The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

The 3-part view of power generation

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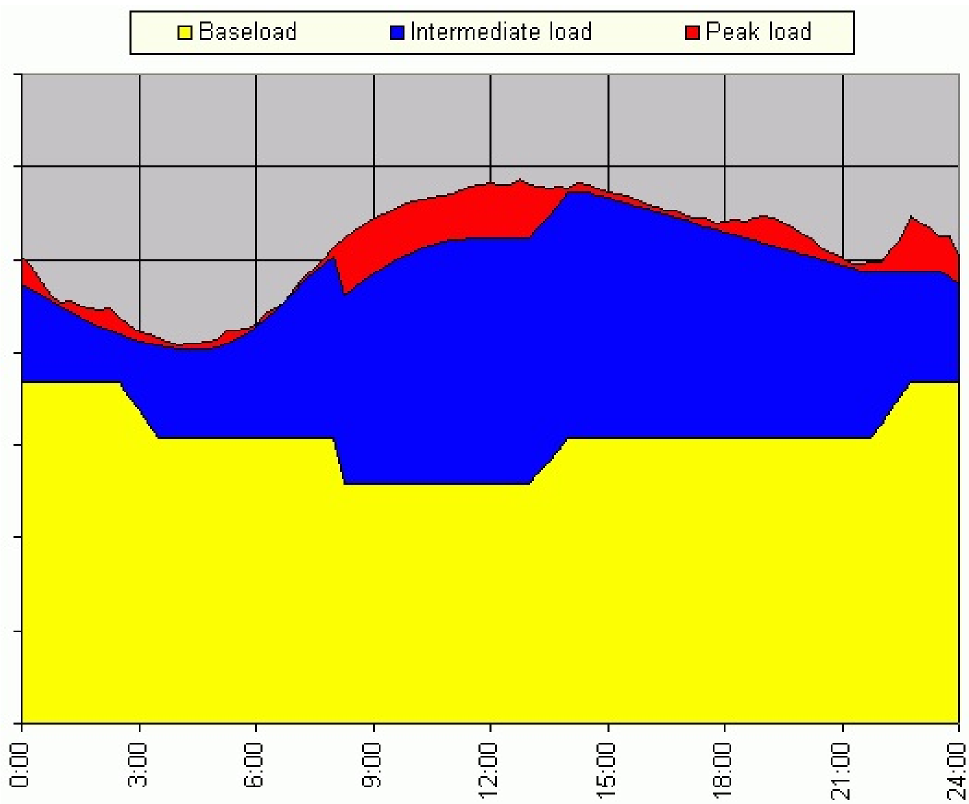
Topic: Demand/Consumption
Tags: base load, electric generation, electric grid, peak load [list all tags]

This is a guest post on my request from ***DoDo****, contributing editor at European Tribune, who works in the railway sector.*

In technical English (and many other languages), electricity generation is commonly divided into two basic load regimes: base load and peak load. However, other languages recognise three basic regimes (for example German: *Grundlast - Mittellast - Spitzenlast*), and this division also appears in English in the usage of some international bodies (for example ENS).



In this article, I want to demonstrate why the 3-part view makes more sense, use it to show the place of exports and renewables in the power mix, and say a few words about the prospects of de-carbonising electricity generation.

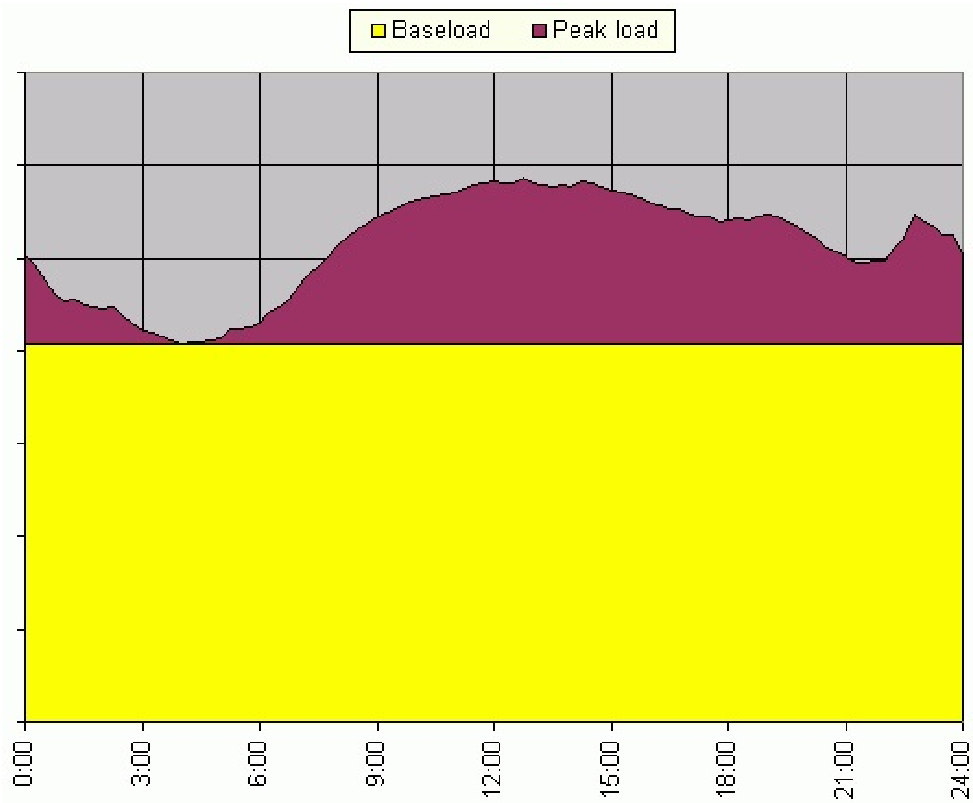
Base, intermediate & peak load

In the common view of technical English, in the conventional power plant mix, there are

1. base load plants, which run at constant power to meet the minimum of demand; and

2. peak load (peaker) plants, which are supposed to meet the variable part of demand, that is, operate in a **load-following** way.

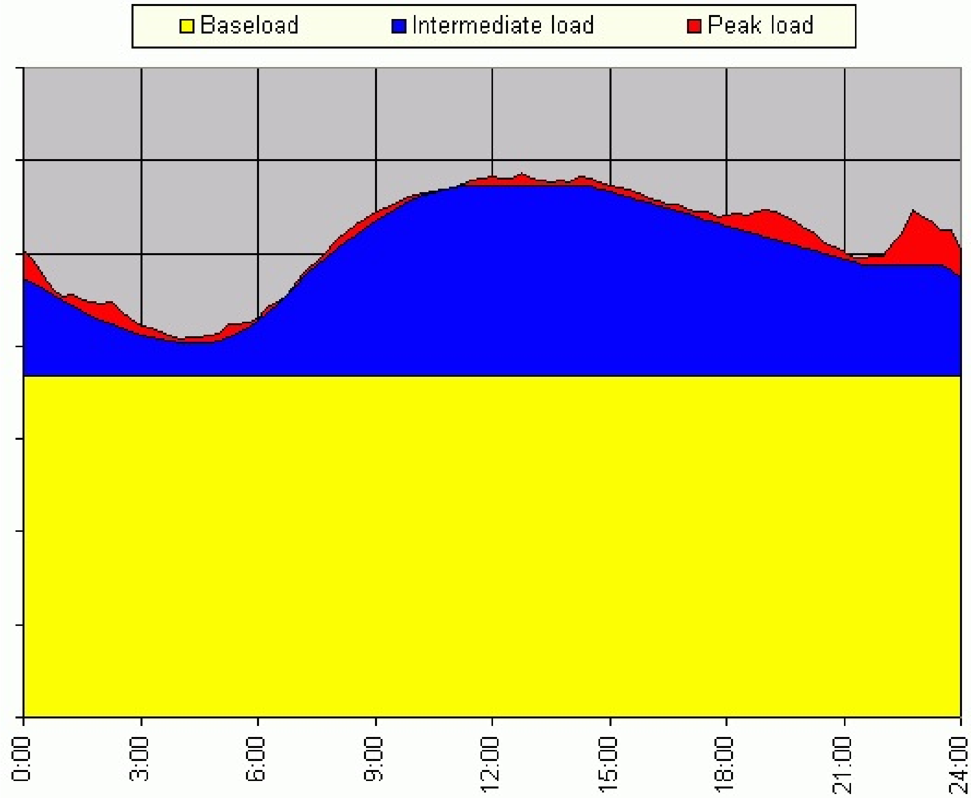
Focusing on the variation with the highest amplitude, the diurnal one, the above view can be represented by the following diagram:



In reality, the variability of demand can be predicted rather well: the daily, weekly, annual fluctuations are very pronounced. Thus, the bulk of load-following can be planned long ahead, making it a **scheduled** form of operation. For the power plant operator, scheduled operation also means that the plant's average load factor, even if well short of 100%, is rather stable and predictable. And this is how we get to the simplest version of the 3-part view of electricity generation:

1. Baseload: plants operated at constant power output
2. Intermediate load: plants operated with slow variation in power output on regular schedule to follow expected variation in demand
3. Peak load: plants operated with fast variation, responding to minute peaks in demand above or below the pre-planned part of supply

Slow-moving intermediate load plants tend to have a non-zero minimum power, and negative deviations from predicted demand are best avoided by giving peaker plants a buffer, too; so both load-following regimes are rarely zero. Graphical representation:



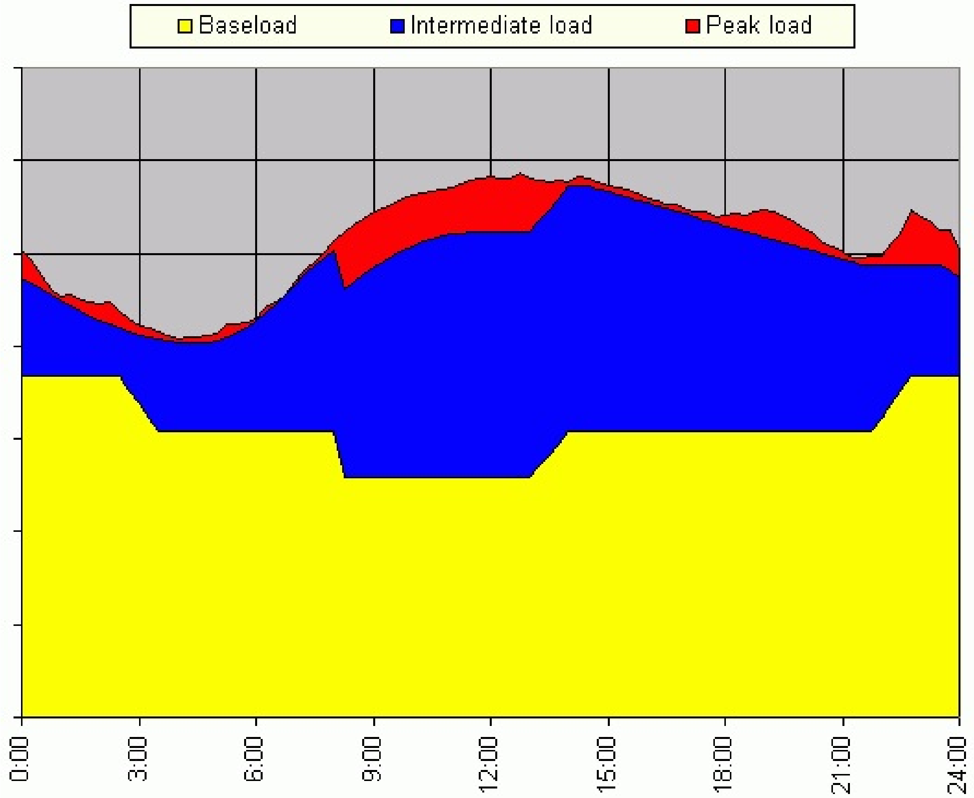
The above picture still contains an over-simplification that hides two basic balancing functions of the system.

- From time to time, conventional baseload plants (typically in the GW range) need to be shut down: for refuelling, or regular maintenance, or upgrades. This is a scheduled change in baseload, hence, the task of compensation falls on intermediate load, which must have reserves of the proper magnitude.
- The power of conventional baseload plants (and not just baseload) can go away in an unplanned way, too, and that rather fast: in case of an accident or power line damage. In this case, compensation is a duty of peak load, which again must have reserves of the proper magnitude.

To include the above two functions, one has to recognise that **baseload is *not* constant**, which calls for a re-worded definition.

1. Baseload: plants operated at maximum whenever possible
2. Intermediate load: plants operated with slow variation in power output on regular schedule to cover the gap between expected demand and expected baseload
3. Peak load: plants operated with fast variation, responding to minute variation in both demand and the scheduled part of supply

Graphical representation:



The reason power plants of different types are predominantly used in one of the three regimes is mostly economic:

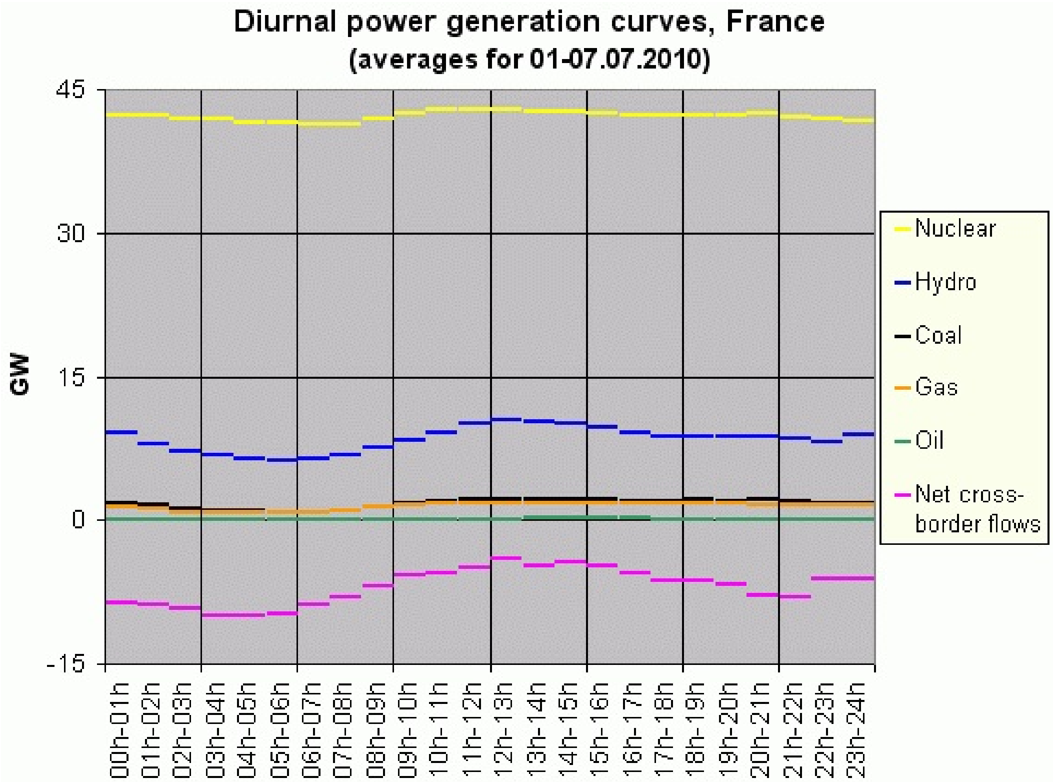
- If the majority of the lifetime costs of a power plant are upfront investment costs (that is mostly the construction costs), or if the plant depends on fuel coming from an open-cast mine (high investment costs in mining itself), then the unit costs of electricity produced will be the lower the more the plant is operated (resp. the more the mining equipment is operated). Hence the owner will want to operate it at maximum whenever possible (the very definition of baseload as per above), and technologies for variable output won't even be developed much.
- If investment, operating and fuel costs are all in the same magnitude, then the plant owner will want to at least operate the plant in a regular way, when at least the average output is steady. This leads to intermediate power.
- If fuel costs dominate, the plant will generate profit whenever on-line, and regularity is not a factor. This is ideal for peaker plants.

With the above, my description of the 3-part view of conventional power generation is complete. Of course, reality is more complex: power scheduling may be subdivided into lots of sub-regimes (ones with 6-hour, 3-hour, one-hour, half-hour, 15-minute, 5-minute tranches, each scheduled ahead for different lengths of time), individual power plants might supply multiple regimes (as gas often does), and there is energy storage. But, these three regimes already describe most basic functions of the system. So now we can explore how some less conventional modes of power generation fit into the picture.

Cross-border flows

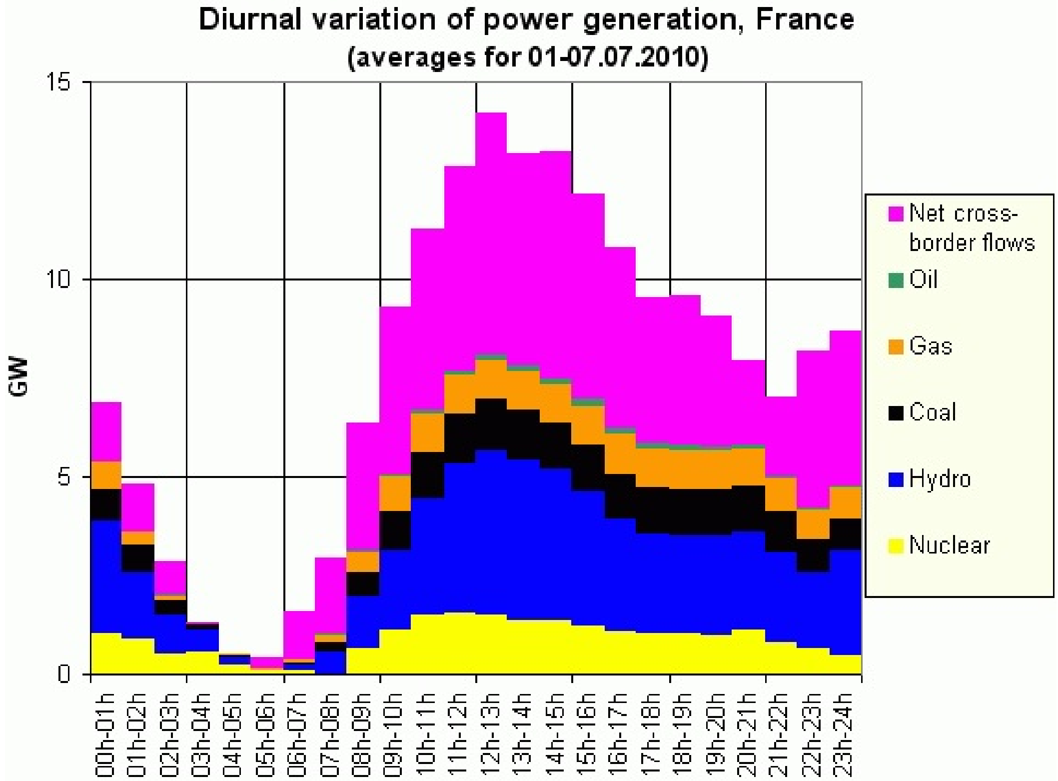
It is widely known that some European countries are significant exporters of electricity, while others are significant importers. What is less widely known is that cross-border flows are exploited for balancing, too.

Let me demonstrate this on the example of France. Grid operator RTE publishes load statistics online, mostly in hourly detail. On the diagram below, I averaged one week's worth of data:



(Note on choice of a shorter time period to average: before 1 July 2010, RTE's published data did not separate coal and gas.)

It is already well visible that cross-border flows, which are a scheduled form of power, have a significant contribution to variation. For a better visualisation of the relative contributions to variation, I subtracted the minimum from each curve and stacked the residuals:



One way to interpret the above is that France is simultaneously exporting baseload and importing intermediate load. Or, we could say that France's electricity sector is not a closed system, the whole system includes the importers. Pointedly, we could say that France needs flexible fossil fuel plants in Italy and elsewhere to maintain a high grid penetration of relatively inflexible nuclear energy.

Intermittent renewables

In recent years, the number one contributor of new capacity in Europe has been wind power. Even more recently, solar power, more precisely photovoltaics, gained significance: though still rather expensive, prices began to fall rapidly and annual installations are now in the gigawatt range. (In Germany, last year the electricity production of photovoltaics surpassed 1% of net consumption, about the level of wind power in the USA.)

In the lifetime costs of both wind power and photovoltaics, fixed, up-front investment costs dominate. Hence, owners will want to operate them without limitation whenever possible. Indeed the preferred support mechanism for renewables across Europe, that of feed-in laws, obligates utilities to purchase all production at fixed feed-in rates, effectively putting them at the start of the merit order. Thus, while it is common to treat wind and solar as separate from the two resp. three classic load regimes, by the final definition above, feed-in law covered wind and solar are *de facto* operated as **part of baseload**.

The one difference compared to conventional baseload is intermittency: for both wind power and photovoltaics, power output depends on weather, time of day, and season. When turbines (resp. panels) are distributed over a grid spread out over a larger geographical area, the weather-related intermittency can be reduced, but doesn't go away.

However, in countries and regions with high wind penetration, grid operators use wind prediction methods that are by now sufficiently precise 24 hours, 36 hours ahead to enable the bulk of the balancing to be scheduled. Solar power can be predicted efficiently, too. Hence, intermittency gives most of the balancing job to intermediate power, where significant reserve capacities already exist. The residual, the difference of actual and predicted output, has to be balanced by peak load.

As emphasized before, conventional baseload is not constant, either. What differs is the pattern and spectrum: instead of relatively fast stepped changes, there are slower but continuous swings -- similar to the other variation intermediate load has to balance, that of demand. As for peak load, the unpredicted short-term fluctuations are not dissimilar to the other irregularities to balance, such as demand surges or blackouts or power plant accidents.

The connection between intermittent renewables and baseload is also apparent in studies on the feasible maximum grid penetration of wind et al in the future: in these studies, classic baseload disappears (see f.e. the diagrams in a German study), and even if power plant types presently operated as part of baseload are assumed to continue, then in a load-following way (f.e. in another German study on operating a future system with or without nuclear exit [diagrams 4a and 4b]).

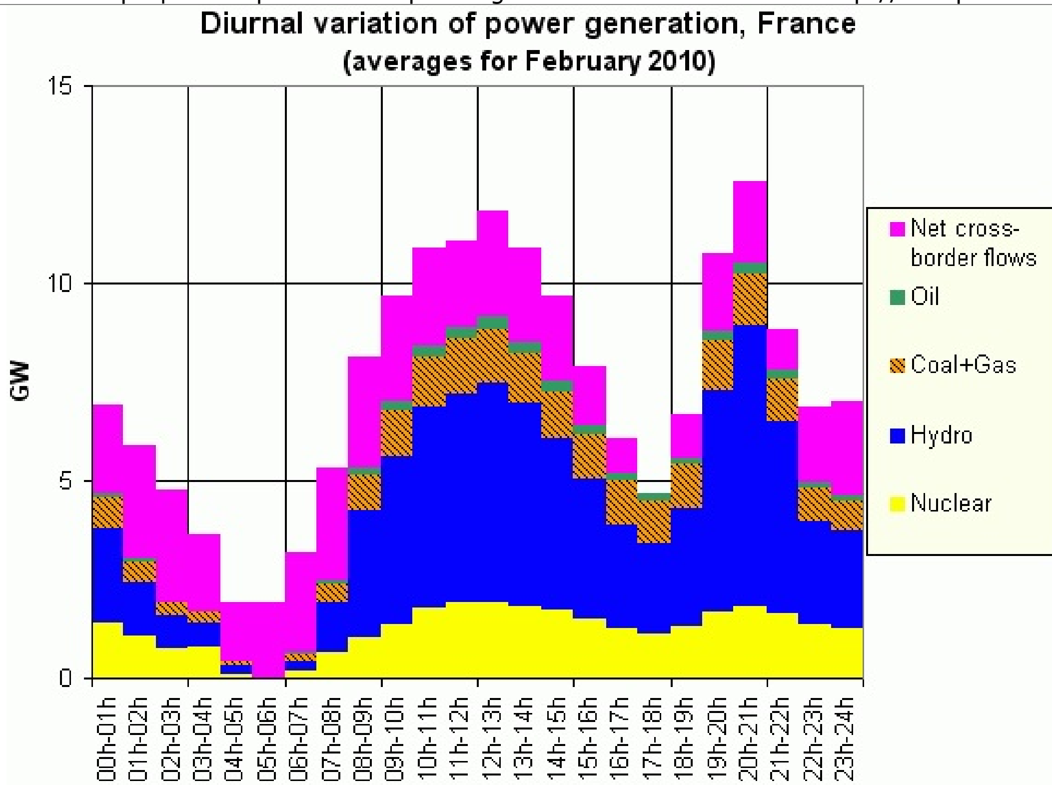
De-carbonising intermediate load

While there are mature technologies to de-carbonise baseload production, as discussed in the previous two sections, intermediate power has to remain significant whatever is chosen as baseload, and intermediate power is dominated by fossil fuel. What are the potential substitutes?

One mature technology already in use (see diagrams for France again) is **hydroelectric power**. However, there are capacity limitations: conventional dams have already tapped much of the resources available outside conservation areas, and those resources are rather uneven geographically. The version employing active energy storage, **pumped hydro**, needs lots of water, too.

Another renewable technology maturing recently is **burning biomass**. This technology provides for a more or less direct replacement of coal, gas and oil (and thus both intermediate and peak load provision). However, biofuels bring a host of other problems, above all a low EROEI and a conflict with agriculture over the limited arable land available.

While the prior discussion focused on supply-side management only, **demand management** has a history, too. For example, in Sweden or France, electrical heating has been advocated because home heating consumption peaks during the night, when other consumption is lower. Ideas for the future include the night-time charging of the batteries of electric cars. However, such demand-side solutions tend to have their limitations due to seasonal variations: for example, electric heating is not used in the summer. Hence, while demand management might reduce the annual total of intermediate power generation (as demonstrated by a comparison of the previously shown graph of diurnal power variation for July with the one for February below), the capacity requirements stay the same.



In the previous section, I considered wind and solar intermittency separately. However, on one hand, there is some negative correlation between the two: when the sky is cloudy, winds tend to be stronger, and solar power peaks in the summer while wind tends to peak in the winter. On the other hand, solar power peaks during the day, while wind tends to peak in the afternoon. Thus, it is possible to combine appropriate capacities of wind and solar so that the combined power output will fluctuate around an average that resembles the demand curve. This is **natural balancing**. Like demand management, this is more a way to reduce the volume of intermediate power than its required capacity.

Solar thermal power generation, when using a heat transfer medium that can be stored, can have a regulated output resembling the demand curve, too. But land area suitable for large-scale solar thermal is geographically limited.

Though there are a host of potential maintenance issues, it is technically possible to operate **nuclear** plants in a **load-following** way, at least in the intermediate regime. However, due to the earlier mentioned economic aspects, this has been done just with some aged plants, with a few that already have amortised investment costs. The EPR is the first full-scale model capable of large-amplitude power variation on a daily basis by design, but it would need government commitment to operate one that way, and years of operational experience to confirm that maintenance won't become an issue.

Classic geothermal power, tapping hot water reserves, is a mature technology, but limited to a few geographical locations, and not even renewable if water reserves are drawn excessively. In contrast, **stimulated** or hot-dry-rock (HDR) **geothermal**, which pumps water into deep dry boreholes, is one of the renewables with potential in the order of magnitude of consumption. This technology allows variable output, and has significant operating costs (needs water, and maintenance of parts under pressure and thermal strain), and thus it is economically suited for intermediate load provision. However, the technology is still at its infancy, and pilot projects indicate that boreholes bring water reservoir and earthquake risks.

Beyond pumped hydro, another energy storage technology is **pumped air**: cavities like disused mines can be used as reservoirs to pump air in and then let it out via turbines. This technology is at its infancy, too.

There is the possibility of distributed energy storage, too: grid-connected **flywheels, batteries, capacitors, fuel cells** can be operated in a grid-supporting way ("smart grid"), and such de-centralisation even increases local security of supply. However, these methods of storage tend to have low RTE and EROEI.

In conclusion, I would say that there is no silver bullet, de-carbonising intermediate load will probably need most of the above at the same time.

Acknowledgment

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