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Assessing Energy Technology Leapfrogs

Summary: The idea of an energy technology "leapfrog" is that emerging markets might avoid the dirty development trajectories of today's mature markets by skipping directly to cleaner technologies not based on fossil fuels. The transition to mobile phone telephony in sub-Saharan Africa is a widely cited example of a successful technology leapfrog. By considering three key characteristics of the mobile phone transition — 1) previous demonstration in mature markets, 2) usefulness of the technology as a workaround that avoids the need to build expensive, obsolete infrastructure, and 3) equivalent (or better) functionality for users — we can better assess which energy technologies are good candidates as leapfrogs.

Why it matters: When it comes to energy technology adoption, uncritical application of a "leapfrog" framing can lead to bad policy and investment choices. Emerging markets have arguably already leapfrogged substantial fossil fuel generation with wind and solar farms. But application of the leapfrog concept to other technologies now called upon to manage wind and solar variability can be more questionable. Technologies that have not yet been proven economical at scale, like the use of green hydrogen as an energy carrier, are not good candidates for implementation in emerging markets, and pitching them as near-term leapfrogs could distract from the urgent need to deploy proven solutions in a timely manner.

Goldemberg's conception of technology leapfrogging in energy

In an influential 1998 paper, Brazilian scientist José Goldemberg suggested emerging markets could "leapfrog" directly to cleaner and more efficient energy technologies, bypassing the heavily polluting, fossil-fuel-intensive development path followed by mature markets [1].

Energy technology leapfrogs could have both **product and process (or system) elements**, Goldemberg notes, and these two aspects could work together, as when a more efficient light bulb lowers household energy demand enough that it can be met with a home solar panel instead of a centralized grid. Technologies involved could have a **centralized or decentralized character**, as illustrated by the home solar vs. grid example. (Work by Goldemberg and others often implicitly assumes decentralized solutions are cleaner than large central grids.)

Key features of a successful leapfrog: The mobile phone transition in Africa

One widely cited example of a successful non-energy leapfrog was the rapid dissemination of mobile phones in sub-Saharan Africa between the mid-1990s and mid-2000s [2]. Three key characteristics of the mobile phone transition helped make it a success:

1) **The technology had long since been demonstrated in mature markets.** Mature markets fully commercialized both product and system elements of mobile telephony many years before sub-Saharan Africa implemented them [3].

2) **The technology was a "workaround" to the cost and difficulty of expanding landline infrastructure.** Existing landlines were, in fact, an important element of the mobile telephony leapfrog in sub-Saharan Africa, as most early calls from mobile phones were to landlines; at the same time, the switch to mobile telephony sidestepped the thorny challenge of further expanding costly landline infrastructure in emerging markets [4].

3) **The technology provided superior functionality for users.** Beyond extending the generalized benefits of telephone connectivity to millions of users, mobile phones offered uninterrupted access to information that could, for example, allow small farmers to maximize income by checking crop prices or tuberculosis patients to better follow their treatment regimens [2].

Grading energy leapfrogs by the success factors of mobile phones

In Table 1 below, I score possible energy leapfrogs according to the three factors above that helped make the mobile telephony transition successful, with explanation of my rationales in the section that follows. The comparison highlights the importance of being specific when defining a particular leapfrog, including which technology is being replaced in which application.

TABLE 1: Evaluating different energy transition "leapfrogs" based on key success factors from the mobile telephony case

New technology	Avoided technology	New tech proven in mature markets	New tech avoids building infrastructure	New tech has equivalent or better function
Mobile phones	Landlines	✓	✓	✓
Grid wind and solar for low-cost electricity in bulk	**Fossil fuel power plants** for low-cost electricity in bulk	✓	✓	✓
Batteries for supply-demand matching	**Peaker units** for supply-demand matching	~	✓	~
Green hydrogen for supply-demand matching	**Peaker units** for supply-demand matching	✖	✖	?
Dynamic pricing for supply-demand matching	**Peaker units** for supply-demand matching	~	✓	~
Distributed solar for residential or commercial uses	**Grid power** for residential or commercial uses	✓	✓	~
Solar (or other RE) mini-grids for all electricity uses	**Grid power** for all electricity uses	✖	✓	✓

✓ = satisfies criterion; ~ = partially satisfies criterion; ✖ = does not satisfy criterion; ? = unknown

Assessment of energy transition leapfrogs

- **Wind and solar are successful leapfrogs for low-cost, bulk generation in emerging market grids.** Piggybacking off of the massive cost reductions achieved in mature markets, emerging markets have successfully installed grid-scale wind and solar farms, substantially reducing the need to build out central station fossil fuel generating units (along with associated fuel processing and transportation infrastructure). For example, grid-scale wind and solar together make up more than 20% of nameplate electricity generating capacity in Kenya, a significantly higher share than mature markets achieved at an equivalent stage in their development trajectories [5].

- **Wind and solar create a need for leapfrogs to match supply and demand.** Because they are not dispatchable, wind and solar must be paired with other technology to match supply and demand on the grid at every location and moment in time. Traditionally, this reliability services role has been filled by "peaker" generators running on fossil fuels, ideally natural gas for its relative cleanliness and operational flexibility. However, gas infrastructure and markets are costly and difficult to develop in countries that do not already have them. This creates demand for reliability services leapfrogs that could serve as workarounds.

- **Batteries for time shifting energy are not yet fully proven in mature markets, except where there is ample dispatchable generation for backup.** California leads the way in time shifting renewable energy with batteries to help match supply and demand over the course of a day, but this success has only been achieved with a significant capacity of existing dispatchable generation (and at a significant cost) [6]. Batteries also have limitations at present when it comes to cost-effectively time shifting energy on longer timescales. Emerging markets should be wary of counting on a battery leapfrog to address near-term challenges of grid integration of wind and solar.

- **Green hydrogen has no characteristics of a successful leapfrog at present.** Mature markets are exploring the possibility that "green hydrogen" produced via renewable-powered electrolysis of water could serve as a zero-carbon energy carrier to compensate for short- and long-term fluctuations in wind and solar. However, this technology has not yet been proven financially or operationally. While the hydrogen pathway might one day obviate the construction of additional fossil fuel infrastructure, at present it is likely to require far *more* expensive infrastructure, including due to hydrogen's tendency to embrittle the steels used in pipelines. While hydrogen might theoretically provide advantages to energy suppliers or consumers at some future point, such potential benefits are years away from being demonstrated even in mature markets.

- **Dynamic pricing of electricity merits exploration as a possible leapfrog.** Electricity consumers in mature markets are mostly accustomed to paying a flat marginal price for electricity irrespective of system conditions. In a market with significant variable renewables, dynamic pricing of electricity would allow customers to reduce demand (and save money) when supply is tight, especially if coupled with smart technology that makes it easy for customers to do so. This can reduce overall costs by avoiding the need to build as much new dispatchable generation. The smart meter technology required to implement dynamic pricing is widespread in mature markets. However, few markets have actually implemented dynamic pricing, so the more important demonstration gap is in the pricing mechanisms themselves. Still, this may be a leapfrog worth exploring, given that:

1) Dynamic pricing of electricity is likely to be crucial for matching supply and demand in electricity markets with very high shares of wind and solar;

2) The key technologies for dynamic pricing have been demonstrated; and

3) There could be advantages to having electricity customers acclimate to dynamic pricing earlier rather than later in the development of electricity markets.

- **Distributed solar for commercial and residential users has been partially successful as a leapfrog.** Commercial and residential customers throughout sub-Saharan Africa have shown rapid, organic adoption of distributed solar in both grid-tied and off-grid applications [7]. Distributed solar technology was already commercialized in mature markets, and in emerging markets, it serves as a workaround to unreliable and/or expensive grid power. Its shortcoming as a leapfrog is that, even with battery backup, distributed solar can't match modern grid power (or even diesel generators) when it comes to letting users draw as much power as they want, whenever they want it.
- **Solar-powered mini-grids still lack cost-recovering demonstrations at a system level.** Mini-grids powered by solar (or other renewable sources), with battery backup, could in theory allow higher power levels and more user flexibility than distributed solar that isn't shared. Mini-grids could be an especially useful workaround in remote locations where central grid power is unlikely to be available soon. However, their shortcoming as a potential leapfrog is that cost-recovering demonstrations are still quite limited, due to challenges including fewer economies of scale and difficulty accommodating fluctuations in demand and renewable supply in comparison to a large central grid [8]. It may be that, rather than being a leapfrog, mini-grids are better thought of as a workaround for energy supply in remote areas until mini-grids can be stitched together into a larger central grid [9].

While others might assess the above technologies differently, the key point is that the often amorphous concept of an energy technology leapfrog can be made more useful by:

- Being specific about which new technology is leapfrogging which incumbent, and in which specific application; and
- Considering whether a new technology has the three key attributes of a successful leapfrog, that it is: ***1) well-demonstrated in mature markets, 2) useful in emerging markets as a workaround that avoids the cost and difficulty (including institutional obstacles) associated with building out traditional infrastructure, and 3) equivalent in functionality (or, ideally, better) for the user than the technology being avoided.***

Endnotes

1. José Goldemberg, "Leapfrog energy technologies," *Energy Policy* 26(10), 1998.
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