Optimizing electricity systems to meet energy and environmental objectives at least cost

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Over the coming decades, electricity systems will become more important as electricity replaces gas and oil in end use technologies, such as electric heat pumps replacing gas boilers, or electricity replacing oil in transport; and more complex because an increasing fraction of electricity demand will be for climate dependent space heating, variable renewable sources will replace easily stored finite fossil fuels for generation, and international trade will grow to take advantage of the temporal diversity of dispersed demand and renewable resources.

Simulating, and optimising such systems with 'downhill' and genetic algorithms, is an aid to devising planning, regulatory and market frameworks that will approach least cost solutions. Modelling will be described that provides:

- a method for finding the least cost combination of the capacities of electricity system components –generation, storage and trade – so as to meet a given set of hourly demands. A constraint of minimum renewable fraction, or maximum fossil/CO_2 emission can be set.

- the minimization of the operational cost of a given system of demands and generation. This utilizes a detailed model that includes renewables, spinning reserve, ramping of thermal generators, pumped storage, and demand side management. The model iterates between generation and demand side management to find the least cost operational pattern, maybe to minimise global opportunity cost? Iterate 1 / 2 with small LM increments to avoid instability until cost reduction less than threshold:

    1. Calc marginal generation cost MCg, (one option for MCg is allocating all costs including start-up etc over energy generated)
    2. Load manage (LM) using criterion; move energy demand from t1 to t2 if net cost less than zero (accounting for MCg, SRMC LM, storage losses etc.) Do for first N least net cost LM options. This changes generation requirement profiles so we have to recalc MCgs with step 1.

Aspects of practically achieving optima will be discussed: for example, the requisite information flows, and technical and market controls that are required to implement load management with heat stores, appliances and interruptible loads.

Debate with David Hirst

The problem as I see it is how to deal with possible future, such as 20 GW (+/- 5 GW with some probability distribution) of wind power arriving say 8-12 hours from now when demand will be 40 GW (+/- 5 GW), so as to minimise cost and achieve required loss of load probability.

How to control demand side input/outputs from N million stores/interruptible loads; ramping up/down of large back-up generators; trade with France, etc…?

Of course the hidden hand of self-interest optimises if market structure OK. The problem is current market prices are not sufficient. Somehow demand and supply agents have to bid in their future offerings, which are then taken up by a 'central controller/dispatcher' when the time comes as required, with payments for offers accepted, whether or not there is energy flow. With high renewable % systems the net-of-renewable future demand to be met by optional generation (thermal, hydro…) is more uncertain, otherwise the system is qualitatively as now. But when storage is included things get much more tricky, especially if there are complex constraints, such as for fridge/freezer max/min temperatures.

The modelling Barrett does accounts for this assuming a Global Optimal Dispatcher (GOD) with, of course, perfect foreknowledge and power – omniscient, omnipotent. The question is how to approach GOD in a human system with imperfect foreknowledge, and certain limits on information about system states, information transfer, and on control.

From David Hirst david@davidhirst.com

I am philosophically very much against any centralised control, preferring subsidiarity (a Roman Catholic dogma!), so that decisions can be made as close to where its impact is felt as possible.

Rather I see predicting the future as a risk business. Many people betting on what they think is the most likely outcome, and this outcome being refined as time approaches. All tempered with some hedging from insurance for the truly unpredictable. This is a market speculator business, and so a trading activity, with price being the output.

What you want is to share the common view that emerges, and allow others, perhaps more risk averse, to do their planning around it. This is what happens today in markets (see Tim Harford [1]). See also [2] for how markets allow a shared view without exposure of private information.) All we need to do is have some agents that make guesses, and modify the quality of the guesses. A genetic algorithm is probably quite good for that.

[1] Harford, T., *The Undercover Economist. Exposing why the rich are rich, the poor are poor - and why you can never buy a decent used car!* 2005 OUP 2006, 978-0-19-518977-3.

[2] Surowiecki, J., *The Wisdom of Crowds*. 2005 Little, Brown, 0-316-86173-1.

I plan to go, as I think the transport fleet (which will need substantial energy storage (my car often has 6 weeks of use in it)) is likely to be a major flexibility element in any expansion of electricity generation, particularly renewables. Battery cars will have substantial flexibility as to when they top up their energy. If hydrogen, then electrolysis can take place when wind is plentiful.

Markets are well geared to providing successful balancing in the face of uncertainty, although, in most markets, there is storage to arbitrage between time periods. In oil, for example, the storage tanks do empty and fill, and one can sell a full tank this month or next. Electricity does not have that luxury, although fridges provide a short term storage, and other demand can provide it for a bit longer. Cars are very attractive for longer term storage (days). I guess biomass (and gas caverns) are the only real option for interseasonal. Storage should pay for itself by taking advantage of the fluctuations in value that occur over time.

Markets manage this by having futures contracts of various sorts and timescales. Some of these are paper contracts, where a risk taker, for a premium, will be prepared to pay you the difference between your desired future price, and the actual price at the time you take physical delivery (or close out on the contract). This provides individuals with low risk opportunities to commit to future consumption or generation plans, and the risk takers assume that there will be swings and roundabouts.

In electricity, the futures contracts can be for weeks or days ahead, and the price can thus vary over this period in defined ways. If there is a refined wind forecast, this would feed in to adjust the curve, lowering the price when wind is forecast, and increasing it when it is not.

If you wish to commit to a production schedule (ie charge up your battery) and do so by a deadline, you (or rather your computer) can choose to take your supply at the times when the prices are low, and not take it when prices are high. If the price curve changes, you can replan, and you may win (a reduced price when it is useful) or lose (you need to use some at a higher price. You can hedge this by doing a fixed price deal for a consumption profile given a price curve.

What this means is that the market makers can cause change in the overall consumption of electricity (or different forms of energy) at different times. While electricity might have price discrimination by the second or minute, heat will do it by the 10 minutes or quarter hour. As prices will be continuously adjusted, and so demand will be continuously responding, you can approach optimality without god, but with the risk taking of many individuals participating in market making. This will not be perfect – there will be prediction errors (and so fire sales) – but it can approach the accuracy of god-like predictions.

To make the god-like predictions centrally, and take into account all the needs and desired and trade-off of many individuals required huge quantities of data, rich data communications, and vast optimising calculations. Broadcasting of the price curves by market makers is much easier, and achieves much the same result.