A 100% Renewable Chicago

An Economic Impact Report Assessing Renewable Energy in the City of Chicago

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ACKNOWLEDGEMENTS

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Key Facts & Figures

All numbers here presented on a per-year basis**
Savings from rooftop solar substantially increase after initial 15 years**

Electricity

Current Demand (2018 upper-range est.)
25.8 million MWh per year

Current Supply (Illinois PJM)
132.8 million MWh per year

Future Demand (2035 est.)
27.3 million MWh per year

Future Supply (Chicago)
27.3 million **renewable** MWh per year

Our Current Mix

36%	Nuclear
33%	Coal
26%	Natural Gas
3%	Wind
1%	Hydroelectric Power
1%	Other

Bridging the Gap to 100% Renewable (2035)

69%	Illinois PJM Wind & Solar
15%	Energy Efficiency
11%	Rooftop Solar
5%	City of Chicago Municipal Commitment

Emissions Reduction

Electricity
15.6 million metric tons

Heating & Cooling (Nat. Gas)
2.0 million metric tons

Transportation
3.7 million metric tons

Employment

(1,177)	Nuclear Loss
(139)	Fossil Fuel Loss
1,282	Wind Construction
618	Wind Operation
3,208	Utility-Scale Solar Construction
1,148	Utility-Scale Solar Operations
638	Rooftop Solar Installation
1,148	Rooftop Solar Sales & Distribution
3,220	Efficiency Installation (large properties)
1,493	Efficiency Installation (small properties)
6,906	Efficiency Indirect (overall)
18,180	Net Total

Savings (from)

Lower Energy Costs
$147,226,433

Rooftop Solar
$42,661,905

Energy Efficiency Gains
$549,305,113

Earnings and Output

Aggregate Earnings
$1.107 Billion

Aggregate Economic Output
$2.919 Billion

I. Introduction

This paper is intended to estimate the aggregate impacts of a transition to 100% renewable energy for the City of Chicago. We examine Chicago's current energy demand and supply, project Chicago's energy demand through 2035, and then test scenarios for a full transition to renewable energy. We then model aggregate job creation, economic output, and emissions reduction potential. In addition to explaining the methodology behind the "A 100% Renewable Chicago: By the Numbers" infographic, this paper provides background detailing how Chicago sources energy. We not specify or recommend any individual policy—this report is intended as a resource and framework to support local advocates, community stakeholders, and policymakers in formulating a community-driven stakeholder process for later implementation.

II. Methodology

We estimated the values in "A 100% Renewable Chicago: By the Numbers" by modelling a mix of new energy generation and energy efficiency improvements necessary to power the City of Chicago through 2035 by all-renewable sources. Several steps were taken to further refine the accuracy of these estimates. We first **projected future energy demand** in Chicago by accounting for anticipated population growth, projections in future energy-use per capita, and national energy forecasts. We then **modeled a set of implementation possibilities** that are possible under the current legal landscape for energy policy in Illinois, including current City and State of Illinois energy programs. Finally, **we calculated economic and emissions impacts** based on those implementation possibilities. Specifically, we assume the following is a reasonable and feasible path to 100% renewable energy for Chicago:

- 100% Renewable Commitment for Municipal Buildings by 2025
- Maintaining wind generation growth in northeastern Illinois for Chicago, 2020 - 2035
- Maintaining utility-scale solar growth in northeastern Illinois for Chicago, 2020 - 2035
- Large-property energy efficiency gains by 2035
- Installation of rooftop solar by 2035

This paper serves to further detail our calculations, in addition to presenting other key findings and some process recommendations for energy-related policy and programs. There are a number of considerations to keep in mind when interpreting these results. First, **these numbers are estimates**; future technology, market conditions, business cycles, inflation, and even trade policy may affect the end number, *either positively or negatively*. However, we believe **these estimates are conservative**; we consistently deferred to low estimates for energy production, efficiency gains, and economic multipliers, while assuming the upper-range of future energy demand.

Second, the majority of numbers presented in "A 100% Renewable Chicago: By the Numbers" are **only for renewable electricity**. A full transition to 100% renewable should also include Heating & Cooling and Transportation. While discussed further in other sections, a full transition in both of these areas requires substantial participation from private citizens, making accurate impact calculations difficult. As such, "Sustained Jobs," "Economic Output," and "Energy Savings" numbers include effects from general energy efficiency upgrades, but do not include additional Heating & Cooling replacement and retrofitting specifically. Likewise, "Sustained Jobs," "Economic Output," and "Energy Savings" include upgrades planned for O'Hare and Midway international airports, but do not include other ground-transportation or rail-transportation investment. "Greenhouse Gas Emissions Saved," however, does include all three categories of electricity, heating & cooling, and transportation, accounting for feasible rate of private participation by 2035. Should statistics for these other areas be included, economic benefits would likely be more significant overall, though would also be distributed between both in-state and out-of-state effects.

Additional Limitations

Our estimates for future energy supply are not exact, and should be further studied by engineering experts with regard to location-specific projects and ancillary service needs. While we have taken several steps to increase the accuracy of our estimates by weighting for a variety of factors, including future technology, capacity factors, and "real" generation factors as compared to actual generation in 2016, we do not account for plant replacement needs, generation necessary for load balancing, or seasonal generation differences.

Most importantly, our generation estimates are calculated on an annual basis for simplicity. Additional analysis will be required to ensure our proposed renewable generation will be sufficient on an hourly time frame, especially with respect to daily peak periods and ramping. This consideration is especially important for renewable generation given its inherent variability throughout the day pending local weather as compared to traditional fossil-fuel-based generation. A sustainable renewable grid will require the proper energy storage and advanced monitoring to ensure consistent delivery. Luckily, Chicago's positioning in the PJM-Interconnection already solves many of these challenges. PJM's frequency regulation market, high energy storage capacity (with ~40% of all U.S. large-scale battery storage)[1], and Demand Response program creates a uniquely favorable environment for renewable generation that enables both supply and demand smoothing.

Given these qualifications, this paper focuses on creating a general picture of future generation on which to base our jobs, income, and economic output estimates, with some built-in flexibility from testing more challenging transition scenarios.

[1] EIA (2018): "U.S. Battery Storage Market Trends."

III. Energy Overview

Like any major city, Chicago's energy landscape is complex, with several several aspects that make it particularly unique. As the third largest metropolitan area in the U.S., the Chicago area stands just shy of being considered a global "megacity".[2] As a group, megacities together consume over 9% of global electricity and 10% of gasoline, and U.S. megacities in particular have been found to consume above-average energy and resources as compared to their global peers.[3] Second, Illinois is a significant energy exporter to other U.S. states, which drives economic development both downstate and in Chicago:[4] major energy companies including Exelon, Integrys, DuPont Danisco, and Nicor are all headquartered in Chicago or surrounding suburbs. Finally, Chicago sources electricity from a competitive retail energy market, which spans across several U.S. states. While this sourcing structure creates barriers for accurate consumption and supply calculations, the following sections detail how these challenges were resolved and provide new public information on the energy assets immediately surrounding the Chicago metropolitan area.

3.1 Energy Regulation Landscape

Energy Markets and Chicago

Chicago rests in a larger energy market that competitively sources and sells electricity across several U.S. states.[5] There are a variety of players that make up this market, in addition to regulatory agencies in individual states that ensure fair competition and oversight for states that choose to participate. Within a given competitive market, there are electricity producers (Independent Power Producers or IPPs), middle-man suppliers (utility companies), and consumers (individual homes, businesses, and other properties). The energy market itself is managed by an Independent Transmission Organization (ITO), or Regional Transmission Organization (RTO), subdivisions of the national grid network in the United States.[6] RTOs serve to coordinate and monitor the distribution of electricity within their region, facilitating competition within a given market while ensuring the proper load is carried throughout the grid.[7] Finally, these markets are generally regulated by a state agency to ensure competitive pricing.

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[2] According to the 2016 U.S. Census as retrieved from *Census Reporter*, Chicago-Naperville-Elgin's population is 9,512,968. Kennedy *et al.* (2014) says megacities are defined as having a metropolitan population of 10,000,000 or more.

[3] Kennedy *et al.* (2015)

[4] EIA (2018a)

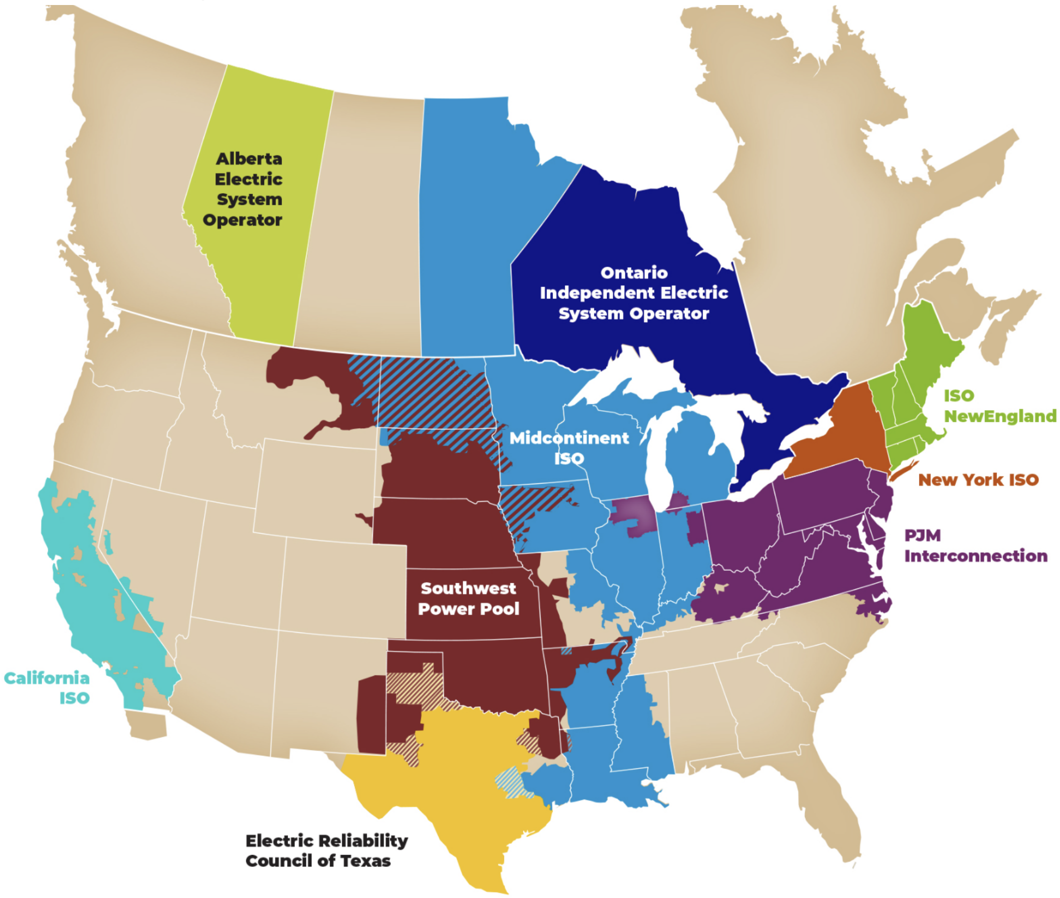
[5] For more information on retail energy markets and their possible benefits, see RESA "Retail Energy" and "Retail Energy History"

[6] For more information on the structure of U.S. energy markets, their infrastructure, and their regulatory subdivisions, see the EPA's overview, "U.S. Electricity Grid & Markets"

[7] PJM (2018)

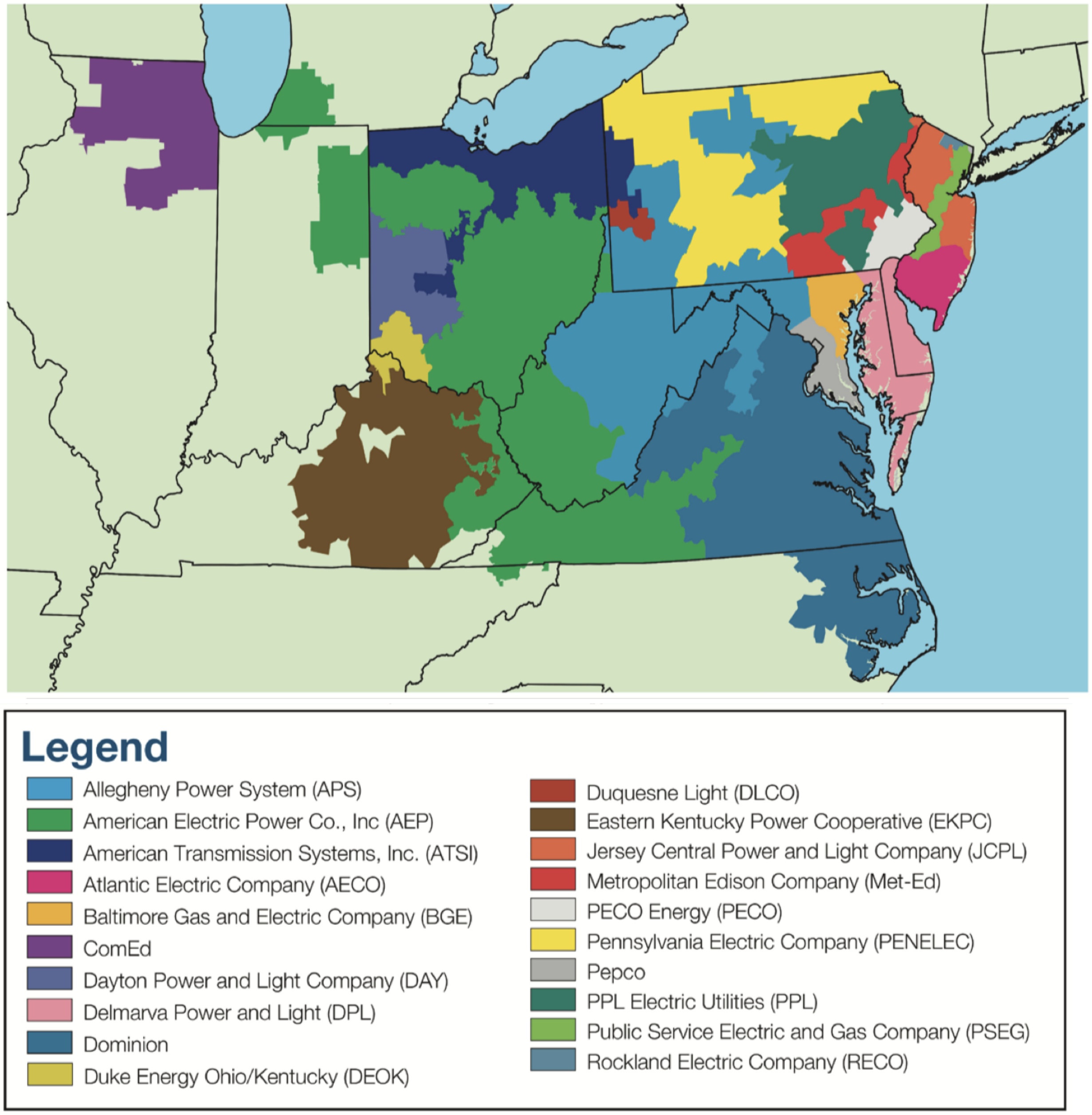
Figure 1 displays a national map of where these markets are located, including the two that serve Illinois, PJM Interconnection and the Midcontinent ISO (MISO). Figure 2 displays a more detailed map of the PJM Interconnection, the RTO that includes the northeastern region of Illinois and the region from which Chicago sources energy. Each color corresponds to an individual utility company, which is responsible for the end delivery, but not production, of energy in the given area.

Figure 1: Competitive Electricity Markets in the U.S.



Source: IRC, 2018. "Our Members." Accessed 31 Aug 2018.

Figure 2: PJM Interconnection Territory

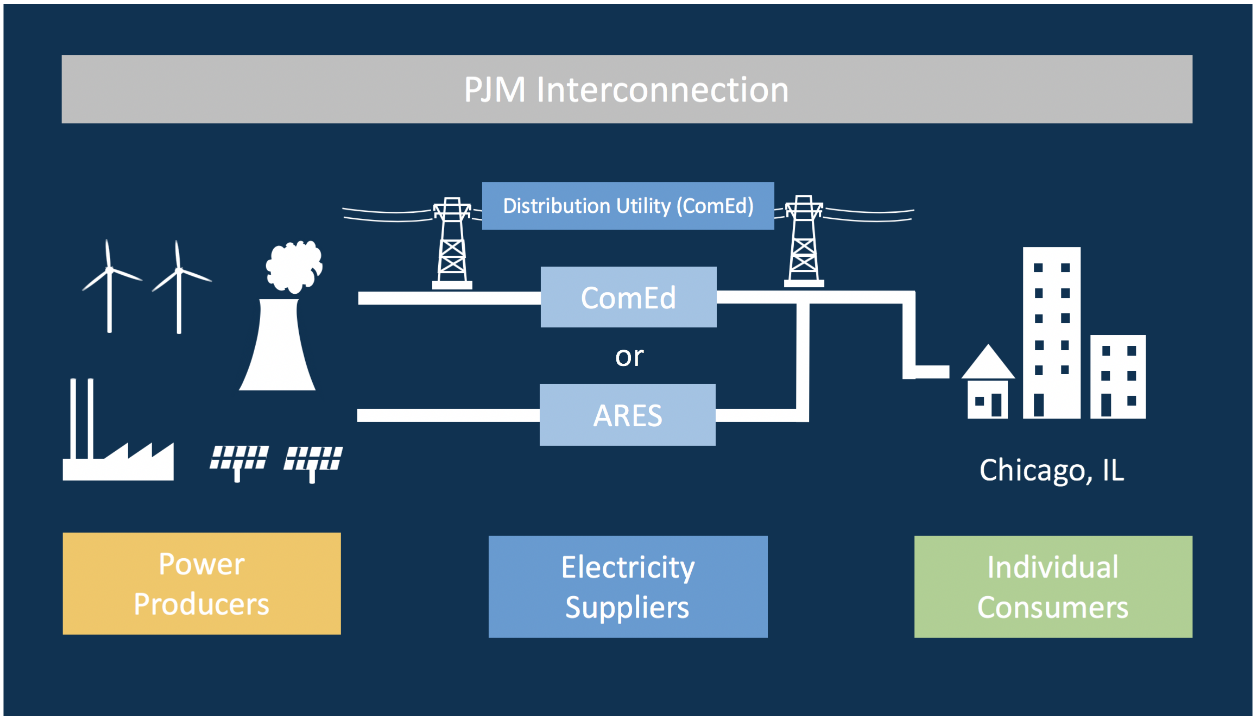


Source: PJM, 2018c.

Energy Markets in Illinois

In Illinois, both the PJM and MISO markets are overseen by the Illinois Commerce Commission, which regulates middleman actors in primarily two ways: 1) the ICC sets a standard delivery fee that *distribution utility companies* are allowed to charge to the end-customer and 2) the ICC regulates the energy procurement process, in which primary *electricity suppliers* seek competitive bids from power producers (IPPs or other electricity generating companies) to purchase electricity on behalf of its customers.[8] When a supplier is purchasing power from generating companies or IPPs, it is referred to as "wholesale electricity market;" when a customer is choosing among electricity suppliers, it is referred to as a "retail electricity market."[9] In Illinois and other states, customers can choose between their designated electricity supplier (ComEd) for a certain market, or from a list of Alternative Retail Electric Suppliers (ARES), which can purchase power based on certain parameters, such as sourcing majority-renewable energy.[10] The distribution utility, ComEd, still delivers electricity to the end customer for all suppliers. Figure 3 helps visualize this complex network of energy generation, specific to the PJM market and Chicago.

Figure 3. Chicago Energy Sourcing Visualization



History of Illinois Energy Deregulation

Competitive energy markets in the U.S. were created through a process known as "energy deregulation," starting in the 1980s and formalized in 1992 with the passage of the Energy Policy Act at the Federal level.[11] Illinois as a state opted to join competitive energy markets in 1997 with the

[8] Illinois Public Utility Act. See DeVirgilio, 2008.

[9] EPA, 2017a.

[10] ICC, 2018. For a full list of ARESs in Illinois, see the ICC's "Alternative Retail Electric Suppliers"

[11] PBS, 2001. For more information on U.S. energy market creation, see "Federal Energy Regulatory Comission."

Electric Service Customer Choice and Rate Relief Act of 1997.[12] The act created a ten-year rate freeze from 1997-2007 to allow time for Illinois's infrastructure to transition to a market structure, though once prices reset, electricity costs rose from 21% to as high as 53% for some ComEd and Ameren customers, respectively.[13] In response, the state created the Illinois Power Agency in 2007, which imposed a new process for energy procurement and is responsible for helping to build new plants to reduce costs over time.[14] The IPA operates as an independent agency but is also subject to Illinois Commerce Commission competitive procurement guidelines.[15] While competitive energy markets have empirically worked to reduce prices for consumers in other states,[16] others contend prices may be higher in competitive markets compared to other procurement structures,[17] in addition to reducing public disclosure and creating negative environmental effects.

3.2 Energy Demand

Chicago's energy consumption can be divided across three broad categories: **electricity**, **heating & cooling**, and **transportation**. Electricity powers residential, commercial, and industrial buildings across Chicago. While most cooling is electric and also demands electricity, heating for most buildings in Chicago is accomplished with natural gas (CH_4). Transportation includes ground transportation (cars, trucks, service vehicles), rail transportation (CTA, Metra), and air transportation (O'Hare and Midway airports), all which use a combination of electricity, gasoline, diesel fuel, and other petroleum products.

Electricity

We estimate that Chicago's electricity consumption in 2018 is approximately 25.8 million MWh per year. For context, this represents about 17% of the Illinois's total consumption.[18] We use three figures to estimate Chicago's energy consumption (see Table 1). First, a City partnership with Accenture aggregated energy data in 2010 between ComEd and People's Gas account information, collecting an estimated 68% of all electricity usage.[19] [20] Second, the Department of Energy in collaboration with the National Renewable Energy Lab created a "State and Local Energy Data" (SLED) tool that collects information from both government and private sources, used here and elsewhere in this report.[21] Third, a Center for Neighborhood Technology (CNT) report prepared for the Chicago Metropolitan Agency for Planning delineates energy usage on a County level, which we

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[12] Carlson *et al.*, 2008.
[13] Ibid.
[14] See the Illinois Power Agency for a brief historical summary.
[15] Ibid.
[16] Carlson *et al.*, 2008.
[17] Rudkevich *et al.*, 1998.
[18] EIA, "2016 Summary Statistics Illinois:" percentage calculated with 2016 total retail sales (MWh) and 2016 Chicago consumption projection.
[19] City of Chicago, 2010.
[20] Authors' calculation: we aggregate total kWh over 12 months and scale by the Accenture estimate [1/.68].
[21] "State and Local Energy Data": U.S. Department of Energy, 2018.

scale to Chicago's current population.[22] While these measures are all imperfect, collectively they suggest a reasonable range of values for the City's current demand. Additionally, while a challenge for many municipalities, better public disclosure of energy data should be a priority for both local governments and utilities to ensure energy information is accessible in the future.

Table 1. Chicago Electricity Consumption, 2018.

Source (Year)	Estimate (kWh/yr)
Accenture/City of Chicago (2010)	23,106,917,691.69
SLED (2013)	24,659,545,000
CNT/CMAP Cook County Data (2005)	26,418,000,000
Average (projected to 2018)[23]	**25,758,730,273.15[24]**

Heating & Cooling

We use similar methods to estimate the City's average consumption of natural gas, used for hot-water and winter-time heating of residential and commercial units (see Table 2). Cooling is mostly included in the above electricity estimates.

Table 2. Chicago Natural Gas Consumption, 2018.

Source (Year)	Estimate (therms)
Accenture/City of Chicago (2010)	1,624,813,612.24 [25]
SLED (2013)	1,130,457,578.16
CNT/CMAP Cook County Data (2005)	1,841,490,920.58
Average (projected to 2018)	**1,587,027,333.02**

Transportation

Energy consumption from transportation presents its own challenges due to a more complex fuel mix. The energy consumed by the Chicago's "L" trains, O'Hare and Midway International Airports, and a small fleet of CTA electric buses are included in the above electricity estimates. Other ground transportation, such as private cars, private trucks, CTA diesel and hybrid buses, Metra trains

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[22] We take County total electricity usage from CNT (2009) and multiply by the ratio of Chicago's population to Cook's population.

[23] Author's calculations: to project to 2018 we apply an .4669% annual growth rate to each estimate to produce three "2018 projections," then average the three resulting values. The annual growth rate is a combination of population and energy intensity, as described on p. 12

[24] While we report this number as a current consumption estimate, we use SLED (2013) as a base for all other non-energy estimates to ensure our calculations can be replicated in other cities using this standardized tool.

[25] Accenture estimates their natural gas data comprises 81% of all gas usage consumption in the City of Chicago.

(excluding Metra Electric District), and city service vehicles are powered by either gasoline, diesel, or other non-renewable fuels. In terms of water and air transportation, the approximately 5,000 recreational boats across the City's harbors[26] and 1,118,390 flights between O'hare and Midway airports[27] also consume significant amounts of energy, though energy improvements for these categories will likely depend on future technological improvements. In Table 3, we present a list of ground transportation figures relevant to the City's future renewable energy mix.

Table 3. Chicago Ground Transportation Energy Consumption

CTA Bus Count[28]	1,864 Buses
Metra Engine Count (Diesel)[29]	146 Locomotives
Total Vehicle-Miles-Travelled, including private (2013)[30]	12,519,753,400 VMT
CTA Bus Vehicle-Miles-Travelled per day[31]	161,192 VMT
Metra Rail-Miles-Travelled per day[32]	40,119,551 RMT
Total Gasoline Consumption (2013)[33]	12,519,753,400 Gallons
Total Diesel Consumption (2013)[34]	101,567,100 Gallons

Demand 2035: Accounting for Population Growth and Energy Intensity

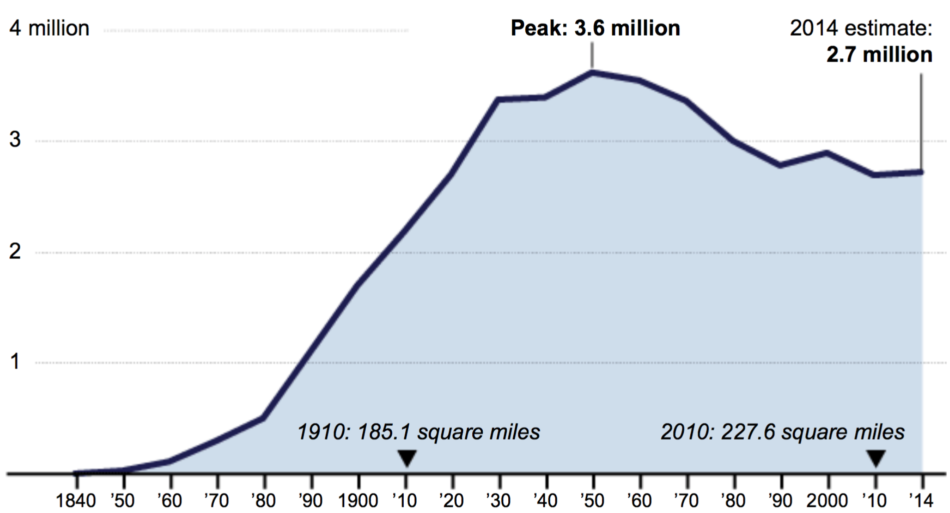
What will Chicago's energy consumption look like in 2035? We account for future population growth and future energy intensity to estimate electricity consumption over the next 15 years. To do so, we assume a linear relationship between population and energy growth, assuming that energy intensity for urban areas remains flat over the period. These forecasts are subject to change with unanticipated consumption, economic growth, or major technology shocks, though we believe they represent a reasonable approximation for planning purposes given the timespan. As stated

[26] Vilvanco (2014)
[27] Retried and aggregated from Chicago Department of Aviation, 2017.
[28] CTA (2017)
[29] Metra (2016, 189)
[30] "State and Local Energy Data": U.S. Department of Energy, 2018.
[31] CTA (2017)
[32] Metra, 2016. P. 188; excluding Metra Electric.
[33] "State and Local Energy Data": U.S. Department of Energy, 2018.
[34] Ibid.

previously, we opt for a higher future demand to model the most challenging foreseeable scenario for achieving 100% renewable energy. Using this upper-range estimate, we find that Chicago will consume roughly 27.3 million MWh in 2035, a 5.8% increase from our current consumption.

Population projections vary considerably for the City of Chicago, and not many are created for the local level. For one projection, the Illinois Department of Public Health (IDPH) estimates a 7.35% decrease by 2025 to 2,506,112.[35] However, Chicago Metropolitan Agency for Planning (CMAP) forecast projects a 15% *increase* by 2040 to 3,054,654.[36] This primary difference is due to calculation method: while IDPH uses current and historical trends, CMAP creates a reference case and then adjusts to fit a "Preferred Regional Scenario." The preferred scenario represents future estimates in a world in which future regional policies delineated in CMAP's *GO TO 2040* planning are implemented, mostly related to transportation.[37] Finally, a look at historical trends would make growth seem generally unlikely, as the City's population peaked at 3.6 million in 1950 and has continued to steadily decrease to today's 2.7 million since then (see Figure 4).[38]

Figure 4: Chicago Population, 1840-2014



Source: Bentle (2015)

While these trends overall suggest a reasonable decrease in Chicago's future population, we wish to model the most challenging scenario to reach 100% renewable energy. We thus choose to take CMAP's projection of 15% increase, yielding an annual growth rate of .4669 %.

An accurate projection of energy consumption must also consider energy intensity, or energy consumption per capita. This measure should account for technology, energy costs, and population

[35] IDPH (2017)
[36] CMAP (2014)
[37] CMAP, 2011.
[38] Bentle (2015)

density over time, and how energy consumption responds to those dynamic factors. While intensity projections are scarce for U.S. cities, a case study of Seattle found that electricity consumption per capita has steadily decreased by -.5% per year for the past twenty years (see Figure 5).[39] Such a figure demonstrates that despite new technology in computing, digital displays, and modern appliances, electricity consumption *per person* has decreased, likely thanks to benefits from higher spatial density and energy efficiency improvements. Kennedy *et al*'s study on global megacities suggests that energy consumption overall grows more slowly for urban areas in developed countries, with Los Angeles demonstrating a per capita consumption as low as -2% per year,[40] though these gains may also be affected by the implementation of energy efficiency efforts.

Chicago-specific trends in income-distribution and housing may however increase future energy intensity compared to other urban areas. Prior literature has demonstrated a link between electricity consumption and average-income, building structure, and other parameters that can represent the key differences between gentrified and non-gentrified neighborhoods. One study found that low-income neighborhoods consume only 57% of the energy that the most affluent urban neighborhoods consume.[41] Given increasing gentrification in several Chicago neighborhoods over the past 10 years,[42] we should expect at least a modest *increase* in an average energy intensity. Unfortunately, little literature exists that examines the direct link between gentrification and energy consumption, and a more comprehensive study of this question should be considered for Chicago in particular. Combining these two counteracting trends, we assume Chicago's future energy intensity to be flat.

We thus use a growth rate of .4669% per year, or a 7.35% increase by 2050. Our final estimate is roughly in line with the EIA's reference scenario of .4% growth in overall energy consumption per year through 2050, though below the projected growth rate of .9% in electricity consumption (see Figure 5).[43] This reference scenario reflects conditions of unchanged regulations but accounts for future economic growth and base technological improvements.[44] As shown in Figure 5, growth rates in electricity consumption have significantly decreased over time, though are estimated to slightly increase through 2050. First, while our estimates for electricity consumption are lower than the EIA's national projections, urban centers behave differently from national averages, and were found to be lower on average for developed countries.[45] Population and energy-intensity based estimates are thus needed for a more accurate forecast, demonstrating our reasoning to build these projections from the ground-up. Second, despite the fact that Chicago population is expected to decrease and energy intensity is also expected to decrease for U.S. urban areas, we still choose to create a more

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39 Haefer, 2014.

40 Kennedy *et al.* (2015)

41 Druckman and Jackson (2008), p. 3185.

42 See Governing (2018). Roughly one sixth of Chicago's census tracts are considered to have been gentrified between 2000 and 2018.

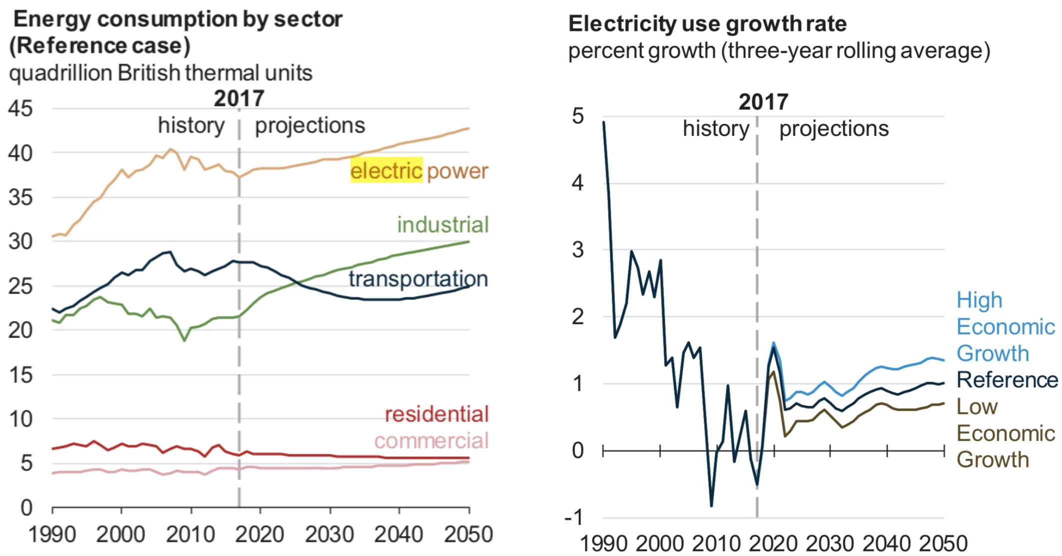
43 EIA (2018b, 12-80)

44 Ibid.

45 Friedman, 2011. Also see Kennedy, 2014.

challenging scenario in terms of both of these metrics, so as to include any potential risk for slightly higher growth rates from national-level effects.

Figure 5. National Energy Consumption, 1990-2050

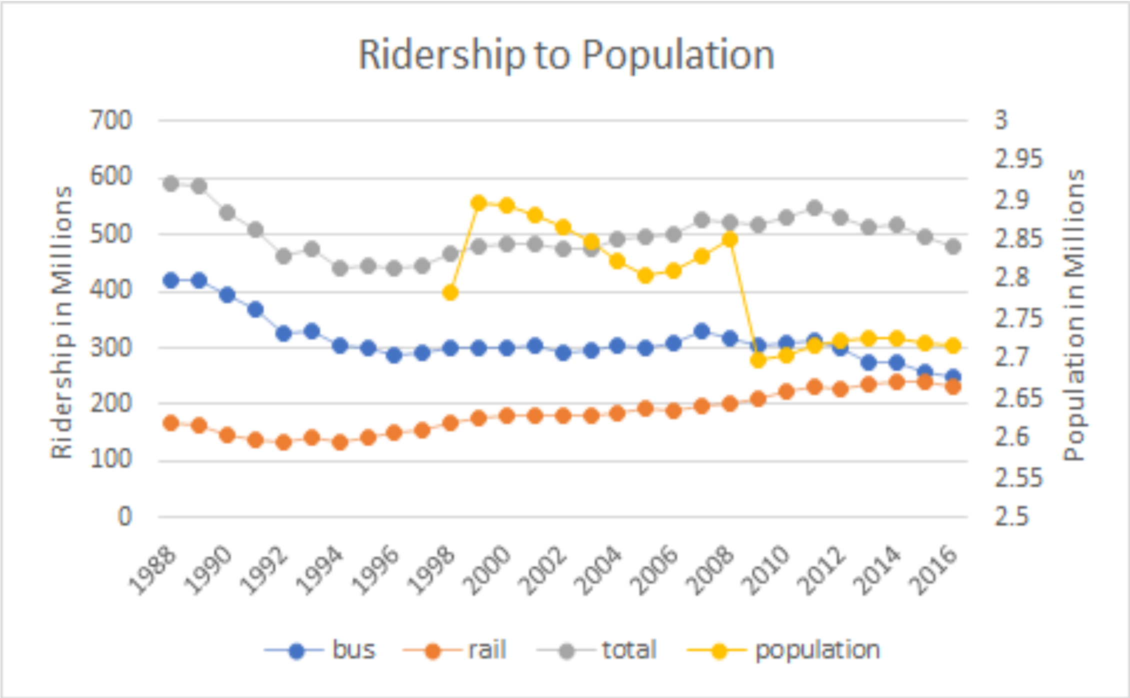


Sources: EIA (2018b, 14) (left); EIA (2018b, 79-80) (right)

Demand 2035: Accounting for future Ridership in Transportation

Barring extreme transitory shocks to Chicago's population, public transportation ridership is loosely positively correlated with Chicago's population. See Figure 6, where the relationship is more pronounced beginning 2009.

Figure 6. CTA Ridership and Population



While our scenario modelling assumes Chicago population will increase by 2035, most transportation ridership planning expects Chicago population and therefore ridership to decline.[46] For the foreseeable future, it became reasonable to assume that taking a linear relationship of the bus and train ridership numbers and projecting forward with this regression method would create accurate estimates of future ridership numbers. The challenge in modeling linearly lay in that, purely mathematically, this assumption would lead us to a 0 ridership (and population count) projection within 20 years. Drawing from historical examples, it is more reasonable to expect modest but flattening population growth, in-line with our modelling, and thus plateauing ridership numbers. As such, we chose to be conservative and expected flatlined ridership numbers over the next 15 years, thus applying the linear decrease to 15 years of ridership.

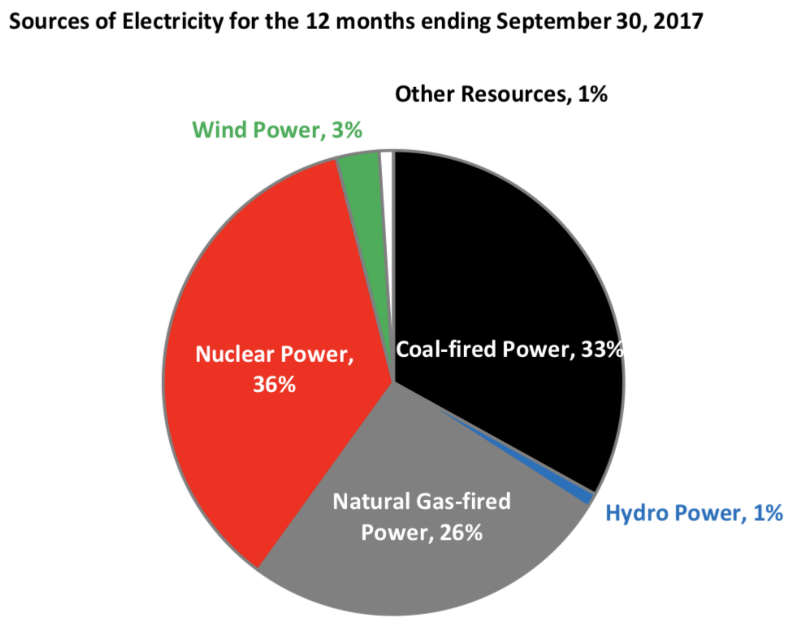
3.3 Energy Supply

[46] CTA, March 2018.

Electricity - PJM

Determining the actual electricity supplied to Chicago currently is not straightforward. Electricity is delivered to end-customers by Chicagoland's designated regulated distribution utility, Commonwealth Edison (ComEd), and supplied by electricity purchased by either ComEd or Alternative Retail Energy Suppliers (ARESs). Both of these intermediary suppliers purchase power from Independent Power Producers (IPPs) or other electricity generating companies anywhere within the PJM territory. For a more detailed explanation of the full supply-chain and regional energy market, see Section 3.1. Ultimately, Chicago's current energy supply can source from *anywhere* within this multi-state regional market. Figure 7 displays the best available publicly released information with regard to the fuel mix of this network, sourcing from environmental disclosures released by ComEd and provided by PJM Interconnection.

Figure 7. PJM Generation Mix



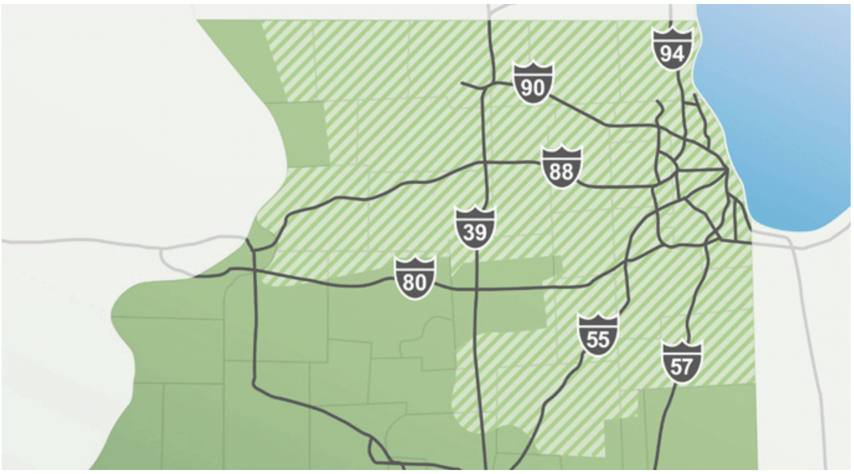
Source: ComEd (2017)

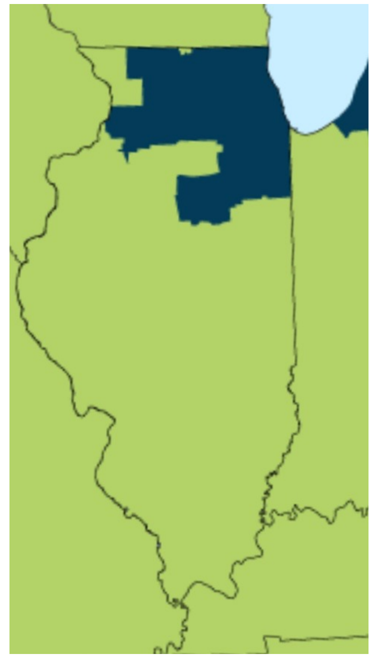
Electricity - PJM in Illinois

A new insight of this paper is aggregating a more specific view of energy assets available in the region surrounding Chicago. Should the City want to source 100% renewable energy directly from local power plants, an understanding of our current assets is essential. Under current energy regulations, Chicago legally can only procure energy from anywhere within the PJM market (see

Section 3.1). For the region in Illinois, this area approximately comprises the Northern third of the state, which is also the ComEd transmission zone (see Figure 8).

Figure 8. PJM Region in Illinois





Sources: ComEd (2018) (left), PJM (2018b) (right)

To estimate the current energy mix in the PJM region *within* Illinois only, we use individual plant and generator data from the Energy Information Agency (EIA), which collects data from legally required plant and generator registration forms. By filtering state data and selecting for only "PJM" Balancing Authority Name, and then further filtering by "Commonwealth Edison" Transmission or Distribution System Owner, we generate a list of individual plants and their generators within this region, and then aggregate the total MW capacity. This data is available on file with the authors.

To estimate *generation* capacity in the PJM-IL region, we convert nameplate capacity in megawatts (MW) to generation in kilowatt-hours (kWh) per year,[47] and then apply a .90 discount factor to determine real annual capacity:

Nameplate Capacity (MW) x 24 hrs/day x 365 days/year x 1000 kW/MW x Capacity Factor x .90
= Real generation capacity (kWh/yr)

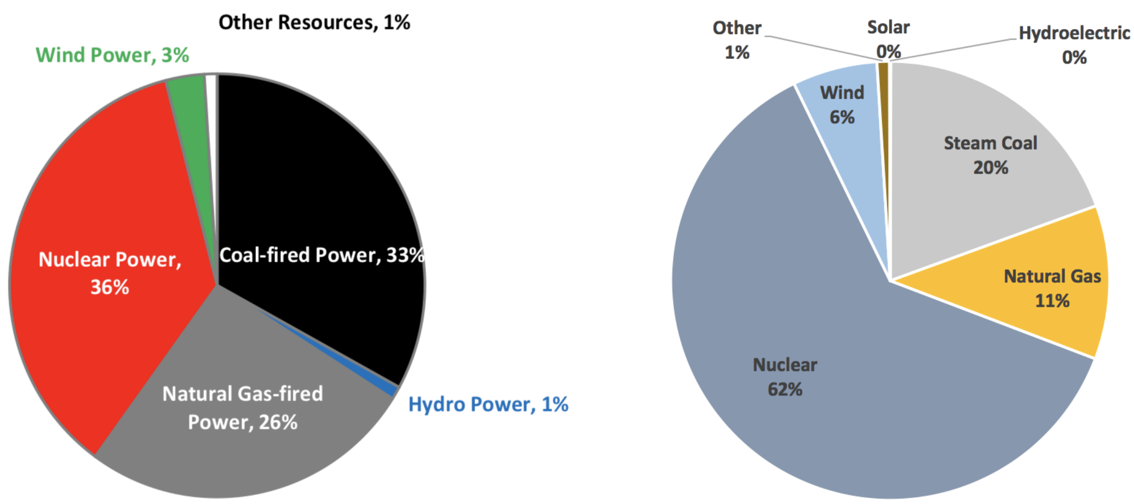
Generators are rated in terms of megawatt capacity, which refers to how much energy a generator can produce at any one moment. Megawatt-hours, however, refer to how much energy a given generator or plant can produce over time, which is more relevant for matching to a given City's electricity demand over a one-year period.[48] After converting, we then apply standard capacity

[47] For base conversion, see AWEO: "Energy and Power Units."
[48] For explanation of energy units and conversion, see the Union of Concerned Scientists: "How is Electricity Measured?"

factors and a .90 "real factor"[49] to more accurately estimate actual generation capacity. Capacity factors refer to how often a power plant can realistically operate.[50] The "real factor" weighting can account for things such as local climate zone, fuel-disruptions, average plant age, and other real-world factors.

Figure 9 summarizes our results, and can be compared to the overall PJM generation mix. On a proportional basis, we find the PJM region surrounding Chicago has roughly double the wind, double the nuclear, half as much natural gas, and two-thirds the amount of coal as the multi-state PJM territory generates.

Figure 9. PJM vs. PJM in Illinois Generation Mix



Additionally, the total generation capacity in this region currently amounts to 132,878,541,924.02 kWh per year. For context, this represents 70.89% of the state's overall electricity generation in 2016, and is enough to power the City boundaries of Chicago **seven times over** should this energy be exclusively sourced to Chicago. However, it must be remembered that the plants creating this capacity are currently able to provide power anywhere within the multi-state PJM territory, stipulated by annual bidding and contracts with energy suppliers.[51] Moreover, should this power be more

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49 By comparing our aggregated generation capacity after applying average capacity factors, we find the aggregation overestimates Illinois's 5-year average generation in between 2012-2016 (196,821,567 kWh/yr) by 10.64%. We thus apply a 1/1.1064 = .90 multiplier to account for factors such as real hours of operation, plant age, and other plant-specific factors. Data from EIA (2016).

50 For more on capacity factors and power plant capacity, see the Department of Energy's "What is Generation Capacity?"

51 For more information on current contracts, see the Illinois Commerce Commission "2018 Procurement Process"

closely directed toward Illinois customers, other communities would also likely procure electricity from these assets.

Natural Gas

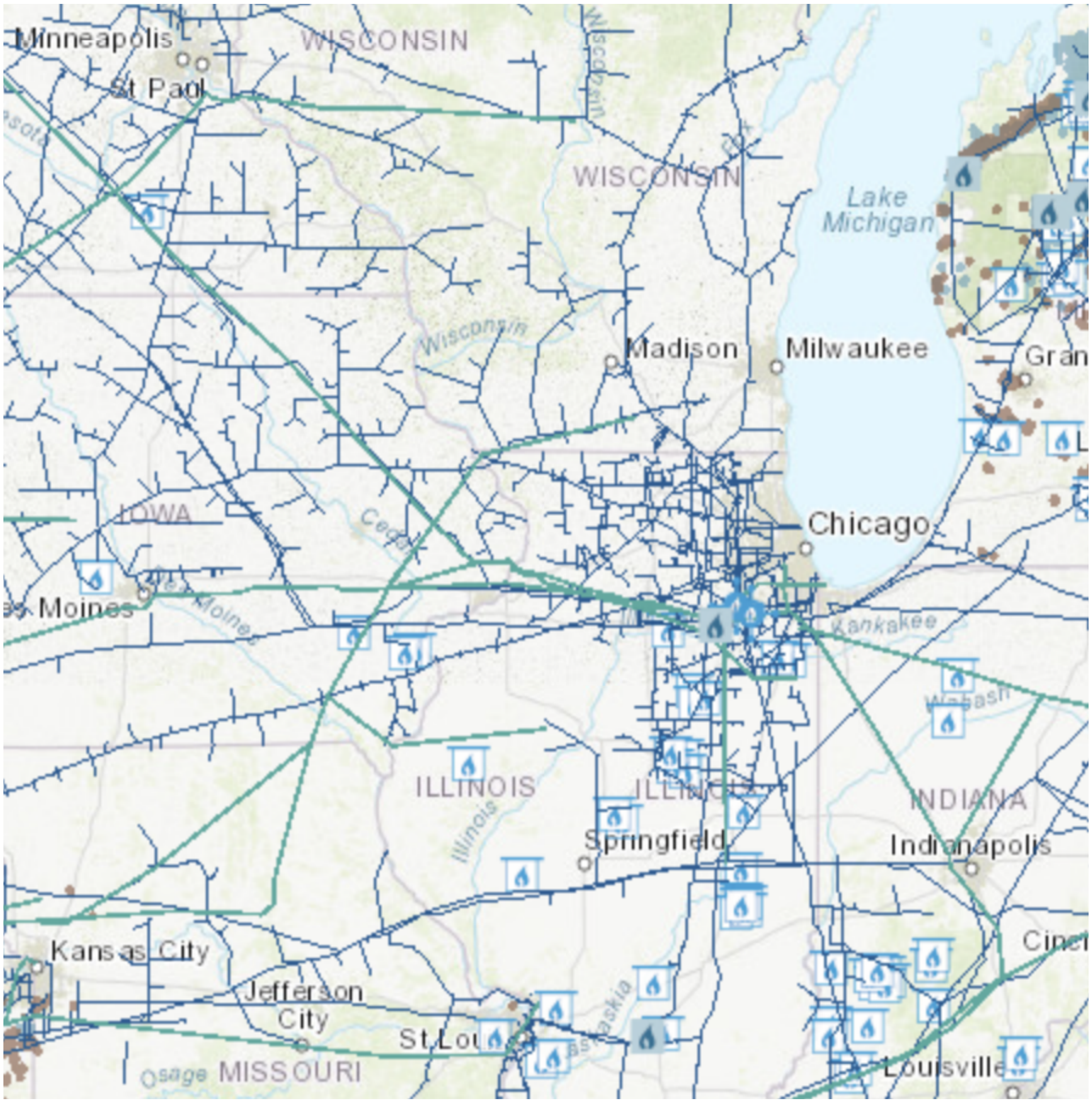
Chicago's natural gas supply comes from a nationwide network of pipelines, connecting production wells, export/import points for other countries, processing plants, storage facilities, and end-consumers.[52] Given the added difficulty and risk in transporting natural gas, these markets are heavily regulated. While most delivery networks are owned or co-owned by private companies,[53] the Federal Energy Regulatory Commission (FERC) sets standard delivery tariffs, approves pipeline construction, and oversees all operations.[54]

Much like electricity, natural gas is distributed to Chicago end-consumers by People's Gas (the regulated distribution utility for the City of Chicago), and supplied by either People's Gas or Alternative Natural Gas Suppliers.[55] Also similar to electricity, Chicago rests in a larger natural gas market, the Midwest NGM, encompassing Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, Arkansas, Oklahoma, Kansas, Nebraska, North Dakota, and South Dakota.[56] However, this market is more heavily regulated and dependent on individual pipelines, rather than territorial borders.[57] Additionally, the People's Gas delivery territory is much smaller than ComEd's, and more dependent on national pipelines and natural gas commodity prices like most other service areas.

Notably, Illinois as a state is an important transportation hub for natural gas, as well as crude oil. 18 natural gas interstate pipelines and two natural gas market centers are located in the state, many near Chicago.[58] Figure 11 displays a map of these respective assets.

[52] EIA (2018d)
[53] Rigzone (2018)
[54] FERC (2016)
[55] See People's Gas for an updated list of current alternative natural gas suppliers.
[56] FERC (2018)
[57] Ibid.
[58] EIA. 2018. "Illinois: State Profile and Energy Estimates."

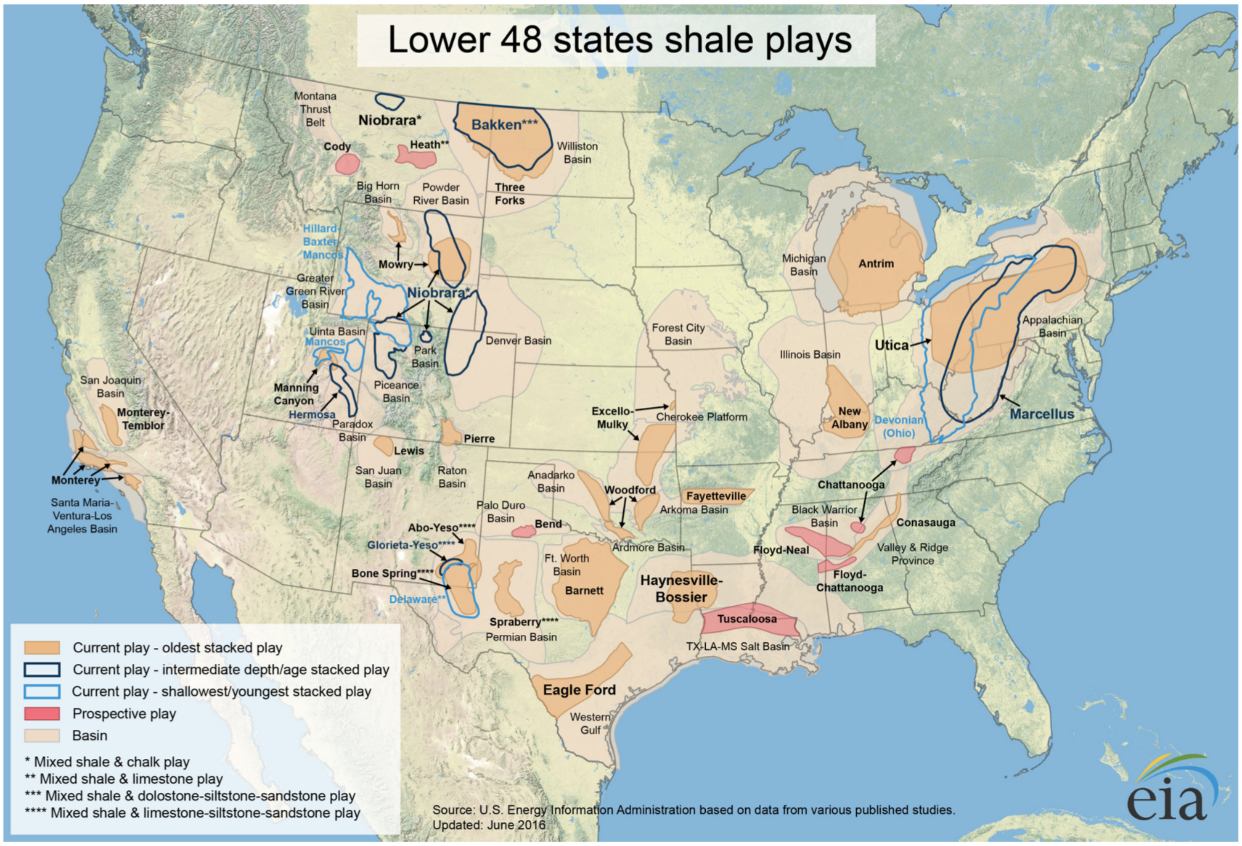
Figure 10. Chicago Natural Gas Infrastructure



Source: the EIA's "[U.S. Energy Mapping System](https://www.eia.gov/state/maps.php)" including Natural Gas Processing Plants, HGL and Natural Gas Market Hubs, Natural Gas Pipeline Border Crossings, Natural Gas Underground Storage, and LNG terminals.

Little natural gas is extracted near Chicago, but the City's usage contributes to national demand for the fuel. A substantial amount of natural gas production is facilitated through fracking in the northeastern region of the United States, including Ohio, Michigan, and Pennsylvania (see Figure 11). In addition to local environmental damage, fracking creates its own harms from an equity perspective tied with local pollution and property devaluation. While not focus of this paper, these effects should be considered when evaluating a transition to renewable energy for any nearby U.S. city.

Figure 11. Natural Gas Fracking, Lower 48



Source: [EIA (2016).]()

While a full transition to 100% renewable energy should include fuel-switching away from natural-gas heating and appliances to all-electric equipment, such an effort will need to rely substantially on private participation. We recommend further study into designing incentive programs and efficiency strategies for natural gas utility companies.

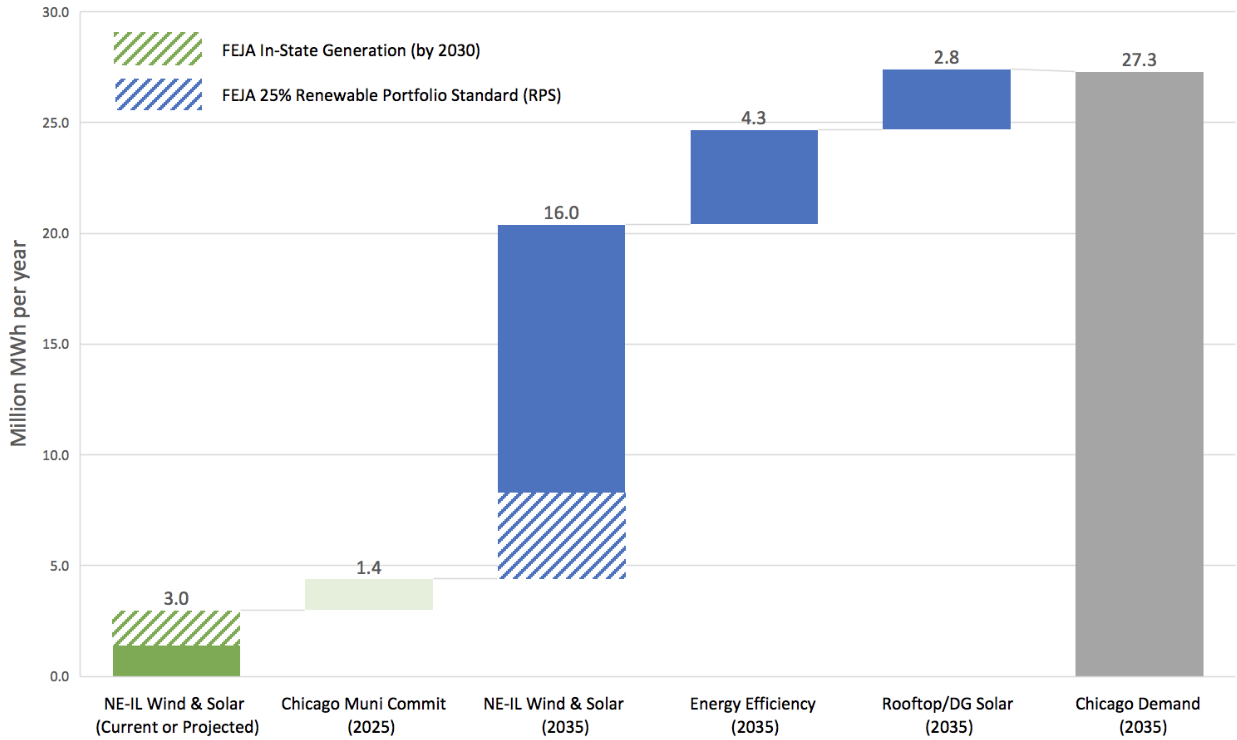
Photo: Wind Farm in Galva, IL 2018, Paul Douglas Institute

IV. Bridging the Gap to 100%

We find that a transition to 100% renewable energy for the City of Chicago is both feasible and economically viable. As detailed in later sections, building the energy infrastructure for 100% renewable electricity represents a relatively small investment compared to the state's overall energy portfolio, and only requires that we sustain projected energy growth rates in renewable generation. Efficiency gains and rooftop solar will further ensure that the City can independently reach a 100% target. While renewable Heating & Cooling and Ground Transportation require significant private participation, lowering costs for retrofitting and wider commercialization of current technology will likely accelerate fuel-switching over time, provided the City and State assist with the right incentives. Most importantly, ensuring the grid is 100% renewable is essential to ensuring electric heating and electric transportation are not just using fossil fuels for their power. Figure 12 displays how we most feasibly and independently achieve 100% renewable electricity. Section 4.1 further details how the City's renewable energy needs can be met with a set of possible scenarios. Section 4.2 and 4.3 quantify the economic benefits and costs the City and broader region may experience with a renewable transition. Section 4.4 estimates and contextualizes emissions reductions. Section 4.5 gives a brief overview on estimated costs for such a transition. Finally, Section 4.6 lists some especially relevant case studies of other cities and countries successfully meeting 100% renewable energy targets, further proving the feasibility of this goal for scale of Chicago.

4.1 Energy

Figure. 12. Bridging the Renewable Gap: Chicago 2035



We model a transition to 100% renewable electricity based on the implementation scenario in Figure 12. This model assumes middle-range participation rates in energy efficiency improvements (85%) and rooftop (or distributed generation) solar (55%). This scenario, hereafter referred to as the "reference scenario," represents how Chicago may most independently and quickly achieve 100% by a 2035 target. We base all jobs, earnings, and economic output estimates based on this reference scenario. We created a total of six scenarios by varying participation rates and timelines available in data files accompanying this report. Notably, this scenario assumes an accelerated renewable generation target on the Illinois state level. Alternatives can be achieved Renewable Energy Credits (RECs) or Virtual Power Purchase Agreements.

Utility-Scale Wind & Solar: Current and Short-Term Contribution

As demonstrated in the plant data, generation facilities in Northeastern Illinois (i.e. the PJM territory) already provide an estimated real 7.91 million MWh per year from wind and .46 million MWh per year from solar as of 2016. If exclusively supplied to the City of Chicago, this amounts to approximately 30% of Chicago's 2016 electricity consumption. However, these assets supply other cities and regions both in Northeastern Illinois and throughout the PJM Interconnection. To model the amount of local renewable electricity realistically available for Chicago, we create a proxy by weighting total wind and solar generation by a ratio of Chicago's 2016 consumption in comparison to the Illinois PJM region 2016 generation, yielding 18.82% of total renewable generation in the region, or 1,498,171,252 kWh.[59] [60]

Prior City and State commitments will further contribute to short-term renewable electricity production. In 2017, Mayor Emanuel announced the City would commit to 100% renewable energy for all municipal buildings by 2025, amounting to 1.8 million MWh per year across all city-owned buildings, public schools, city colleges, and park districts.[61] We include a discounted 1.4 million MWh in our above estimates to ensure there is no double-counting between efforts made to reach the City's current target and future efforts to procure energy from power producers outside of the City. Otherwise, there would be a risk that not enough renewable electricity would be generated in aggregate. We thus assume a fair amount will be independently generated through rooftop solar, building retrofitting, energy efficiency improvements, and other independent construction, while the remaining amount will be part of the aggregate demand needed to be produced outside of City boundaries.

Third, the Illinois Future Energy Jobs Act (FEJA) passed in December 2016 will impose additional requirements on energy suppliers in Illinois, including ComEd.[62] Its provisions include a 25% Renewable Portfolio Standard (RPS) required by 2025 and certain energy efficiency targets.[63] Under the RPS, ComEd and other state suppliers are required to procure renewable energy through purchasing Renewable Energy Credits (RECs) across three subcategories, funded through a 2% cost cap on consumer electricity rates.[64] While the RPS mandate applies to *all sourcing*, meaning anywhere within the PJM territory, the act also requires 1300 MW of wind and 3000 MW of solar to be built within the state by by 2030.[65] Finally, the act also sets new energy efficiency targets, including 21.5% energy savings for ComEd by 2030.[66] To bring our model in-line with FEJA mandates, we assume that approximately 60% of the new statewide wind and solar generation will be constructed within PJM, reflecting the fact that the Illinois PJM region represents approximately 67.51% of Illinois total statewide generation.[67] This results in approximately 3,378,819,600 kWh per year in wind and

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[59] Authors calculations: (25,006,566,458 kWh per year in Chicago consumption / 132,878,541,924.02 kWh per year of Illinois PJM generation in 2016) = .1882 x 7,973,790,160 kWh per year of Illinois PJM wind generation in 2016 = 1,500,596,790.30 kWh in Illinois PJM wind generation approximately available for Chicago

[60] Authors calculations: (25,006,566,458 kWh per year in Chicago consumption / 132,878,541,924.02 kWh per year of Illinois PJM generation in 2016) = .1882 x 47,191,370.23 kWh per year of Illinois PJM solar generation in 2016 = 8,880,998.53 kWh in Illinois PJM solar generation approximately available for Chicago

[61] City of Chicago, Office of the Mayor, 2017.

[62] IL S.B. 2814

[63] Judd, Rebecca. 2018. "Overview of the Future Energy Jobs Act"

[64] The three subcategories include 1) utility-scale and brownfield energy projects, 2) general market community solar, and 3) low-income community solar.

[65] Ibid.

[66] Ibid.

[67] See Plant_Data

4,480,193,376 kWh per year in solar.[68] We then weight these amounts to determine the new capacity realistically available for Chicago, assuming the existence of competing contracts from other communities, yielding 635,893,848.72 kWh in wind and 843,172,393.36 kWh in solar, or an additional 1,479,066,242.08 total kWh per year.[69] In Figure 12, we also visualize the contribution from the RPS in terms of renewable generation. However, we choose to exclude the RPS in our direct calculations since this requirement will not exclusively apply to electricity generation within Illinois. Local job creation, for instance, is hard to predict from the Illinois RPS since qualifying new construction could occur in other states. Finally, the efficiency gains target is in-line with our estimated contribution from efficiency improvements, detailed in "Energy Efficiency."

Utility-Scale Wind & Solar: Long-Term Contribution

In our reference scenario, we assume wind and solar from Northeastern Illinois should supply approximately 16 million MWh per year by 2035.[70] Is this amount feasible? We examine historical and projected growth rates to understand this amount in context. Between 2006-2016, we find that after weighting for capacity factor, the state's "real" generation factors, and scaling to only the PJM territory in Illinois, wind grew by 680,591.23 MWh and solar grew by 4,125.88 MWh per year.[71] Figure 13 (next page) displays capacity growth across all of Illinois for by fuel type, demonstrating an especially clear increase for wind in recent years, while solar has yet to have significant investment.

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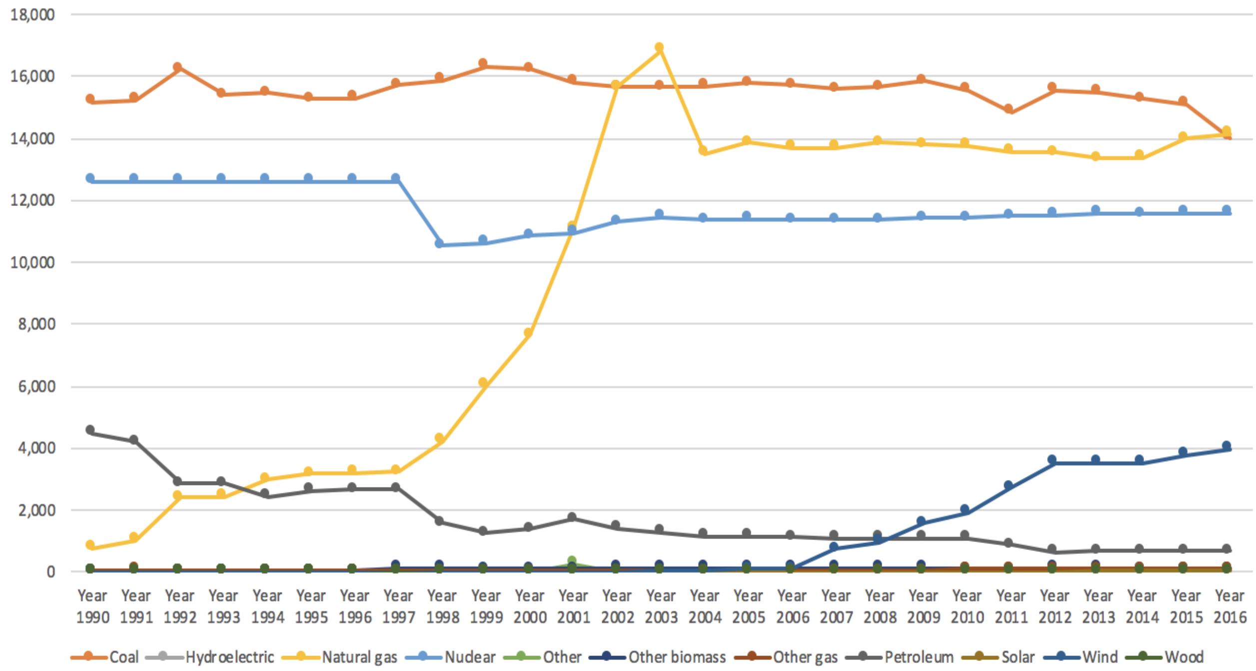
[68] Authors calculations: 1300 MW wind x 1000 x 24 hrs/day x 365 days/year x 1000 kW/MW x wind Capacity Factor x .86 real wind factor; 3000 MW solar x 1000 x 24 hrs/day x 365 days/year x 1000 kW/MW x solar Capacity Factor x .67 real solar factor

[69] Authors calculations: weight by (25,006,566,458 kWh per year in Chicago consumption / 132,878,541,924.02 kWh per year of Illinois PJM generation in 2016) = .1882

[70] This amount "fills the gap" between renewable energy projected to be available by 2025 and Chicago's estimated 2035 electricity consumption, subtracting projected energy efficiency gains and the installation of 55% of feasible rooftop solar

[71] EIA, 2018. Illinois Capacity 1990-2016. Scaled by .67, representing (Illinois PJM) / (Total Illinois) generation

Figure 13. Illinois Energy Capacity 1990-2016 by Fuel Type (MW)



Source: Constructed via Illinois EIA generation capacity data (MW) from 1990-2016.

However, these growth rates should not be taken on face, since new generation from FEJA will significantly alter future growth rates. FEJA will especially alter the growth rate of new solar generation, since solar development so far has been minimal compared to wind. Between 2016 and 2030, we estimate generation growth rates from FEJA exclusively will amount to approximately 241,344,257.14 additional kWh/yr in wind and 320,013,812.57 additional kWh/yr in solar each year within the Illinois PJM territory.[72] With these additional contributions, we estimate growth rates for the period with the FEJA target through 2030 to be the higher of the two growth rates for each energy type, specifically: for wind, we use the historical 680,591.23 additional MWh/yr rate for wind generation, and the new 320,013.81 additional MWh/yr rate for solar generation.

What generation is therefore feasible by 2035? Subject to new legislation and investment, our estimated generation growth rates would indicate that between 2020 and 2035, 16,009,680.64 additional MWh / yr could be constructed to meet Chicago's consumption in 2035.[73] For the purposes of our estimates, we assume that this new generation amount would be representative of plants constructed exclusively for the City of Chicago. This assumption allows us to estimate the impacts directly created by the City's projected future consumption. The additional generation required for surrounding communities within this 15 year window could represent only a moderate

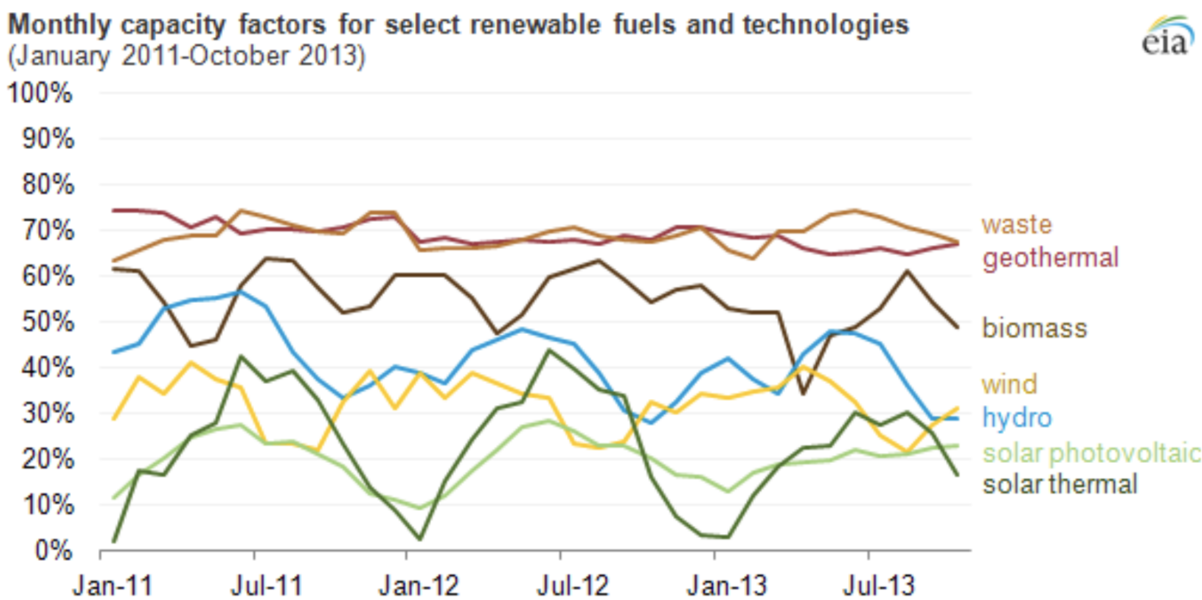
[72] 3,378,819,600 kWh/yr in wind and 4,480,193,376 kWh/yr in solar new capacity contributed from FEJA in IL-PJM / 14 years (2016-2030), assuming a linear growth trajectory

[73] (680,591.23 MWh/yr in wind + 320,013.81 MWh/yr in solar) x 16 years (2020 - 2035, inclusive)

increase from these rates, since suburban single-family homes and offices would more easily be able to generate their own energy through rooftop solar, though further study will be required to address the entire territory.

As noted earlier, the end necessity for solar or wind generation may be in reality be slightly higher, as we do not account for plant replacement needs or hourly and seasonal generation differences. The main challenge here is that capacity factors vary month-to-month from seasonal weather differences (see Figure 18). However, we believe our modelled generation construction creates a reasonable foundation for providing a minimum estimate of future employment and other impacts based on needed minimum production. Additionally, our prior assumptions in creating a challenging demand scenario creates inherent flexibility to help offset these other real-world impacts on generation. Finally, it should be noted that solar and wind capacity factors are inverse to each other—while wind capacity factors drop below their average in the summer, solar capacity factors rise above their average, as shown in Figure 18. The more even the mix, the less that seasonality may impact renewable generation. Battery storage and future technology may enable further mitigation of these issues and expand average plant lifespan.

Figure 14. Renewable Capacity Factors by Month, 2011-2013



Source: U.S. Energy Information Administration (EIA), Electric Power Monthly, Tables 6.7a and 6.7b, 2014. See "Monthly generator capacity factor data now available by fuel and technology" for results summary.

Energy Efficiency

As of 2018, we identified and included four major efficiency programs being implemented in Chicago: the Chicago Energy Benchmarking System, Retrofit Chicago, Energy Impact Illinois, and Energy Shared Savings. Chicago Solar Express, Community Weatherization Action Teams, and Energy Action Network are also needed and beneficial programs. Chicago Solar Express, for example, aims to expedite and support solar panel permitting.[74] Community Weatherization Action Teams worked to create weatherization kits for individual homes across the City.[75] Energy Action Network, a volunteer-based nonprofit, sponsors three sub initiatives: Low-Income Home Energy Assistance Program (LIHEAP), the Share the Warmth Program, and ComEd's Residential Special Hardship Fund.[76] All of these sub programs aim to provide assistance on paying electric bills for individuals facing financial hardship due to various reasons. However, we exclude these three particular programs in our estimates since they have a more indirect effect on real kWh/yr savings.

Chicago's Energy Benchmarking System aims to "raise awareness of energy performance through information and transparency, with the goal of unlocking energy and cost savings opportunities for businesses and residents".[77] As of 2016, the list of covered buildings includes all commercial, institutional, and residential buildings larger than 50,000 square feet.[78] Buildings that are enrolled in the benchmarking system receive an ENERGY STAR score based on a four-star rating system. Properties that have a star score of below three can earn an additional star if they have improved by at least 10 points in the past two reporting years.[79] Data from 2016 show that 3,523 properties are included in the benchmarking system. There are over 40 property types in the system. Most popular property types (based on the amount of energy they use) include office, multifamily housing, laboratory, and hotel.[80]

Retrofit Chicago targets buildings reducing their energy by 20%.[81] While significant progress has been made, only 76 buildings have so far benefitted from the Retrofit Chicago improvements.[82] The program deals with 4 different types: single family homeowners, buildings 2 to 4 residential units, buildings with 5 or more residential units, and renters.[83] On the program's website, the listed customer benefits are as follows: 1) Free energy assessments with free energy-saving products and installation 2) Rebates for energy efficient appliances and other products 3) Financing tools such as income qualifying grants for bungalow and vintage homeowners, energy savers loans, and on-bill

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[74] See the City's page on Chicago Solar Express

[75] See the Peggy Notebaert Nature Museum's coverage of "Chicago's Community Weatherization Action Teams"

[76] See the Chicago Climate Action Plan's page on Residential Programs

[77] See the 2017 Chicago Energy Benchmarking Report

[78] Ibid.

[79] Ibid.

[80] According to 2017 data from the Chicago Energy Benchmarking Reports

[81] See Retrofit Chicago's About page

[82] Ibid.

[83] Ibid.

financing 4) Connecting to qualified contractors.[84] Together, the combined efforts of Retrofit Chicago and the Chicago Energy Benchmarking have achieved estimated energy savings of $17.6 million per year so far.[85] It is important to remember that while the benchmarking program targets only large properties, Retrofit Chicago is open to a wider range of properties.

Energy Impact Illinois is designed for single-family homeowners, and helps individuals lower bills and improve the value of homes.[86] Based on 2005 prices, "the region's average household could save $550 per year in natural gas and electricity following a retrofit, while savings for a typical commercial account would be $6,400".[87] When adjusted for inflation, energy savings amount to $8258.6 for commercial buildings and $709.09 for households.[88] To calculate the total impact in Chicago of this program, we made some assumptions. First, we took the total number of households in Chicago (517,114)[89] and deducted the total number of multifamily housing properties included in benchmarking (1,339)[90] to find 515,775, the sum of small multifamily housing properties and single-family homes. While the ideal calculation would include weighting for distribution of small multifamily housing properties versus single-family homes, this data is not available. We thus multiply this total by the projected savings per average household ($709.09). This leads to the following calculation:

$$515{,}775 \text{ households} \times \$709.09/\text{household} = \$365{,}731{,}000$$

suggesting that efficiency improvements in small-properties could save the city over $365 million.

Finally, Energy Shared Savings encourages energy savings by individual schools in Chicago. Since 2010, the program has successfully motivated CPS schools to reduce energy consumption, creating an aggregate savings of $692,000. As "Schools who are able to reduce their facilities energy consumption by at least 5% earn $.04 per kWh of electricity and $.10 per therm of natural gas saved. Since 2010 CPS Schools have earned a total of $692,000"[91]

We believe that all the mentioned efficiency programs should be used and expanded upon to improve Chicago Energy Benchmarking. In order for buildings to have a higher energy star score, they should be taking advantage of Retrofit Chicago, Energy Impact Illinois, Energy Shared Savings, and possibly other programs to their fullest potential. We will talk more about the importance of this collaboration in the "Program Coordination" section. It is still worthy to note here that if the

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84 Ibid.
85 See the 2017 Chicago Energy Benchmarking Report
86 See CMAP's page on Energy Impact Illinois
87 Ibid.
88 Calculated from 2005 to 2018 via the CPI Inflation Calculator from the U.S. Bureau of Labor Statistics
89 Department of Energy (2018)
90 Retrieved from Chicago Energy Benchmarking Report's 2017 data
91 Chicago Public Schools, 2015.

Chicago Energy Benchmarking is extended to include smaller properties in addition to large properties, tracking the impacts of these efficiency programs could be much easier. This could also potentially make the citywide target setting processes for energy usage more realistic as the benchmarking data would be more comprehensive.

To calculate the potential total energy savings of Chicago Energy Benchmarking, we exported 2016 data from the benchmarking website for all the properties in the system with respect to 35 property types.[92] We obtained 35 different tables with all buildings for each type, alongside with their respective gross floor area (sq ft), energy star score out of 100, Source Energy Use Intensity (kBtu /sq ft), and other technical categories. The Benchmarking System is set up in such a way that for each property type, the national average for Source EUI corresponds to an energy star score of 50. First, we pulled out national Source EUI averages for each property type and created a new column for it in all our tables.[93] Then, we asked the following question: If each building in benchmarking met the national average for its own property type (or had an energy star score of at least 50) , how much energy savings would this generate? For each building, we took the difference between its Source EUI and the national average. We obtained a number in terms of kBtu /sq ft. A positive number means that the building is operating above the national average and there are some potential energy gains. A negative number means that the given building is already using up less energy than the national average. To get the number in energy units, we multiplied it by the gross floor area of the building, and obtained a result in kBtu. This number represented all energy types including natural gas and electricity. Since we are only interested in electricity outcomes, we needed an estimate for what fraction of energy usage went to electricity. We used data from EIA's "Energy Consumption Surveys" regarding percentage electricity end-use by property type and US census region.[94] For example, we could see from the data that approximately 56% of the energy usage of financial offices in the Midwest region goes to electricity. After repeating this process for all buildings in 35 different property types, we ended up with an estimate of energy savings in kWh per year. Figure 14 displays a summary of our results. This data will be available on file with the authors.

[92] Retrieved from Chicago Energy Benchmarking Report's 2017 data

[93] EnergyStar Portfolio Manager, 2018.

[94] EIA, 2018. All 2018 consumption surveys available here.

Figure 14. Potential Large-Property Energy Efficiency Savings

Property Type	Potential Energy Savings (million MWh/yr)
Office	1.364
Multifamily Housing	1.342
Laboratory	0.314
Hotel	0.269
Mixed Use Property	0.185
Supermarket	0.174
Hospital	0.172
Convention Center	0.129
Prison	0.127
K-12 School	0.107
Retail Store	0.106
Financial Office	0.099
College	0.089
Performing Arts + Museum+ Movies	0.087
Ambulatory Surgical Center	0.078
Medical Office	0.076
Enclosed Mall	0.066
Worship Facility	0.062
Wholesale Club	0.061
Residence Hall	0.034
Strip Mall + Lifestyle Center	0.015
Other - Mall	0.014
Social Meeting Hall	0.011
Senior Care Community	0.008
Library	0.008
Outpatient Rehabilitation	0.008
Other - Public Services	0.006
Other - Education	0.005
Other - Lodging	0.005
Automobile Dealership	0.003
Residential Care Facility	0.003
Adult Education	0.002
Urgent Care	0.002
Courthouse	0.001
Bank Branch	0.001
Total	**5.031**

We can see that the total potential energy savings is 5,031,169,742 kWh per year. The top 5 types that Chicago would be saving energy from are Office, Multifamily Housing, Laboratory, Hotel, and Mixed Use Property. This total represents approximately 20% of current electricity consumption of Chicago. When multiplied by the average electricity price in the Chicago area, total potential energy savings in dollars is $794,924,819.2 per year.[95] It is useful to remind that in our calculations, we did not assume that all buildings meet the national average for Source EUI. We simply assumed that buildings operating above average lowered their energy consumption to the national average, and other buildings maintained their previous consumption levels. Second, we vary participation rates in improving EUI, assuming 85% participation for larger-properties in the 2035 reference scenario (Figure 12). While 85% participation may seem high on face, this does not necessarily mean that 100% of all large-properties will need to meet this target, as some may likely exceed the national average for their property type to make up the difference. Moreover, we do not even include energy savings from small-properties, as more public data would be needed.

[95] Bureau of Labor Statistics, 2018b; authors calculations: [5,031,169,742 kWh /yr x US$ .158 / kWh]

Rooftop and Community Solar
We estimate private solar generation contributions by combining modeled solar potential with participation rate scenarios. Private solar generation encompasses community solar, rooftop solar, and distributed generation solar: terms to describe any private individual or group of individuals installing photovoltaic solar cells on or near their property. This includes community cooperatives and microgrids, such as the ComEd-backed Bronzeville microgrid, one of the first in the U.S.[96] This also includes potnetial for community Solar Garden programs.[97]

Existing estimates vary for Chicago's local solar potential. For this report, two online datatools, Google's Project Sunroof and the Department of Energy's State and Local Energy Data (SLED), are averaged to arrive at 4,999,749,500 kWh per year.[98] Both models use Chicago roof area, though differ in other data sources and model parameters. Google's Project Sunroof, for example, combines local weather data, average efficiency factors for a typical solar panel, and machine-learning analytics to identify suitable roof area with geospatial data.[99] While advanced, these tools both give estimates on *potential* total solar capacity, notwithstanding actual construction by private individuals and companies. In our reference scenario (Figure 12), we assume a 55% participation rate - i.e. 55% of roofs suitable for solar construct their given capacity. While seemingly generous, we 1) believe prior City and State incentive programs, in addition to FEJA, will serve to accelerate private installation and 2) extra capacity will be created from non-rooftop solar installations, such as microgrids or similar projects.

Private participation is vital to ensuring Chicago can commit to 100% renewable energy, especially in Heating & Cooling (to reduce or eliminate natural gas) and Transportation (to reduce or eliminate gasoline and diesel fuels). While electricity is less dependent on individual investment in the long-run, private individuals reducing energy consumption and installing their own generation will be essential to hit the 2035 target. For alternative timelines and lower participation rate scenarios, please see our attached data files.

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96 BusinessWire, 2018.

97 For more information on community solar gardens, see the CUB's fact sheet.

98 Project Sunroof (2018) estimates 6,700,000,000 kWh/yr, while Department of Energy (2018) estimates 3,299,499,000 kWh/yr.

99 Ibid.

4.2 Employment

While a transition to 100% renewable energy may be feasible within the next 15 years, will it be economically beneficial? And for whom? This section and Section 4.3 describe the methodology used to quantify the potential economic benefits listed in "A 100% Chicago: By the Numbers," while also considering those who may directly lose from such a transition. All estimates are based on the reference scenario presented in Figure 12, assuming a full transition to 100% renewable energy mid-range private participation by 2035.

Utility-Scale Wind - Construction

As modelled in the reference scenario, 16 million additional MWh per year is needed by 2035, approximately 10.821 million of which will come from wind.[100] This proportion converts to roughly 3,600 MW capacity of additional wind, slightly more than double of PJM-IL current wind capacity.[101] Two methods are used to estimate construction employment from the creation of this onshore wind capacity. First, 3,600 MW is run in the National Renewable Energy Lab's JEDI model for Onshore Wind. The JEDI model uses a combination of economic multipliers, state-specific consumption patterns, default plant costs, and wage averages to convert MW capacity to total cost, jobs, economic output, and other economic variables.[102] We use the model defaults and Illinois state multipliers in the year 2020, the earliest possible year construction benefits may be realized. Our second method uses green energy economic multipliers identified by Wei, Patadi, and Kammen (2010). Their paper analyzes and averages 15 other studies of the relationship between green energy generation, employment, and other economic impact, in terms of jobs / MWp, meaning jobs per average MW installed.[103] The average between the two models results in 1,282 FTE (full-time equivalent) fifteen-year jobs over the construction period.

Utility-Scale Wind - Operations and Maintenance

We use the above method for indirect jobs, mostly from operation, with some from either management or other indirectly-induced jobs. We calculate the average as 618 FTE (full-time equivalent) jobs for the remainder of the plants' operational lives, likely lasting beyond the 2020-2035 time frame.

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[100] Since wind is projected to grow at twice the rate as solar, we estimate approximately 10.821 MWh of 15.9 million MWh/yr will source from wind [680,591.23 MWh/yr *15.9 years]

[101] To achieve a conversion to MW, 15.9 million MWh per year is divided by (24 hours x 365 days x .34 average wind Capacity Factor x .86 "real" wind generation weighting); Plant_Data, 2016: 3,603.15 MW nample capacity.

[102] NREL: National Renewable Energy Lab, 2018b

[103] See Wei, Patadi, and Kammen (2010) Table 2, Comparison of jobs/MWp, jobs/MWa and person-years/GWh across technologies.

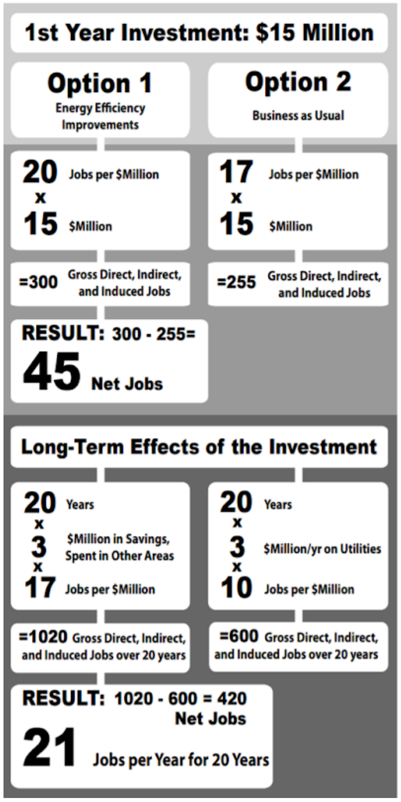
Utility-Scale Solar - Construction

As modelled in the reference scenario, the remaining 5.120 million MWh translates to roughly 2300 MW in solar generation.[104] We run 2300 MW with the JEDI model for concentrated solar and average with Wei, Patadi, and Kammen (2010) across both photovoltaic and thermal solar CIM job multipliers to find 3,208 FTE (full-time equivalent) twenty-year jobs over the construction period.

Utility-Scale Solar - Operation and Maintenance

We use the above method for indirect jobs, mostly from operation, with some from either management or other indirectly-induced jobs. The average between JEDI run and Wei et al (2010) suggests 982 FTE jobs during the plant(s) lifetime, likely lasting beyond the 2020-2035 time frame.

Efficiency Programs - Installation
(Figure 16. $15 Million for Energy Efficiency Improvements)



The challenge for estimating efficiency jobs created through improvements Chicago Energy Benchmarked large properties is that required City investment is unclear. To obtain the net job number without an initial investment value at hand, we used an example case that based its job projections on methods from the American Council for an Energy-Efficient Economy (ACEEE).[105] The case is based on the New York City Greener, Greater Buildings Plan. "The New York Greener, Greater Buildings Plan was enacted in 2009. Four local laws require, among other actions, annual benchmarking of building energy performance and retro-commissioning. A number of firms have employed energy analysts to help meet compliance and the subsequent demand for interpreting benchmarking metrics and applying the information to investment decisions. New York City estimates that the laws will generate $700 million in savings and support roughly 17,800 construction jobs over 10 years. These reported numbers are likely gross effects, but the employment returns to efficiency should be sufficient to promote net job creation" (ACEEE/Real World Examples). Since this example states that the predicted energy savings is $700 million for the Greater Buildings Plan, and it uses ACEEE's method to calculate net jobs (construction jobs), it is a comparable case to ours. When we take the ratio in this example and apply it to $794,924,819.2 (total potential energy savings for benchmarking), and adjust the result from New York's population to Chicago's population and applying the 85% participation rate, we find that 3,220 construction jobs could potentially be created over the next 10 years.

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[104] To achieve a conversion to MW, the number of megawatt-hours needed per year is divided by (1000 MWh/kWh x 24 hours/day x 365 days/yr x average solar Capacity Factor of .25 x "real" solar factor of .67)
[105] Per an ACEEE fact sheet on "How Does Energy Efficiency Create Jobs?"

Efficiency Programs - Indirect

To be able to understand the impact of $794,924,819.2 of energy savings on job creation in Chicago we turned to the ACEEE report,[106] which uses the following methods: On average, $1 million spent in the US economy supports approximately 17 total jobs (including direct and indirect), but this ratio varies by industry; in energy, $1 million of spending only supports 10 jobs Therefore, $1 million saved in energy expenditures and spent elsewhere will sustain 17 - 10 = 7 net jobs. Using our projected $795 million saved per year in energy expenses, we can calculate

$$\$795\text{m/yr} \times 7 \text{ net jobs} / \$1\text{m} = 5565 \text{ net jobs} / \text{yr}$$

sustained, assuming that the money saved from energy efficiency is spent into the general economy. Applying our participation rate, we estimate approximately 4,729 jobs will be created.

Rooftop & Community Solar - Installation

To estimate job creation from solar panel installation, we first use Average Installer Efficiency provided by the National Solar Jobs Census.[107] We then cross-reference these rates with 1) feasible solar installation area from Google's Project Sunroof[108] and 2) proportion of total roof area by building type in Chicago made available by the SLED data calculator.[109] In the City of Chicago, residential feasible solar rooftop area comprises about 72%, while Commercial/Industrial is approximately 28%. An average between Google Sunroof and SLED capacity estimate for Chicago gives 4,287.5 MW. Weighting for a 55% participation rate in the 2035 reference scenario, we have

$$\underbrace{(4{,}287.5\text{MW} \times .72 \times 4.82 \text{ jobs/MW})}_{\textbf{(residential)}} + \underbrace{(4{,}287.5\text{MW} \times .28 \times 3.06 \text{ jobs/MW})}_{\textbf{(commercial)}} = 14{,}840 \text{ total jobs}$$

When applied to the construction period, we create approximately 638 jobs if installed by 2035.

Rooftop & Community Solar - Operations, Sales, and Management

To estimate indirect jobs created by solar installation, we estimate the average indirect jobs created per solar installer using tables provided in the National Solar Jobs Census.[110] Specifically, we estimate that for every installation job created per year, 1.8 jobs are created across operations, sales, and management that are also likely to be local. When using the reference scenario and a 2035 target date solar installation, Chicago would generate approximately 1148 sustained jobs over the installation period, and likely thereafter.

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[106] ACEE, 2011.

[107] The Solar Foundation, 2017. P. 26: Residential = 4.82 jobs/MW solar installed, Commercial = 3.06 jobs/MW solar installed, Utility-Scale = 2.42 jobs/MW solar installed.

[108] Project Sunroof, 2018.

[109] Department of Energy, 2018: SLED,

[110] The Solar Foundation (2017, 15). We add 20.1% for Administrative, 12.6% for Management, 26.5% for Sales, and 4.3% for Other, and proportion to the Installer 35.2% labor-share of the Installation value-chain.

Nuclear Job Loss

The impact from Chicago transitioning to 100% renewable energy on nuclear generation in Illinois is difficult to estimate, given that they transact through the PJM Interconnection. Because Chicago sources energy on a open and competitive energy market, Chicago becoming 100% renewable does not necessarily entail *any job loss*. Nuclear plants can still export to PJM, even if Chicago only purchases renewable energy. However, it reasonable that the decrease in demand for existing energy overall may increase the financial pressure on already struggling nuclear plants in Illinois.

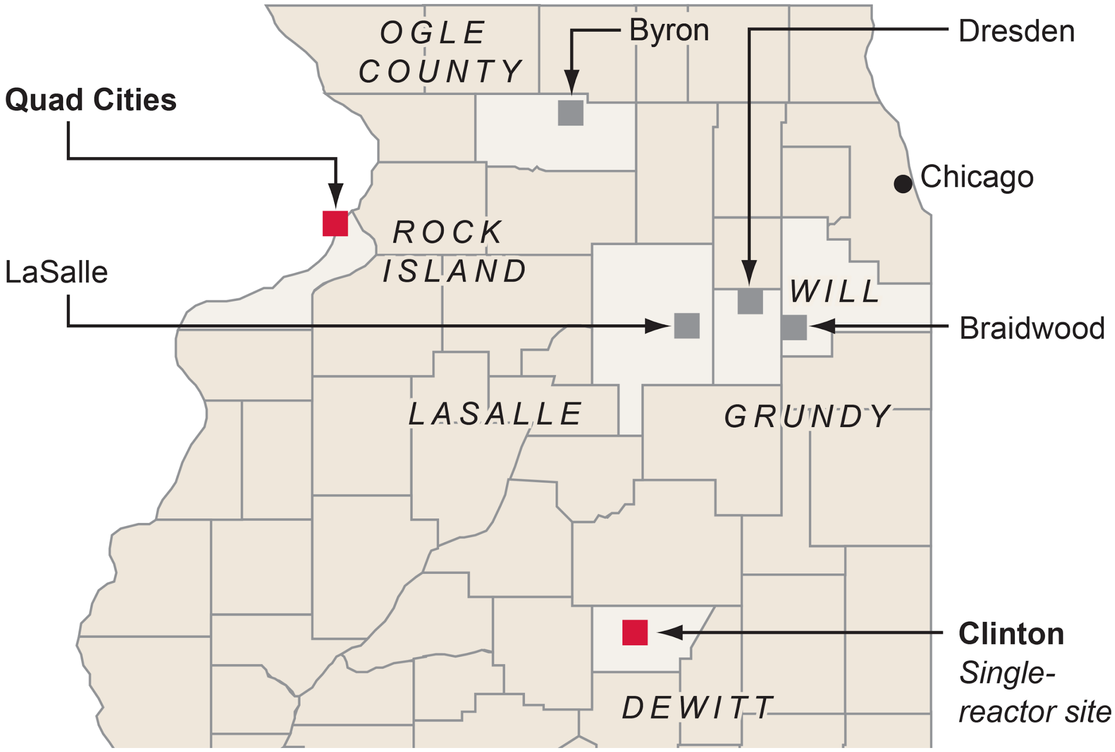
In response to the risk of early plant closures, a report was prepared for the Illinois General Assembly by the Illinois Commerce Commission (ICC), Illinois Power Agency (IPA), Illinois Environmental Protection Agency (IEPA), and Illinois Department of Commerce and Economic Opportunity (DCEO), concerning the various impacts[111]. The DCEO reported on the employment and economic impact of the early closure of three Illinois plants – Byron (PJM), Quad Cities (PJM) and Clinton (MISO). These plants combined represent 45% of Illinois nuclear capacity.[112][113] While they are no longer at immediate risk of early closure, the loss of Chicago demand could put them in a similar position yet again. Understanding this potential economic loss from nuclear generation is essential to developing policy for expansion in clean energy.

The DCEO report found that the early closure of the Byron, Clinton and Quad Cities plants would have "significant negative economic impact", including 2,500 direct job losses at nuclear plants, 4,431 indirect job losses, $1.8 billion in annual lost economic activity and a 10-16% increase in wholesale power prices.[114] Yet, the report was also optimistic that economic losses can be mitigated. Investments in energy efficiency and renewables were estimated to create 9,600 new jobs by 2019, and $120 million in annual energy cost savings.[115]

To determine potential nuclear job loss, we scale these numbers to any possible reduction in demand from Chicago sourcing exclusively renewable energy. We find that nuclear job loss would approximately amount to 1,177 total jobs.[116] However, it should be noted that none of these jobs are even located near the City, as the majority of nuclear plants in Illinois are further down-state (see Figure 17).

[111] ICC et al, 2015.
[112] PlantData_Zarek
[113] See Appendix D of ICC et al, 2015: "MISO & PJM Nuclear Facility Summer Rated Capacity."
[114] ICC et al, 2015.
[115] Ibid.
[116] Authors calculations: 6,931 jobs x (Chicago Consumption in kWh/yr / IL-PJM generation in kWh/yr)

Figure 17. Nuclear Plants in Illinois



Source: Exelon; graphic published by [*The Chicago Tribune*, June 2016]. Red plants refer to closures considered before the passage of the Future Energy Jobs Act (FEJA).

Fossil Fuel Job Loss

We estimate the job loss from traditional fossil-fuel power plants in the Chicago metropolitan area by the potential decline in demand resulting from Chicago switching to 100% renewable energy sources. As stated previously, because Chicago sources energy on a open and competitive energy market, Chicago becoming 100% renewable does not necessarily entail *any job loss*. Rather, job loss from the fossil fuel industry in Illinois would likely be more due to any national decline in fossil-fuel energy demand, especially since Illinois is a major energy exporter as mentioned previously. Since Chicago only consumes 19.76% of the Illinois PJM territory's total generation when weighted for the state's real generation factor, we assume a maximum of 20% decline in demand for fossil fuel energy in the region directly attributable to the City of Chicago.[117] As of May 2017, there were 440 total power plant operators in the Chicago-Naperville-Arlington Heights metropolitan region.[118] Generously assuming all current power plant operators are fossil-fuel related, we estimate a local job loss of 440*.2 = 88 operators. By yet a different measure, we subtract potential current nuclear (62%, accounted for above) and wind (6.3%) mix proportions in Illinois PJM, and estimate 139.40 fossil-fuel-related jobs. We use this higher number in "A 100% Renewable Chicago: By the Numbers."

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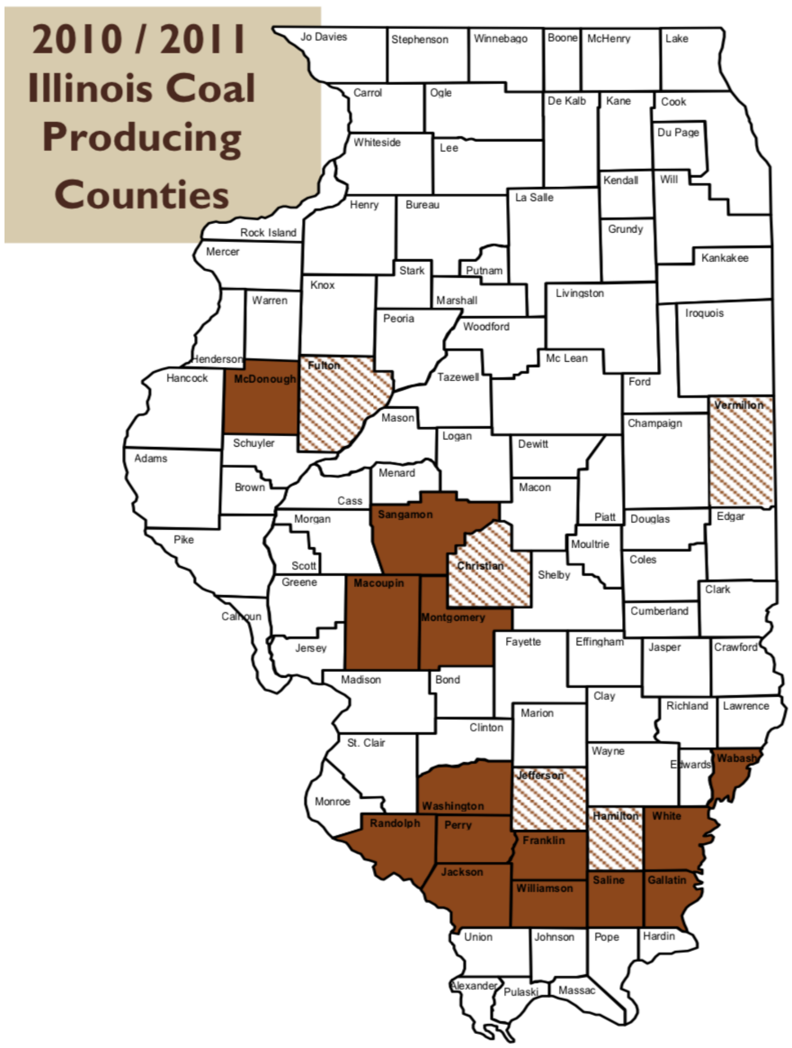
117 Plant Data.

118 Bureau of Labor Statistics, 2018a.

A reasonable objection to these figures would be that they fail to include supply-chain sourcing. Yet we find that in Illinois, jobs related to coal mining have already decreased significantly, independent of a 100% renewable transition in Chicago. Between 2015 and 2016, the coal-mining industry in Illinois lost over 1,200 jobs, leaving only 2,800 jobs in the entire state.[119] Moreover, while coal-mining may provide good jobs to communities with few other high-paying opportunities, most of these communities are in the southern part of Illinois, outside of PJM territory (see Figure 18). Chicago's impact on state coal-mining would thus likely be negligible.

Figure 18: Coal-Mining in Illinois, by County



Source: Illinois Department of Commerce and Economic Opportunity, 2012. "The Illinois Coal Industry." P. 3.

[119] Keilman, John. 2016.

4.3 Savings, Earnings, and Economic Output

Savings from Energy

Estimated savings in energy costs are presented in Table 4. With the exception of bill savings, calculation methodologies for these respective figures are relatively simple. Additional information is provided in the Table's third column.

Table 4. Estimated Savings in Energy Costs

Source of Savings	Savings	Methods and Calculations
Energy Bill Savings	$147,226,433	See below
Solar Installations	$42,661,905	$3,000 avg. savings @ 55% participation for Chicago homeowners.[120]
Energy Efficiency (Benchmarked Large Properties)	$238,170,807	kWh Efficiency Gains x electricity price average per property type[121]
Energy Efficiency (Small Properties)	$311,134,306	Average efficiency savings of $550 per Chicago area household, adjusted for inflation x number of non-large property residential units.[122]
Airport Efficiency Improvements (O'Hare + Midway)	$1,509,000	Projected[123]
Total	**$1,182,812,242**	--

[120] Project Sunroof, 2018. Average household savings estimated for the South Side of Chicago, 60615. Retrieved on 25 Aug 2018.
[121] Actual electricity prices are often higher than the $.06-.07 cents estimated by ComEd. See the Bureau of Labor Statistics "Average Energy Prices, Chicago-Naperville-Elgin" for estimated current real price per household. Our calculation uses Electricity Local's price estimates by property type. See Bencharmking_Savings_Estimates.
[122] CMAP, 2013: $550 in 2005 dollars = $709.69 x number of non-larger residential buildings (515,775). While $550 per urban Chicago household is likely a high-estimate more suited to the metropolitan area (i.e. suburbs), our calculation is likely a significant *underestimate* since we use the number of buildings rather than individual households, maintaining a conservative approach.
[123] See the Chicago Department of Aviation's page on Energy Management

Determining energy bills savings is complex. While other models estimate Chicago energy bills may actually increase under a 100% renewable mix that build real electricity costs from the ground up,[124] we use more recent but simplified cost estimates available from the EIA[125] to create a model of future energy bill costs for Chicago residents. As shown in Table 5, energy costs are projected to decrease for several fuel-types, though will decrease at different rates. We compare Chicago's current generation mix and future renewable mix between estimates for levelized costs of energy in 2022 and 2040. Levelized cost of energy includes a variety of generation price determinants, including initial "capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type."[126] LCOE thus represents long-term costs based on the construction of future plants and the necessary replacement or upgrades of extant power plants.

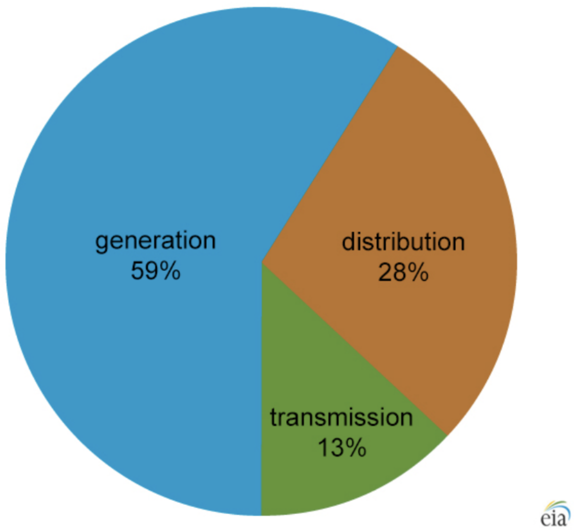
Table 5. Proportional Generation Cost, 2022 vs. 2040

Average LCOE for New Generation	2022 ($/MWh)	2040 ($/MWh)	Per. Change	IL-PJM Current Mix (2016)	IL-PJM Renew. Mix (2050)	2040 Cost Difference (Current Mix)	2040 Cost Difference (Renewable Mix)
Coal with 30% CCS3	130.1	113.6	-13%	9.70%	0.00%	-0.012302075	0
Coal with 90% CCS3	119.1	102.4	-14%	9.70%	0.00%	-0.013601175	0
Covential CC	50.1	53.6	7%	2.33%	0.00%	0.001630073	0
Advanced CC	49	51.7	6%	2.33%	0.00%	0.001285714	0
Advanced CC with CCS	74.9	75.9	1%	2.33%	0.00%	0.000311526	0
Convntional CT	98.7	100.8	2%	2.15%	0.00%	0.000457447	0
Advanced CT	98.7	84.7	-14%	2.15%	0.00%	-0.003049645	0
Adanced Nuclear	92.6	78.1	-16%	62.00%	0.00%	-0.097084233	0
Geothermal	44.6	47.9	7%	0.00%	0.00%	0	0
Biomass	95.3	84.8	-11%	0.00%	0.00%	0	0
Wind, Onshore	59.1	49.7	-16%	6.30%	80.00%	-0.010020305	-0.127241963
Wind, Offshore	138	110.4	-20%	0.00%	0.00%	0	0
Solar PV	63.2	52.1	-18%	0.00%	20.00%	0	-0.035126582
Total	-	-	-	100%	100%	**-13.24%**	**-16.24%**

Our results indicate that while electricity generation costs will decrease by 13.24% by 2040, all-renewable generation cost will slightly outpace traditional sources at -16.24% by 2040. However, generation costs alone do not makeup the total cost for the end consumer. Figure 19 demonstrates the average proportion of generation, transmission, and other fees passed on to consumer.

[124] The Solutions Project, 2018.
[125] EIA, 2018e.
[126] Ibid.

Figure 19. "Major Components of U.S. Average Price of Electricity, 2017"



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2018*, February 2018, Reference case, Table 8: Electrical supply, disposition, prices, and emissions

To estimate savings from renewable energy, we first total 2013 electricity consumption from the SLED database with price estimates by property type.[127] We assume the 16.24% reduction contribution from renewable energy in reducing generation costs by 2040, and apply the contribution to the 59% generation share of average electricity costs. We thus find that a renewable energy mix will generate energy bill savings of 9.58% on average, or $147,226,432.61 in aggregate savings per year in terms of 2040 cost estimates.[128] The contribution alone from renewables represents 1.77% reduction compared to our current mix, or $27,201,543 reduction.[129] Again, these calculations represent conservative estimates. However, forthcoming technological improvements in wind plants, for example, have been projected to reduce current LCOE estimates in wind generation by up to 50%.[130] It is also important to remember these electricity price reductions exclude the savings from energy efficiency improvements or rooftop solar installations.

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[127] Department of Energy, 2018; Electricity Local, 2018: we estimate $1,536,810,361.30 by multiplying SLED consumption with Electricity Local prices.

[128] Authors calculations: $1,536,810,361.30 x .0958

[129] Authors calculations: (.1624 - .1324) x .59 generation share x $1,536,810,361.30

[130] Dykes et al, 2017.

Earnings and Economic Output

In general, this paper uses two methods to calculate earnings and long-term economic output. First, earnings and economic output directly from the NREL JEDI models are used when available, mainly for utility-scale wind and utility-scale solar.[131] For other employment, including solar installation, operations and induced solar installation, and fossil fuel employment, earnings are calculated by using Bureau of Labor Statistics average wages,[132] and then scaled by a standard economic multiplier to determine earnings-based economic output.[133] An exception to this general rule is our included nuclear estimates, which cite a multi-agency state analysis for earnings and output loss estimates.[134] Final economic output is aggregated from both earnings-based output from new employment income, and savings-based output from energy-cost reduction income.

4.4 Emissions Reductions

Emissions data is drawn from the Department of Energy's "State and Local Energy Data" (SLED) tool. The City of Chicago currently emits 15,565,719 metric tons from electricity consumption, 9,839,523 metric tons from natural gas, and 7,473,365 metric tons from gasoline and diesel transportation emissions of CO_2 equivalent greenhouse gases (GHG).[135] While these amounts represent the total feasible emissions reduction for the City of Chicago, natural gas and transportation both require private participation. We thus assume a 20% total reduction in natural gas emissions from efficiency improvements and some electric retroffing, and a 50% total reduction in ground transportation emissions, across private vehicles, CTA, and Metra vehicle replacement. We therefore estimate 21,270,305.86 metric tons of emissions reductions is feasible by 2035 with current, known technology. Figure 20 displays conversions to trees, vehicle-miles-driven, and other real-world equivalents to contextualize this amount (next page).

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131 See here for utility-scale wind and here for utility-scale solar.

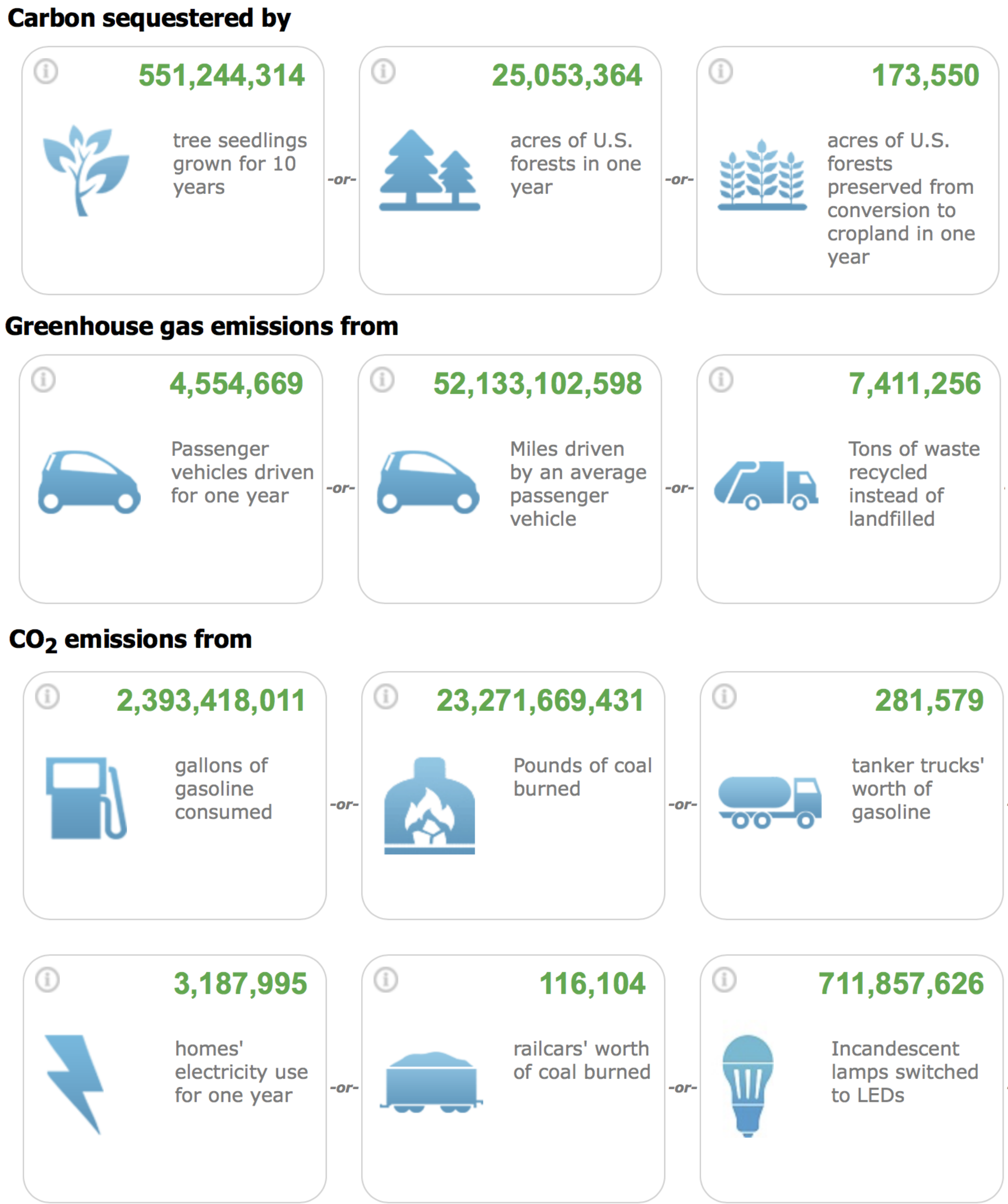
132 See Bureau of Labor Statistics, 2018a, for example.

133 Watkins. See a list of urban economic multipliers here. We use a highly conservative 1.5x new economic income multiplier as compared to historical averages for other urban centers.

134 ICC et al, 2015.

135 Department of Energy, 2018.

Figure 20. Chicago Emissions Reduction Equivalents



Source: EPA, 2017b.

4.5 Construction & Operation Costs

Summing the total cost of a 100% renewable energy transition would both be difficult and misleading, as a large proportion would be voluntarily contributed by homeowners, landlords, businesses, and other privator actors. The City also has a fair amount of autonomy in deciding how many dollars to contribute, as most direct local funding would theoretically support incentive programs for rooftop solar, energy efficiency improvements, and eventual private heating (natural gas) and transportation fuel-switching. Finally, total public costs incurred to governments would be also distributed across local, state, and even federal funding in most cases. Private grants could also further help cover these costs.

With these qualifications in mind, we estimate utility-scale renewable generation construction would cost approximately $22.9 billion. This comprises $6.096 billion for 3600 MW nameplate capacity in wind turbines construction and $14.514 billion for 2300 MW nameplate capacity for concentrated utility-scale solar construction.[136] As included in the NREL's JEDI models, these costs are inclusive of construction materials, supporting infrastructure, labor, engineering, and permitting costs.[137] As stated earlier, necessary plant replacements and seasonal generation variation may require more capacity to be built, making for a higher total cost. The financing structure used to fund these projects may also significantly affect these estimates. However, as previously cited in this report, levelized cost of energy (LCOE) for renewable energy continues to decrease overtime, with wind projected to decrease by as much as 50% as forwarded by one study.[138] Therefore these costs should not be taken on face, but rather as a very general context for estimating a component of the transition's potential cost.

4.6 Case Studies: Other 100% Renewable Countries and Cities

Over 80 cities across the U.S. have already committed to 100% renewable energy, including Atlanta, GA, Milwaukee, WI, St. Louis, MO, and San Diego, CA.[139] Seattle, WA currently sources 90% renewable electricity, primarily through their municipal utility which became carbon neutral as of 2005.[140] The City of San Francisco revised its energy target to 50% renewable by 2020 as of 2017, on-track to reach its 100% renewable energy commitment by 2030.[141] While these cities can serve as both a model and a motivation for Chicago to transition to 100% renewable energy, entire countries

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136 NREL: National Renewable Energy Lab, 2018a, using JEDI model "Total Installed Project Cost"

137 Ibid.

138 Dykes et al, 2017.

139 See the Sierra Club's "2018 Case Study Report."

140 Seattle City Light, 2018.

141 San Francisco Department of the Environment, 2018; *San Francisco Chronicle,* "SF's green energy goal is a decade ahead of target," 2017.

have already successfully switched or plan to switch to entirely renewable sourcing. To serve as a supplement to the Sierra Club's "2018 Case Study Report" examining major U.S. cities, we present a few examples of the progress in other countries to showcase how achieving 100% renewable energy at a scale even larger than Chicago is possible.

Denmark

Denmark is a world leading country in wind energy production. In 2016, 61.6% of its net electricity generation came from renewables, 44.2% of which from wind.[142] It has set goals to reach meet 30% of its energy needs with renewables by 2020, and 100% by 2050. Ahead of schedule, 29.2% of Denmark's gross final consumption of energy came from renewables in 2014. Given its geography, Denmark has a high potential for wind energy, and has been leading its development since the 1890s.

Denmark's ambitious renewable energy goals and early success with wind power make it a valuable case study for renewable energy transitioning. Its capital city, Copenhagen, has pledged to become the world's first carbon-neutral city by 2025. In fact, the country itself, with a population of 5.7 million, 88% living in urban settlement, and an area only twice that of the Chicagoland area, it is not dissimilar to Chicago.

National policies are important to recognize given the small size of Denmark, even though they are not all feasible on or applicable to the municipal level. From the mid-70s to the mid-90s, Denmark's strategies for wind energy promotion included:[143]

- Long-term government support for R&D
- National testing and certification of turbines
- Feed-in tariffs
- Investment subsidies

Denmark's culture and policies promoted co-operative ownership of wind turbines; 23% of Denmark's wind capacity was owned by 100,000 members in 2004.

The city of Copenhagen has a large focus on low-carbon transport, including dedicated bike lanes and a sharing system.[144] They have also increased the proportion of cars running on electricity, biofuels or hydrogen to 64%, and is replacing diesel buses with carbon-neutral alternatives.[145] 98% of city heating is provided by energy efficient district heating.[146]

142 Energinet, 2017.
143 Meyer, 2004.
144 See Berger, John. 2017: "Copenhagen, Striving To Be Carbon Neutral: The Economic Payoffs."
145 Ibid.
146 Ibid.

Germany

Germany has taken large steps towards increasing renewable generation, committing to 80% renewable energy by 2050, and phasing out nuclear generation entirely.[147] Its *energiewende*, or energy transition, is important to consider for Illinois, as they both rely heavily on nuclear and coal.[148] Currently, it has achieved 27% renewable energy,[149] and decreased nuclear generation from ~25% in 2011 to 12% in 2016. This generation has largely been replaced with wind and solar generation.

Importantly, this large-scale energy transition maintains impressive public support – 92% in 2015.[150] Germany involves its citizens directly in the transition by allowing them to profit from selling their energy to the grid.[151] The transition away from nuclear and fossil fuels has created an estimated 334,000 jobs in the renewables sector by 2016.[152] All other energy sectors combined only employ 182,000.[153] While Germany is not as renewable on a percentage basis compared to other countries listed here, the required scale, proven economic benefits, and high public approval standout as other key metrics in evaluating 100% renewable sourcing, and suggest that Chicago could enjoy the same benefits.

Portugal

Portugal was able to generate enough renewable electricity in March of this year to meet the entire country's demand for a brief period.[154] This in part due work achieved in pursuit of both the country's and the EU's renewable energy targets. "Europe 2020 strategy", as stated in the EU legislation in 2009, is a commitment to achieving a 20% reduction in greenhouse gas emissions from 1990 levels. In the legislation, there was an obligation to set national targets for increasing the share of countries' total energy consumption accounted for by renewable energy. In Portugal's case, the country's 2020 target was set at 31%, yet renewable energy sources accounted for nearly 103% of electricity produced in Portugal in March 2018, producing more renewable energy than the country could consume.[155] This momentary success is primarily a result of Portugal's aggressive efforts to meet its environmental commitments since exiting the bailout program in 2014.

Furthermore, Portugal plans to build additional capacity to ensure this milestone can be met regularly. In February 2018, the government extended the area in which it is constructing a new offshore wind farm. If this plan is successful, it "has the potential to generate €254 million in investment, €280 million in gross added value, €119 million to the balance of trade and 1,500 new

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147 Kunzig, 2015.
148 World Nuclear Association, 2018.
149 Kunzig, 2015.
150 Ibid.
151 Ibid.
152 See *The German Energiewende Book*'s "Will the Energiewende kill jobs?"
153 Ibid.
154 See NPR's "In March, Portugal Made More Than Enough Renewable Energy To Power The Whole Country"
155 See NPR's "In March, Portugal Made More Than Enough Renewable Energy To Power The Whole Country"

jobs".[156] Moreover, in its efforts to increase renewable energy usage, Portugal decided to suspend subsidies amounting to €20 million a year for fossil fuel producers. Renewable electricity usage oscillated between 86% and 143% in terms of daily share of consumption in the past months. Hydro and wind power each took up about 50% of the monthly consumption. The total production of renewables in Portugal in March avoided the emission of 1.8 million tons of carbon dioxide. The high share of renewables decreased the average daily wholesale market price (39.75 €/MWh).[157]

Portugal's ability to generate such a high volume of electricity suggests 100% renewable sourcing is possible on a large scale. Like Chicago, Portugal has no natural advantage for procuring renewable energy. For instance, while Norway and Iceland have both been functionally producing enough renewable energy to qualify as 100% renewable for years.[158] Yet their generation primarily sources from geothermal and hydroelectric power, mostly due to their unique natural resources. Portugal's ability to generate such a large amount of renewable energy without such resource advantages is a testament to the feasibility for their success to replicated elsewhere.

V. Other Key Findings

Regulatory Framework for Sourcing Illinois PJM Energy

A key insight of this paper is highlighting that 1) the region surrounding Chicago has proportionally higher wind generation than the multi-state PJM territory and 2) maintaining growth rates of renewable electricity within this region will easily create enough generative capacity for the City by 2050 alone, without other efficiency or private contribution. It therefore may be advantageous to focus on procuring energy from this smaller local region. Additionally, the economic benefits calculated in this report derive from construction and generation that we assume is conducted within the PJM region surrounding Chicago. In order to realize these benefits fully, policymakers should consider ways to ensure this investment is concentrated close to home.

Should energy markets in Illinois remain deregulated, municipal electricity aggregation may be the option requiring the least legal and regulatory changes to guarantee direct delivery of this locally sourced renewable electricity. Under HB 0722 (2009), Public Act 96-0176 amended the Illinois Power Agency Act to allow for aggregation of electrical load by municipalities and counties beginning in 2010.[159] With municipal aggregation in Illinois, cities are allowed to create contracts with Alternative Retail Energy Suppliers (ARES) on behalf of their citizens, in hopes of achieving lower rates and other public preferences.[160] Chicago previously pursued municipal aggregation in

[156] Ibid.
[157] Ibid.
[158] Ibid.
[159] IGA: Public Act 096-0176, 2009.
[160] Ibid.

2012 after voters approved a ballot measure asking for an opt-out aggregation program,[161] voting yes for the following ballot initiative: "Shall the City of Chicago have the authority to arrange for the supply of electricity for its residential and small commercial retail customers who have not opted out of such program?"[162] While initially successful in procuring non-coal energy and lowering rates, Integrys, the chosen supplier, eventually raised rates significantly beyond ComEd's price and the program was abandoned. However, the price rise was likely attributable to the inability to direct funds to in-state energy development due to RPS funding rules that existed during the time,[163] which have since been removed following FEJA.

Community aggregation as a program has been very successful elsewhere. Following the creation of a CCA option in 2002,[164] CCAs across the state have created 710 MW in solar, 312 MW in wind, and are saving an aggregate of $90 million in energy bills per year.[165] Moreover, they can provide increased local control, concentrate economic development, and lower prices over time, pending state cooperation.[166] Additionally, they can create high participation rates through an opt-out setup and, thereby generation further price reductions through the scale of the contract.[167] If implemented correctly under a new regulatory landscape without RPS interference, municipal aggregation would be a worthy plan for policymakers to pursue to accomplish the broader goal of 100% renewable energy, both by guaranteeing direct energy production and by concentration economic benefits to the local area. However, several other options exist for the City to pursue 100% renewable energy sourcing, including Renewable Energy Credits (RECs) or Virtual Power Purchase Agreements.

Nuclear Subsidies

Illinois has substantial nuclear capacity, 90.8% of which is located within the ComEd PJM region.[168] Nuclear makes up 62% of Illinois PJM production capacity, with 5 plants providing a nameplate capacity of 11277 MW.[169] Recently, these plants have faced uncertain economic viability. Exelon, the operator of all Illinois nuclear plants, threatened to close two plants – Clinton in the MISO region, and Quad Cities in PJM.[170] In response, Illinois legislature passed the Zero Emission Credit (ZEC) program, subsidizing nuclear energy. The power plants remain operational, but the subsidy is currently being challenged in court.[171] The U.S. Department of Justice and Federal Energy Regulatory Commission (FERC) have argued that federal rules do not prohibit these subsidies,

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[161] Mayor's Press Office. 2012.
[162] Chooljian, Lauren. 2012.
[163] Lydersen, Kari. 2012.; Roberts, David. 2012.
[164] See CA-AB 117.
[165] CalCCA, 2018.
[166] Fairchild & Weinrub, 2017.
[167] Pentland, 2013.
[168] Plant_Data
[169] Ibid.
[170] See New York Times, 2016: "Exelon to Close 2 Nuclear Plants in Illinois"
[171] FERC, 2018: Amicus Curiae Brief in *Village of Old Mill Creek* et. al *v. Anthony M. Star* et al

though final results are still pending.[172] Furthermore, if plants do not close early in the case these subsidies are terminated, they may decide to close at the expiration of their Nuclear Regulatory Commission license.

While the status of these plants remains uncertain, their closing is not of direct consequence for Chicago. Retail choice and restructured energy markets allow Chicago to choose renewable energy without waiting for the closure of nuclear plants. However, the economic impacts of decreased demand for nuclear are important to consider when plants are reliant on subsidies to operate. Illinois is a net exporter of electricity, and its nuclear generation is a significant contribution to its economy. Policies in collaboration with state legislature should encourage in-state renewable generation to both meet Chicago's demand, and transition the local economy towards clean energy.

Future Transportation Ridership & Access

It is important to recognize that future greenification of energy resources used by the Chicago Transit Authority is primarily financially constrained. A consistent theme of our research in the transportation area was that public transportation agencies in Chicago, namely the CTA and Metra, are facing increasing budget shortfalls and decreasing ridership demand. For instance, cash flow for the CTA primarily comes from ridership revenue and municipal allocations, both of which will see little growth in the foreseeable future due to low population growth projections and more or less flatlining tax revenue informing the Chicago budget.

In light of these constraints, the primary directive for public transport development should be energy efficiency, in line with lowering costs to increase free cash flow for other projects. Faster uptake of electric bus vehicles and replacement of old rail cars with models capable of regenerative braking are the most effective methods to reduce traction energy demand. The CTA is currently projected to have 20 electrically powered buses by 2020, which would make up barely 1% of the 1800-strong, diesel-guzzling fleet. Additionally, we recommend the City and other regional bodies should further consider investment in both agencies to expedite renewable fuel-switching for their respective assets as described in Section 3.2. As transportation generally accounts for a large proportion of Chicago emissions, energy improvements in these agency's respective assets will be imperative to a future powered by 100% renewable energy. Moreover, increased access and better schedules will also be important for encouraging individuals to switch from individual vehicles to more resource-efficient public transportation. Given transportation is vital to any 100% renewable strategy, further attention should be given to ensure these considerations are a part of any larger strategic planning.

[172] Ibid.

Program Integration

A key challenge in generating estimates for efficiency programs for this report was their lack of coordination. We identified the following individual programs over the course of our research: Chicago Energy Benchmarking, Retrofit Chicago, Energy Impact Illinois, Energy Shared Savings, Chicago Solar Express, Community Weatherization Action Teams, and the Energy Action Network. While Chicago Energy Benchmarking is exclusively for large properties, the remaining list can still be overwhelming for an individual trying to retrofit their residence or seek information on solar installation. Additionally, in terms of research purposes, data is not integrated between these programs. To allow more accurate estimates of the benefits from and investment required for these programs, metrics such as individual retrofits, estimated efficiency gains, and average costs on a per building basis should be aggregated and disclosed. As modelled in this report, energy efficiency initiatives will likely contribute a significant amount of potential savings across the city, and these suggested process improvements may serve to better facilitate and quantify those gains.

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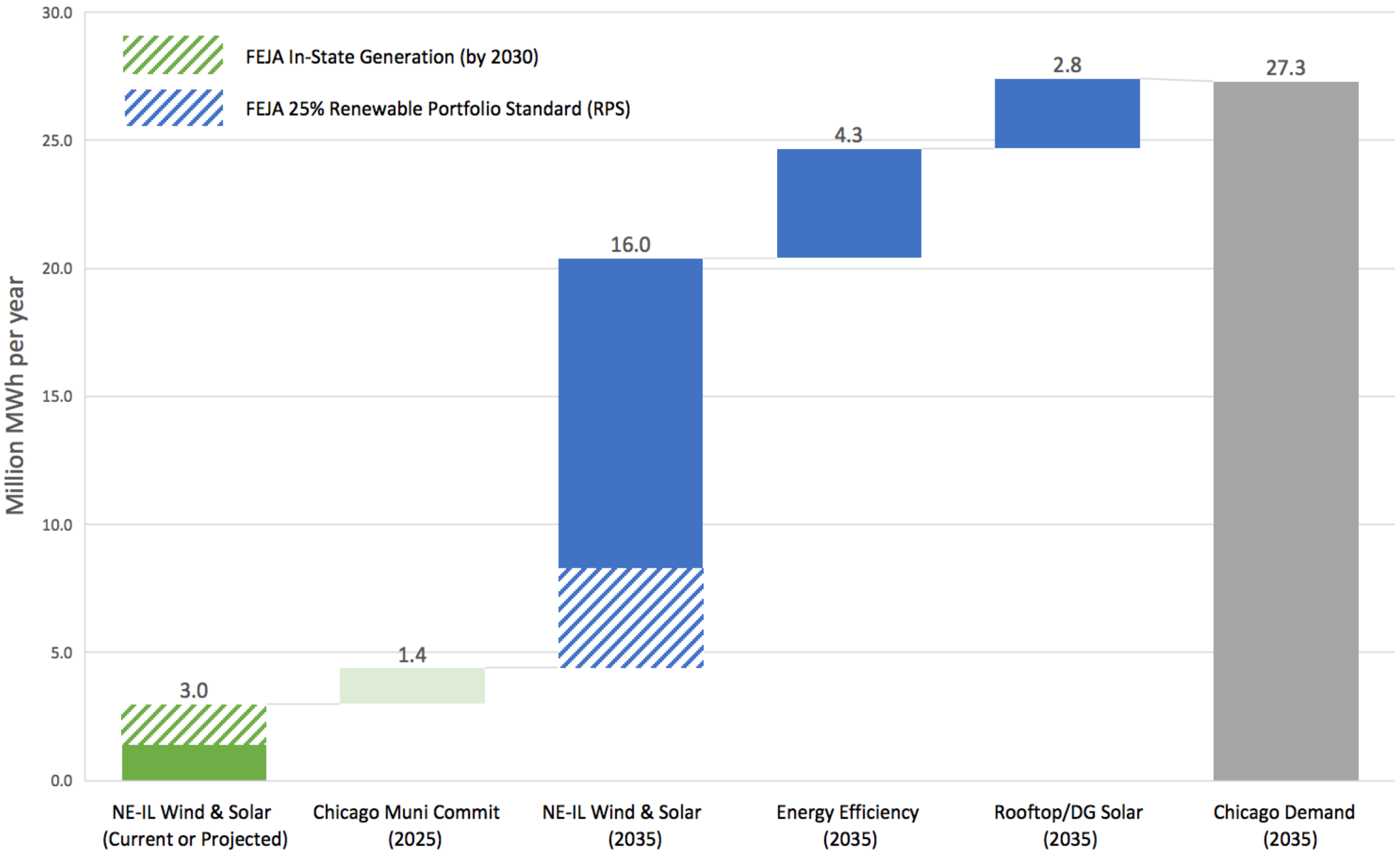
VII. Appendix

I. Path to 100% Renewable Energy (Reference Scenario)



*In this scenario, we assume 55% of feasible rooftop solar is installed and 85% of all benchmarked large properties in Chicago are retrofitted to meet at least national energy use intensity (EUI), weighted for their climate zone. This assumption does not necessarily mean that all buildings will need to meet our efficiency target, as some will likely exceed the national average for their property type to make up the difference.

II. Green Job Occupations, Employment, and Average Wages (National)

Occupational group	All green revenue			Some green revenue			No green revenue		
	Employment	Percent of employment	Annual mean wage	Employment	Percent of employment	Annual mean wage	Employment	Percent of employment	Annual mean wage
All Occupations	1,949,520	100.0%	$48,210	6,110,380	100.0%	$54,440	18,267,090	100.0%	$58,130
Management	95,360	4.9%	$110,220	428,390	7.0%	$108,450	1,428,280	7.8%	$124,230
Business and Financial Operations	83,740	4.3%	$71,250	279,960	4.6%	$64,750	1,216,160	6.7%	$69,530
Computer and Mathematical	25,540	1.3%	$77,270	196,340	3.2%	$68,280	1,422,100	7.8%	$78,940
Architecture and Engineering	105,670	5.4%	$77,130	404,910	6.6%	$70,900	822,600	4.5%	$75,920
Life, Physical, and Social Science	174,930	9.0%	$57,660	185,160	3.0%	$57,510	324,850	1.8%	$68,670
Community and Social Service	3,030	0.2%	$47,170	44,870	0.7%	$45,780	75,790	0.4%	$44,500
Legal	6,670	0.3%	$115,150	39,350	0.6%	$144,720	562,080	3.1%	$116,020
Education, Training, and Library	13,090	0.7%	$53,440	941,770	15.4%	$66,810	918,970	5.0%	$58,650
Arts, Design, Entertainment, Sports, and Media	22,200	1.1%	$50,750	155,910	2.6%	$52,520	647,880	3.5%	$73,260
Healthcare Practitioners and Technical	7,900	0.4%	$66,640	57,830	0.9%	$57,740	113,510	0.6%	$67,310
Healthcare Support	70	(1)	$35,260	9,270	0.2%	$31,760	26,400	0.1%	$34,350
Protective Service	26,320	1.3%	$44,090	54,190	0.9%	$40,350	106,880	0.6%	$39,930
Food Preparation and Serving Related	2,160	0.1%	$27,190	26,790	0.4%	$27,620	27,550	0.2%	$25,040
Building and Grounds Cleaning and Maintenance	35,620	1.8%	$29,080	186,050	3.0%	$28,900	627,090	3.4%	$27,520
Personal Care and Service	18,780	1.0%	$24,320	45,730	0.7%	$27,130	71,440	0.4%	$31,210
Sales and Related	84,560	4.3%	$38,020	180,010	2.9%	$46,920	629,940	3.4%	$61,200
Office and Administrative Support	194,440	10.0%	$37,260	877,470	14.4%	$35,970	2,918,530	16.0%	$37,850
Farming, Fishing, and Forestry	29,260	1.5%	$25,670	86,420	1.4%	$25,150	625,000	3.4%	$23,690
Construction and Extraction	137,060	7.0%	$44,910	895,310	14.7%	$47,000	2,539,890	13.9%	$45,270
Installation, Maintenance, and Repair	135,470	6.9%	$49,140	278,480	4.6%	$44,580	1,000,620	5.5%	$42,210
Production	208,180	10.7%	$39,240	462,710	7.6%	$36,780	1,520,970	8.3%	$36,150
Transportation and Material Moving	539,470	27.7%	$35,390	273,450	4.5%	$34,570	640,560	3.5%	$36,720

Footnotes

(1) Estimate is less than 0.05 percent of the green revenue category employment.

Source: U.S. Bureau of Labor Statistics, 2012. "Employment, percent of employment, and annual mean wages by occupational group and share of revenue from Green Goods and Services (GGS) in-scope industries, November 2011."

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