
Assignment # 11**NicIso**

The electric power system of NicIso can be represented as a 3-bus system. The characteristics of the fossil-fired generation resources are shown in Table 1:

Generators in NicIso bid their marginal cost. Marginal costs are a function of current fuel prices and emissions allowances prices. To simplify your work, marginal costs for next year have been calculated and are provided in Table 1. These costs assume the fuel prices to NicIso generators as reported in a recent survey.

Table 1: Generation resources

Plant ID	Plant Name	Fuel Type	Nameplate Capacity (MW)	Marginal Cost (\$/MWh)	CO2-eq Average Emission Rate (lb/MWh)	Bus
A	ALL	Coal	1148.4	44	2375.399	1
B	ASH	Coal	413.6	47	2144.04	1
C	BEL	Coal	2491.2	37	1961.67	2
D	CLI	Coal	1530.5	35	1967.268	2
E	MAR	Coal	2119	39	2035.088	3
F	MAY	Coal	763.2	45	2348.824	3
G	ROX	Coal	2558.2	38	2034.134	3
H	ASH2	Natural Gas	423.5	32	2144.04	1
I	BUC	Natural Gas	697.9	19	818.39	1
J	DAN	Natural Gas	697.9	22	840.076	1
K	DAR	Natural Gas	583.2	40	1724.951	1
L	LEE	Natural Gas	920	23	964.873	1
M	LIN	Natural Gas	1753.6	46	1971.32	2
N	MIL	Natural Gas	799.2	36	1493.624	2

O	ROC	Natural Gas	977.5	30	1240.686	2
P	SHE	Natural Gas	2244.8	24	982.976	2
Q	SUT	Natural Gas	730	21	835.701	3
R	WS	Natural Gas	271.2	33	1367.639	1
S	WA	Natural Gas	979.7	31	1282.978	3
T	FOI	FuelOil	670	25	7200	3
Nuk1	CAT	Nuclear	2,410.0	12	0	1
Nuk2	MCG	Nuclear	2,500.0	12	0	2
Nuk3	OCO	Nuclear	2,800.0	12	0	2
Nuk4	BRU	Nuclear	2,882.2	12	0	3
Nuk5	HBR	Nuclear	768.6	12	0	3
Nuk6	HAR	Nuclear	950.9	12	0	3

All the transmission lines in NicIso have the same impedance¹, and their capacity limits for real power transfers are given in Table 3:

Table 3: Capacity of Transmission lines

Max Capacity (MW)	
Branch 1-2	900
Branch 1-3	900
Branch 2-3	900

The projected demand at NicIso for next year is summarized in Table 4. There are different projections of future demand depending on assumptions about air conditioning, EV adoption, and industrial activity. For future years, demand is projected to grow at 0.9% per year under a low growth scenario and up to 2.5% per year under a high demand growth scenario. Some people say an even larger growth should be considered to account for electrification of space heating, cooking, and transportation.

Table 4: Total system load²

¹ Note that if all the impedances are the same then any impedance value that you assume will result in the same proportional distribution of power across lines. We will use a DC approximation to power flow, where we assume that the resistances of the lines are much smaller than the reactances and hence can be ignored.

	Average hourly load (MW)		# of hours in 2021		Peak Load (MW)	
	peak hours(v)	off-peak hours(vi)	peak	off-peak	peak hours	off-peak hours
Winter (i)	19450	16504	1056	1176	29652	27163
Spring (ii)	19760	15839	1040	1144	30975	28917
Summer (iii)	25782	20388	1056	1152	33567	31191
Fall (iv)	20847	18610	1024	1112	32675	29557

- (i) Winter is defined as the days from December 21 to March 20
- (ii) Spring are the days between March 21 and June 20
- (iii) Summer are days between June 21 and September 20
- (iv) Fall are the days between September 21 and December 20
- (v) Peak hours are hours 7-22 on weekdays
- (vi) Off-peak hours are hours 23,24,1,2,3,4,5,6 on weekdays, and all hours on weekends

Local load exhibits the same seasonality as system load, and is distributed at each bus according to Table 5:

Table 5: Local load

Bus	% of system load
1	20
2	45
3	35

NicIso also has large significant power generation capacity from six nuclear plants. It is too expensive to start-up and shut-down these power plants, so they are always online and injecting into the grid a constant power output equal to 97% of their capacity. The only exception is during the spring when they are shut down for maintenance, so the normal power output is reduced 50%. The characteristics of the nuclear plants is summarized in Table 6.

Table 6: Nuclear Power Plants

Plant ID	Plant Name	Fuel Type	Nameplate Capacity (MW)	Marginal Cost (\$/MWh)	CO2-eq Average Emission Factor (lb/MWh)	Bus
Nuk1	CAT	Nuclear	2,410.2	12.2	0	1
Nuk2	MCG	Nuclear	2,440.6	12.2	0	2
Nuk3	OCO	Nuclear	2,666.7	12.2	0	2
Nuk4	BRU	Nuclear	2,003.2	12.2	0	3
Nuk5	HB	Nuclear	768.6	12.2	0	3
Nuk6	Harris	Nuclear	950.9	12.2	0	3

Finally, busses 1 and 2 of NicIso have transmission ties with 2 different neighboring authorities that allow them to import up to 1200 MW of electricity at a cost of \$90/MWh and \$100/MWh respectively.

The current political and regulatory situation:

The state of NicIso restructured its electricity industry almost 15 years ago. Although it is not clear whether restructuring has reduced electricity prices, improved environmental performance, or enhanced reliability, there have not been any serious challenges in the recent past. However, this year, things have changed. Several coal fired power plants have been retired in anticipation to ambitious legislation mandating that the state's publicly regulated utilities get 95% of their electricity from carbon-free sources by 2040 and now there are several hours in the year when NicIso depends on electricity imports.

NicIso officials are in the process of assessing the overall reliability of the system if some capacity is retired and considering demand growth. For now, their focus is on achieving resource adequacy under normal conditions to ensure that the LOLE of the system does not exceed 1 day in 10 years which according to some old modelling exercises, requires a reserve margin of 11.5%. In this assessment of resource adequacy only baseload powerplants will be considered because lack of data and other constraints prevent an accurate estimation of the contribution to reliability from some wind, and solar resources in the system³.

NicIso does not have a capacity market but several stake holders argue that an adequate capacity payment is necessary to motivate investment in new installed capacity and perhaps avoid the retirement of the state's nuclear power plants or NicIso risks having tremendous prices spikes and black outs in the near future. The nuclear power plants of NicIso are old and will soon require significant maintenance to be able to renew their operating licenses.

³ Data on the capacity, location and performance of non-fossil fired resources is being collected by two interns and will be available to you after you present the first report to your boss.

Electric utilities agree that it is necessary to conduct ASAP an analysis of the alternatives to replace any capacity that may be lost due to power plant retirements and/or if demand grows. The first stage of such analysis focuses on the possibility of replacing old and coal power plants with carbon free technologies. The state of NicLand imports all its fossil fuels, but has great potential for solar electricity and some for wind. NicIso officials are also currently assessing the need for future transmission investments.

Your Job:

Your team must conduct quantitative and qualitative analysis that helps NicIso and the state of NicLand make decisions regarding their electricity future. Both NicIso managers and state officials want to hear your recommendations about the design of the electricity market and the design of statewide energy policy. The next meeting is in two weeks, and they want you to present an assessment of the current situation and an analysis of different strategies that NicLand must pursue to enjoy a clean, affordable and reliable energy system, now and in the future. Specifically, you must present a plan to reliability and economically achieve significant penetration of low-carbon emitting power generation resources and reduce CO2 emissions in NicLand. The plan may specify the mix of supply and demand-side alternatives that would reduce NicIso's CO2 emissions by 95% by 2040. Of course, this requires estimating today's emissions and estimating carbon emissions under a BAU scenario. It also requires demonstrating that such a mix of resources and programs will not jeopardize NicIso's reliability. Since NicIso is only an RTO/ISO and does not own any physical resources, you also need to determine what kind of policies would be required to incentivize the necessary investment in new infrastructure as well as compulsory retirements.

You must present a report of no more than 8,600 words (where each table and figure count as 300 words). You may include attachments with supplementary information (and you can cite them in the main body of your document), but your boss and other busy people may not read them, so your report should be a standalone document)⁴. You are glad you have a solid education and a pretty good understanding of how power systems and markets operate.

As a first step in your analysis please include in your report Table 7 and Table 8 described below (each one counts as 300 words for a total of 600 words). For these preliminary calculations you may only consider the information provided so far up to this page. You can ignore ramp rates, and min up and down times constraints of the generators, and also ignore variable renewable resources.

⁴ A good report describes the objectives of the analysis, the assumptions, the methods used, the conclusions and recommendations, and the caveats, limitations and opportunities for future analysis.

Table 7. NicIso Operation outcomes in 2022 for 8 projected **typical load levels**. These results are calculated ignoring intertemporal constraints and hence do not account for minimum generation limits, ramping limits, or minimum up or down times for the generators. The typical load levels are the projected average load for on-peak and off-peak hours for each season.

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Some useful information about the system:

1. Nuclear Power:

To stay operational beyond 2023 (and until 2050), the nuclear power plants in NicIso require maintenance that would cost a total of \$1,000/kW of capacity. The maintenance work would be completed during the regular spring shutdowns. It would reduce the available Nuclear Power generation capacity during spring by 50% during the first five years (2023, 2024, 2025, 2026) and then only by 10%.

2. Renewable energy:

Utility-scale solar PV: NicLand has a total of 650 utility-scale solar PV facilities with a combined name plate capacity of 4,834 MW. The installed capacity of these facilities ranges between 1 and 100 MW, and the average is 7.4 MW. Data on the combined solar PV generation during 2020 and the day-ahead forecast is available in the spreadsheet A11-NicIso-PV hourly production and forecast current.xlsx. The PV facilities are equally distributed across the three buses, and it is acceptable to assume that the variability and uncertainty on PV production are identical for the three regions.

NicLand investors are considering the installation of other PV solar energy centers. Although land near buses 2 and 3 is expensive or protected from development, there is an opportunity to expand utility solar PV generation capacity at bus 1. The costs of developing utility-scale solar PV in that region (CAPEX) are similar to those provided by NRELs Annual Technology Baseline Database (ATB)⁵ for Kansas City. In general, it is estimated that a 10MW facility would occupy 100 acres of land, and its construction would generate 240 jobs for one year.

There is no measured data on solar irradiance for the specific sites under consideration that can be used in a study that will be made public. Similarly, there is no data on the variability and uncertainty of annual, monthly, and hourly PV production. However, there is data on the electricity production from the SPS1 facility. This data is provided hourly for years 2011-2018 and is included in the spreadsheet A11-NicIso-PV hourly production.xlsx. Solar experts who have used the NREL PVWatts tool⁶ have found that the solar resource at this facility is representative of other sites considered for PV development in NicLand.

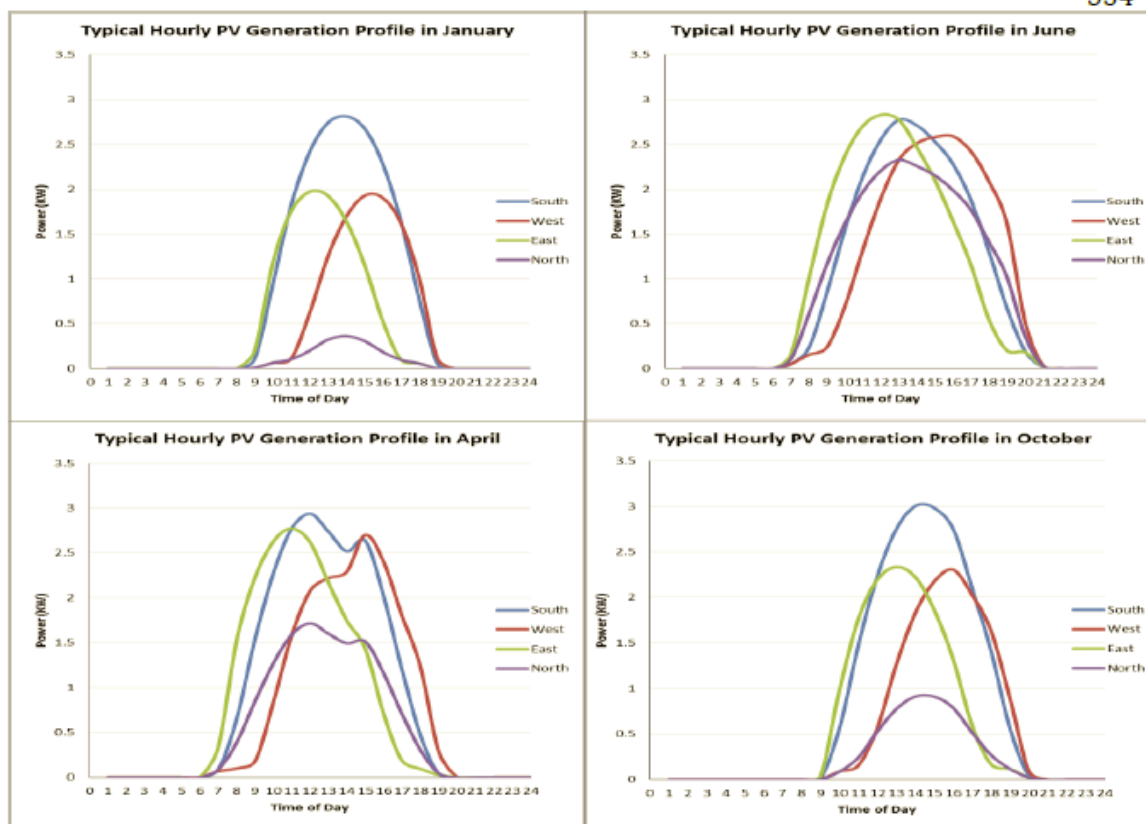
Residential roof-top solar: NicLand has 7.4 million customers; residential customers account for 40% of the load, commercial customers for 30%, and industrial customers for the rest. Because the current land use around buses 2 and 3 makes it difficult to install utility-scale solar facilities, a local university has looked at the potential for residential roof-top solar in those areas and the whole state. They found that 50% of households served by NicLand have the necessary conditions and roof space to accommodate a PV array of 4kW. Their study shows that the average capacity factor of these roof-top solar arrangements would be 15%.

To deal with the steep evening down-ramp in PV production that would create a duck-curve-problem in NicLand, some people have suggested that NicIso pay \$500 to households whose PV panels are oriented West instead of South. The changes in the daily generation profile for

⁵ [ATB | NREL](#)

⁶ <https://pvwatts.nrel.gov/>

different orientations are presented below. All the PV data presented for extant and potential PV capacity assumes a due South orientation. The reduction in annual solar power output from a due south system is 11% for east-facing systems, 6% for west-facing systems, and 7% for north-



facing systems.

Figure 1. Typical PV power output of a 4kW system for different seasons and panel's orientation.

Other solar: There is also potential for developing a large CSP or ISCC facility in a location in NicLand that could be connected to bus 1 (with a 50km-long transmission line). The location is close to a large natural gas pipeline. The solar resource is the same as the one already developed in the state and data on a CSP can be found in the ATB. Details on the ISCC technology can be found in the paper “*Integrated Solar Combined Cycle Power Plants: Paving the Way for Thermal Solar* by Bandar Alqahtani and Dalia Patiño-Echeverri”⁷.

⁷ <https://doi.org/10.1016/j.apenergy.2016.02.083>

Wind energy: NicLand is in a region with limited wind development and there is also significant opposition to this technology. Your boss has discouraged you from considering it unless some back-of-the envelope calculations show that other options are not enough, and that wind energy must be considered to reduce costs and improve reliability. The intern helping you has found that south of bus 3 there is enough land to accommodate up to 3GW of installed wind capacity (located about 100km of distance from bus 3). Costs of land-based wind development can be found in NREL's Annual Technology Baseline (ATB) Spreadsheet – 2020 while transmission costs can be found in the paper: '*Cost of Wind Energy: Comparing Wind Resources to Local Resources in Mid-Western United States*' by David C. Hoppock and Dalia Patino Echeverri. It is estimated that new transmission capacity in NicLand costs about the same as new transmission in the state of Iowa. The performance of wind power in this region is estimated to be remarkably like the performance of all the wind facilities in a neighboring area which have a total installed capacity of 2700 MW (outside of NicLand). Fortunately, very granular data for both wind energy forecasts and production is available for the same year for which we have demand PV production and wind data. This data is in the file A11-NicIso Wind Data.xlsx.

3. Demand Response and End-use energy efficiency:

Demand response: To deal with wind and solar intermittency, there is also the potential to invest in energy efficiency and create a demand response program. NicIso is considering implementing a program like the one available at PJM⁸. They calculate that about 90% of the commercial and industrial load in each bus comes from customers willing to join a demand side management program. NicIso has explored the possibility of paying \$40/kW of capacity/year plus \$0.15/kWh.

End use energy efficiency:

The people of NicLand have recently hosted a team of experts on Integrative Design⁹ and now everyone wants building energy efficiency to be given serious consideration. Details of this are provided at the end.

4. Reliability: NicLand legislators have ruled that the electricity system of the state should be highly reliable and should consider the possibility of extreme weather events in winter and summer. Each year there is a 10% probability of occurrence of an extreme weather event. An extreme weather event causes a surge in demand and generator outages. Studies show that under an extreme weather event demand could be as high as 1.18 times peak winter demand. This demand could be sustained for an average of 4 days.

Regarding outages, natural gas fired plants may see a reduction in power output due to multiple causes. The reduction is a random variable that follows a uniform probability distribution function with parameters 20%-40%. At the same time, during extreme winter weather conditions there will be significant reductions in both wind and solar power. The reduction in power production from both wind and solar can be modeled also as uniform distribution with parameters 50%-100%. There is also wide consensus that spinning reserves always should be at least as follows:

⁸ <https://business.directenergy.com/large-business/business-solutions/demand-response/demand-response-pjm>

⁹ See video and read paper the paper "How big is the energy efficiency resource?" by Amory Lovins at: <https://iopscience.iop.org/article/10.1088/1748-9326/aad965/meta>

Table 1: Spinning reserve requirements

Spinning reserves requirement as a fraction of net demand	3%
Spinning reserves requirement as a fraction of PV or wind production(*)	5%

*Unless there is very large storage capacity co-located with the facility that makes it fully dispatchable.

5. Energy storage:

Battery Energy Storage: recent studies have shown that cost reductions in Li-ion batteries make this technology an attractive resource for the region. A recent study examines co-location of li-ion Battery Storage Systems with PV. It shows that for low levels of PV penetration, the optimal power rating of a Battery Energy Storage System (BES) seems to be lower than 20% of the PV capacity and that batteries of short duration (i.e., 2 hours) are more cost-effective (i.e., result in a lower Cost of Carbon Abatement). BES of longer duration (4 hours and 6 hours) are more cost-effective when there are larger shares of PV. The shares of PV are measured as an expected percentage of the total energy generated in the system. A low PV share is seen as a capacity of PV able to generate about 5% of the annual energy of the system while a large share is equivalent to a 25% generation of the system electricity.

Table 2: Parameters of li-ion batteries

Efficiency during charge	%	95%
Maximum charge limit for battery	%	100%
Efficiency during discharge	%	95%
Maximum discharge limit for battery	%	100%

The costs of BES can be found in NREL'S ATB (and another good source is Lazards¹⁰). However, it is important to note the economies of scale that can be achieved when BES and PV are co-located as reported in an NREL report ¹¹).

¹⁰ <https://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen/>

¹¹ <https://www.nrel.gov/docs/fy21osti/78882.pdf>

Long-duration energy Storage: Because achieving reliability with large shares of variable energy generation (such as wind and solar) may require long-duration storage (more than what is currently economic for BES) a commission of European experts recently recommended that NicLands government takes a serious look at hydrogen¹².

Also, it is known that geologic formations in NicLand allow the installation of a CAES system with storage capacity of 20,000MWh.

Preliminary studies suggest the capital costs for a diabatic CAES plant are of the order of \$500/kW. Developing underground storage capacity costs about \$2/kWh. The natural gas consumption of one of these plants is about 4,800Btu/kWh. For each kWh of output, about 0.8kWh of compressor input are required. General information (to provide to the public) about this and other types of storage that could be considered (such as pumped hydro storage¹³ of which there seems to be a potential for 50MW in NicLand) is described in Bradbury et al.¹⁴

6. Electrification of the transportation system:

Electrification of the transportation System: Although electrification of the transportation fleet would not reduce CO₂ emissions from electricity generation system, the overall emissions reductions from the transportation sector would count towards NicLand's economy decarbonization target. For this reason, NicLand's government may want to subsidize the adoption of electric vehicles through the installation of charging stations throughout NicLand. NicIso could pass to electricity consumers the cost of subsidizing the capital cost of EV, if the cost of achieving CO₂ emissions reductions is lower than with other strategies. If subsidizing EVs, the target of 95% reduction of CO₂ emissions from the electricity sector will be reduced because reductions in the transportation sector count the same. Preliminary studies suggest that if the capital cost of EVs starts being subsidized in 2023 then the market share among all vehicles by 2040 will significantly increase. With subsidies of 20% the EVs share of total Vehicles Miles Travelled by 2040 will be 30% or twice the share achieved under the no-subsidies strategy.

These electric vehicles would replace conventional vehicles that have an average fuel economy of 25 miles/gallon, travel on average 18,000 miles per year, and emit CO₂ emissions from gasoline combustion at a rate of 8.8 kg/gallon. It is unclear at this point if the government of NicLand should invest in residential charging stations, or for charging stations at the workplace. Although some groups say that V2G (vehicle to grid electricity) could be an alternative for NicIso, recent bad press about the accelerated reduction in the lifetime of the batteries associated to this use has reduced the willingness to participate from some future EV users. It is estimated, that about 40% of the users would be willing to be called to sell electricity to the grid at any hour when their EV is charging. Officials agree that analysis on electrification of the transportation system is of less importance at this point but would be very well received if there is expertise in the team that allows a very high quality report.

¹² https://www.sciencedirect.com/science/article/pii/S0306261920305237?casa_token=o-M2fRFcLQAAAAA:8u6t-3JY0eITWIUzOMfQUoQINychWvFliJoVyCbCMmt98Cz2GMru86WMrpaGtzJ9Y0LJd2Qmkw

¹³ <https://www.ferc.gov/industries/hydropower/gen-info/licensing/pump-storage.asp>

¹⁴ <https://doi.org/10.1016/j.apenergy.2013.10.010>

7. CCS: There is no potential for CO₂ storage or beneficial use in NicLand so any CO₂ captured from power plants in NicIso would need to be transported at least 1,000 miles for use in enhanced oil recovery or for storage in saline aquifers. Your boss has also discouraged you from considering this alternative unless you see it is necessary to achieve a solution to NicIso's de-carbonization goals that is both economic and reliable. Preliminary studies show that all the coal-fired and natural gas plants in NicIso can be retrofitted with post-combustion CO₂ emissions control for about 1.3 times the capital costs of these equipment in a new plant (the costs of a CCS system for a new plant can be found in the ATB). The CCS equipment would capture up to 90% of the CO₂ emitted. To optimize the conditions for CCS operation these retrofit plants would also control the emissions of SO₂, NO_x, mercury and particulate matter and the costs would be included in the costs of the CCS retrofit.

8. Other information

Linear distance between nodes in NicIso is about 250 miles.

Capacity Markets: The association of IPPs has expressed to NicIso officials the concern that current and expected LMP prices in the region and expected low capacity factors for conventional resources may not provide enough incentives for investment in new plants or for keeping existent plants, and hence, capacity payments may be needed. Analysis on this issue from the perspective of investors/owners and from the perspective of consumers would be very relevant.

Energy efficiency:

A large share of the population is extremely interested in exploring energy efficiency alternatives for NicLand. Your boss has told you that you can focus on this if there is expertise and interest in your team. Due to lack of data, he has asked that you please make reasonable and defensible assumptions on the program implementation and potential benefit (i.e. the % reduction in load that is possible given customer behavior, rebound effects, etc.). For this part you can also use the following information about NicLand:

Home appliances:

20% of households in NicLand have more than one refrigerator. The median age of primary refrigerators is 7 years while the median of the secondary refrigerator is 15 years.

Cooling and heating demand:

HVAC demand is growing due to ongoing construction of new homes with central AC and retrofitting of mini-split systems in existing homes to cope with a warming and humid climate. (Current share of homes with HVAC is 50%). There is only one climate zone in NicLand with 4180 heating degree Days and 1322 cooling degree days (using a 65 F degree base).

Lighting:

Currently only 25% of households have switched to compact fluorescent lighting (CFL and a negligible amount has switched to LEDs.

Residential demand: Other assumptions about household use of electricity can be made based on the average values for the US presented in the Residential Energy Consumption Survey RECS¹⁵. <https://www.eia.gov/consumption/residential/>

¹⁵ <https://www.eia.gov/consumption/residential/>

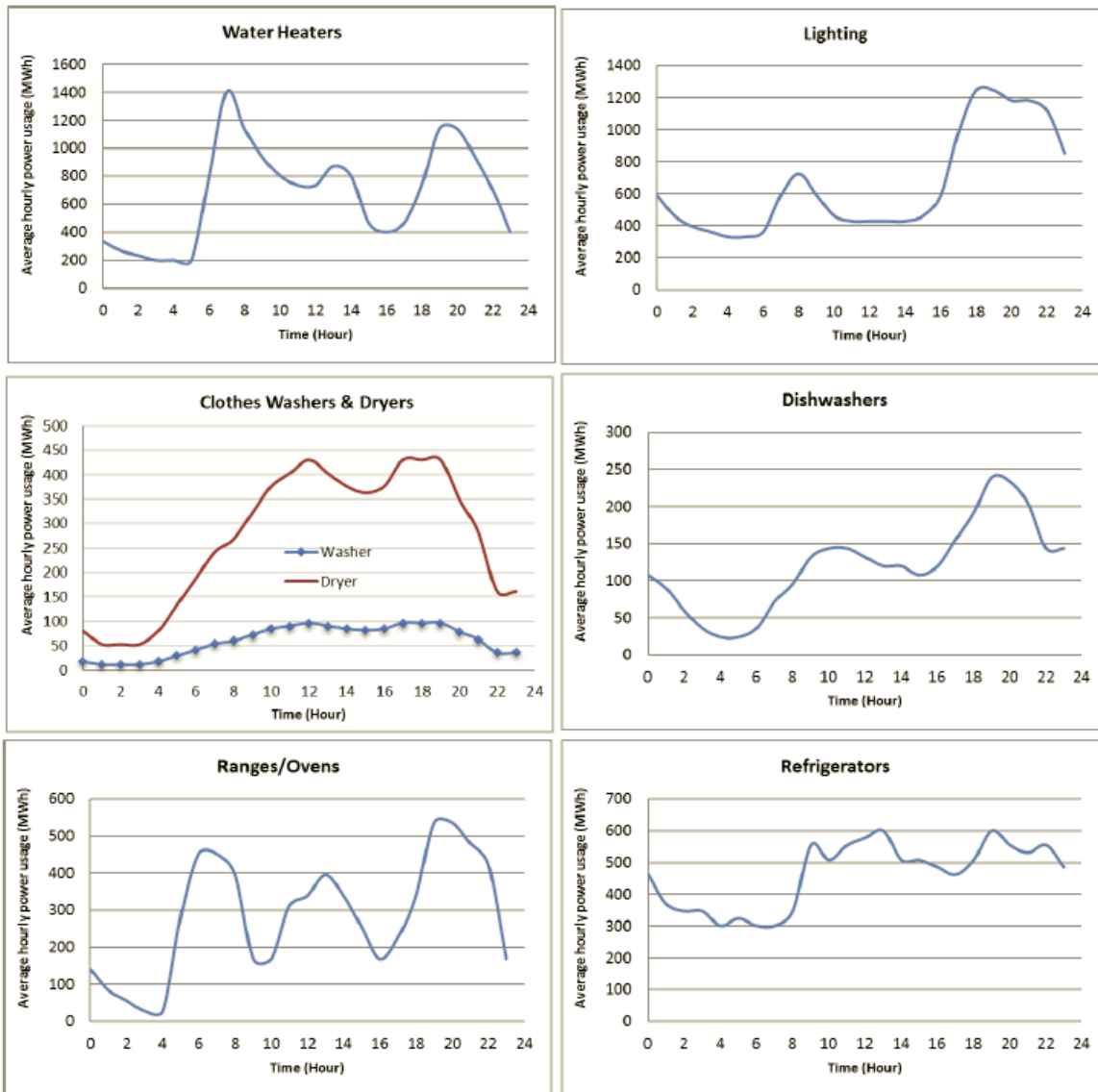


Figure 2. Hourly electricity consumption patterns from household appliances in NicLand

Important:

Your boss is aware of the complexity of the task and does NOT expect an analysis that considers in depth every single issue raised in current discussions, but he expects a **comprehensive analysis of the many technological, market design, and regulatory alternatives to achieve environmental goals, reliability standards, and economic efficiency**. When analyzing supply or demand side alternatives to decarbonize and or increase reliability, you must use metrics well understood in the industry such as the LCOE, Cost of Carbon Abatement, total required investment for the NicLand region by 2030 and by 2040, total electricity sold by 2030 and 2040, expected electricity cost increases per costumer, and reliability metrics.

The clarity of your report is of particular importance. **Your document should concisely describe the problem, clearly state general and specific objectives and scope, describe the methods of analysis, and present all assumptions and results in a way that makes them comparable with other studies for other regions, and from other analysts.** To provide clarity on the methods of analysis and the data used it would be nice to provide a flow chart explaining the process followed to analyze the data and compare strategies. All reports should present results of a business-as-usual case –when there are no new plants of any kind- for years 2023, 2030, and 2040 as well as results for different portfolios of demand and supply side alternatives and the associated costs, revenues, reliability, and prices to consumers. Report should clearly recommend a portfolio and a strategy of policy mechanisms and market design changes to achieve it.

A wide variety of individuals and organizations will scrutinize the report (see instructions below) and will consider it an impartial and credible analysis **if they can understand and find all the information necessary to replicate the calculations presented.**

You and your team should submit a written report by the stated deadline and submit a link to a video of a 20 minutes presentation summarizing your analysis.

Please **DO NOT ask questions** to your Boss about this assignment. Make and document any necessary assumptions and try your best.

Instructions for report:

Please follow the presentation guidelines in the syllabus. As mentioned above, you and your team should submit a document that does not exceed 8,000 words (tables and figures count as 300 words each). You are allowed (and encouraged) to include all relevant supplemental information in an appendix, but the report should be a standalone document. Please add an attachment with a brief description of how the team collaborated to write the report and small photos of all the team members or one group picture and a caption with all the names.

You are free to make any assumptions if these do not contradict any of the information presented above, and are reasonable and defensible given data from the continental U.S. Please focus your analysis on the information provided above.

For this assignment please upload at least two files in Sakai per team: A word file with the report, and files with all the models for the analysis. Your word file should include a link to your recorded 15minutes presentation. Your grade depends on the depth and clarity of the report, and on the clarity and usefulness of your models. Teams are NOT allowed to collaborate or share results or insights with others. *In order to make your models useful for other users please document them thoroughly, providing context and instructions.