6	7.5
BAPCOL 1	Thermal	1.2	0.2	7.5
BAPCOL 2	Thermal	1.2	0.2	7.5
BAPCOL 3	Thermal	1.2	0.2	7.5
Dangriga RICE 2/3-1	Gas	1.2	0.4	7.5
Dangriga RICE 2/3-2	Gas	1.2	0.4	7.5
Chalillo 1	Hydro	3.2	0.1	3.5
Chalillo 2	Hydro	3.2	0.1	3.5
Mollejon 1	Hydro	7.6	0.0	8.4
Mollejon 2	Hydro	7.6	0.0	8.4
Mollejon 3	Hydro	7.6	0.0	8.4
Vaca 1	Hydro	8.6	0.7	9.5
Vaca 2	Hydro	8.6	0.7	9.5
Mexico (CFE)	Mexico	60.1	-3.5	100.0
Belcogen	Biomass	3.1	1.7	12.5
San Pedro Battery	Storage	5.0	4.8	10.0
Orange Walk Battery	Storage	5.0	4.1	10.0
Total Utility Generation MW/MVAr		**172.9**	**20.9**	
Total Load Served		**163.3**	**32.2**	
Total Losses MW		**9.6**		
Total Losses %		**5.6%**		

Table 11: Generation Night Peak Max Economy Dispatch Base Strategy

Generator	Type	PGen (MW)	QGen (MVAr)	PMax (MW)
Vientos del Caribe 1	Wind	12.0	1.8	15.0
Vientos del Caribe 2	Wind	8.0	1.2	10.0
Vientos del Caribe 3	Wind	8.0	1.2	10.0
Ladyville Battery	Storage	6.0	3.2	10.0
Hydro Maya	Hydro	2.3	1.3	2.5
Independence Battery	Storage	6.0	4.7	10.0
Chalillo 1	Hydro	3.5	1.1	3.5
Chalillo 2	Hydro	3.5	1.1	3.5
Mollejon 1	Hydro	8.4	1.1	8.4
Mollejon 2	Hydro	8.4	-0.16	8.4
Mollejon 3	Hydro	8.4	-0.16	8.4
Vaca 1	Hydro	9.5	2.3	9.5
Vaca 2	Hydro	9.5	2.3	9.5
Mexico (CFE)	Mexico	69.5	4.0	100.0
San Pedro Battery	Storage	6.0	4.8	10.0
Orange Walk Battery	Storage	6.0	4.8	10.0
Total Utility Generation MW/MVAr		**174.9**	**30.7**	
Total Load Served		**163.3**	**32.2**	
Total Losses MW		**11.6**		
Total Loses %		**6.6%**		

2. PSR suggests that this approach by Siemens lacked rigor and was inconsistent with prudent utility practice. Noting that:

   2.1 "The LCEP report does not seem to cover the modelling of primary resources based on time series data (e.g. reanalysis) nor calibration of these datasets with actual measurements to remove any bias in the dataset.

   2.2 In the LCEP report the production of variable renewable sources as wind power and solar power was apparently not modelled in a chronological production costing model with, for instance, hourly or sub(hourly) time steps and there were no considerations regarding space and time correlations of scenarios. The variability and uncertainty of the renewable production was also not considered in the analysis. This approach is important, as it includes the variability of electricity production in the scenarios that will happen in real life operation, thus enabling considerations regarding the adequate reserves that are required in each moment by the power system.

   2.3 It was not clear from the LCEP report how operating reserves relate to the increase of variable renewable sources in Belize. As shown, this relationship is the essence of the RPD methodology that is incorporated in the co-optimization of energy and reserves.

   2.4 This modelling approach could analyse bottlenecks/constraints in the transmission system, quantify losses and performance issues, and suggest solutions or mitigation options. Thus, the tool could be used to support the network design considering multiple operating scenarios for Belize. This will be important considering the increased penetration of RES in the power system."

3. The Consultant agreed with Siemens that "Solar + Storage" is likely the least cost resources to be added in the short-run and calculated that:

   3.1 Based on the load profiles for 2023 and modelling the current utility-solar pipeline of 15 MW from BAPCOL and 60 MW from the Saudis would require 100 MWh of BESS to economically modulate its production and offtake.

   3.2 Adding an additional 50 MW of utility solar (total 125 MW) would require 300-400 MWh of BESS. However, a 15% increase in the load to 140 MW_e, expected for in-service date of 2025, lowers the modulating BESS capacity to 250 MWh.

4. The Commission also has its concerns regarding the model by Siemens as follows:

   4.1 Hydro Maya – because of the run-of-river feature dispatch of 1.3 MW in the daytime and 2.3 at nighttime for the same day is not possible;

4.2 BAPCOL units and the new RICE units cannot be operated at 1.2 MW;
4.3 The LM2500 cannot be operated at 6.2 MW;
4.4 It has not been proven that when Belcogen is exporting 3.1 MW, it can supply 1.7 MVars.

5. The Commission notes the following concerns in respect of the RAA undertaken by Siemens:

5.1 The modeled dispatch of Hydro Maya, BAPCOL units, the LM2500, and Belcogen's export capabilities raise doubts about the reliability and accuracy of Siemens' analysis and underscore the need for a more robust modeling approach.
5.2 The production of variable renewable sources such as wind and solar power was not modeled with sufficient detail, including hourly or sub-hourly time steps, and did not account for space and time correlations of scenarios. This omission is critical for accurately assessing the variability and uncertainty of renewable production.
5.3 The relationship between operating reserves and the increase of variable renewable sources was not clearly defined, and the treatment of the Mexican supply raises the issue of whether the goal is energy security or energy independence (a concept that this Commission views as farfetched).
5.4 The modeling approach failed to analyze bottlenecks or constraints in the transmission system, quantify losses, and identify performance issues, which are necessary for supporting network design and considering multiple operating scenarios.

6. The Commission expects that BEL shall prepare and file a proper dispatch model in the conduct of resource adequacy analysis.

III. THE COMMISSION'S DETERMINATION

A. Findings and Analysis

1. A Least Cost Expansion Plan should be composed of three key components:
   a. A Load Forecast; and the Load Forecast is to drive;
   b. the Generation Capacity Expansion (*utility-scale and distributed*) and dispatch optimization, as well as;
   c. Grid Modernization, the necessary network investments. Such associated network investments are essential to ensure that the LCEP addresses network infrastructure needs in tandem with supply-side and demand-side expansion.

This holistic approach is crucial for optimizing system reliability, resilience, and efficiency while minimizing overall costs.

2. As indicated earlier, BEL's Load Forecast, as presented in the LCEP, appears to be highly understated. Based on BEL's own recent projections, achieving the forecasted load for 2042 would likely occur much earlier, possibly by 2027. This discrepancy underscores the importance of accurate load forecasting to inform planning and investment decisions effectively.

3. Load forecasting serves as the cornerstone of utility planning across various operational segments, including power supply planning, transmission and distribution systems planning, demand-side management, operations, maintenance, financial planning, and rate design. Accurate load

forecasting is crucial for ensuring reliable and efficient operation, avoiding equipment failures, and mitigating the risk of system-wide blackouts.

4. Given the unreliability and inaccuracy of the Load Forecast in this LCEP, the Commission FINDS that the additional generation resources, as recommended by Siemens up to 2042 and shown in the restated Table 4 below, shall be adopted, with some modifications as stated in Paragraph 5 below. These additional generation sources must be operational before the end of 2027:

Rice Gas

Total MW	In Service year	POI (Location)	Note
22.50	2024	Dangriga	Build 115 kV line to Dangriga

Solar

Total MW	In Service year	POI (Location)	Note
20.00	2024	Orange Walk	Model @ 80% Pmax during peak daytime
20.00	2026	Ladyville (Includes Belize Solar)	Model @ 80% Pmax during peak daytime
20.00	2034	La Democracia	Model @ 80% Pmax during peak daytime
20.00	2036	West	Model @ 80% Pmax during peak daytime
20.00	2038	La Democracia	Model @ 80% Pmax during peak daytime
20.00	2040	La Democracia	Model @ 80% Pmax during peak daytime
20.00	2042	West	Model @ 80% Pmax during peak daytime

Storage

Total MW	In Service year	POI (Location)	Note
10.00	2023	San Pedro	Model 5 MW at night -10 day
10.00	2023	Ladyville	Model 5 MW at night -10 day
10.00	2023	Independence	Model 5 MW at night -10 day
10.00	2023	Orange Walk	Model 5 MW at night -10 day

Wind Belize Coastal

Total MW	In Service year	POI (Location)	Note
20.00	2029	San Pedro	Model @ 80% Pmax day or night
20.00	2031	Corozal	Model @ 80% Pmax day or night

5. The Commission raises the following exceptions in relation to the implementation of the additional generation sources stated in Table 4 above:

(a) The Commission does not approve the 22.5 MW RICE Plant nor the 115 kV line to Dangriga.

The Commission does not have adequate information to determine whether the operation of the 22.5 MW RICE Plant would lead to a path of least cost. Secondly, the Commission does not have adequate information to determine whether the new 115 kV lines between La Democracia and Dangriga would similarly lead to a transmission expansion that is least cost.

Thirdly, on January 20, 2024, BEL wrote to the PUC indicating that:

"*…the original request for the 21 MW Plant in San Pedro was made pursuant to data analysis demonstrating sustained spikes in demand for electricity with the potential to exceed energy supply capacity and BEL's further assessment that the procurement processes for new generation cannot be completed in time to bridge the gap in power supply.*

BEL takes this opportunity to inform the PUC that the Company is furthering its analysis in the context of the Least Cost Expansion Plan (LCEP) to affirm that the 21 MW mobile gas turbine can achieve similar or better technical and economic performance as the gas-to-electricity plant options originally contemplated in the LCEP. BEL therefore retracts its original request for approval of the acquisition of the gas turbine until further notice."

The Commission will await BEL's further analysis before deciding on this matter.

(b) The Commission adopts the 140 MW of utility solar, as the saturation threshold for this technology in meeting the 155 MW of peak demand to 2027.

(c) The Commission adopts the 40 MW of BESS, proposed by Siemens.

Furthermore, the Commission was guided by the modeling work of Consultant and has increased the planned BESS deployments to 2027 by an additional 20 MW. Thus, the planned capacity of BESS to be deployed up to 2027 horizon is 60 MW.

(d) The Wind for Belize Coastal goes beyond the 2027 horizon and as such, the Commission reserves a Determination on that 40 MW of additional generation for a future LCEP.

6. The Commission also has certain observations regarding the LCEP that was submitted by BEL, including but not limited to the following:

(a) BEL has significantly delayed the submission of the LCEP contrary to its statutory obligation to provide the Commission with information as requested;

(b) BEL has constantly changed its set of assumptions and making new ones following the submission of the LCEP;

(c) BEL has built the LCEP and at a later point, the Subsequent Filing, on the assumption that Mexico and BAPCOL will be dropped from the energy mix;

(d) BEL has failed to supply the Commission with a Grid Code, nor has it provided any study to support that the grid can accommodate the addition of solar power to the mix;

(e) The LCEP, as submitted, only supports the energy needs of BEL up to 2027 and as such, there is a need for the preparation and filing of an updated LCEP for a twenty-year horizon beyond 2027.

(f) The Government of Belize has pursued financing for 40 MW of Battery Storage through the World Bank and as such, the Commission holds the view that this will be procured accordingly.

(g) The Government of Belize has similarly signed a loan agreement with the Saudi Fund for Development to build a 60 MW solar power plant, this presumably will likewise be procured accordingly.

(h) On June 7, 2023, the Commission also approved an application made by BEL for 7 MW of solar power in Chan Chen and 8 MW of solar power in Maskall to be produced by Blair Atoll Power Company Limited ("BAPCOL").

IV. THE COMMISSION'S APPROVAL AND ORDERS

After examining the application filed by Belize Electricity Limited and considering other relevant facts and documents, the Commission hereby makes the following ORDERS:

ORDER

1. The Commission adopts the Least-Cost Expansion Plan (supply-side) and ORDERS Belize Electricity Limited shall implement as augmented and/or modified by the stipulations in Section III above;

2. The Commission adopts the Least-Cost Expansion Plan (network reinforcement/expansion side) and ORDERS Belize Electricity Limited shall implement as augmented and/or modified by the stipulations in Section II D above;

3. The Commission ORDERS that Belize Electricity Limited shall, along with any other authorised entity as prescribed by law, prepare and file with the Commission a Least-Cost Expansion Plan for the upcoming 20-year horizon (2027|46) by December 31, 2025;

4. The Commission ORDERS that Belize Electricity Limited prepare and file with the Commission, within two months from this Order, a four-year plan from 2024 to 2028, that will reflect all Decisions taken in this Final Determination and accompanying Orders;

   Given the long implementation period for transmission projects, the LCEP is intended to inform the Commission in respect of essential transmission investments to be undertaken in the current FTP 2024|28. It will also guide the Commission on future supply-side investments for meeting demand exceeding 155 MW, while meeting or exceeding energy transition targets;

5. That within thirty (30) days of the Order, Belize Electricity Limited and Public Utilities Commission shall form an ad-hoc working group to:

   (a) Make the necessary preparation for the procurement of the additional 65 MW of solar and 20 MW of Battery Storage;

   (b) establish a Grid Code and prepare a plan for required upgrades to the national grid for all market participants connected to the National Grid to comply with the approved Grid Code;

   (c) Agree upon a forecasting methodology for future submissions to the Commission; and

(d) Agree upon the terms of reference for the 2027|46 Least Cost Expansion Plan

6. BEL is ORDERED to obtain consent from the Commission for the construction and operation of any new generation or transmission plant, pursuant to Part VI of Statutory Instrument No. 39 of 2024, ("*ELECTRICITY LICENSING AND CONSENT REGULATIONS, 2024*").

BY ORDER dated this 12th day of March, 2024

DEAN MOLINA
CHAIRMAN

Appendix A – Report from PSR

Review of the Least Cost Expansion Plan of Belize

Prepared to

PUC BELIZE

June 2023

REPORT

R

Table of contents

1 INTRODUCTION

Siemens PTI was engaged by Belize Electricity Limited (BEL) to develop a least cost and least risk system expansion plan (LCEP). The LCEP is a roadmap that will guide how BEL generates, transmits, and supplies electricity through 2042.

The LCEP results of a collaborative effort between Siemens and Belize Electricity Limited (BEL). It followed a 5-step process to analyze candidate portfolios based on two different strategies: (a) to prioritize the development of internal resources in Belize; (b) rely on international purchases.

This report reviews the LCEP Report version 2.4, that was released on August 26th, 2022.

2 PROBLEM DEFINITION AND EXISTING SOLUTIONS

Due to the accelerated growth in the consumption of fossil fuels that emit greenhouse gases, the LCEP must consider the Nationally Determined Contributions (NDC) of Belize as the power sector is a relevant emitter of CO_2. Furthermore, a transition towards low carbon power production can be important to reduce CO_2 from other sectors of the economy. If, for instance, the increased electricity demand related to the electrification of transport is supplied by renewable energy sources (RES), there will be a reduction of emissions from the use of fossil fuels, such as gasoline or diesel. Thus, the LCEP must strengthen the consideration of other sectors that may contribute to the growth of future demand.

RES, mainly wind and solar photovoltaic, stand out to reduce the dependence of fossil fuels while minimizing costs and diversifying the energy matrix. This has contributed to a massive insertion of the RES in the Electric Systems globally and prospects are that their share of the energy matrix will continue to grow over the years.

Power system operators are rightfully concerned about the effects of the growing use of RES-based generation on the stability of the power system. One reason for concern is that RES-based generating lacks physical spinning inertia. The frequency stability of the grid is thought to be negatively impacted by this feature, which makes grids more susceptible to greater Rates of Change of Frequency (ROCOF) and larger transient frequency deviations from disturbances. Moreover, the growth of RES also contributes to the increasing need for active power reserve - an ancillary service required to cope with uncertainties and variations in load and/or renewable generation.

Concerns regarding the reliability of the grid's frequency also increase with the growth of RES-based power and distributed generation. To provide system inertia and stabilize grid frequency, control schemes that resemble synchronous generators have attracted a lot of attention in the literature. Battery Energy Storage Systems (BESS) have emerged as one of the possible solutions for contributing to inertia and active power reserve, with advantages such as fast response capability, sustained power delivery, and the possibility of installation in parts of the transmission grid with specific requirements.

The LCEP report seems to address the high penetration of RES in Belize with a combination of *must run* gas-fired generation and BESS. Nevertheless, possible alternatives for coping with a decrease in system inertia and power active reserve have not been assessed.

3 ANCILLARY SERVICES

Ancillary services are those associated with a set of products apart from energy productions related to provision of energy, necessary for the maintenance of security and quality levels of the electric systems. The increased dynamics of the grids and the rapid insertion of intermittent sources in the system have required a greater demand for these services, which are mostly provided by generators, and in accordance with the regulatory framework of each country.

3.1 Frequency Control

The frequency in an electric system must be within a permissible control range around a nominal reference value to ensure that the load is supplied safely and adequately. Meaning that despite the normal variation in the frequency, it should be within a range in which the consumer equipment can operate in a satisfactory manner.

Frequency stability in electrical systems is associated with the balance between load and generation. The imbalance between load and generation can cause frequency deviations from the reference. In this situation, the performance of frequency control mechanisms is fundamental to ensure the stability and adequate performance of the system.

Traditionally, the frequency control of systems is mostly performed by rotating machines synchronized to the grid, which can store kinetic energy in their rotating mass and the possibility of controlling the power produced. After the occurrence of events that cause unbalance between load and generation, these machines can provide an inertial response and increase or reduce the power supplied within the limits of the operating range to correct frequency deviations from the reference.

3.2 Inertia

When a load-generating imbalance occurs, the speed of the frequency variation changes according to the magnitude of the imbalance and the moment of inertia of the machine, as described in the equation below [1]:

$$\frac{d\omega}{dt} = \frac{\omega_0(P_m - P_e)}{2H}$$

Where $d\omega/dt$ is the rate of change in frequency (Hz/s), ω_0 is the system nominal frequency (Hz), $(P_m - P_e)$ is the power change per unit on machine base (MVA) and H is the stored energy at rated speed in MW.s/MVA rating.

The greater the moment of inertia of the generator, the lower the rate of speed change. In situations of power unbalance, the excess (or lack) of generated energy is added to (or subtracted from) the kinetic energy stored in the spinning mass of the machine. This behavior, inherent in synchronous machines, plays an important role in the operation of a power electrical system by reducing the ROCOF.

Traditionally, RES are an asynchronous form of generation and are connected to the grid via power converters. Thus, the increased penetration of wind and photovoltaic generation in the electrical system leads to a reduction of its equivalent inertia, since these sources do not add inertial response to the system, as do the synchronous machines adopted in conventional generation. This increases the ROCOF and, consequently, the risk that a load-generation imbalance could take the frequency to levels dangerous to the stability of the system, possibly resulting in load shedding and, in extreme situations, major blackouts.

However, with proper control of the inverter, it is possible to emulate the inertial response of a synchronous machine, which is commonly referred to as synthetic inertia. In the literature, several control strategies to obtain an inertial response from renewable sources can be found [2, 3, 4]. Synthetic inertia is given by the ability to respond quickly and automatically to frequency variation, in the time scale of seconds, through the injection or absorption of active power in the grid. In this way, besides wind and solar generators, other resources could potentially participate in fast frequency control, such as energy storage systems and demand response mechanisms.

3.2.1 Grid-Following Controllers

Power Electronics devices have been of great importance in making alternative energy sources (RES other than hydropower) viable for electric power generation. Most electric power generation solutions based on alternative energy sources require power electronics technologies. Wind turbine generators, for example, may be connected directly to the grid. However, this implicates fixed speed operation, which limits the efficiency of the unit. Photovoltaic is a DC source and requires inverters to connect to traditional AC grids and possibly also DC/DC converters to connect to a DC bus. Additionally, converters may be used to control the generating unit to keep it at the Maximum Power Point Tracking (MPPT).

Grid-following (GFL) controllers consist of two main subsystems: a Phase-Locked Loop (PLL) that estimates the instantaneous angle of the measured converter terminal voltage and a current-control loop that regulates the AC current injected into the grid. For this configuration, the PLL provides the angular reference for the current commands and is responsible for the following behavior. Since the current is the physical quantity being controlled, this is often referred to as current control. GFL AC terminals emulate a current source with real and reactive outputs that follow the references. The inverter acts as a constant real-reactive power (PQ) source for fixed power commands.

This control strategy is known as grid-following because it requires that each inverter have a specific terminal voltage that the PLL can latch onto and follow. The system voltage and frequency, in this setting, are regulated by resources external to each grid-following inverter. One of the problems with using GFL is that it does not contribute to the inertia of the system and does not provide an inertial response when there is an imbalance in the network, leading to stability problems and challenges for the operation of the system.

3.2.2 Grid-Forming Controllers

The term grid-forming (GFM) can be referred to as any inverter controller that regulates instantaneous terminal voltages and can coexist with other GFL and GFM inverters and synchronous generation on the same system. Or its definition can be restricted to inverter controls that do not require a PLL. This contrasts with GFL units that act as current sources, require a PLL, and cannot function without an externally regulated voltage.

Droop controllers, virtual synchronous machines, and virtual oscillator controllers are the three main categories of existing grid-forming controllers.

Droop control is the most well-established grid-forming method is droop control, which was first proposed by [5]. Its key feature is that it exhibits a linear trade-off between frequency and voltage versus real and reactive power, much like a typical synchronous machine does in steady state. These so-called "droop laws" are referred to as the P-omega (real power-frequency) and Q-V (reactive power-voltage) relationships. Even though the droop implementation does not provide inertia support for the grid, adding a low-pass filter (LPF) adds inertia emulation.

The virtual synchronous machine approach is based on emulating a synchronous machine within the control of an inverter [6, 7, 8, 4]. Specifically, inverter terminal measurements are fed as inputs to a digital synchronous machine model whose emulated dynamics are mapped to the inverter output in real time. The complexity of the virtual machine can vary widely, from detailed electromechanical models to simplified swing dynamics. Implementations that closely approximate machine characteristics, possibly even with virtual flux dynamics, have both Q-V and P-omega characteristics and are often referred to as "synchronverters." At the other end of the spectrum, virtual inertia methods are simpler and capture only the dynamics of an emulated rotor and its P-omega deviation at steady state.

In recent years, another method of inverter control has emerged that is based on the emulation of nonlinear oscillators: virtual oscillator controllers [9]. Like a virtual synchronous machine, real-time measurements are processed by the digitally implemented model whose output variables modulate the inverter power stage. The main difference is that the model takes the form of an oscillator circuit with a natural frequency that matches the nominal frequency of the AC grid, and its remaining parameters are set to match the nominal voltage and control bandwidth. Although the virtual oscillator may look completely different, it has been shown to exhibit the Q-V and P-omega droop laws in steady state.

The use of GFM converters is an alternative for RES to also contribute to system inertia.

LCEP considered only one battery operating as GFM converter. This solution can be improved if all batteries perform grid support features.

In addition, **all RES** should be able to provide grid support, such as virtual inertia, not only wind.

3.3 Spinning Reserve

The reserve requirement for a safe operation of an electric power system is the amount of operating reserve necessary to compensate for load and/or generation fluctuations at intervals shorter than the dispatch order time of the equipment to ensure that the frequency is maintained within an acceptable range around the set point. In other words, the generation system should respond quickly and automatically, in a time frame shorter than the operator's time. Since rapid response is required, the machines designated for operating reserve must be synchronized with the grid to provide power when needed.

Historically, the reserve requirement is calculated to cover:

- load forecast errors
- load variations between dispatch intervals in real time
- forced outages of generating units
- contingencies in the transmission system

However, the increased penetration of variable renewable sources is increasing the need for the reserve requirement. This occurs due to the fact that these sources are not controllable, given the dependence and volatility of the primary resource. In this case, the reserve must be calculated in a way that also covers the variations in short-term renewable generation and the generation forecasting error. Even if perfect models were available, in such a way that the deviation of the wind generation forecast would be zero, it would still be necessary to size an additional portion of the power reserve to cope with its variability along the daily day since the generation schedule is made for each 30-minute step. In other words, it is necessary to have an operational reserve in addition to the conventional one to cope with the instantaneous variations of wind generation throughout the 30 minutes. This need is identical to the one that is verified for monitoring the system load because, from the point of view of conventional plants, wind generation behaves as a negative load.

Thus, it can be said that the sizing of the operating reserve is associated with the uncertainty of the net demand (load and renewable generation) and the probability of contingencies occurring in the generation and transmission systems. In this way, the electrical systems maintain an operative reserve in sufficient quantity to guarantee the balance between load and generation, even in cases of failure of large generators or transmission lines. This reserve is composed of generation capacity retained in the energy supply and/or interruptible loads that are available to respond.

It is important to emphasize that the failure of a generator or transmission equipment causes a power imbalance instantaneously. In contrast, due to the portfolio effect, a reduction or increase in non-controllable renewable generation will take a longer time to impact the balance between load and generation. In addition, there is predictability, even if not entirely accurate, in the short term. This means that the equipment and strategies for providing the reserve service for these cases may be different from what is traditionally used for contingency operating reserves. Non-spinning and additional reserves can also be used because they have a slower response time and are commonly cheaper.

The amount of reserve required can be calculated using deterministic criteria or probabilistic methods. Although easy to apply, deterministic methods do not consider the stochastic nature of the problem. Since the reserve is related to variables that have associated uncertainty (load and generation projections, equipment failure events), the definition of the reserve requirement by a probabilistic method is more adequate.

3.4 Black start

Black start is the ancillary service traditionally performed by hydroelectric plants that allows the system to be recomposed in case of a disturbance that leads to the total or partial shutdown of the loads.

3.5 Battery Energy Storage System (BESS)

An energy storage system (ESS) might be a viable solution for providing inertia and primary frequency control. Conventional power plants rely on synchronous generators, which inherently exhibit an inertial response to sudden frequency deviations. When spinning reserves are available, they participate in load-frequency regulation defined by their droop characteristics. Unlike conventional power plants, RES-based plants are connected to the grid via power electronic converters that decouple the grid frequency from the speed of the rotating machines in wind turbines. Therefore, RES-based plants, by themselves neither provide inertial response nor participate in load-frequency regulation, and their large-scale integration may result in loss of inertial response and primary frequency reserve.

Wind and photovoltaic systems are usually operated with MPPT - maximum power point tracking. Some reserves must be maintained if an inertial response or primary frequency reserve is expected from these plants. Some methods are proposed to provide an inertial response and/or primary frequency reserve from RES-based plants by curtailing their power generation [10, 11]. However, this approach does not utilize the maximum output of RES, which is highly undesirable. Furthermore, BESS which offers a variety of storage technologies is a suitable alternative to provide inertial response, primary frequency reserve, and black start capacity.

The LCEP report considers the total BESS investment going into operation in 2023. The entry of BESS could be gradual and in line with the expansion of renewable sources. This would probably lead to benefits related to technological advances and cost reductions in the coming years.

This amount of battery investment comes from a new reliability criterion introduced to the expansion planning process. This was accomplished by considering zero imported energy from Mexico, although this importation is considered reliable by the Belize operator.

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4 METHODOLOGY REVIEW

4.1 Background

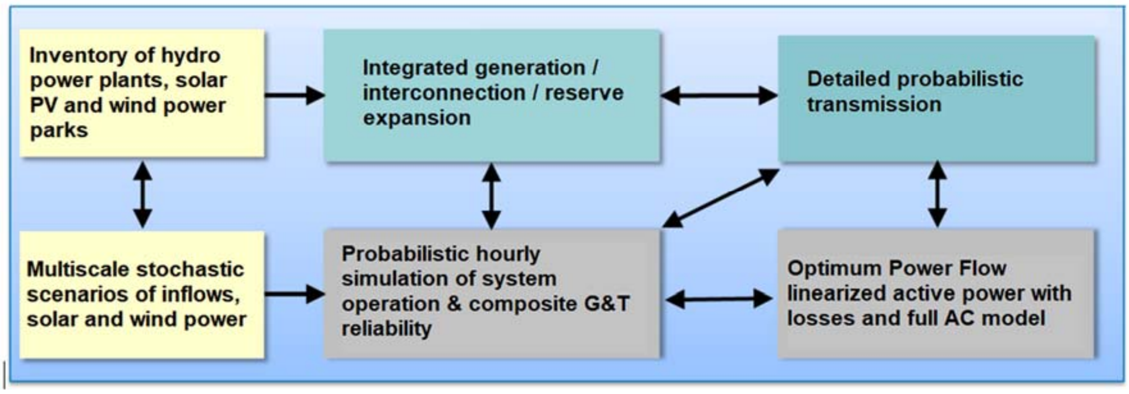
This section reviews the methodology used in the LCEP report. It combines described methodology and an inferred methodology, if the methodology was not directly described in the Siemens report. Whenever this applies, we will note in this review. It would be interesting to confront this view with the authors for clarity. In the past, there were essentially two groups of power systems:

- *Energy constrained*, generally hydroelectric dominant-case as Brazil or Norway, where the concern was variability of inflows, storage, and energy rationing risk, but did not have problems of meeting the peak demand; and
- *Peak constrained*, which were concerned with unit commitment, load-carrying ramp, loss of load probability (LOLP) but had no concerns about power rationing.

The insertion of renewables has led to a *convergence* among all countries, which now care about energy as much as power, variability, storage, and others. A portfolio of small-scale hydropower, biomass cogeneration, wind and solar power can be combined to provide flexibility for power systems. Projects that are less capital-intensive and have faster construction times can attract a wider range of investors and reduce the risk of cost overruns and delays. The shorter construction time also mitigates load growth uncertainties. The purpose of a least cost expansion planning (LCEP) study *should not* be to centrally decide what is to be built, but (i) to provide information to the market, which makes competition more effective and therefore benefits the consumer; (ii) gain insight into the impact of technological change, such as penetration of renewable energy or storage.

These impacts can affect the design of the market, for example leading to the creation of new ancillary services, as well as the need for centralized investments in infrastructure, for example, more flexible transmission networks to accommodate the variability of renewables.

The following figure shows the main modules of a modern electrical planning system.



4.2 Inventory of renewable projects

The inventory of wind and solar project candidates has two main challenges: (i) the choice of the location of the candidate projects can be complex since it must consider not only the capacity factor but also the distance to the transmission network; and (ii) probabilistic operational simulations require long wind and solar radiation records. However, when available, measurements typically span over 1-3 years before project construction.

The challenge of choice of location may be circumvented using resource maps in conjunction with relevant layers of information, as in the case of hydropower, such as access roads and distance to the grid. On the other hand, the challenge (ii), the creation of longer wind series, can be solved with global databases such as reanalysis data MERRA 2 or ERA-5. Both datasets have more than 30 years of hourly resolution of winds velocities from circulation models. These datasets should ideally be calibrated based on measured (field) data.

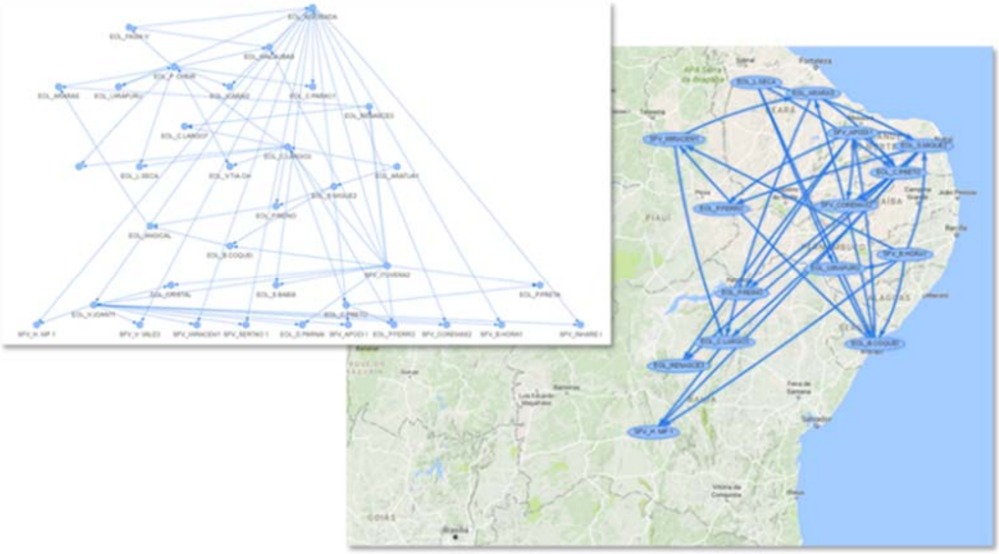
A similar process can be used for creating solar project candidates: use of wind maps and reanalysis data for project location and calibration to remove bias in the data with the use of actual measurements. In the case of solar PV, it may also be important to model the *distributed generation* (DG) - basically rooftop solar - with a similar approach as in the utility scale projects, though the conversion of resource (radiation) to power is different in some ways because DG is often installed in sub-optimal conditions (e.g. wrong roof orientation, shadowing by neighboring buildings, trees, and other factors). The fact that DG usually has a fixed tilt, whereas utility-scale projects commonly use 1-axis trackers is also an important difference in the modeling of the source of energy.

The LCEP report does not seem to cover the modeling of primary resources based on time series data (e.g. reanalysis) nor calibration of these datasets with actual measurements to remove any bias in the dataset. In addition, it would be important to communicate in a very transparent way the Current inputs, assumptions and scenarios that are part of the study. As a reference, the Australian Energy Market Operator (AEMO) disseminates these workbooks.

The lack of similar workbooks in the LCEP study considering different datasets and aspects, such as load forecasts, characteristics of supply options and network components, dispatch and power flow modeling, economic and financial modeling study, and others should be remediated.

4.3 Stochastic modelling of renewables and inflows

This expected operational cost is calculated over a set of inflow/renewable scenarios. Due to the spatial correlation of wind and solar production in different regions, as well as the spatial correlation between inflows and wind in some regions, it is not adequate to model each scenario independently; it is necessary to represent the joint probability distribution of all the climate-related data, encompassing both variable renewable generation (wind and solar power), seasonal biomass cogeneration production and hydropower for existing and future candidate projects. This joint representation should be multiscale, that is, wind and solar are represented with hourly resolution or less, whereas inflows are typically represent on a weekly basis. One alternative is to use of a Bayesian Network to produce integrated, multiscale wind, solar and inflow scenarios. It is a statistical model that represents a set of variables and their conditional dependencies via a graph.



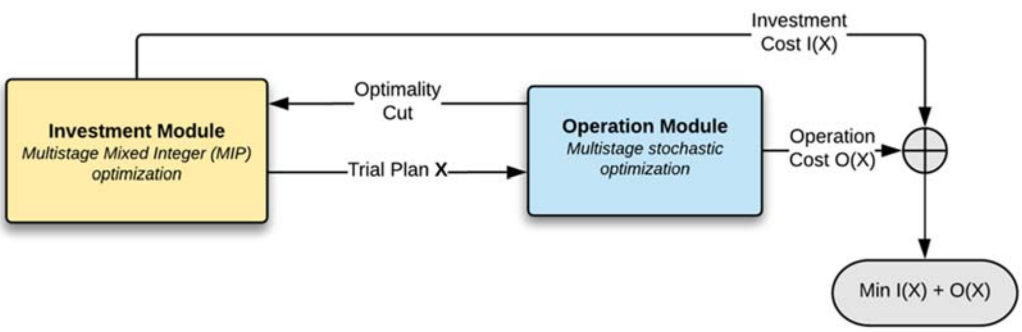
The joint renewable and inflow scenarios produced can be used by a stochastic operational model.

In the LCEP report the production of variable renewable sources as wind power and solar power was apparently not modelled in a chronological production costing model with, for instance, hourly or sub(hourly) time steps and there were no considerations regarding space and time correlations of scenarios. The variability and uncertainty of the renewable production was also not considered in the analysis. This approach is important, as it includes the variability of electricity production in the scenarios that will happen in real life operation, thus enabling considerations regarding the adequate reserves that are required in each moment by the power system.

4.4 Expansion of generation, interconnections, and reserve

In a simplified way, the power system expansion planning objective is to determine the set of generation and transmission reinforcements along the planning period that minimizes the present value of investment costs plus the expected value of operation costs (basically fuel costs for the thermal plants plus penalties for load supply shortages).

This optimal plan is obtained through the iterative solution of two optimization models: the investment decision and the operation planning.



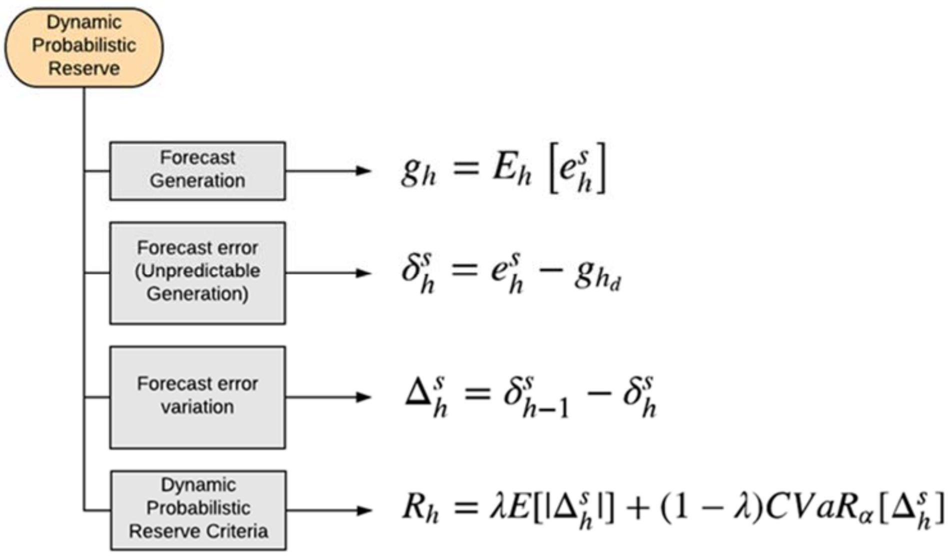
The purpose of the expansion model is to minimize the present sum value of the investment cost and the expected value of the operating cost. One of the recent methodological advances of planning studies was to represent a third component in this sum, which is the construction of *reserve capacity* to manage the variability of the constructed renewable sources. This simultaneous optimization of energy and reserve investments is known in the literature as *co-optimization*.

The investment module determines a trial expansion plan (represented by the vector X) and its associated investment cost, represented as $I(X)$. This trial plan results from the solution of a mixed integer programming (MIP) optimization problem. In turn, the operation module determines the expected operation cost $O(X)$ associated with the trial plan sent by the investment module. This expected cost is obtained through the solution of a multistage stochastic optimization problem.

In addition to calculating the expected operation cost $O(X)$, the operation module produces a linear constraint whose coefficients are the derivatives of the operation cost with respect to each investment decision, $\partial O(X) / \partial Xi$, i=1,... ,I of the trial plan vector X. This constraint, known as an *optimality cut*, is sent to the investment module. The augmented MIP problem is then re-solved and produces a new trial plan, which is again sent to the operation module, and so on. This iterative process, known as *Benders* decomposition, ensures convergence to the global optimal plan.

Probabilistic reserve constraints can be considered in the capacity planning model. The first component is defined *ex-ante, usually* as a percentage of the hourly demand to compensate for forecasting errors and natural fluctuations throughout the day. The objective is that flexible resources, such as hydro plants, fast response units and batteries will respond to the short demand variability.

The second component is a *Dynamic Probabilistic Reserve* (DPR), which is related to the variability of the electricity production, and it is meant to secure the system operation against deviations between the forecasted VRE production and the verified one. As shown, DPR calculations are based on generation scenarios prepared by a specialized model.



As mentioned, the DPR must be *probabilistic*, that is, it must consider the stochastic process of variation of VRE production in consecutive hours; and *dynamic*, that is, it must consider that VRE production varies throughout the hours of the day and throughout the months of the year. In practical terms, this means that the operating reserve due to VRE is represented as an hourly profile (24 hours) that varies per month, due to the seasonal pattern of production of the VRE, and per year, due to the entry of new VRE capacity.

The calculation of the reserve for each month and region (e.g. Northeast) has four steps:

1. Determine the *Forecast Generation* of the VRE – in this step, the average hourly generation profile will be assumed to be the forecast generation. This calculation is done using VRE gen-

eration scenarios. For example, if there are 50 scenarios, and that each one is composed of 30 days × 24 hours/day = 720 hours of VRE production, we will have 50 × 30 = 1500 samples for the first hour; the same for the second hour; and so on. The hourly generation profile is the average of these 1500 values for each hour.

2. Determine the *Forecast Error* – for example, suppose that the VRE generation at hour 1, for a specific scenario, is 60 MW, and that the forecast for hour 1 is 55 MW. In this case, we will have a forecast error of 60 – 55 = 5 MW. These 5 MW correspond to the "stochastic" (unpredictable) component of VRE generation, and therefore requires reserve. The calculation of the deviations is repeated for each of the 1500 scenarios for hour 1; then for hour 2; etc. The result is a matrix with 1500 lines (scenarios) and 24 columns (hours of the day). Each element of this matrix contains an error in MW, positive or negative, with respect to the average time profile.
3. Determine the *Forecast Error Variations* of VRE production between consecutive hours – for example, suppose the error for hour 1, scenario 1 is 5 MW; and that for the next hour (hour 2, scenario 1), is -3 MW (negative value). This means that there is an error variation of 5-(-3) = 8 MW of VRE generation between hours 1 and 2. In turn, this points to the need of an increase in the generation to compensate 8 MW for time 1, scenario 1. This process is repeated for the 1500 scenarios of hours 1 and 2, and the result is a vector for the reserve requirement.
4. Determine the probabilistic reserve of each hour, R^*, as the following expression:

$$R^* = (1-\lambda)\, E(R) + \lambda\, MAX(R)$$

Where $E(R)$ in the expression is the average of the absolute values of the reserve R for each hour, and $MAX(R)$ the maximum value of the vector. Finally, the weight l represents the Risk Criterion of the Planner (λ =0.3 represents a reasonable compromise). Using this value, 70% of the reserve value is based on the expected value when all scenarios are considered and 30% based on the maximum required reserve, amongst all scenarios.

The DPR calculation method has some interesting aspects:

- It may jointly represent the hourly demand and VRE generation, thus the net load. This is useful if the two processes are correlated.
- The methodology dynamically adjusts the reserve in a “rolling horizon” scheme, where it is possible to select the “look ahead period”;
- Different risk criteria can be used, such as CVaR measured along stages & scenarios;
- It can also be used to measure the value of *forecast accuracy*, which would be given by a set of weights measuring the probability of each VRE scenario. If there is perfect forecast, the weight would be 1 for the *known* scenario and zero for the remaining. If there is *no* forecasting ability, all probabilities are the same, thus 1/S.

It was not clear from the LCEP report how operating reserves relate to the increase of variable renewable sources in Belize. As shown, this relationship is the essence of the RPD methodology that is incorporated in the co-optimization of energy and reserves.

The final methodology consists of the solution of a planning problem with an iterative method:

(i) The investment module, that determines a candidate expansion plan *X;*

(ii) The dynamic probabilistic reserve module (DPR), that determines the amount of reserve *R* required to absorb the variability of load, the existing renewable generation and future renewable contained in the candidate plan *X*;

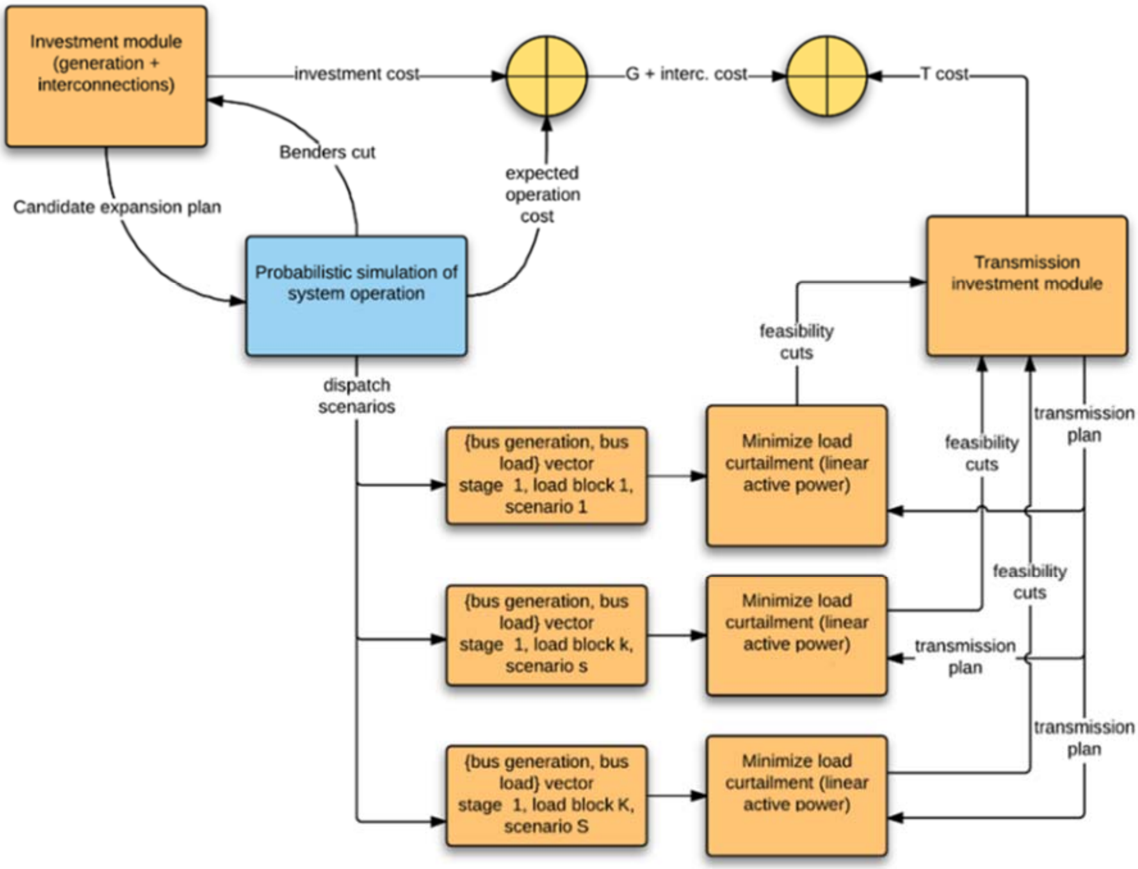
(iii) An operating module determines the expected value of the operating cost resulting from plan *X* and associated reserve *R*;

(iv) Finally, a reliability module calculates the EENS resulting from *X* and *R*. If the plan is not reliable, new projects are added to the expansion (reiterate).

4.5 Transmission Expansion

Another significant advance in planning methodologies was in determining the transmission network reinforcement. In this case, the objective is to minimize the total cost of the reinforcements necessary to meet without overload the various scenarios of generation and demand resulting from the probabilistic simulation of the system operation.

The following figure shows the solution scheme of this problem, known in the literature as "robust optimization".



It is observed that the upper left part of the figure represents the generation and interconnection expansion model seen previously. (For simplicity of presentation, dynamic probabilistic reserve and reliability modules were not represented.) The operational simulation produces a generation vector and demand for each bar of the transmission system for each scenario $s = 1, ..., S$ and for each demand block $k = 1, ..., K$.

As mentioned, the purpose of the optimum transmission expansion model, represented on the right side of the figure, is to minimize the cost of the reinforcements to ensure that the power flows for each of the *S.K* do not present overloads.

It is observed in the figure that the reactive expansion problem has a similar structure to the transmission problem: to determine the set of minimum cost reinforcements that avoid voltage problems in the *S.K* generation and demand scenarios. The difference in this case is that the operational analysis requires models of optimal AC power flow, which, by being non-linear and non-convex, make the solution more complex.

New planning methodologies require the following analytical tools: (i) preparation of sensible renewable generation projects based on resources; (ii) generation of integrated scenarios of renewable generation; (iii) co-optimization of generation-reserve-transmission expansion; (iv) simulation of stochastic production with hourly resolution; (v) probabilistic transmission network planning, both active capacity and VAr.

This modeling approach could analyze bottlenecks/constraints in the transmission system, quantify losses and performance issues, and suggest solutions or mitigation options. Thus, the tool could be used to support the network design considering multiple operating scenarios for Belize. This will be important considering the increased penetration of RES in the power system.

5 LCEP ASSUMPTIONS

5.1 Objective function

It is said that the LCEP's objective is to procure, produce and deliver energy at a least cost with minimal price fluctuations and in support of quality of life, productivity of enterprise and national development. Naturally these may be opposing objectives: a least cost plan on average may be subjected to large price fluctuations and a plan with stable prices may cost more for the customers on average than an alternative plan.

It is, however, possible to combine these objectives. If the LCEP results from the use of an optimization model, one possibility is to write as the objective function.

$Z = \text{Min } \lambda \, E[X] + (1 - \lambda) \, CVaR[X]$, where

E [X]	Expected value of the net present value of investments + operation costs.
CVaR [X]	Conditioned value at risk of the net present value of total costs.

CVaR measures the expected value of losses from a given level of risk. It considers worst-case scenarios with a probability of occurrence smaller than α, as shown in Figure 1.

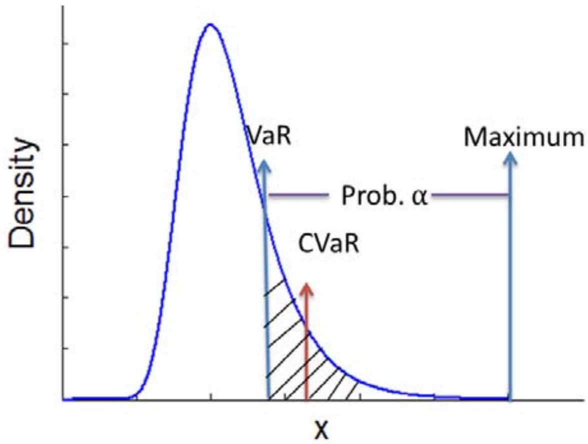


Figure 1 – CVaR definition

Alternatively, LCEP optimization model may be written with the addition of a constraint:

$$CVaR[X] - E[X] \leq R$$

Where R is a variability-related parameter.

The smaller its value, less variability is tolerated when selecting the expansion plan, constituted by the selected portfolio of candidate projects. Naturally, this controlled variability of costs will also indirectly control the variability of the end user tariffs, described as separate objective in the report.

Two more criteria should be met by the LCEP:

- 75% of the production must be renewable by 2030 and 100% renewable by 2050
- electricity supply must be reliable and have quality, with minimal interruptions.

5.2 Load forecast

The load is projected to grow at an average of 2.3% for the next twenty years with a low band of 1.7% and a high band of 2.6%. These rates are taken from historical data. The load related to electric vehicles is then forecasted and added to this organic growth.

Historic growth over the last two decades has been ~4% growth year-on-year. Siemens is thus assuming a lower growth rate over the next 20 years.

This assumption of a fixed growth rate is overly simplistic, especially in the short term, when more knowledge of economic growth or investments related to relevant projects is usually known. The literature shows a variety of methods to project energy demand, such as: (i) traditional statistical methods (top-down), including univariate models, linear regressions, econometric models, and others; (ii) artificial intelligence methods, such as neural networks, fuzzy logic, and support vector machines and (iii) bottom-up or end-use methods.

We now provide some guidance for load forecasting methods and experience:

5.2.1 Literature review

Esteves et. al presents an extensive literature review on electricity demand forecasting models. The authors evaluated more than 50 scientific articles on the subject published since 2008 and concluded that the most cited works are those that use statistical methods (67%) followed by computational intelligence models (24%). Among statistical models, linear and econometric regressions (65%) are the most relevant. The work also shows increased academic interest in the development of hybrid models.

More recently, Debnath and Mourshed analyzed 483 models applied in the context of energy planning. Again, the authors corroborate that statistical models are more used, in the specific field of projecting energy and electricity demand. Likewise, an interesting perspective provided by the work is the geographical analysis of the use of models. Naturally, computational intelligence models are applied more frequently in developed countries, with greater availability of data. For developing countries such as those in South America, statistical models have a drastic predominance.

Below is a brief description of each projection method.

5.2.2 Traditional statistical models

Statistical approaches require an explicit mathematical model that provides the relationship between load and various input factors. Among the traditional statistical methods, we highlight univariate models (Box-Jenkings and exponential smoothing), linear regressions and econometric models (multiple regressions, ECM error correction models, vector models VAR / VEC, autoregressive distributed *lag* ADRL and others).

Univariate Box-Jenkings models integrated moving average autoregressive (ARIMA) and decomposition models, such as exponential smoothing appear in the literature frequently. These are used in a technically simple modeling context, as they only consider past information from the series itself to explain the future.

International researchers who have worked on medium- and long-term electricity demand forecasting using univariate models In Brazil, Maçaira projected long-term electricity consumption using exponential smoothing models, which decompose the time series into structures of level, trend, and seasonality. The work shows good adjustments to historical data through the evaluation of sampling error, in addition to being a good approximation to the values of national studies carried out in Ten-Year Plan (PDE) and the National 2050 Energy Plan (PNE).

While effective, one of the main criticisms of univariate models for demand forecasting is the abstraction of exogenous variables and their influences. In general, for developing countries, economic growth implies higher energy consumption and vice versa. Thus, econometric models are one of the most used topics to forecast demand in the medium to long term since they correlate it with different macroeconomic variables. In this type of analysis, several factors are considered: heteroskedasticity, multicollinearity, unit roots, error correction, cointegration and others.

Suganthi and Samuel carry out an extensive literature review of more than a hundred studies in which multivariate econometric models were used. They conclude that explanatory variables most used to project demand in these models are GDP, energy price and population. Sadorsky uses the VEC model to analyze the relationship between renewable energy demand and economic growth in emerging countries, such as Argentina, Brazil, Chile, Ecuador, Paraguay, Peru, and Uruguay.

5.2.3 Artificial intelligence models

Artificial intelligence methods use techniques and systems that mimic human aspects in computers, such as perception, logical reasoning, learning, evolution, and adaptation. In the universe of demand prediction, the most used techniques include artificial neural network (ANN), support vector machine

(SVM) and fuzzy logic. These can be considered non-traditional or modern methodologies in load forecasting problems. Currently, such techniques are commonly associated with econometric models.

ANN models are inspired by biological neurons and brain structure with the capacity to acquire, store and use experimental knowledge. The most common ANN architecture for load forecasting is multi-layer feed forward Kialashaki and Reisel and others use linear regression models integrated with ANN to forecast demand in the medium and long term. They conclude that these models can estimate demand with high accuracy, based on validations and comparisons within the sample with other official forecasts.

In Bolivia, Sanjinés Tudela used neural network applications to forecast electricity demand. They compared univariate models with a model based on artificial network training, that had a lower mean absolute percentage error (ASM).

The SVM method, generally used for data classification and regression, has emerged as a relatively new and competitive approach to load projection. The essence of SVM is the construction of an optimal hyperplane. As an example, Hong uses SVM to project electricity demand in Taiwan and indicates the achievement of better performance compared to other methods, such as linear regressions and ANN.

One of the main problems when predicting time series, especially for emerging countries, is the lack of accurate historical data. Fuzzy modeling emerged as a suitable option for the projection of demand in these cases, since it aims to model reasoning approximately, imitating the human capacity to make decisions in an environment of uncertainty and imprecision. Recognizing the influence of socioeconomic variables on energy demand, Torrini et al use an extended *fuzzy* model, which includes explanatory variables such as national GDP, industrial value added, and population, to map input variable rules and provide long-term annual forecasts for Brazil. Although the results show a lower ASM value than the exponential smoothing model used for comparison, the projection tends to overestimate future demand, when compared with the results predicted by the EPE in its Ten-Year Plan. It is concluded that the fuzzy model developed is more sensitive to variations in GDP than other models.

In this context, despite the great diversity of models that use artificial intelligence techniques to forecast demand found in the international literature, the complexity of the method must be considered, in addition to the fact that other methodologies can provide a better interpretation of the relationship between the dependent variable and exogenous, as is the case with econometric models.

5.2.4 Bottom-up models

It is evident that traditional load forecasting methodologies based on the analysis of historical standards cannot capture the impact of new technologies, as these have not been observed in the past. In this context, *bottom-up* or end-use models follow a technological perspective and seek to describe in more detail the energy system, efficiency, lifetime, and other characteristics of end-use energy technologies. Unlike the top-down methodology, which treats the variables of interest at the aggregate level and provides direct results for them, bottom-up models disaggregate these variables into components (e.g., uses) and then accumulate the results of each component to generate the variables of interest. The great advantage of these models is that they allow a deeper analysis of the impacts of structural and technological changes on systems. This may be necessary for Belize, considering the prospects of an increased electrification of the transportation in the country, which currently accounts for a large share of the primary energy consumed. However, the high level of disaggregation requires a larger data set, which may be a challenge in some applications.

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5.3 Capacity Expansion candidate options

The LCEP study assessed the existing generation resources as well as the candidate generation resources that can be selected for the expansion plan. It includes adding reciprocating internal combustion engines (RICE) and repowering the LM2500 at Mile 8. It also includes adding new Variable renewable energy (VRE) sources, such as wind and solar photovoltaic power and storage.

A comparison of the different resources is made through the levelized cost of energy (LCOE) metric for all sources.

The LCOE is an incomplete metric because power systems require a combination of services (energy, capacity, reserves, controllability, fast response, etc.) and the different sources contribute to the provision of these various services differently and need to be combined to fulfil the system requirements. Ideally, all projects should be modeled based on their technical (capacity, flexibility, operative constraints, heat rate, efficiency, etc.) and economic (e.g. CAPEX, disbursement schedule, fixed and variable OPEX, leverage level, loan rate, etc.) parameters.

The LM2500 conversion, for instance, has a very high LCOE, but it may be necessary to provide peaking capacity. Solar and wind, on the other hand, now have low LCOE values, but do not provide a controllable source of electricity, and so on.

5.4 International interconnection

International Interconnections were considered including the current and expected cost and conditions to purchase power and energy from Mexico and the possibility of contracting directly with generators located in that country.

6 CONCLUSIONS

6.1 Study results

The two expansion scenarios (Belize-centric and considering more imports) rely heavily on wind power - either imported from Mexico or in Coastal Belize- and solar photovoltaic. In fact, from 2025 until the end of the horizon (2042), all investments come from these two variable energy resources. In the two initial years of the planning period, investments in RICE and an upgrade of LM 2500 are considered, both using fossil fuels.

However, the largest investment in the short term is in BESS due to a full investment in the first year of the horizon (2023) common in both scenarios. The first thought is that this investment should be more modular and distributed in time, benefiting from probable cost decreases due to technological gains. However, it appears to be related to the N-1 criteria, that assumes that the import capacity from Mexico is nil.

This dynamic strategy would also allow higher variability of renewable production related to new investments in solar and wind to be more closely compensated by new investments in storage throughout the horizon. It is also clear that storage is fully acquired in the first year in the LCEP and BESS can have a useful life shorter than the study horizon of 20 years.

Current BESS technologies are mostly Li-based, as considered. The LCEP could also develop different storage technologies of various time scales and characteristics, such as Flow (Redox) Batteries, Liquid Metal Batteries or even Pumped Hydro Storage (if local topography is favorable) can provide greater economic life.

Both scenarios reach a similar net present value of total costs (NPV). The largest investment by far is solar PV, followed by similar investment values for wind power and battery storage.

	Reference Strategy Expert Design		Belize Centric Expert Design	
	Capacity MW	**Capital Costs (2022US$ Millions)**	**Capacity MW**	**Capital Costs (2022US$ Millions)**
Mexico Wind	35	$50.6	0	$0.0
RICE Natural Gas	23	$25.4	23	$25.4
Solar PV	160	$183.6	180	$208.3
GE LM 2500 Upgrade	8	$11.5	8	$11.5
Battery Storage	40	$50.2	40	$50.2
Wind Belize Costal	0	$0.0	40	$56.1
Total	**265**	**$321.3**	**290**	**$351.5**

Investments on transmission reinforcements add another 54 million (2022 USD) during the planning period for a minimum condition to accommodate new generation investments for expected load growth in the period (“minimum required investments”). An investment plan of 84 million USD results from a “recommended investments case” which would enable the existing network to meet the N-1 contingency criterion. In terms of effective cost, measured as $/MWh, both plans are similar ($104.3/MWh for “minimum” and $107.2/MWh for “recommended”).

In terms of analysis, it is said that three sensitivities were used (low hydro production, low demand growth and high demand growth) and seven scenarios: High International Pricing, Low Capital and Low International Pricing, High Technology, High Regulation, Low Regulation, Climate Crisis, and Low Hydro – High Demand.

This separation between sensitivities and scenarios is not clear, but results were reflected in a Balanced Scorecard, **which identified the Belize Centric as the Preferred Portfolio because of lower NPV**, **greater robustness** considering the sensitivities that evaluated the portfolio for conditions that differ from the ones used in portfolio selection **and larger emissions reductions** compared to the Reference Expert Design Portfolio, meeting the 75% renewable mandate by 2030 and exceeding it by 2042.

6.2 Observations of the selected portfolio

1- The LECP concentrates on building solar and wind resources + natural gas fired RICE for ancillary services, such as provision of sufficient inertia and reserve for voltage regulation. Other options for the system, such as the installation of synchronous condensers, the modernization or retrofit of obsolete hydropower to increase the provision of services or the provision of synthetic inertia by solar and wind power, as well as reactive power appear to be disregarded. The concern here is that economical options may have been overlooked.

2- The electricity services delivered by a strong integration of solar PV and BESS must meet the technical requirements of the grids and achieve a low-cost structure. The LCEP, as it is, does not provide this guarantee because a chronological representation and simulation results.

3- Of relevance the fact that the RICE plant will be responsible for a large emission of greenhouse amount gases, which will make the decarbonization effort of the country more difficult. The selection of RICE as a resource capable of providing both capacity and ancillary services is understood, but it should be challenged by the very ideal of the LCEP, which is to find the *combination of resources* that provides the least cost.

4- The adoption of BESS in the first year of the study horizon appears to be a consequence of the introduction of the N-1 criterion that assumes that the import capacity from Mexico is zero. While there are several advantages in adding BESS to the system, the criteria may pose a high economic burden to users, that will experience sharp tariff increase.

5- It would make sense to install BESS in smaller modules distributed over a larger period of the planning horizon as the cost of BESS decreases in future years.

6- The amount of BESS to be installed at each moment would ideally come from an alternative methodology that co-optimizes energy and reserves, as presented. This gradual entry of BESS in line with the expansion of renewable sources should be associated with the GFM controller to provide both inertial response and primary frequency reserve.

Other key conclusions of LCEP review are assembled below:

6.3 Load forecast

7- Future load is projected with overly simplistic methods (a fixed growth rate). There is room for improvements in the methodology, at least for the initial years of the horizon, when there is more knowledge of the economic growth rate of the country and single-point sources of demand may be known (ex. large hotel installation, industry, or any other possibility of a significant load growth).

8- Transportation accounts for roughly 50% of the primary energy consumption of the country. Thus, it would be advisable to refine the study to investigate the impact of future electric vehicles to the system load. This study is important considering the Belize's NDC. Presently LCEP study considers that transport will have a share in the electric load of less than 10%. This appears to be a conservative assumption of electrification of transport.

9- The consequence of underestimating low demand growth in future years may be less critical for generation assets, because the LECP is mostly based on "modular" solar and wind installations and more critical for the transmission expansion, which could anticipate reinforcements, upgrades of voltage levels and retirements of obsolete equipment.

6.4 Supply options

10- There appears to be a potential for adding one more hydropower plant to the Belize system in the same cascade of the existing one. This appears to be solely ignored since it would have a higher LCOE when compared to solar or wind power. However, the profile or energy production from a hydropower plant is very different from a solar or wind power plant. Short term variability is much lower, the seasonal production profile is more marked and there may be synergies between hydropower and solar or wind. In Brazil, for example, the dry season (less hydropower) coincides with the months of increased wind production. This kind of synergy is only captured if the various resources are modelled in an integrated way in the LCEP and will never be possible with the LCOE alone. In summary: unlocking the flexibility of hydro is a value proposition that can lower cost structure.

11- Furthermore, the design of the hydro project should consider the possibility of a small reservoir that would be able to hold water for some hours, acting as a "water battery". If so, hydropower could provide some of the services to the system that have been allocated to BESS in the LCEP, and that possibility should be investigated from start: the hydropower project would be designed and budgeted (perhaps not one project, but alternatives of the project as pure run of river plant, with no storage, a project with 4h of storage, a project of 8h storage and so on). There are specialized tools, like HERA, that can be used for a swift assessment of alternatives. An optimization model, in turn, would select if any of the possible designed hydropower plants would be economical by examining, as mentioned all possible services (not just energy, but reserves, capacity) in an integrated way.

12- Biomass conversion technologies interlock with Belize economic development goals, e.g. sugarcane, waste, etc. and, again, were not considered as expansion options.

6.5 Transmission options

13- A stronger, integrated, and planned transmission network for the future demand may be preferable in the long term, in terms of present value of total investment and operation cost, than a succession of intermediate upgrades as load increases in the system, leading to a myriad of voltage levels that could be unified to a higher amount for the accommodation of the future loads, especially if there is a considerable growth due to the electrification of transport.

14- The transmission expansion plan should address and propose solutions to the problems related to the high penetration of RES, like the decrease in inertia and power active reserve.

15- The assumption of working with four main regions that is understandable from the point of view of system reliability and resilience. Nevertheless, considering the heterogenous spatial distribution of generation resources and demand, the target of supply self-sufficiency of each region may lead to much higher costs related to heavy investments in generation and BESS assets distributed in the regions and smaller investments on transmission reinforcement.

16- Another consequence of a weaker transmission reinforcement is that it will not enable synergies of the various generation sources, such as solar, wind, biomass, and hydropower in the country, sometimes referred as "portfolio effect".

17- As integrated approach to energy and electricity planning is desirable. An example is the growing share of electricity in the energy matrix, which increases the need for supply reliability going forward. In turn, increased reliability could be achieved by different means, such as evolving the national transmission network topology to a mesh pattern or harmonizing the different voltage levels in the country. These options should be investigated as well.

6.6 Transparency

A comprehensive dataset would be important to review the work in greater depth. As a recommendation, LCEP should have a specific webpage with a structure similar to AEMO's or Brazil's Decenal Expansion Plan. LCEP does not come from accompanying datasets (assumptions book, results), but which would certainly help.

Appendix B – Report from Agostinho Miguel Garcia

BELIZE SOLAR PV PLANT TRANSACTION

LOAD STUDY

Prepared by Agostinho Miguel Garcia

September 2023

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1 INTRODUCTION

The purpose of this report is to summarize the findings of the load study undertaken based on the hourly load and generation data shared by the Public Utilities Commission of Belize (PUC).

The following table summarizes the main data shared by PUC in September 2023 in terms of load and peak generation from each generation source available (CFE are the imports from Mexico and is also counted as a generation source to simplify).

Table 1 - Main data (from data shared by PUC)

	Solar PV	Belcogen	SSEL	CFE	BEL DIESEL	BAPCOL	Gas Turbine	CHALILLO/MOLLEJON	Hydro Maya	VACA	Total
2019											
Generation (kWh)	312 531	69 000 024	23 522 143	383 840 658	11 542 924	87 019 755	22 069 463	41 165 121	9 835 581	23 624 446	671932645
Share	0,05%	10,27%	3,50%	57,12%	1,72%	12,95%	3,28%	6,13%	1,46%	3,52%	100,00%
Peak generation (kWh)	366	16 212	11 736	59 362	2 402	11 736	16 212	27 748	3 503	19 384	168660
Maximum load (kWh)											130141
Minimum load (kWh)											58301
2022											
Generation (kWh)	740 760	59 026 966	34 754 326	323 154 314	12 218 174	15 063 464	2 327 879	152 189 575	13 436 727	73 139 566	686051752
Share	0,11%	8,60%	5,07%	47,10%	1,78%	2,20%	0,34%	22,18%	1,96%	10,66%	100,00%
Peak generation (kWh)	962	14 905	12 334	56 845	2 342	12 334	14 905	35 728	3 212	19 463	173030
Maximum load (kWh)											110342
Minimum load (kWh)											58363
2023											
Generation (kWh)	898 165	49 970 276	31 153 105	354 264 922	13 389 982	21 070 278	8 593 703	156 561 860	11 863 125	74 973 961	722739376
Share	0,12%	6,91%	4,31%	49,02%	1,85%	2,92%	1,19%	21,66%	1,64%	10,37%	100,00%
Peak generation (kWh)	962	15 237	12 107	56 718	2 342	12 107	15 237	35 728	3 212	19 463	173114
Maximum load (kWh)											124393
Minimum load (kWh)											60189

As it can be noted the peak generation may differ from the nameplate capacities of each plant and vary also per year[1]. The maximum load is also below the peak generation.

The methodology used to make the simulations in this load study was the following:

- must run plants were defined: existing solar PV, the biomass plants BELCOGEN and SSEL and a certain minimum percentage of the nameplate capacity of the hydros, namely 15% during the first half of the year and 25% during the second half of the year (these values were provided by PUC as a guidance).
- addition of a solar PV plant production totalling the intended simulation capacity of solar PV. Several configurations of solar PV were considered, namely fixed and 1 axis horizontal tracking. The latter was used for the simulations as it reflects the highest yield and under the low latitude of Belize does not reduce peak generation.
- the added solar PV is then subtracted from the available generation data (all available generation that was not considered as must run) resulting in either an excess of solar or no excess.
- the excess is then used to consider potential battery storage (BESS) needs.
- BESS was visually identified as a range for both power capacity in MW and energy capacity in MWh by looking at all months in terms of excess. It should be noted that BESS is not to be sized based in peak needs but needs that reflect an utilisation of the BESS fully of at least 70% of the time. This would allow for the BESS to be financially viable and also fully used.
- finally potential BESS sizes were used to identify the excess solar generation that would still happen under the simulated data. It should be understood that solar generation cannot be predicted ahead in time for months or even weeks

[1] Hydro Maya is 2,6 MW, Chalillo/molejon is 32,5 MW, VACA hydro is 19 MW, BEL diesels at 2,4 MW, Gas turbine is 18 MW, BELCOGEN is 12 MW, SSEL is 10 MW, BAPCOL is 23,5 MW and existing solar PV is 1,36 MWp.

as it is weather dependent and weather forecast loses substantial precision after 72 hours. Thus the results are mostly to be understood as probabilities of happening and as the solar data was based on P50 values (50% probability of real data being above or below the used data), that is also reflected in the conclusions of this study.

It was noted from the table above that load was higher in 2023 (though half of the year 2023 are planning and not actual) and therefore results are presented for 2023.

The results of the simulations are shown below for:

- Scenario 1: 75 MW of solar PV: BAPCOL 15 MW and Saudi PV 60 MW
- Scenario 2: 125 MW solar PV: BAPCOL 15 MW, Saudi PV 60 MW and IFC solar PV 50 MW

This study does not differentiate where solar power is brought in versus existing generation. That will be studied with a grid integration study.

1.1 Scenario 1 – 75 MW of solar PV

The scenario 1 considers the addition of 15 MW BAPCOL and 60 MW Saudi PV projects into the grid. The table below shows the major results of the simulation following the methodology included above.

Table 2 - Major results of the scenario 1

Maximum hour (kWh)	52 232
Maximum daily (kWh)	226 830
Total extra (kWh)	8236436
Total extra (kWh) % of total solar generation	4,27%
Recommended BESS size (MW)	10
Recommended BESS energy (MWh)	100

Without BESS, 4,27% of the solar PV production would not be absorbed. Installing a a 10MW/100MWh BESS would reduce the excess to 0,72% of the solar PV generation.

The table below shows the battery monthly needs based on the graphs included in Annex 1 and the guidance included in the methodology.

Table 3 - Monthly BESS MW capacity needs for scenario 1

Months	Capacity (MW)	Months	Capacity (MW)	Months	Capacity (MW)
January	10	**May**	10-15	**September**	10

Months	Capacity (MW)	Months	Capacity (MW)	Months	Capacity (MW)
February	10-15	**June**	0	**October**	5-10
March	10-15	**July**	15	**November**	5-10
April	15	**August**	10	**December**	15-20

1.2 Scenario 2 – 125 MW of solar PV

The scenario 2 considers the addition of 15 MW BAPCOL, 60 MW Saudi PV and 50 MW IFC projects. The table below shows the major results of the simulation.

Table 4 - Major results of the scenario 2

Maximum hour (kWh)	102 232
Maximum daily (kWh)	762 230
Total extra (kWh)	93262654
Total extra (kWh) % of total solar generation	28,98%
Recommended BESS size (MW)	50-60
Recommended BESS energy (MWh)	300-400

Without BESS, 28,98% of the solar PV production would not be absorbed. With a proposed BESS of 60MW/350 MWh, the solar PV production not absorbed is reduced to 4,74%. With a proposed 50 MW/300 MWh the solar PV production not absorbed is reduced to 6,79%.

The table below shows the battery monthly needs based on the graphs included in Annex 2 and the guidance included in the methodology.

Table 5 - Monthly BESS MW capacity needs for scenario 2

Months	Capacity (MW)	Months	Capacity (MW)	Months	Capacity (MW)
January	50-60	**May**	50-60	**September**	50
February	60	**June**	30	**October**	50
March	60	**July**	50-60	**November**	40-50
April	60	**August**	50	**December**	50

2 ANALYSIS AND RECOMMENDATIONS

Scenario 1 without BESS leads to losses of solar generated power of 4,27% and at an average tariff of 0,04 USD/kWh to a yearly loss of 329'457 USD. If we assume this loss for 10 years[2], the savings will enable an 8 MWh BESS[3] against the 100 MWh deemed necessary according to the simulation, demonstrating that the BESS investment would not be viable. **Scenario 1 is validated in terms of solar capacity without BESS.**

Scenario 2 without BESS would lead to almost 30% solar power loss and at the same tariff as above would result in 3'730'506 USD in yearly losses. The savings over 10 years based on the same BESS cost as above, would enable a 93 MWh BESS against the 300 MWh required, faring better than in scenario 1, but still falling short[4]. **Scenario 2 requires BESS to be viable.**

Table 6 - Main results for both scenarios 1 and 2.

Parameters	**Scenario 1** **75 MW**	**Scenario 2** **125 MW**
Maximum hour (kWh)	52 232	102 232
Maximum daily (kWh)	226 830	762 230
Total extra (kWh)	8236436	93262654
Total extra (kWh) **% of total solar generation**	4,27%	28,98%
Recommended BESS size (MW)	10	50-60
Recommended BESS energy (MWh)	100	300-400
Loss after BESS	0,72%	4,74%[5]

Adding 125 MW in scenario 2 would not be possible to be commissioned before 2025 or 2026. The load would have grown between 2% and 5% per year by then[6]. This leads to a future scenario where the load would have grown between 6% and 15%, reducing potentially the battery needs to 40 to 50 MW/250 to 350 MWh.

A BESS of 40 MW/240 MWh (equivalent to 6 hours of storage) at the costs considered above would mean a 96 MUSD investment and would meet the needs of scenario 2.

2 This is very theoretical as the load will grow and will reduce the extra.

3 Assuming a cost of 400 USD per kWh.

4 This simplistic analysis does not take into consideration potential higher revenues for power sold during more expensive times.

5 The value for a BESS of 350 MWh

6 Based on the data supplied

ANNEX 1 – RESULTS OF SCENARIO 1

The following graphs show visually the results of the simulation, included above.

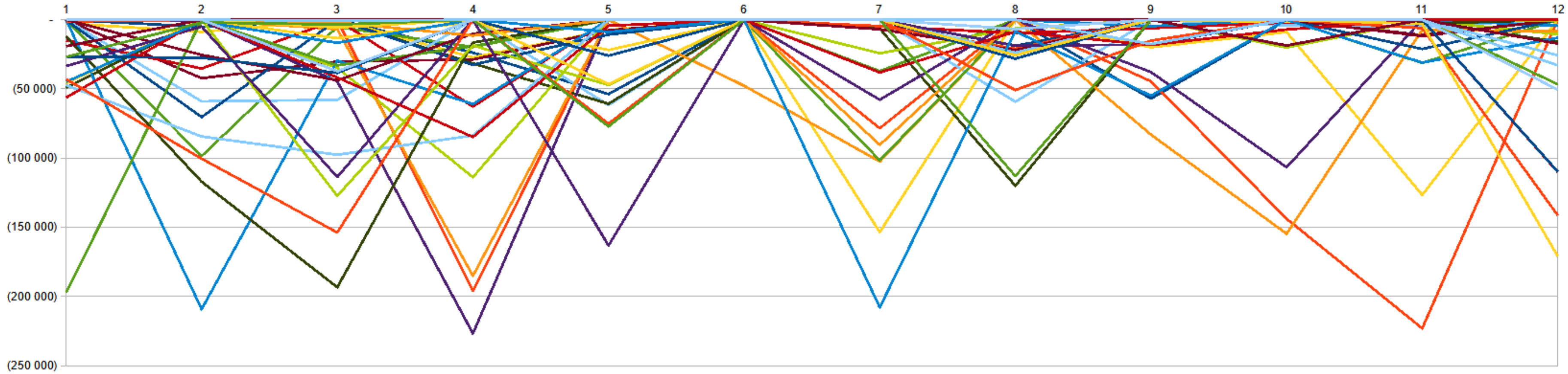

Figure 1- Excess daily generation for Scenario 1 (y-axis in kWh and x-axis shows the months of the year)

The graph points towards a level of 100 MWh of BESS being required, which would reduce the excess to 0,72% of the solar PV generation.

For the BESS capacity the following graph show the needs for each month.

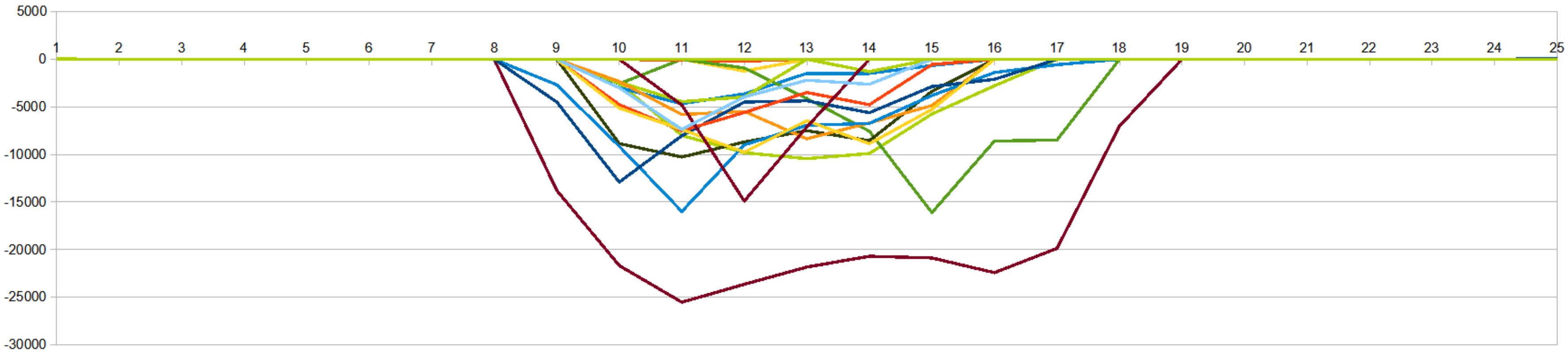

Figure 2- Excess hourly generation in January for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

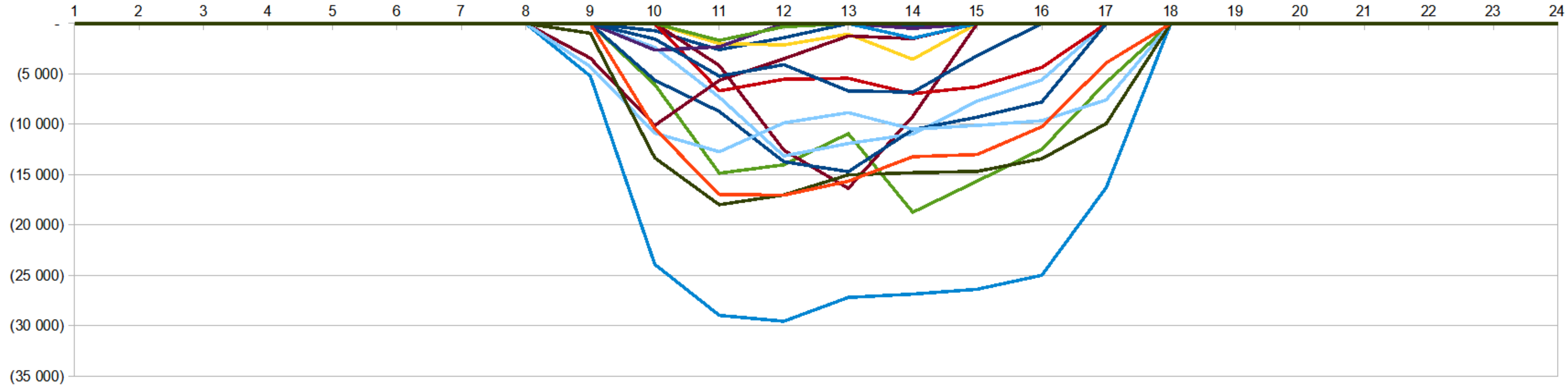

Figure 3- Excess hourly generation in February for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

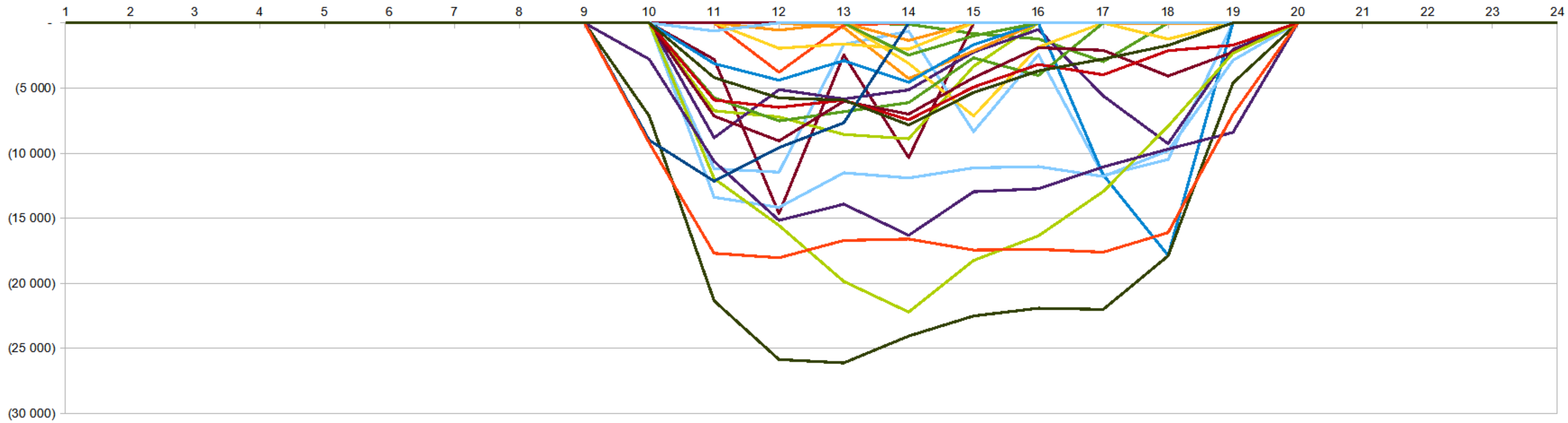

Figure 4- Excess hourly generation in March for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

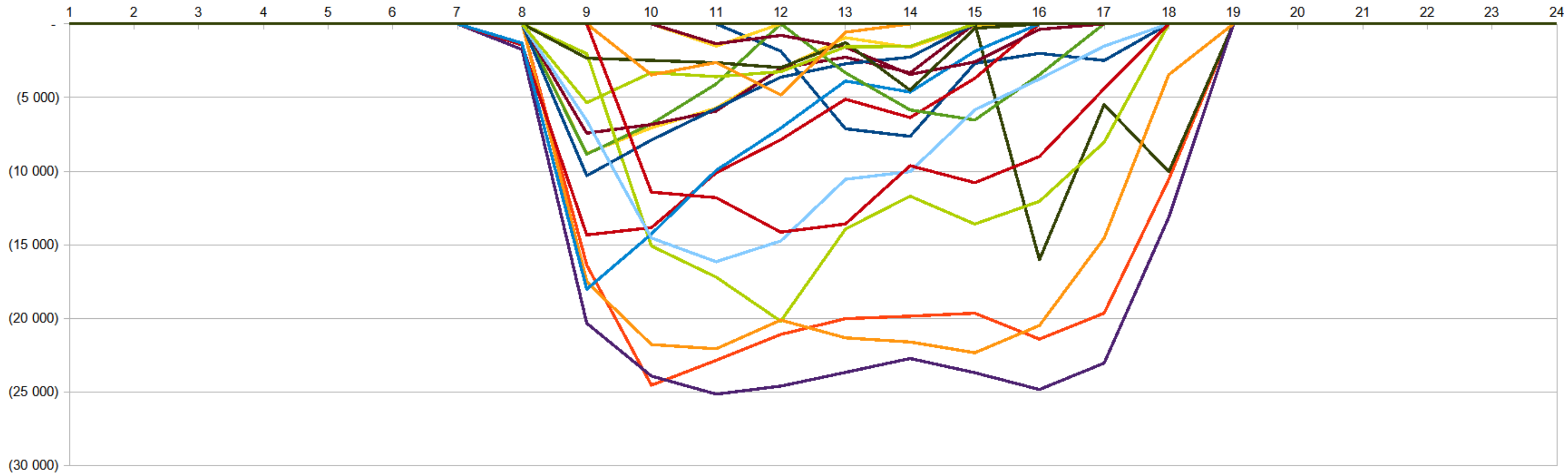

Figure 5- Excess hourly generation in April for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

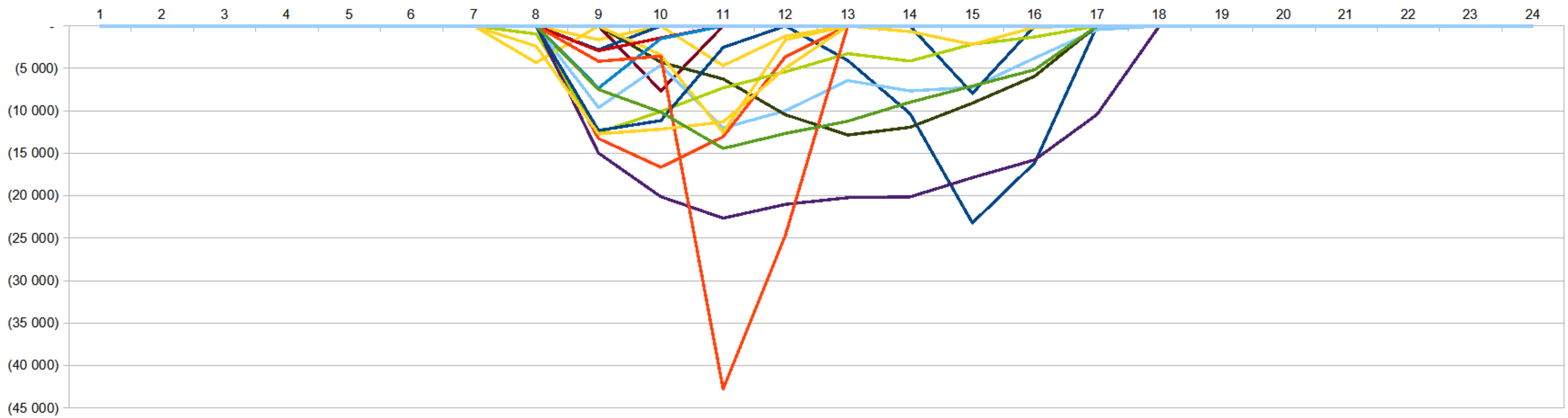

Figure 6- Excess hourly generation in May for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

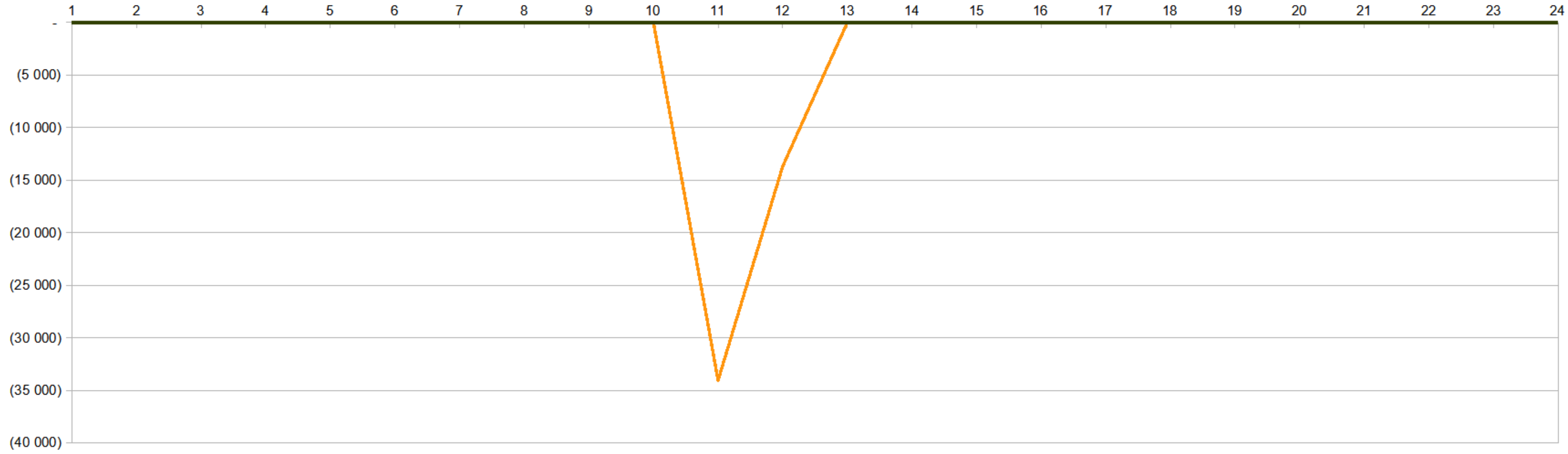

Figure 7- Excess hourly generation in June for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

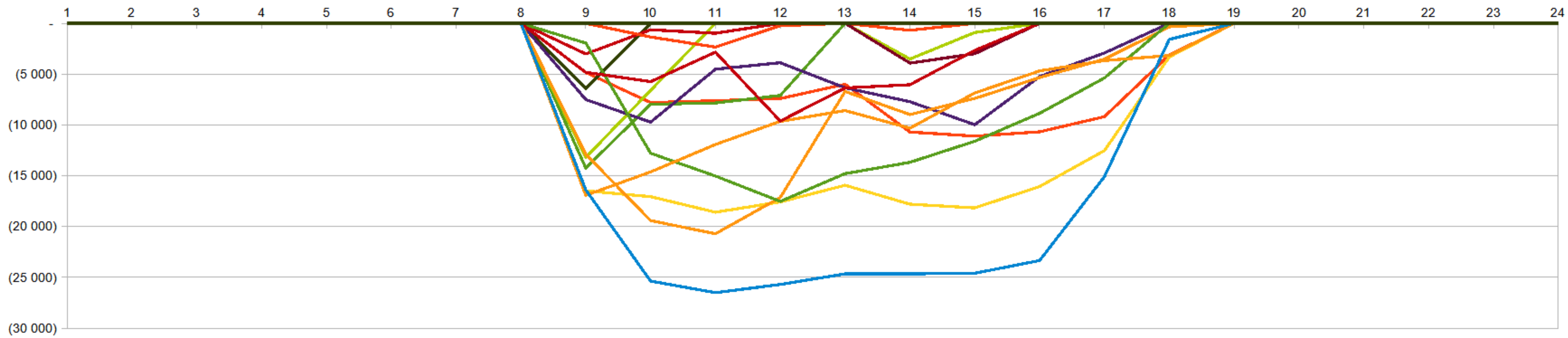

Figure 8- Excess hourly generation in July for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

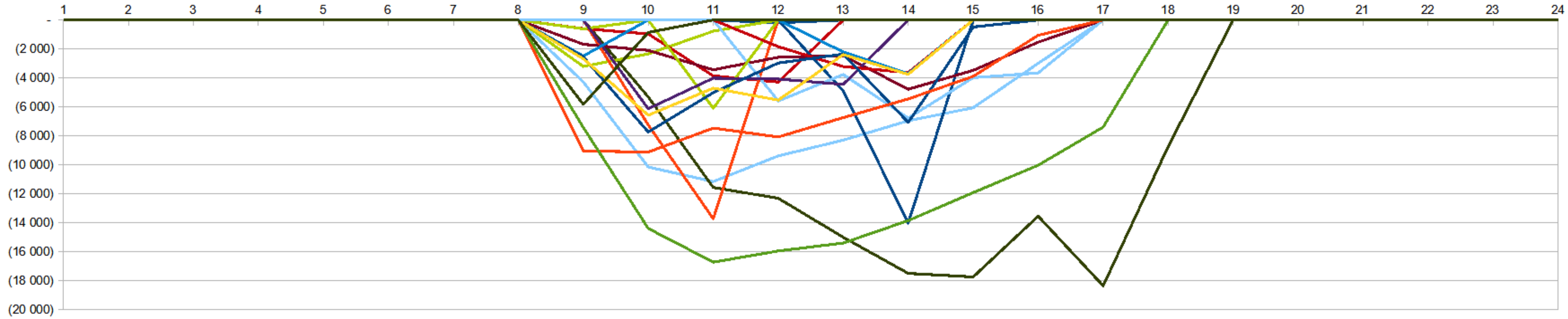

Figure 9- Excess hourly generation in August for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

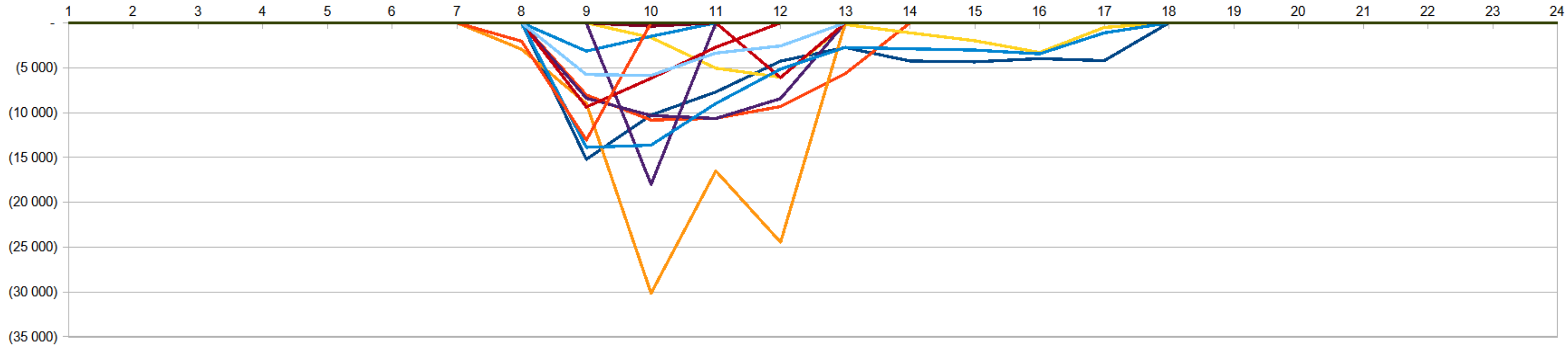

Figure 10- Excess hourly generation in September for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

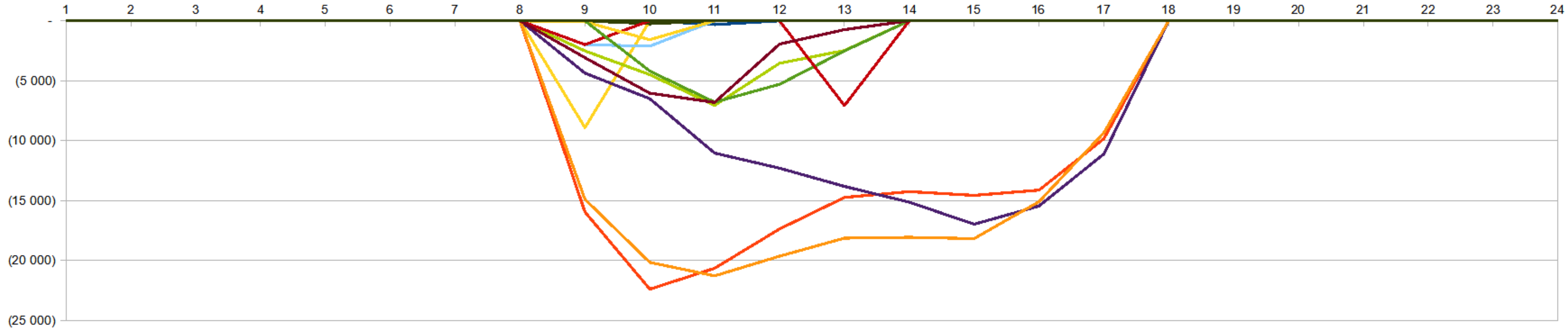

Figure 11- Excess hourly generation in October for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

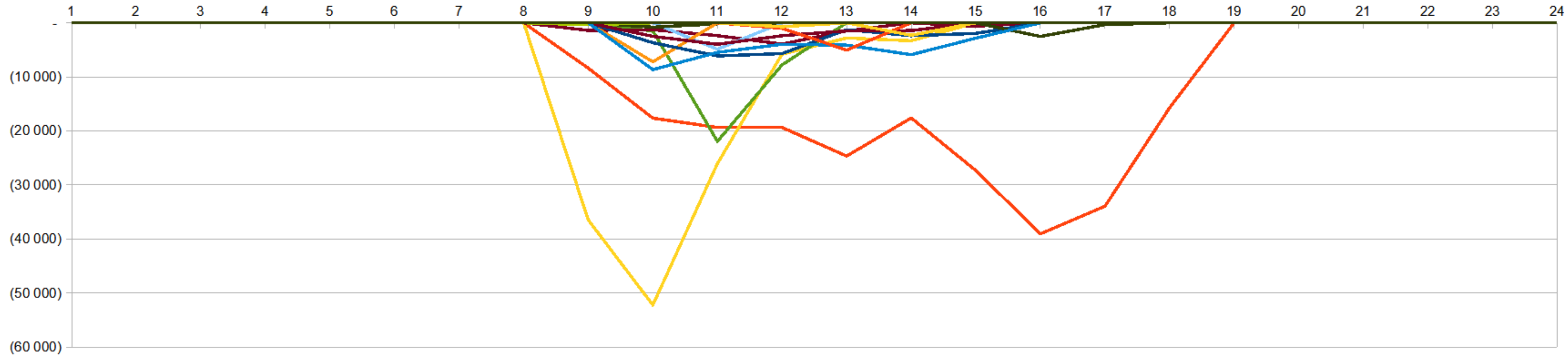

Figure 12- Excess hourly generation in November for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

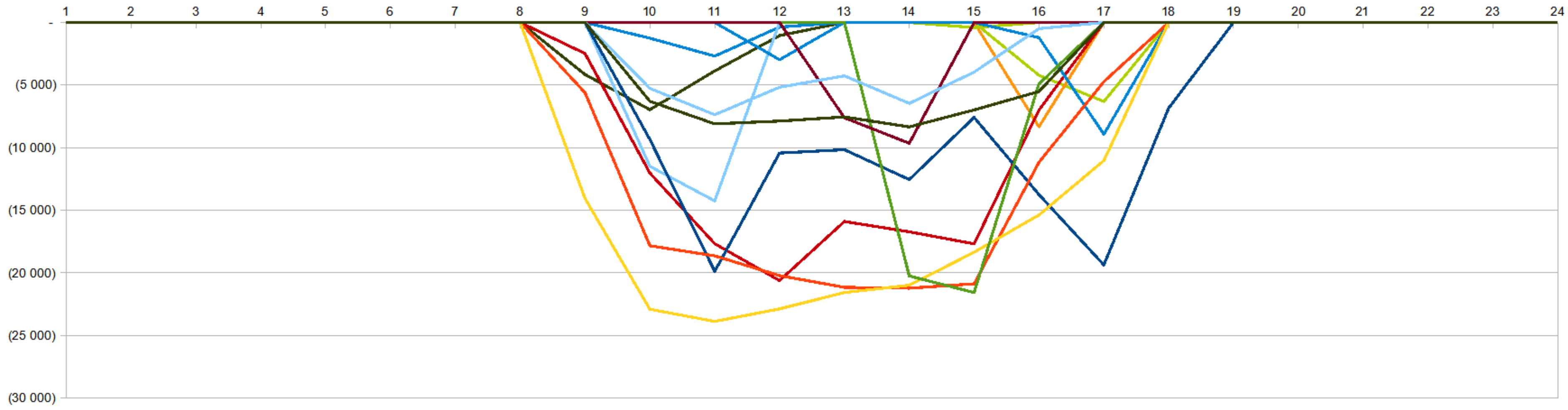

Figure 13- Excess hourly generation in December for Scenario 1 (y-axis in kWh and x-axis shows the hours of the day).

ANNEX 2 - RESULTS OF SCENARIO 2

The following graphs show visually the results of the simulation, included above.

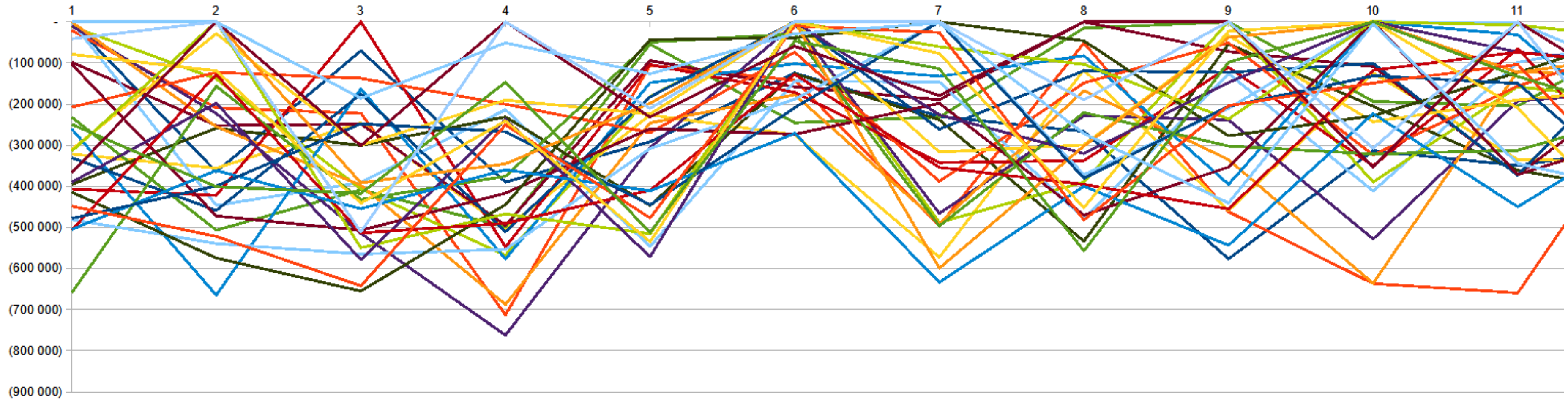

Figure 14- Excess daily generation for Scenario 2 (y-axis in kWh and x-axis shows the months of the year)

The graph points towards a level of 300 MWh of BESS being required, which would reduce the excess to 0,72% of the solar PV generation.

For the BESS capacity the following graph show the needs for each month.

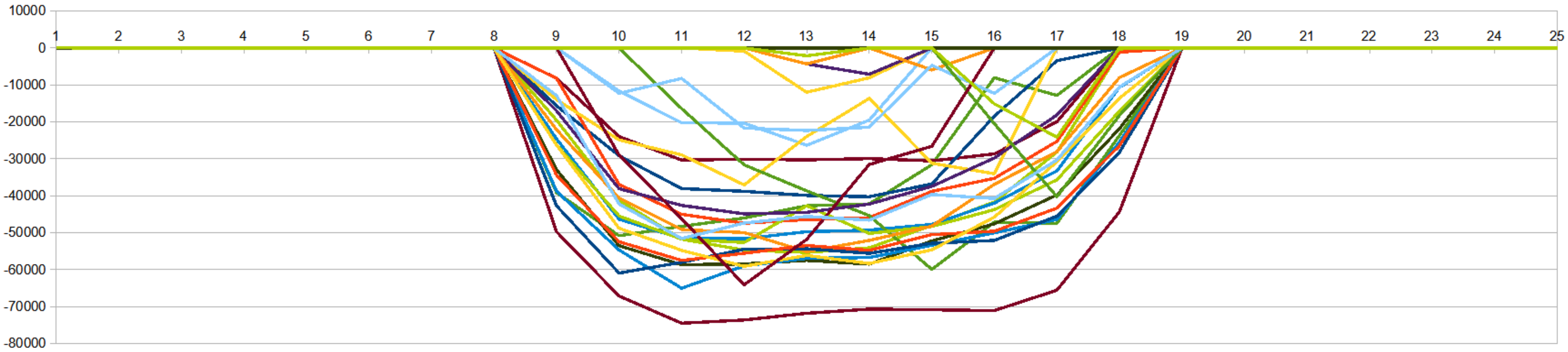

Figure 15- Excess hourly generation in January for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

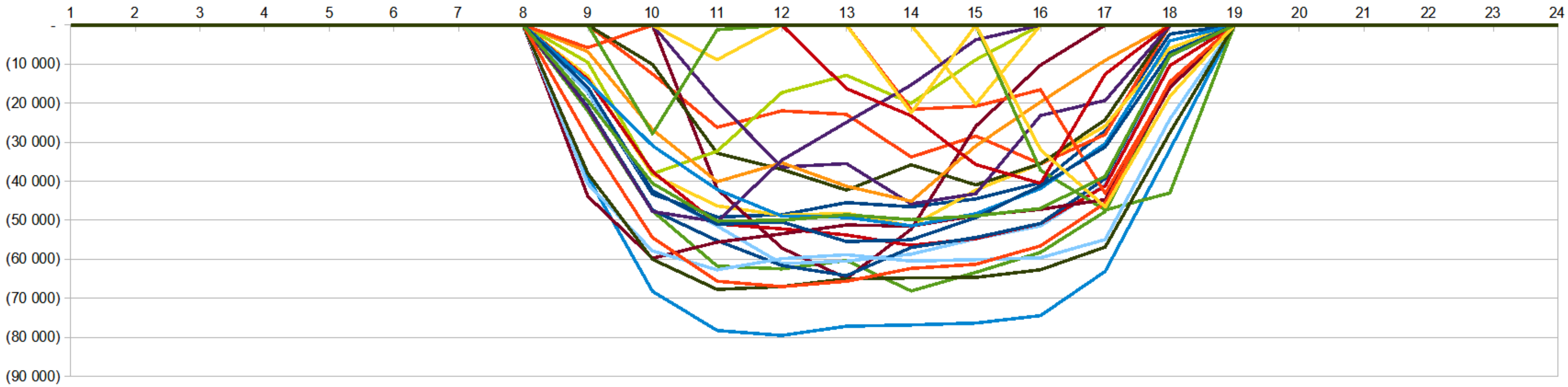

Figure 16- Excess hourly generation in February for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

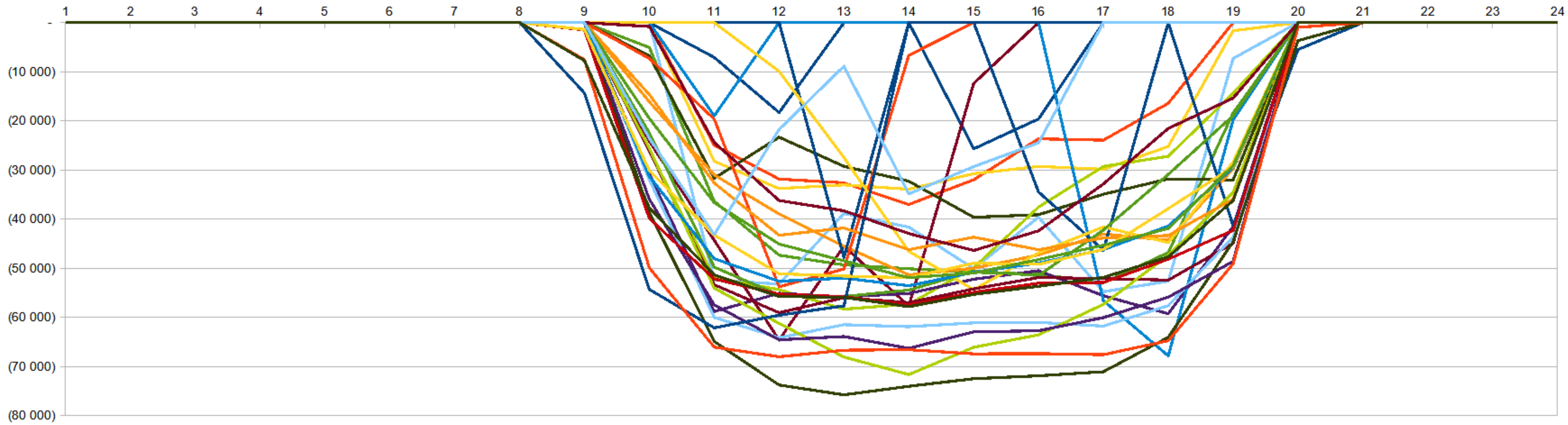

Figure 17- Excess hourly generation in March for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

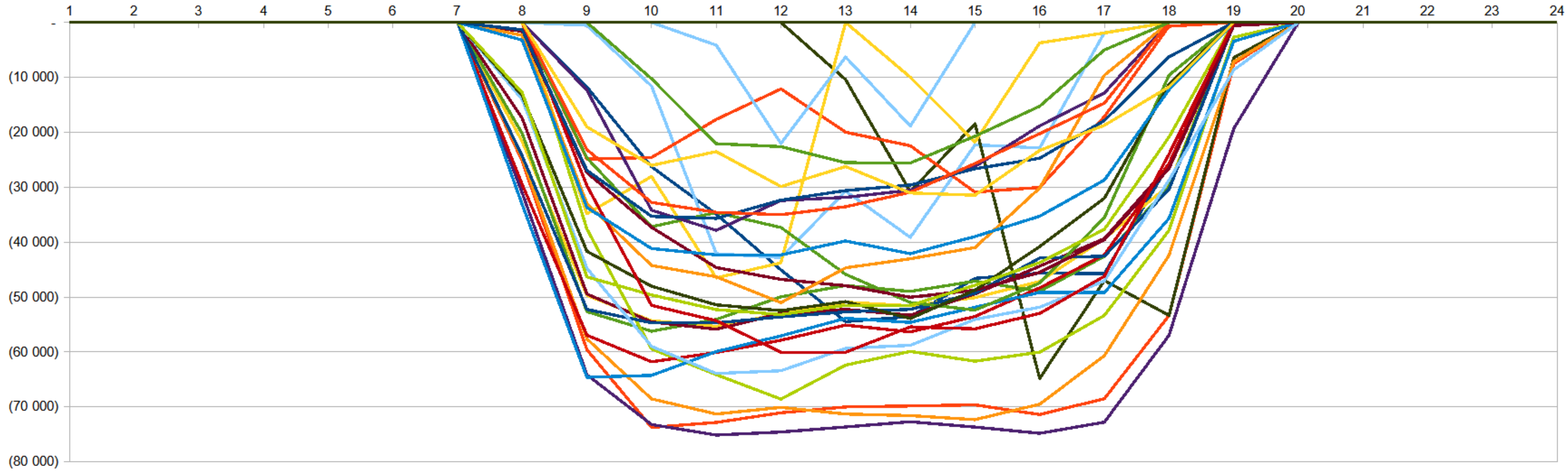

Figure 18- Excess hourly generation in April for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

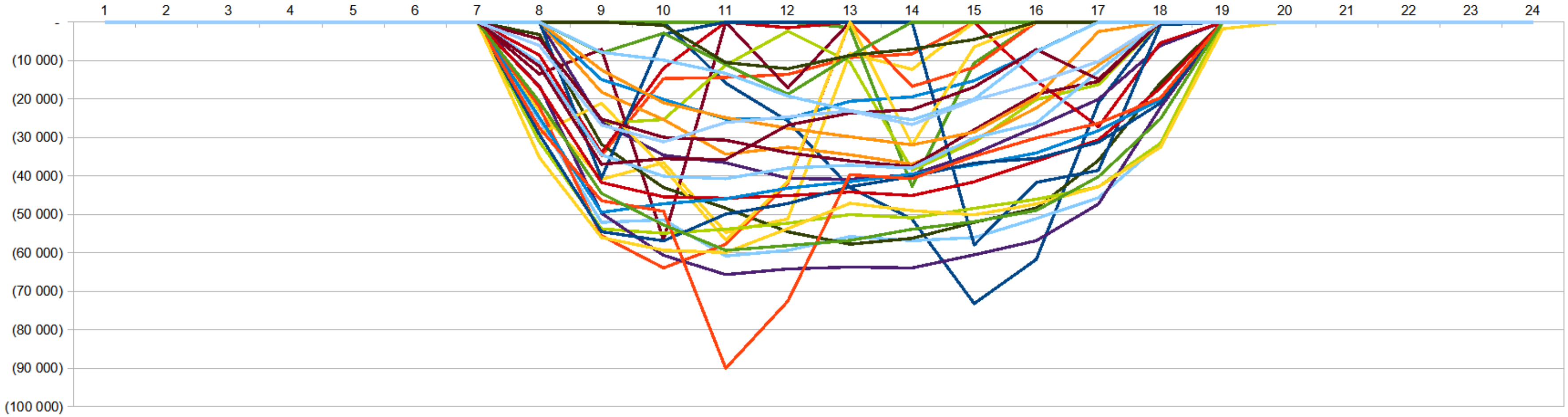

Figure 19- Excess hourly generation in May for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

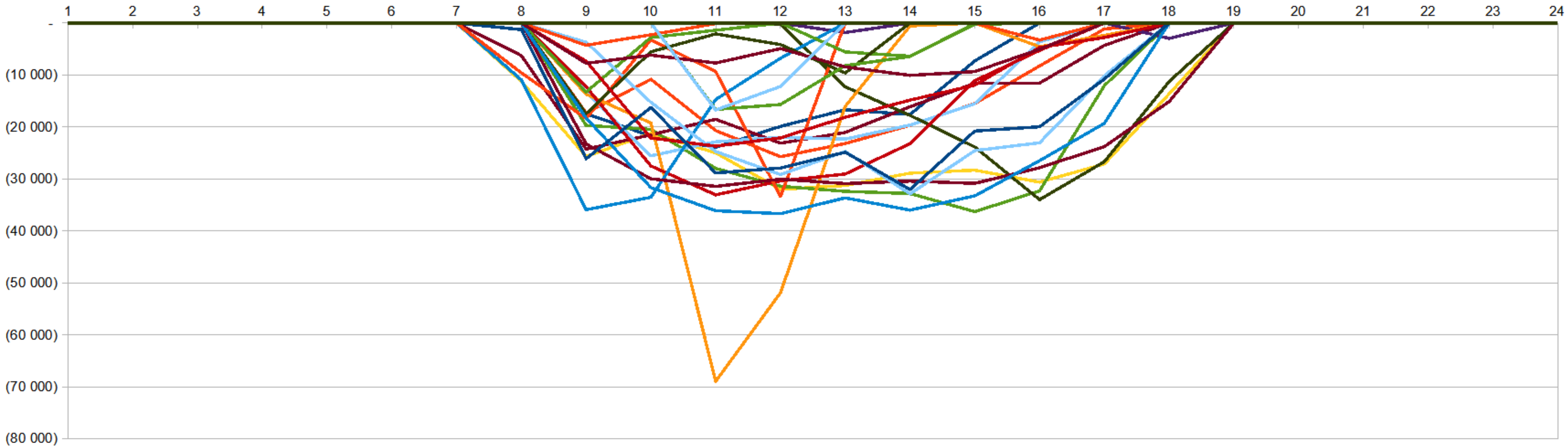

Figure 20- Excess hourly generation in June for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

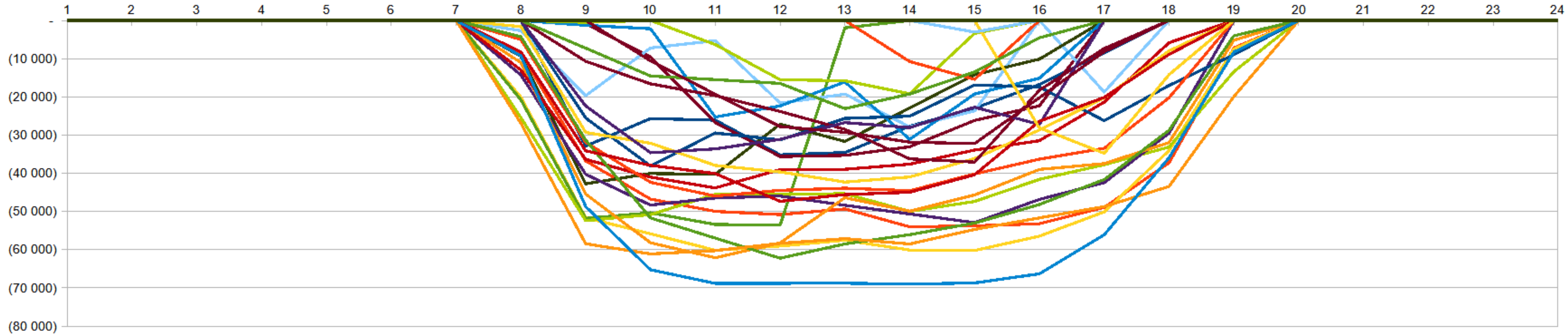

Figure 21- Excess hourly generation in July for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

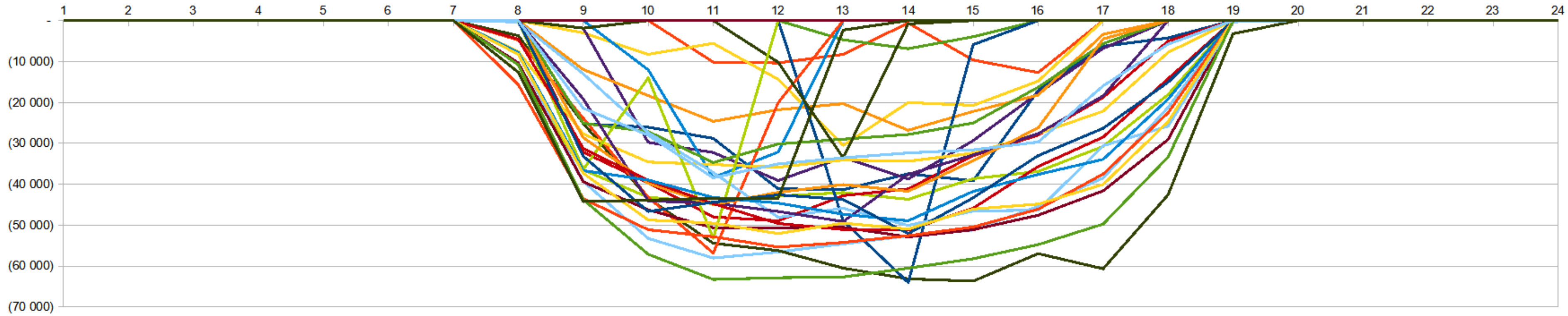

Figure 22- Excess hourly generation in August for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

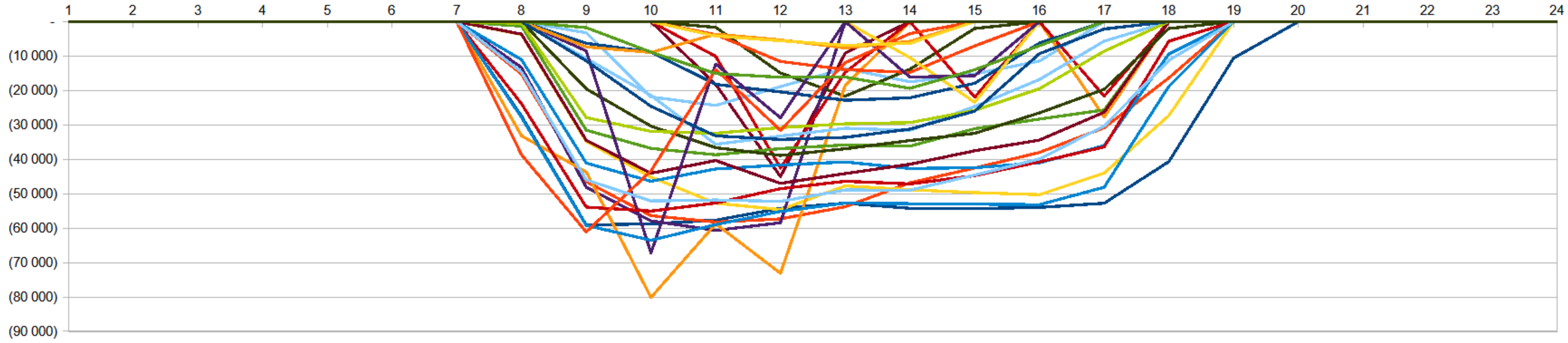

Figure 23- Excess hourly generation in September for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

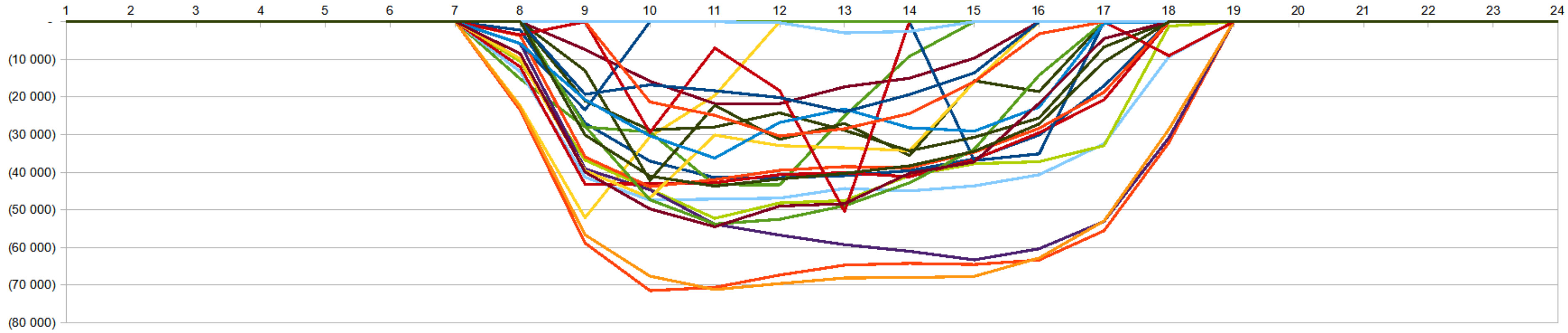

Figure 24- Excess hourly generation in October for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

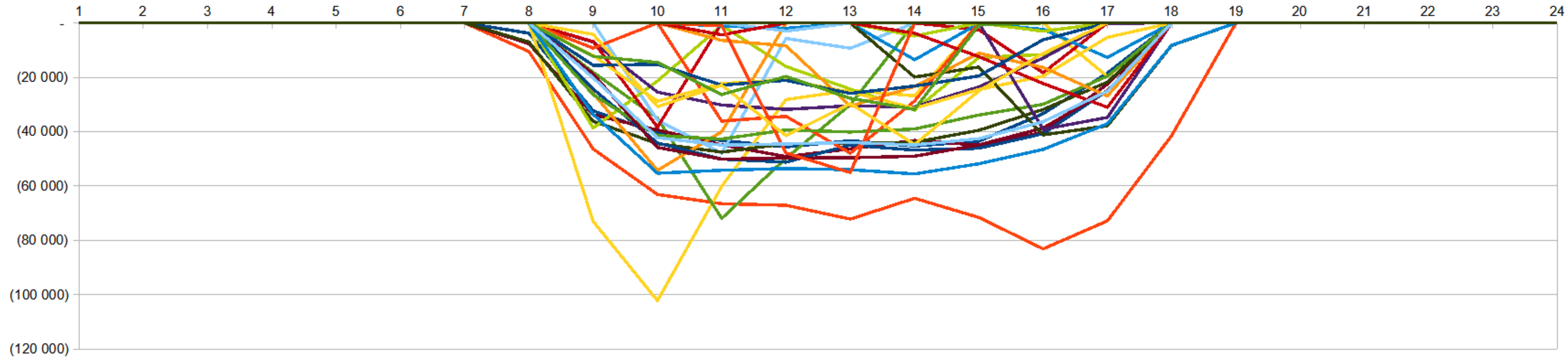

Figure 25- Excess hourly generation in November for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).

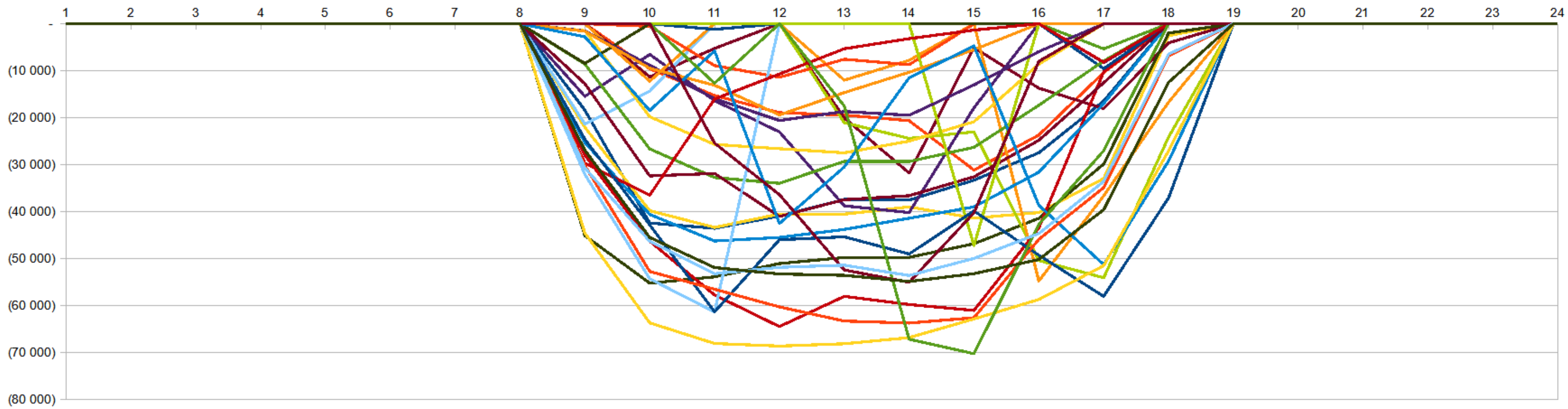

Figure 26- Excess hourly generation in December for Scenario 2 (y-axis in kWh and x-axis shows the hours of the day).