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The Good Fairy and the Bad Raisin Pickers: The Dilemma of Renewable Energy[1]

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Abstract: This paper discusses the possibility of an efficient arrangement of electricity production from renewable sources. In order to support a stable supply of electricity, a combination with complementary, controllable energy sources – storage or traditional power stations – is necessary to overcome the storage problem, i.e., the dependence on the volatile and uncontrollable availability of wind and sun as (non-storable) primary energy. A simple model of a natural monopoly is used to demonstrate that such a combination is not sustainable if market entry is free and electricity is traded on the spot market. We also discuss alternative public policy instruments (taxes, subsidies, and entry regulations) which may help to overcome this problem and ensure an efficient provision of electricity.

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1. Introduction

The paper starts with the story of the baker and the fairy. However, what looks like a fairytale can be, rather directly, applied to the issue of renewable energy and the inherent storage problem. This will be demonstrated in section 3. The conclusion of this exercise will be that we need a joint arrangement that combines suppliers of renewable energy with the more traditional thermal power stations. The latter serve as storage capacity and buffer. Section 4 proposes a cooperative solution of the two parties. The model in section 5 however demonstrates that, despite its efficiency, such a cooperative solution may invite raisin picking as the market arrangement is (perhaps) not sustainable. In section 6, we discuss closing down the spot market, regulating short-run entry in the energy market, and other policy measures (taxes, subsidies, and entry regulations) that support an efficient solution.

This paper does not discuss the question of whether the "storage problem" can be solved by means of a supra-regional network of renewable electricity producers. While supra-regional power lines can provide some diversification in the supply of renewable energy, this may not suffice during "supra-regional low-wind nights".

2. The Baker and the Fairy: a Fairytale?[2]

In *Sustain*, a small, isolated village beyond the mountains, each villager buys a bun for 1 Euro every day. Say they spend 30 Euros a month. To produce a bun, the baker spends 40 Cents on flour, milk, water, energy, etc.: these are his costs for an additional bun, i.e., his marginal costs. But there are also fixed costs: he has to pay rent for the bakery and a salary for his young helper. There are also fixed expenditures on electricity, water and cleaning materials, and imputed costs for depreciation. Given these fixed costs and the number of villagers, the baker faces fixed costs of 10 Euros for each costumer. Therefore, total costs amount to 22 Euros per customer. Since each costumer has a willingness to pay 30 Euros, the baker earns a surplus of 8 Euros per costumer every month. Both the costumers and the baker are happy.

However, one sunny day a benevolent fairy came to visit the village and offered a bun to each costumer for free. She repeated her visit and free offer

[2] This fairytale was introduced in Berz (2013).

every day when there was sunshine. As it turned out, the probability of sunshine was 50 per cent, but the sunny days were not foreseeable. In the beginning the villagers were quite happy about this present because they saved 15 Euros per month on buns. However, after a few weeks they found that the baker closed down his bakery, cancelled the lease on his house, and sold his machines and the rest of the flour he had in stock. Covering the residual demand of 15 buns per villager per month would have caused the baker 6 Euros of variable cost and 10 Euros of (quasi-)fixed cost.[3] The resulting deficit of 1 Euro per villager would have proved disastrous for the baker in the longer run. The villagers, in turn, ended up quite unhappy because they no longer got a *fresh* bun on rainy days – even though their willingness to pay was 1 Euro – regardless of the weather.

Could this outcome have been avoided? Perhaps so if we consider the possibility that the willingness to pay goes up on days when the fairy does not deliver. Thanks to their savings on sunny days, customers could reallocate their entire bun budgets to rainy days so that baker's revenues would be the same as without the fairy. However, given the unpredictability of the weather, the baker cannot be expected to go without income for uncertain number of days or even weeks (especially in the summer). Insurance against this kind of calculation risk is effectively costly – and indeed unavailable for the baker in remote *Sustain*.

In the end, the fairy might well feel the unhappiness of the villagers and, hearing their complaints and even accusations, stop visiting the village. Then the villagers are left with no buns at all, rain or shine, and despite their willingness to pay 30 Euros each, no baker will set up shop in the village because they have all heard that a benevolent fairy may appear at any time and inadvertently drive them out of business.

It seems that the trouble arises from the fact that fairies do not have to cover costs and can give their buns away for free, *but not all the time*. In an ideal world, the fairy would team up with the baker and the pair would offer buns for 1 Euro every day – on sunny days, they sell the fairy's free buns; when there is no sunshine, the baker will have to make them at his usual variable cost. Because of the 50 percent chance of sunshine, the baker's total cost will be 16 Euros again. But since total revenues are 30 Euros, the baker and the fairy can share a joint surplus of 14 Euros. Alternatively, the fairy might insist that the price of a bun be reduced to let the villagers benefit

[3] We assume that fixed costs were zero when the baker does not produce at all, i.e., they are not sunk but quasi-fixed.

from this fruitful cooperation. While this concludes the fairytale, it has at least one real-world application.

3. The Dilemma of Renewable Energy

The production of electricity by renewable energy power stations (RPS) from solar or wind energy is characterized by substantial investments and corresponding fixed costs, negligible marginal costs, and the random availability of the natural resource. Of course the fixed costs are generally sunk and thus no longer relevant for decision making once the RPS is installed. The same can also be said of the baker. While he can sell his machinery, most of his investment can hardly be recovered. This also holds, e.g., for a coal-based electric power station.

In our "village beyond the mountains", whose inhabitants do not live on buns alone but also require electricity, the sun does not shine all day, and rain and wind are even more unreliable, so a fully renewable and consistent supply of power is difficult to achieve. Either the villagers procure electric energy from far away, which implies substantial technical and social costs,[4] or they risk being out of electricity for an unpredictable portion of the time as large-scale storage of electricity is still an unsolved problem. Of course on sunny and windy days surplus electricity could be conserved in pumped storage hydropower plants but there are often environmental, ecological and political limitations to the construction of new and larger basins. The primary energies of solar and wind power cannot be stored at all, the storage capacity of hydropower is rather limited and power-to-gas technology is still at a nascent stage. In order to guarantee a secure supply of electricity, it seems necessary either to import energy "from far away" or to additionally enlist traditional, non-renewable sources of power: coal, oil, and gas (COG). However, these inputs entail much higher marginal cost than sun, water, and wind. This also holds for imported electricity, which may or may not be produced from renewable inputs.

[4] Depending on the distance, up to thirty percent of the energy will be lost during transmission. Furthermore, the construction of new power lines often faces massive public resistance.

	Installed Capacity		Actual Production		Utilization
Wind	63,0 GW	27,10%	13,40 GWa	20,14%	21,27%
Sun	56,2 GW	24,17%	5,58 GWa	8,38%	9,93%
Coal	39,9 GW	17,16%	18,51 GWa	27,82%	46,39%
Gas	31,7 GW	13,63%	10,13 GWa	15,23%	31,96%
Water	14,2 GW	6,11%	2,17 GWa	3,27%	15,31%
Bio	11,5 GW	4,95%	5,12 GWa	7,70%	44,55%
Uranium	8,1 GW	3,48%	7,86 GWa	11,80%	96,98%
Battery	0,6 GW	0,26%	n.a.		
other	7,3 GW	3,14%	3,77 GWa	5,66%	51,62%
Sum	**232,5 GW**		**66,54 GWa**		

Data for 2021 from BMWK (2022), GWa = Gigawatt years

Table 1: Capacity utilization of various power generation technologies

The storage problem of wind and solar power is evident from their low degree of capacity utilization (cf. Table 1). The production of electricity from these sources is driven by meteorological conditions, i.e., by supply constraints, while generation by nuclear and COG power stations ('COGs') is determined by the demand for electricity and its daily, weekly and seasonal variation. Interestingly, the installed wind power capacity of 63 GW is close to the total production of 66,54 GWa in 2021. If we add the 56,2 GW of installed solar capacity, it would appear there is a huge excess capacity of renewable energy. However, due to the volatility of wind and solar power, their joint capacity of about 119,2 GW only yielded an actual production of 18,98 GWa. The capacity was (almost always) fully used when activation was possible, but if there was no wind then the turbines remained idle.

Pending a satisfactory solution to the storage problem, COGs will continue to be required for the foreseeable future to ensure the security of electricity supply. But will they still be available? On sunny and windy days, RPS supply electricity at much lower prices than fossil power plants. COGs can create revenues only if renewable generation falls short of demand. But will the price in these days of shortage be high enough for the COGs to cover their fixed costs? Most of these fixed costs are sunk and therefore not relevant for the decisions of the operators of existing COGs, but they do matter for new investments in modern technology.

Fixed costs and revenue volatility are major factors in the decision to build new COGs. Similarly important are any expected developments in the demand for electricity and changes to the economic or regulatory framework, be it the possibility of today's COGs no longer producing

efficiently from a technical point of view because of aging or due to environmental concerns. The political decision to phase out nuclear power in Germany was an example of the latter. In competition with RPS, and without appropriate regulation or public subsidies investments in COGs will likely be too small to ensure security of electricity supply at a "manageable" price. Of course, a spot-market equilibrium can be achieved even in this situation – at very high prices and with negative consequences for industrial and household consumers of electricity that will spill over to the whole economy, including reduced international competitiveness, loss of output, and lower employment.

4. The Cooperative Solutions

If prices are high on days of shortage, renewable power production will tend to expand into areas where natural conditions are less favorable, e.g. less windy turbine sites. Then the costs of production will increase. If this is to be encouraged, but prices to be kept low, public subsidies seem to be an appropriate instrument. However, once we consider public intervention, a wide range of alternative policies are also available, some of which are more promising than luring RPS into inefficient arrangements. At this point it pays to recall the fairytale. Ultimately it suggested a cooperation between the fairy and the baker, which yielded a surplus that can be shared among the stakeholders. In the fairytale, the cooperation was greatly facilitated by the fact that one of the parties has no costs to cover and cares only about the happiness of the costumers. Thus, the arrangement did not require intervention by a powerful third agent like the state. Is such cooperation also feasible between RPS and the COG operators?

Next let us look at potential technologies that allow a stable renewable energy-based supply of power. Figure 1 compares power generation technologies according to their controllability and dependence on provision, with their relative positions being based on the details provided in Table 2 in the appendix. Electricity production from "sun" and "wind" depends on current weather conditions and thus cannot be actively controlled. To ensure a stable supply, these technologies must therefore be supplemented by some technologies such as power-to-gas, if available. That is, excess wind or solar energy produced on "good days" will be transformed into gas to be burned in traditional power stations on "bad days".

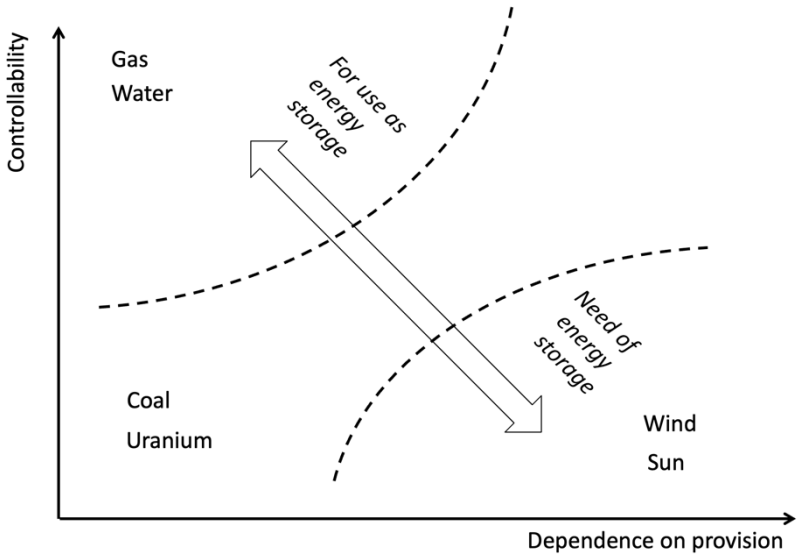

Figure 1: Energy technologies and their contribution to the storage problem

Figure 1 indicates gas as a perfect complement technology for sun and wind, whereas coal and especially nuclear power (primary energy carrier: uranium) are less suitable because they have much lower ramp rates. However, the power-to-gas technology also comes with some problems attached. For instance, a significant portion of the electric energy is lost in this process due to waste heat. Compensating for this loss would require huge additional capacity of wind and solar power.

Another issue is the price arrangement: What price to choose? One could of course argue for a zero-profit price that covers capital costs and administrative expenditure. However, should prices cover the average costs of the RPS, the COGs, or of the power-to-gas arrangement? Of course, we would argue in favor of the latter because otherwise a cooperation of RPS and COGs seems unlikely and the costumers may suffer from unstable prices, creating uncertainty. But such prices invite undercutting if the particular (short-run) situation implies more favorable costs than the medium or long run.

A final problem of the power-to-gas arrangement is that the very same power stations that contribute to the power-to-gas scheme can produce non-renewable energy by burning coal, oil or natural gas. To reduce their average costs and recoup some of their fixed costs, they may be tempted to

produce electricity even when wind and solar power suffice to cover the load. In principle, the RPS could react by lowering the price, but there could be enough legal and technological inertia to allow the COGs to earn surpluses by successfully competing with the RPS. Examples include fixed-price contracts with costumers which may not be adjustable in the short-run. However, especially during prolonged periods of strong renewable power generation it seems more likely that the RPS offer their produce at a price below that which has been fixed for a joint agreement on power-to-gas.

In the next section we will discuss the conditions for a cooperative arrangement between RPS and COGs that guarantee a stable provision of electricity at minimum total costs.

5. The Efficient Market Solution and Raisin-Picking Entry: A Theoretical Appraisal

In this section we assume that the spot market for electricity drives short-term market entry, perhaps on a daily basis, while forward markets yield arrangements for longer time periods. We discuss the issue of electricity supply in terms of market entry and sustainability, using a highly stylized, theoretical model to analyze several related problems. Markets are assumed to be contestable unless barriers to entry are introduced by policymakers or evolve endogenously. According to Baumol (1982) and Baumol et al. (1982) markets are contestable if both entry and exit are costless. A potential entrant "can go in, and, before prices change, collect gains, and then depart without costs, should the climate grow hostile" (Baumol 1982: 4). It immediately follows (for the non-monopoly case) that, in equilibrium, (a) profits are zero, (b) prices equal marginal costs, and (c) production is efficient. Properties (a) and (b) imply that equilibrium prices are equal to minimum average costs. Because of free entry there are no quasi-rents, as identical production techniques are available to both entrants and incumbents without differences in costs. However, an equilibrium (in pure strategies) may not exist if average cost curves are U-shaped (Holler 1985b), or there are more than one equilibrium, creating a substantial coordination problem, if cost curves are linear, at least over a finite range (see Holler 1985a).

Figures 2 and 3 show the pricing and market entry problem if the electricity produced by RPS falls short of the demand. Total demand D is illustrated by the identical curve D in Figures 2 and 3; it is assumed to be independent of supply and does not change. Moreover, we assume without

loss of generality that marginal cost equals zero for both RPS and COGs, and fixed costs are 10 for RPS and 6 for COG. Let us assume there is a third player, 'THPL', that can combine the respective advantages of RPS and COG technology in a cooperative solution at a total fixed cost of 16 and satisfy the demand for electricity at any time. Let's see how this player is treated at the spot market.

Costs in Figures 2 and 3 are subadditive. The figures illustrate the case of a natural monopoly (Baumol 1982; Faulhaber 1975) as total costs are minimized if any level of output is produced in a single production unit.

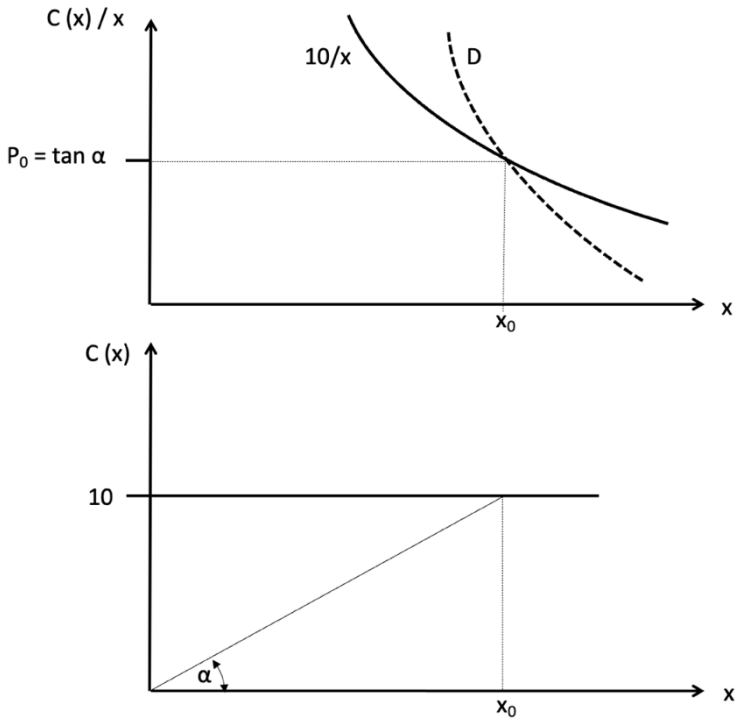

Figure 2: The natural monopoly of RPS

Figure 2 illustrates a situation where the demand x_0 is fully covered by the RPS. The zero-profit price is $p_0 = 10/x_0$ if markets are contestable. Next, we assume a reduction of renewable energy: On a calm night, generation by RPS reduces to x', as in Figure 3. To satisfy demand, the THPL must fire up its COG capacities at total costs of 16 and a market-clearing, cost covering price of $16/x_1 = p_1$, supplying the quantity x_1. (In Figure 3 this price

is represented by tan γ =16/x_1.) However, this price invites the RPS to offer x' at a price which is above 10/x' (= tan β) but slightly below p_1, allowing them to make a profit. Note that these profits are maximal if the RPS use their full capacity x'. The demand x_1 – x' remains unsatisfied, at least at a price of p_1. Raisin picking[5] is profitable; the natural monopoly sketched in Figure 3 is not sustainable under contestability assumptions; the price p_1 is not in the *Core*.[6]

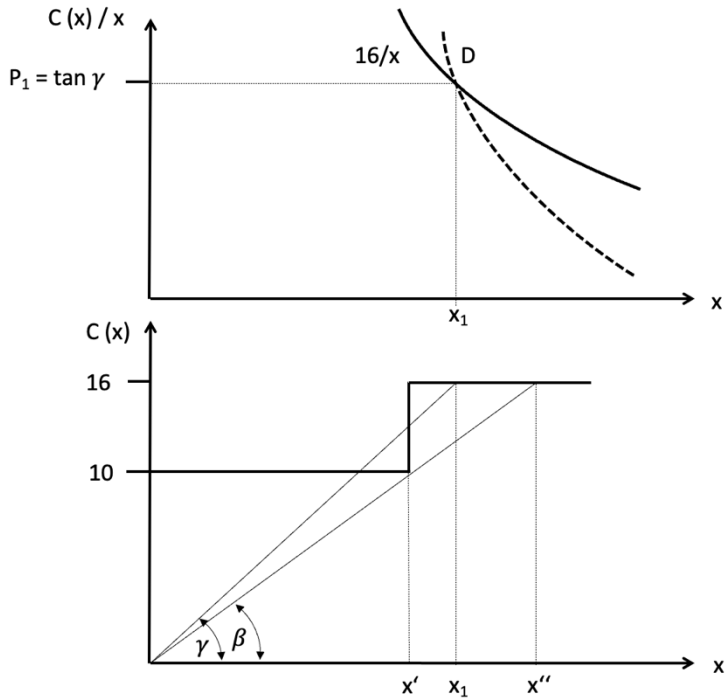

Figure 3: The natural monopoly of the THPL

If x_1 – x' corresponds to clientele with a higher willingness to pay, then we can think of a solution in which the THPL supplies these users at a (much)

[5] Some authors speak of *cherry picking*; the implications are the same.

[6] See Faulhaber (1975) for a game theoretical analysis of the natural monopoly, sustainability, and cross-subsidization. The *Core* is a game theoretical solution concept that implies stability for coalitions which satisfy its conditions. However, the *Core* can be empty as no coalition and associated payoff distribution satisfies these conditions (see Owen 1995: 218-220).

higher price of $16/(x_1 - x')$. (Note that we assumed that the THPL incurs total costs of 16 if it has RPS and COG jointly producing in cooperation.) As a result, we will see high price volatility in the spot market with incalculable risks for both consumers and the THPL: While the THPL must fear being undercut by the pure RPS, prices rise to extreme heights in calm and cloudy weather. Avoiding these outcomes would require rationing or a market regulation which bans undercutting the market-clearing price in the interval $[x_1, x']$.

If the share of RPS in the production of energy drops even further and the equilibrium $(p°, x°)$ is such that $x° > x''$, then undercutting no longer pays and cooperation is likely to prevail at a price $p° = 16/x°$. This is a stable solution with a high degree of stability, but it presupposes sufficient COG capacity. With a threat of entry and x_1, this condition is unlikely to be met – not least because COG is increasingly replaced by RPS for environmental reasons.

6. Closing Down the Spot Market and other Policy Measures

Since the costs of the RPS are largely sunk and their marginal costs are negligible, RPS can deliver electricity at a rather low price, but they will only enter the market if they can expect to redeem their costs. The regulator may invite RPS to the market by guaranteeing them a fixed price, the feed-in-tariff, which has been part of German renewable energy policy since 1991. The observed growth in renewable generation capacity indicates that this price is favorable and invites entry. However, considering our theoretical analysis, such a policy may prevent the efficient provision of electricity. But how to sustain a collaborative solution like that offered by THPL if entry is profitable? We can think of self-enforcing solutions as a result of repeated interaction between RPS and COG, e.g., in the context of power-to-gas or related technologies, that require the cooperation of both parties.[7] Government agencies should be able to support such arrangements by designing adequate policies. They can subsidize contracts that guarantee the stable provision of sufficient electricity. Alternatively, the government can introduce a tax for the RPS such that their zero-profit price will be $16/x$ in the example given in Figure 3, or subsidize the THPL providers so that they can provide electricity at a price of $10/x$ for any x. Such policies have

[7] Theoretical results on iterated games derived from Folk Theorems should be useful for describing conditions that support a cooperative outcome.

become prominent under the label "nudging," i.e., giving incentives or disincentives to decision makers to behave in a desired way.[8]

The State can block the entry of providers who cannot (or do not want to) guarantee (which necessitates cooperation between RPS and COG power stations) that they will fully satisfy the daily electricity demand. This amounts to abolishing the spot market for electricity in favor of a forward market. RPSs looking to enter the market must then find complementary sources of energy, storage, or COG partners, effectively becoming a THPL as defined above.

In her book *The Entrepreneurial State*, Mariana Mazzucato (2014) argues that the State's innovative activities and the support for private innovators are pivotal for the dynamics of business and economic growth. She suggests that the state should massively support green technology also because it exacts a reorganization of the private sector, triggering Schumpeterian creative destruction on a grand scale. The State is large enough to absorb major risks – and "foolish" enough to be creative and to innovate on shaky grounds.[9] However, State activities might be captured by private business simply to shift the costs of innovations to the public, especially of course if these costs are substantial, but also if the private sector is invited to do so, as is often the case in academic research at public universities. Accepting state activities seems to require an adequate structure of the private sector and, rather likely, a reshaping of markets. An increase in state activities should not trigger an increase in corruption. A precondition for curbing corruption is of course to inform about the degree, range and contribution of state activities, e.g., regarding the promotion of renewable energy, and to understand their economic preconditions and consequences.

The evolution of the power market towards a dominance of the spot market can be understood as a "natural result" of a market economy. Hedging options as futures market products, as we discuss in this article, are not in themselves a new idea. Rather, they are exactly what is increasingly being pushed out of the market because they are not as

[8] For "nudge," see Thaler and Sunstein (2008). Many other forms of nudging are involved in the "liberal paternalism" that favors green technology. Chapter 6 of Mazzucato (2014) is entitled "Pushing vs. Nudging the Green Industrial Revolution." On "liberal paternalism," see, e.g., Thaler and Sunstein (2003).

[9] See Mazzucato (2014: 3). Of course, this is also due to the fact that State agents, public administrators and policy makers are in general not held accountable for failures. This provides the necessary "foolishness" for creativity.

profitable as the spot market. However, this should not be construed as an argument against the futures market, but rather represents the core of the problem. The futures market is just as free a market as the spot market. However, the regulator has to decide which market is better suited to controlling the complex power system with all its sensitivities, including the risk of blackout. The future electricity supply will be almost fully renewable and therefore heavily dependent on external factors like the weather. The resulting volatility of supply is a fundamental challenge for the control of the power grid – i.e., in the operating decisions of the individual power plants and the dynamization of consumption, e.g. via "smart meters" But in times of ever-improving weather forecasts, it would be a step backwards to rely on the spot market to control the power grid, which is only a secondary effect from the grid's perspective. In other words, if a backup power plant must ramp up or households must reduce their consumption because the price of electricity rises as the wind dies down, it is too late to ensure system stability. In a system of perfect grid control, the power plants adjust their output *before* excess supply or demand arises. Without perfect control, we will see "costly" price fluctuations which a "smart grid" can only *react* to but not avert.

Our analysis shows that the support of green technology should be balanced, rather than exclusively determined by what we can do. We should also consider what we need and what we want. We do need a bun every day, so a fairy that delivers buns 15 days a month at random might not make us happy – even if the buns are for free – if that means the baker goes out of business.

Appendix

Table 2: Characterization of power generation technologies

Characteristics of power generation technologies

Primary energy / Characteristic	Sun	Wind	Gas	Coal	Uranium	Water	Waves	Tidal	Geothermal
Availability of ressource	renewable	renewable	exhaustable	exhaustable	exhaustable	renewable	renewable	renewable	renewable
Volatility	high	high	low	low	low	high	high	low	low
Reconvertibility	yes	yes	yes	no	no	yes	yes	no	no
Storability	no	no	yes	yes	yes	yes	no	no	no
Storage capacity	n.a.	n.a.	high capacity (low storage costs)	high capacity (low storage costs)	high capacity (low storage costs)	low capacity* (high storage	n.a.	n.a.	n.a.
Controllability	LOW (flexible but only within volatility)	LOW (flexible but only within volatility)	HIGH (full flexibility)	LOW (inertial)	LOW (inertial)	HIGH (full flexibility within storage capacity)	LOW (flexible but only within volatility)	HIGH (flexible within regular presence)	HIGH (full flexibility)
Dependence on provision	HIGH (and high volatility)	HIGH (and high volatility)	LOW (Independent on presence)	LOW (Independent on presence)	LOW (Independent on presence)	LOW (Independent on presence within storage capacity)	HIGH (and high volatility)	HIGH (but low volatility)	HIGH (but low volatility)

* In relation to the total market. Based on the individual hydroelectric power station, the storage capacity is 100% of its power generation potential.

Glossary for Table 2

Availability of resources: 'Renewable' means that the primary energy source may be considered inexhaustible.

Volatility: Volatility of the availability of primary energy

Reconvertibility: Ability to restore the primary energy carrier from electricity – only meaningful if the primary energy carrier is storable.
Storability: Storability of the primary energy carrier
Storage capacity: (Low) storage costs of primary energy
Controllability: Agility of start and shut down of the power plant if the primary energy source is available
Dependence on provision: Dependence of power generation on the availability of primary resources in combination with "no storability", eminently relevant when volatility is high.

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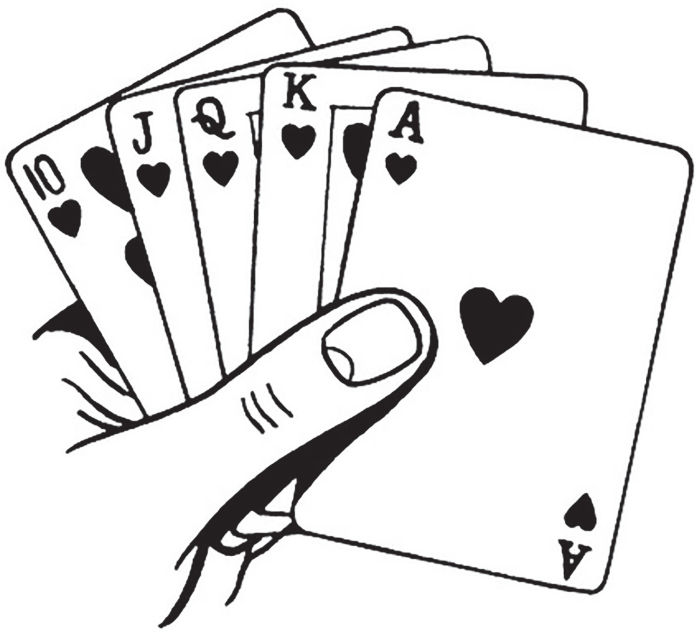

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