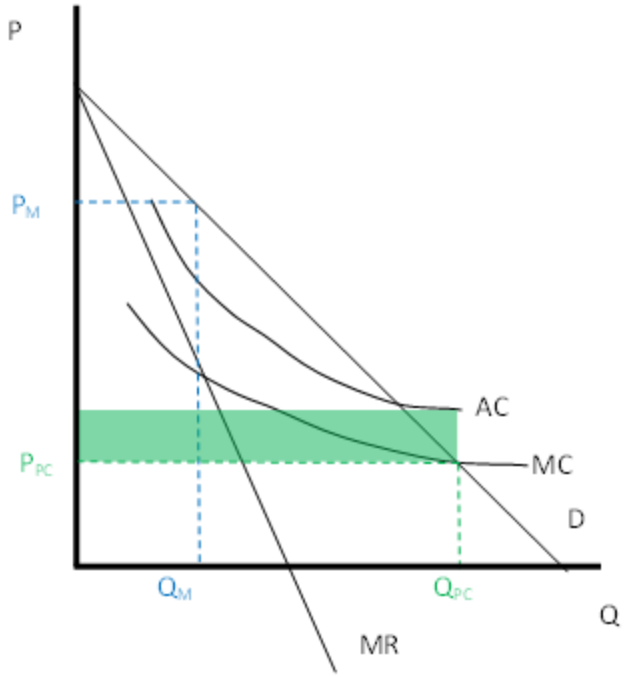
Lecture # 22 – Electricity Markets

I. Understanding the Electricity Grid

- Increased electrification is important to the energy transition.

- To understand the potential of renewable energy for electricity generation, it is important to understand how the electric grid works.
    - Electricity cannot be stored. What goes on the grid must match what comes off.
        - US has three main grids
        - New York is in the Eastern Interconnection
        - New York managed by the New York Independent System Operator (NYISO)
            - Calculates who can provide the power needed at lower cost
            - Have plants adjust every five minutes to keep the system balanced
            - Use weather forecasts to try to project production from wind and solar
    - Because of this, wholesale prices can vary by a factor of 10 or more within a given day.
    - Distinguish between two types of generation sources:
        - Dispatchable: operator has temporal control over. Can decide when to shut off or turn on.
        - Intermittent: Production varies due to exogenous factors, such as amount of wind blowing.
            - Generation is out of control of the operator
            - However, these plants can be shut down easily, so there is an upper limit on generation
    - Even when the owner has control, some plants can be switched on and off more quickly than others.
        - Ramping rates: how quickly plants can change the level of output.
        - There are also differences in often the plant must shut down for required maintenance.
        - Flexible sources with rapid ramping ability include:
            - Gas-fired peaker plants
                - Low fuel efficiency, but are flexible
                - Also have low start-up costs
            - Hydroelectric
        - System is designed to meet demand extremes. Some peaker plants may only run a few days a years.

- Generation costs
  - Electricity generation has large fixed costs
  - Variable costs such as fuel costs and maintenance are typically low relative to fixed costs.
  - Thus, electricity generation has characteristics of a natural monopoly. Simple marginal cost pricing does not allow investors to recoup fixed costs:



  - To account for fixed costs, generation costs are typically measured using <u>levelized cost</u> of electricity
    - Levelized cost is the constant price for power that would equate the net present value of revenue from the plant's output with the net present value of the cost of production.
      - It is the price a generator would need to recoup both their fixed and marginal costs.
    - Key assumptions that lead to different estimates:
      - Inflation rates
      - Real interest rates
      - How much the generator will be used
      - Productivity of the generator
        - E.g. how much will it be used and how much electricity will it produce
        - Future generation particularly relevant for renewables, as may depend on quality of the site
      - Future input costs (particularly fuel)
      - Future market prices

II. What Determines Electricity Prices?

- How are electricity prices determined?
    - In the United States, how electricity is bought and sold varies by region.
    - Most customers are served by investor-owned utilities. These operate in either traditional regulated markets or deregulated competitive markets.
    - Regulated markets
        - Historically, most utilities were vertically integrated monopolies, meaning they owned the generators, transmission lines, and distribution lines.
            - Today, about one-third of US electricity demand is serviced by this traditional model.
        - Because they operate as monopolies, state regulators oversee how these utilities set prices to protect consumers.
            - Retail prices are set to recover a revenue requirement: the utility's operating and investment costs plus a "fair" rate of return.
            - Under this structure, customers bear the investment risk.
                - Utilities recover costs through rates regardless of whether the power plant performs well or is even completed.
        - Utilities may trade with one another in wholesale bilateral markets (e.g., buying excess hydro power when cheaper than generating their own).
            - These transactions are regulated by the Federal Energy Regulatory Commission (FERC).
    - Deregulated markets
        - Beginning in the 1990s, many states transitioned to deregulation to create competition and lower costs.
        - Utilities sold power plants to independent energy suppliers. They kept the transmission and distribution lines, which remain regulated as natural monopolies.
        - Retail deregulation
            - Customers can choose their independent electric supplier rather than being forced to buy from the local utility.
            - Retailers compete on price or specific preferences (e.g., clean energy).

- Wholesale deregulation
  - Regional Transmission Organizations (RTOs) replaced utilities as grid operators and managers of centralized wholesale markets.
  - Investment risk shifts from the customer to the independent power suppliers.
  - RTOs run two main types of markets:
    - Day-ahead market**:** Day-to-day auctions for producing electricity.
      - Represents about 95% of transactions
      - Based on forecasted load for the next day
    - Real-time market
      - Typically run once every hour and once every five minutes
      - Accounts for real-time load changes to balance supply at all times.
    - How markets work
      - Suppliers bid a price to sell.
      - RTOs use these bids to decide which units to dispatch (e.g. to run to produce power) and in what order
        - RTOs dispatch units from least expensive to most expensive.
        - E.g.: Wind plants have zero fuel costs, so they bid $0 and are dispatched first.
        - Prices are determined by the marginal cost of the last power plant needed to meet demand
        - For plants with lower marginal costs, additional revenue helps cover fixed costs
        - Prices may differ by location due to transmission line congestion.

- Challenge: value of electricity varies depending on how much and when generated
  - Consider fixed costs versus variable costs
    - A nuclear plant's levelized cost is lowest if run constantly (e.g. baseload power) to recoup fixed costs
    - Natural gas can be turned on and off to meet peak demand
  - Renewable energy changes this.
    - Because marginal cost of renewables is 0, it is offered to wholesale markets at very low costs
      - As a result, some utilities in Texas give consumers free electricity in the evening
  - Grid operators typically absorb all renewable power provided to the grid.
  - The remaining demand is the "net load", to be met by other power plants
    - For example, with high solar penetration, net load is low at midday, and peaks when people come home in the evening.
    - If used during periods of peak net load, wholesale prices of electricity will be higher
      - Solar produced during day, which coincides with peak demand
  - Negative wholesale electricity prices
    - In some cases, producers find it cheaper to *pay* the grid to take their electricity than to shutdown
      - To avoid costs of ramping down and ramping up later
        - Nuclear can place low bids, because most costs are fixed costs
        - But because of these fixed costs, note that nuclear's levelized costs are larger
      - To receive subsidy from production tax credit for wind
    - Negative prices occurred 6% of the time in 2022
  - Competition from other sources has also hurt nuclear power
    - Nuclear can also place low bids, because most costs are fixed costs
      - However, because of these fixed costs, note that nuclear's levelized costs are larger
      - Competition from natural gas and wind is forcing nuclear plants to retire early
        - Some states, such as NY, are thus considering subsidizing nuclear power plants to compensate them for producing zero-carbon electricity
          - Nuclear supporters argue that other carbon-free sources, such as wind and solar, benefit from subsidies

- Use of batteries to reduce fluctuations is growing
    - In California, installation of batteries subsidized
        - Used to store solar energy during the day, which is used the same evening
    - In Texas, batteries used to smooth short-term price fluctuations (often just 30 minutes or so)
    - But battery storage limited to a few hours

- Rising electricity prices have become a concern for consumers and politicians
    - *Question:* How might data centers and AI affect electricity bills?
        - Reasons data centers may increase prices
            - Demand growth strains generation capacity
                - Note supply should respond in the long run
            - To pay for grid infrastructure upgrades to accommodate data centers
                - Particularly an issue of data center demand later falls
                - Long-term contracts can reduce this risk
        - Reasons data centers may help lower prices
            - Fixed costs spread across more customers
                - Note this doesn't happen if utilities negotiate special rates for data centers.
        - Overall, effect of data centers depends on:
            - Is there extra capacity?
            - Who bears the costs of grid upgrades?
    - *Question:* What are other reasons that electricity prices have been rising?
        - Economy-wide inflation increases costs
        - Transmission costs are increasing
            - Replacing old equipment
            - Increasing resiliency
        - Rates vary geographically
            - E.g., wildfires in California increase costs to utilities
            - High natural gas prices in Northeast
            - Data centers contributing to price increases in PJM RTO
        - Effects of renewables
            - Renewables increase costs in states with mandates **and** low quality renewable resources
            - Household solar incentives reduce customers paying fixed costs

III. The Role of Transmission Lines

- Inadequate transmission infrastructure is a challenge for expanding renewable energy
    - Wind and solar must be located where resources are available
    - Electrification of other sectors will increase electricity demand, also requiring new transmission capacity
    - Problems caused by inadequate transmission
        - Curtailment: quantity of electricity provided to the grid is reduced to keep in balance has been increasing
            - Wind and solar can be immediately and temporarily reduced (e.g. by disconnecting solar from the grid) and reconnected when needed again
            - Curtailment of wind and solar has been growing as generation of each expands/
        - Negative wholesale electricity prices
            - Indicate a transmission issue because negative prices occur when other locations have positive prices
                - Thus, someone is willing to pay for the power generated, but we cannot get it to them.
    - Why is expanding transmission lines difficult?
        - Difficulty connecting new projects to the grid (new i**nterconnection** lines).
            - New connections must be reviewed and approved
                - Local grid operators must ensure the project won't cause disruptions, such as if the grid cannot handle the new power provided
                    - May require upgrades to approve a project
                - Takes four years on average
            - There is a large backlog for these projects.
                - PJM Interconnection announced a freeze on new applications until 2026 (covers territory from Illinois to NJ)
            - Fewer than 1/5 of wind and solar projects make it through the "interconnection queue"
                - Many developers submjit6 multiple proposals, knowing they won't be able to afford them all

- The US electricity grid is mostly decentralized
    - Historically, mostly disconnected individual utilities made independent decisions.
    - Fuel was delivered to power plants located near population centers
    - Regulated utility markets allow utilities to recover costs of constructing new capacity
        - But buying power from elsewhere is an operating cost that does not increase profits
- No central authority approves new transmission projects
    - New projects must be approved by a combination of federal, state, and local authorities
    - Who pays isn't clear
        - Additional transmission lines are a public good
        - But developers of projects typically asked to pay if new transmission lines required
        - Reducing congestion benefits a broader region
    - Moving power creates winners and losers
        - Moving renewable power from where it is generated lowers supply in those areas, thus raising prices
        - Owners of existing power plants in areas receiving more power will face additional competition
        - Regulated utilities do not benefit from potential cost savings

- *Policy question*: should households be rewarded for distributed generation
    - Distributed generation is producing electricity at the consumer site, such as with solar PV panels
    - Electricity generated reduces the consumer's bill, since they take less power off the grid
        - As a result, utilities have been lobbying to reduce solar incentives
    - Should they also be paid for any surplus power that they contribute to the grid (net metering)?
        - Pros:
            - Solar PV generates power at peak times, when it is more valuable
        - Concerns:
            - This doesn't reduce distribution costs
                - Some of the consumer's bill would have paid for these fixed costs
            - Consumers cannot control when the power goes on the grid
            - Richer homeowners are more likely to own solar panels. Higher subsidies mean that more of the costs of generation are paid by customers without solar panels, who tend to have lower incomes.
        - Over 40 states allow net metering
            - Since 2013, Hawaii, Nevada, Arizona, Maine, and Indiana have phased out net metering.
            - California reduced the subsidies they pay for solar in 2022.
    - How can policy address the costs of distribution?
        - Find new ways to value non-utility PV electric (NY)
        - Time of use rates that rise with demand (CA)
            - Encourages more investment in batteries
        - Fees for customers with solar panels on roofs (KS)