By the TiLT Capital Partners team, on September 13th, 2020

Energy is not a mere technicality anymore…

For anyone that has been in the energy sector for the last 20 years, it has been quite a rollercoaster ride to say the least. From the Enron debacle, to the European Green Deal, through the emergence and investment boom in renewable energies, to the cleantech and shale hydrocarbon bubbles, **the energy sector has been turned upside down** and now sees a new paradigm emerging.

The novelty of this paradigm shift is the **rapid intrusion of multiple technologies in the sector**, and the fact that these technological shifts come **from outside the energy sector**.

For about 200 years and up to the turn of late 1990s, energy was shaken to its foundations by the surfacing of absolute game changers every 50 or 100 years: steam engine, electrical engines, alternative current transformer, internal combustion engine and nuclear power. **Energy technologies have been at the heart of the first two industrial revolutions**, liberating industry from energy scarcity or from insurmountable logistical challenges such as heavy-duty transportation.

This led to radical transformations of the economic system and of society, by profoundly modifying travel times, industrial output and computing capabilities. **The energy system was hence subsequently rhythmed by the technical optimization of these technologies**, until the next disruption happened.

The word "disruption" is not used loosely here: the Cambridge dictionary defines disruption as "*the action of completely changing the traditional way that an industry or market operates by using new methods or technology*". **Disruptions are meant to be important in magnitude, profound in their consequences and go beyond the mere technological prowess**, generating:

- An industrial expansion on a global scale;
- An evolution of public policies and regulations to create new standards;
- A transformation of infrastructures (transportation, telecommunications, etc) to adapt to new usages;
- Social evolution, whereby behaviors are transformed and integrate new usages.

Indeed, a new paradigm has emerged over the last two decades. **Digital technologies and deeptech introduced a high pace of rapid technological evolution that disrupts almost all aspects of the energy system**. The implications for investment in this strategic sector are radical, as they modify the payback cycles, the risk-return profiles, the market designs as well as regulations.

In this paper, we try to give an overview of **the implications for the sector and for investment of this shift from technical optimization to technological innovations**.

A bit of history…

To understand how deeply intertwined energy disruptions and industrial revolutions are, it is worth taking a helicopter view of these "energy" disruptions and how they transformed our economic system and way of life as part of past (or current) industrial revolutions. The following table provides such a view[1]:

	Technological disruption	Year / Period	Energy vector	Implications
1st industrial revolution	**Steam engine** (Denis Papin / Sadi Carnot / Thomas Newcomen / James Watt)	1769-1788	Coal	- Increases the work power vs. other forms of energy - Stable energy production, key for industrial applications - High power to weight ratio, allowing for transportation applications - Replaces hydraulic engines, less suited for industrial applications - Allows for the development of machine tools - Mechanized cotton spinning increases 500x output per worker
2nd industrial revolution	**Electrical engine** (Michael Farady / Zénobe Gramme / Nikola Tesla)	1831-1888	-	- Electrification (lighting, household appliances) - Emergence of assembly lines as electricty enables placing of machine tools in the order of work flow - Dramatic improvements in occupational health and safety - Electrification of bulk transportation, notably railways - Speed variation allowing for precise output control
	Alternative current transformer (Lucien Gaulard / John Dixon Gibbs / Nikola Tesla)	1882-1888	-	- Allows for transportation of high power output on long distances - Introduces the notion of system balancing thanks to rotating power - Drastic reduction of losses due to Joule effect
	Internal combustion engine (Barsanti & Matteucci / Etienne Lenoir / Nicolaus Otto / Karl Benz / Rudolf Diesel)	1860-1892	Gas / Oil products	- Allows for harvesting energy of high density fuels such as Oil - Combined with oil, sets the basis for the mass development of the automotive industry - Enabled the aerospace industry - Basis for gas fired power generation
	Hydroelectric turbine (James Francis / Aristide Bergès / Lester Pelton)	1848-1878	Water flow / gravity	Thanks to its high power output (compared to available alternatives): - Defining innovation for the emergence of metallurgy - tied directly to the development of electrical arc furnace (Paul Girod) - With AC transmission, opens high voltage transportation era
3rd industrial revolution	**Nuclear energy** (Enrico Fermi / Leo Szilard / Eugene Wigner / Alvin Weinberg)	1942-1956	Uranium	- Harnesses high density fuel (~2 million times denser than Oil) - Central to matters of energy supply security and independance for many countries from fossil fuels - Enabled by computer science advancements

This schematic of industrial revolutions over time calls for t**wo comments that are key to understand the current evolutions:**

1) The **second industrial revolution**, the root of modern economy, was actually a roughly 50-year period in which **a complete ecosystem** of scientists, inventors and entrepreneurs led to the emergence of a coherent and comprehensive industrial system. It was furthermore backed by political evolutions and a strong intellectual movement that appeared towards the late 18th century.
2) Mass adoption of computers is often coined "the 3rd industrial revolution". It profoundly changed work organization and led to a dramatic increase in productivity. But this revolution had little to do with energy, rather with materials (silicon) and computer sciences. Yet, as electronics developed, it paved the way for an increasing use of electricity in society. **Nuclear energy became part of the answer but did not trigger nor foster this 3rd industrial revolution**. As such, it departed from the traditional causality chain of the first two revolutions, in the sense that it was enabled by computer science and not the reverse.

[1] This table aims at giving **a** historical perspective. Disruptions do not happen by the will or inventiveness of one person but when an ecosystem allows them to emerge. Also, the attribution of an invention to one or a few individuals can be difficult, we kindly ask you to refer to much more precise sources for a deeper dive in each technology.

But as this evolution coincided with a massive surge in electric consumption, nuclear in turn appeared as a technology of choice for providing vast amounts of energy and for diversifying away from fossil fuels in the wake of the oil shocks.

The implication of the disruptive nature of these technological innovations was that **any competing technology was sidetracked and abandoned or confined to niche markets**. As a consequence, economic rationality called for the energy sector to focus on optimizing these disruptive technologies, as there was no perspective for the emergence of alternatives that could displace the pillars of such transformational technologies.

An example of such continuous, **long-term technical optimization can be seen in the history of the internal combustion engine**, which efficiency increased 30% between 1860 and 2010[2], despite being a 150-year-old technology.

Technical optimization: the legacy law of the energy system

This technical optimization process, enhanced by sporadic technological advancements, has been akin to **a law in the energy sector**: just as it is the case for internal combustion engines applied to the automotive industry, it is also the case for gas turbines, steam turbines, electric motors, etc. Hence the prominent role played by technicians and engineers in the sector, as they were tasked to **constantly optimize the efficiency and durability of the energy assets they were managing**.

Another important consequence of this optimization process was the **low displacement risk of an energy asset** : notwithstanding market risk or negligence, an energy asset (be it in generation or in transportation and distribution) had little chances of becoming stranded before its payback period was achieved. If a brand-new Combined Cycle Gas Turbines appeared in the market, it would have a 2-3% efficiency advantage over existing plants, displacing only the older ones, generally long amortized. The optimization process furthermore enabled older assets to benefit from new designs, new solutions to bridge the gap with the newest generation (dry-low NOx burners, higher heat resistant materials for heat exchangers, etc.) and new operating patterns (lower technical minimums, by-passes, etc.).

Finally, this process was **at the heart of the oligopolistic nature of the energy system**: to survive and thrive in this sector, one had to 1) own a diversified portfolio of assets, requiring significant capital (multi billions of €) and 2) have a large qualified team of professionals able to operate and optimize this portfolio, ideally better than the few other competitors.

Yet, **over the last 15 years, this feature has been put to the test by unprecedented technological evolutions** outside the energy sector that brought down most entry barrier that applied to this sector until the early 2000s.

And then, energy did not drive the revolution…

Towards the mid-2000s, renewable energy sources– mostly wind – started being in the radar of energy incumbents. Actually, the quiet revolution had been going on for at least a decade : small developers had been assessing wind resources, developing the first wind farms for utility scale

[2] Source: Q. Xin, C.F. Pinzon (2014) "Improving the environmental performance of heavy-duty vehicles and engines: key issues and system design approaches", in **Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance**

purposes, and OEMs such as Vestas, Enercon, GE, Siemens, etc. were seeing their order books growing at dramatic pace as they improved both the scale and technology of wind turbines.

Remarkably, **incumbents - with the exception of Iberdrola - failed to see the disruptive nature of renewable power before the surge of the late 2000s**. Entrapped in the oligopolistic model mentioned above, these large players failed to see how small subsidized assets could possibly disrupt the energy system. They continued investing massively in the traditional energy assets, betting on their market power based on strong balance sheets and technical expertise.

Yet, the implications of wind development, and even more so of solar development a few years later, were massive and built on **a convergence of trends**:

- For the first time in history, electricity could be **produced by small players with limited capital**: a €5m to €10m initial capital and cheap financing against highly contracted assets enabled small players to borrow large amounts of money to finance renewable assets and build impressive portfolios and become a participant to the energy generation sector.
- Wind and solar assets are developed as utility assets but are governed by a physical resource constraint: land availability. The consequence is a **much lower granularity of generation assets**, spread across a geographic area. Decentralized solar took this feature to heightened levels. **The challenges it posed to grid operators**, both as TSO and DSO levels, appeared quickly as a transforming feature of the industry.
- Renewables benefited from significant subsidy schemes (although much lower than fossil fuels, even today still[3]) on the backdrop of policies aiming at fighting climate change. But as costs came down, **they became a low short run marginal cost energy supply** (10 to 20 €/MWh), much cheaper than fossil-fuel based generation assets. This announced the dramatic decrease in energy prices seen in Europe, combined alas with the 2008-2011 crisis, and led to electricity prices falling at times below zero.

Renewables development announced the fall of high entry barriers in electricity generation, but also the more distributed nature of the energy system as well as the trend towards decarbonization. On top of that, it **illustrated the shift between a sector driven by technical expertise to a sector that was set to become more and more impacted by technological evolution**.

Technical optimization of renewable assets is indeed limited: they require some surveillance of rotating parts (gearboxes in particular for wind turbines) and a bit of cleaning, but almost no technical management. Genuine efficiency gains in wind and solar assets came from blade design, evolution in drive technologies, improvements in solar cell efficiency through materials science, to name just a few.

In this respect, renewables development has **strong ties with the emergence of the 4th industrial revolution**, which is hardly a mere continuation of the digital revolution of the 1970s and 1980s. The main characteristic of this revolution is a **convergence of technologies**: artificial intelligence, robotics, the Internet of Thingsthings, autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing are all components of

[3] See IRENA (2020) **Energy subsidies - Evolution in the Global EnergyTransformation to 2050**. Out of the $634bn of energy subsidies globally in 2017, 447bn went to fossil fuels and 128bn to clean techs.

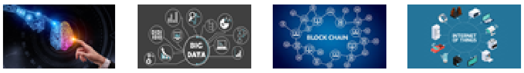
this revolution. No single technological development can be identified as the founding pillar of this revolution.

All of these profoundly impact society: from the way we work, we move, we shop, etc. **The world is becoming more decentralized, electrified and digital**.

In terms of energy, the emergence in the 2010s of some key technologies offers the perspective of transforming the way the energy system has been organized for nearly two centuries. **Digital technology and deep tech advances completed what RES development initiated**.

Digital technologies

Artificial intelligence, big data, blockchain, IoT

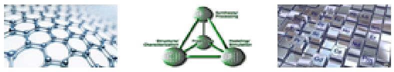


Energy applications

- Sensors and metering
- Building information management => smart buildings
- Digital twins for energy efficiency
- Virtual power plants and virtual power lines
- Smart grids and congestion relief
- Mini-grids and multidirectional electricity flows system
- Generative adversarial networks
- Virtual market access infrastructure for new entrants
- Decentralized assets management and aggregation
- Vehicle-to-grid management
- Predictability algorithms (consumption, generation and storage management)
- Demand - Response
- Energy data visualization and home energy management
- Energy communities with peer-to-peer trading

Deep tech

Nanotechnology, materials science and chemistry



Energy applications

- Efficient fuel cells with decreasing costs
- Efficient electrolyzers with decreasing costs
- Energy storage (Lithium-Ion, flow batteries, solid storage)
- High temperature thermal applications (higher efficiency)
- Improved sensor and metering capabilities
- Wind farms with direct drive (removing gearboxes)
- High efficiency solar cells (including multi layer solar cells)
- Organic Photovoltaics
- CO2 capture and processing
- Power electronics (Gallium Nitride, Silicon Carbide, etc.)
- Low losses networks
- Radiative cooling
- Electric vehicle development (higher range, lower costs)

The striking feature of all these new applications in the energy sector is that they all reinforce the **trends towards decentralization and smaller granularity of the energy system, and faster pace of innovation**. The latter is especially important as these technological advancements often come from other industrial sectors, triggering quicker adoption and mass scaling (Electric Vehicles (EVs) for batteries, consumer electronics and EVs for wide band gap semiconductors, peer-to-peer trading for blockchain, etc.).

When looking back on the disruptions that impacted the energy sector, the consequences are quite mind-boggling:

1. **Entry barriers have fallen from generation to retail**, putting incumbents in the dire situation of reinventing a business model while managing the decreasing profitability of large legacy assets providing bulk of their dividend base. As a result, these incumbents will represent a fraction of the investments needed in this sector. To give an idea, European Utilities account for €50-60bn investment per year, while the European Commission estimates the necessary investment for a genuine energy transition at €575bn per year[4];

[4] Please see TiLT Perspectives #4 for an analysis on this topic. https://sites.google.com/tilt-capital.com/new-website/blog?authuser=0#h.p_5h7QWOY_P43w

2. **Clients** once blindsided are becoming not only **more informed** of their energy consumption and patterns, but also **active players** of the energy system. Home appliances and equipment become energy assets as part of aggregation business models, targeted by new entrants as new sources of revenues (by providing grid services for example);
3. Because of the pace of innovation in other sectors, **long investment cycles** that were the rule in the energy sector are **put to the test** as rapid cost decrease and technological breakthroughs threaten constantly to make an asset stranded. Even the more airtight fossil fuel based PPAs cannot withstand massive cost decrease of competing technologies such as solar or wind, as seen for example in Chile, where coal and gas based PPAs were denounced in the wake of the dramatic cost decrease of solar power in the country, offering a much more appealing alternative.
4. Policies encourage this shift, **but regulations have a hard time keeping up with the pace of innovation** and the way it shifts value from one segment of the chain to the other. The EU-ETS, combined with RES targets, has enabled Europe to organize the progressive shift towards decarbonized sources of energy. Yet, these regulations had to be adapted to account for new realities, for economic downturns, etc. **The work lying ahead for regulators is particularly challenging**, and of massive importance to ensure that investments will flow.

What does this mean for investors in the energy transition sectors?

First, it requires a **constant monitoring of the developments in the energy sector**, calling for an understanding of the interlinkages between technologies, markets, and regulation. But it also requires to keep an eye on developments in adjacent sectors, creating a whole new challenge for the investment teams.

Second, **skills will need to adapt**. An intimate understanding of the energy sector will be the basis for grasping the possible impacts of technological evolutions on different segments of the value chain. But digital and marketing expertise for example will certainly take more importance, as well manufacturing experience.

Third, it necessarily **questions the sanctity of "long-term contracts" and long-term business models**. Whereas historically, an energy asset backed by a long term contract was akin to a bond, it is today more likely to be challenged by emerging technologies, forcing clients to assess the merit of denouncing a deeply out-of-the-money contract.

Fourth, **partnerships will be essential** to the emergence of players able to scale and to lead this energy transition. Partnerships between different types of investors, between public and private entities, between multinational companies and SMEs.

Eventually, the paradigm shift that made the energy sector go from an oligopoly based on technical expertise to an ecosystem of players driven by technological disruptions **opens massive investment opportunities**. Short term, it calls for allowing **new players to emerge as solid SMEs or midcaps**, bringing to market sound and relevant solutions to the challenges of the sector. Longer term, it should lead to a **rebirth of large energy corporates** that will have managed their legacy assets and that will be able to become large scale aggregators and deployers of these new solutions.

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