Physical Internet
Efficient Sustainable Logistics
4th INTERNATIONAL
PHYSICAL INTERNET CONFERENCE
4th-6th July, 2017 in Graz: Graz University of Technology, Austria

Hyper-connected Modular Renewable Energy Production

Changliang Liu[1] , Suzanne Marcotte[2] , Grainne Lynch[3], Stephen Spulick[4]

1. CILT (London), CIRRELT, and McGili, Montreal, Canada
2. Department of Management & Technology, UQAM and CIRRELT, Canada
3. Enterprise Systems Partners (ESP), Cork, Ireland
4. U.S. Army Medical Materiel Agency, Maryland, United States of America

Corresponding author: liuchangliang.mcgili@gmail.com, marcotte.suzanne@uqam.ca, grainne@lynchpin.ie, stephen.spulick@gmail.com.

Abstract: *To develop and pilot the concept of hyper-connected modular and decentralized production, we should rethink Edison's vision of producing electricity on one's own. In other words, a PI-enabled Realization Web will be designed with self-supplied PI-facilities (nodes), which could form the micro-energy network with self-production, supply and utilization. This is a decentralized and hyper-connected renewable energy production network. This counters Westinghouse's idea to provide centralized electricity to nodes via transmission lines, which leads to the current conditions of electricity production using fossil fuels and hydro power.*

world. Tenders are currently being won at less than $30/MWh. This will continue to fall by an estimated 10% per year for the next 10 years (Rifkin, 2015).

A better future aligning with the Physical Internet (Realization Web) is the mega & micro-energy network featuring a large number of small power sources located near the end-users, rather than a small number of large sources located far away (Montreuil, 2011). At first glance, this shift toward micro-power may seem like a return to electricity's roots over a century ago. Thomas Edison's original vision was to place many small power plants close to consumers. The grid will be transformed into a digital network capable of handling complex, multi-directional flows of power (Edison, 1883). Mega-power and micro-power systems will then work together. Therefore, diversifying the energy mix will be crucial in the evolving Energy Internet Era.

The objective of this research is to identify the gap between the academic and industry perspectives in the field of clean energy industry, to envisage and design the integrated renewable energy network from the whole system perspective, and finally to introduce the proposed solutions for the potential market in an effective and efficient way. The remainder of this paper is structured as follow. Section 2 presents the background while section 3 presents the problem addressed and the objectives of this research. Section 4 then presents an analysis and provides insights and solutions. Finally, section 5 introduces the next steps that we propose for future research.

2 Background

2.1 Supply chain process perspective

A renewable energy service supply chain is critical in modern life, from its generation, transmission and distribution up to its consumption and storage. Assessing the renewable energy flow from the supply chain perspective is described in Figure 1 below:

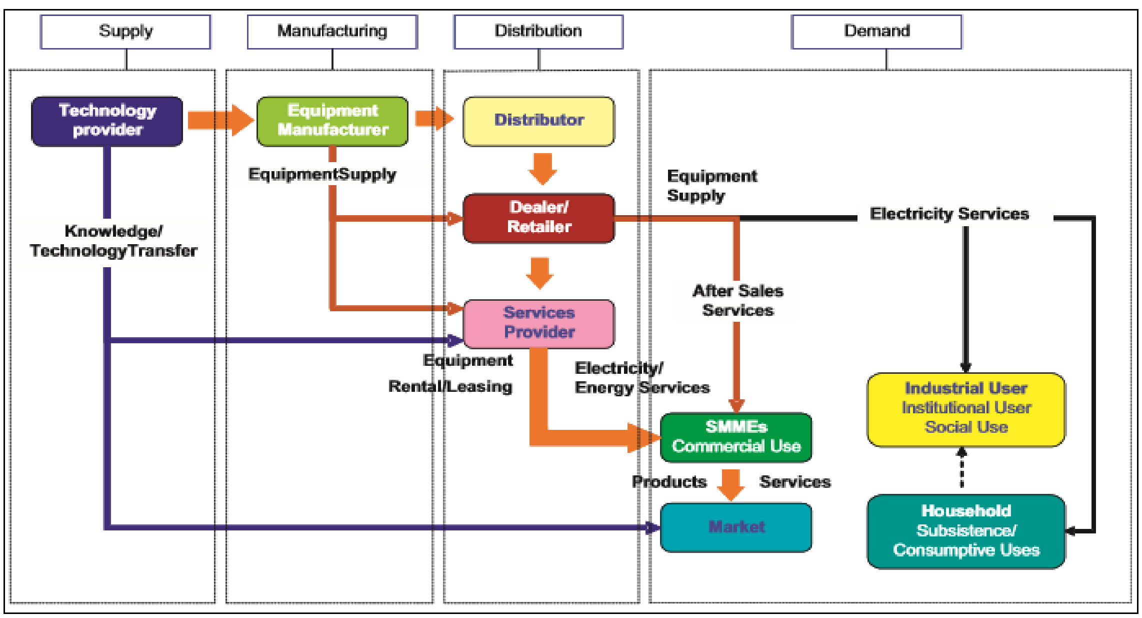

Figure 1: Renewable energy (RE) supply chain process, adapted from Wee and Yang (2012).

If we look at the investment statistics of RE in 2016, more for less (more RE installations with less capital invested) phenomenon happens, major reasons why installations increased even though dollars invested fell was a sharp reduction in capital costs for solar PV, onshore and offshore wind. Renewable energy (excluding large hydro) accounted for 53.3% of the new electricity generating capacity added worldwide in 2016, the highest proportion in any year to date.

Transforming today's centralized power grid into something closer to a smart, distributed network will be necessary to provide a reliable power supply---and to make possible innovative new energy services, such as the Brooklyn Microgrid (BMG) in New York City and Demand Energy Enel in Germany (2017). The technology exists to enable a radical overhaul of the way in which energy is generated, distributed and consumed, an overhaul whose impact on the energy industry could match the internet's impact on communications. The distributed network will bring direct impact on the renewable energy production and storage, in terms of their locations, energy management analytics and related optimization techniques, and also will bring indirect social impacts, for example, it will give consumers more choices to select as energy sources.

The structure of the electricity market continues to be a challenge not just for renewable energy developers but also for energy ministries around the world. There is the issue of how to reward flexible generation and storage, so that the system is always able to respond when wind and solar production drops. The other challenge is the political regulation; different regulations limit the research and massive renewable energy project's scale development in the solar and wind industry. Unless regulators restore the economic incentives for investment, the future looks bleak. Apart from that, Crypto-currencies like Bitcoin could enable a truly independent peer-to-peer and global collaborative commons by providing a decentralized means to directly exchange verifiable value. Solar energy has now reached its singularity, a tipping point beyond which a technology grows exponentially. Energy transformation has never before been this fast. Similar to mobile phones and cars, solar and wind will follow an S curve of growth. We are just at the start of an energy revolution driven not only by climate change but by simple economics.

2.2 Centralized Network

From the long history of the energy evolution, there are significant disadvantages in the capacity market (which means the centralized energy network), which cause the current conventional energy dilemma. Here are some of the main disadvantages. Dirty energy generation exceeds consumption in a greatly imbalanced way. The weather and human errors frequently led to blackout. Overall, the end-consumers had no choice but rely heavily on the monopoly of power companies; the delayed maintenance response and huge cost from macro-grid network are not sustainable in the long term. Therefore, a new style of energy demand is needed: provide cheap, clean, reliable power in the face of new technologies, new types of user behaviors and an all-encompassing need to address climate change.

2.3 Decentralized Network

In the Integrated Grid Network, the core components are the micro-grid (wind and solar power in the smart house, apartment and hospital), energy storage technology and macro-grid. Our focus in this research is the micro-grid, to try to bridge the gap between the academic and real implementation in practice. According to Bloomberg New Energy Finance (BNEF), renewable energy sources are set to represent almost three quarters of the $10.2 trillion the world will invest in new power generating technology until 2040, as rapidly falling costs for solar and wind power, and a growing role for batteries, including electric vehicle batteries, in balancing supply and demand (BNEF, 2017).

Towards a demand-led energy system, the key components include the control centre, energy storage and micro-grid, complementing with the macro-grid as shown in Figure 2. Many owners of photovoltaic (PV) plants make use of the battery storage solutions to harness the energy of the sun even when it is not shining. This allows them to cover much of their own energy needs with green solar power. Higher-capacity battery storage facilities are also available these days. Not only does the utility distribution network need an upgrade to support the influx of renewable energy generation to the grid system, it must also consider that without local energy storage, the network is seriously inefficient. Energy storage is crucial to protect the vulnerability of the grid and to more effectively manage supply with demand.

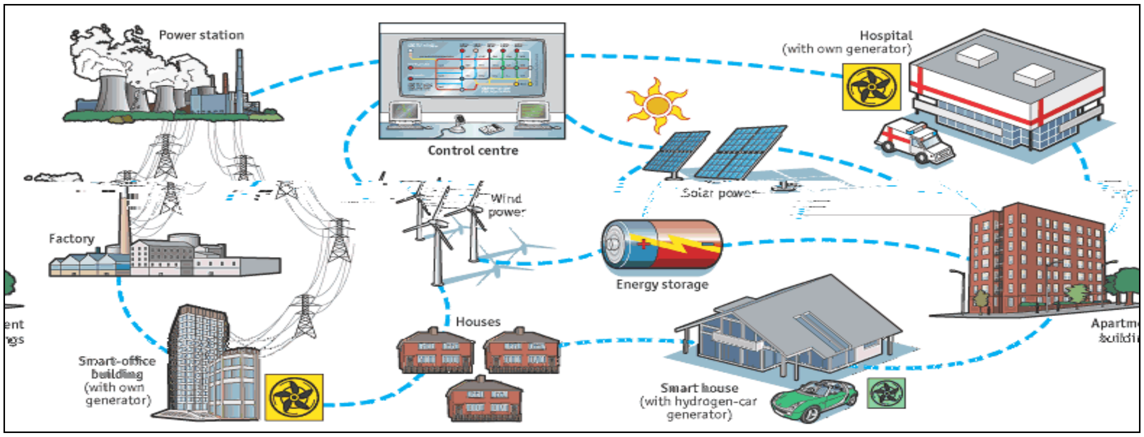

Figure 2: Integrated Grid in a distributed energy network, adjusted from Economist (2004)

For TESLA as an example, energy storage has the potential to represent a $12 billion market in the following five years. The ability to provide the network infrastructure to support energy storage and local distribution with EV recharging stations provides TESLA with a competitive advantage. The combination of the new highly efficient panels, the volume of product coming out of a new factory, and a simplified manufacturing process (automation and customization) is a big reason why the TESLA (SolarCity) expects its costs for residential solar to fall well below $2.5 per watt by the end of 2017, when the Buffalo facility reaches full production. At that point, the solar panels coming out of the Giga-factory (TESLA's massive plants in the solar industry) may seem as conventional as commodity panels produced in China today. It is, however, SolarCity’s willingness to take on such risks that makes the Buffalo facility so ambitious. Over the last 10 years, the Silicon Valley company has made residential solar a popular choice for many consumers through smart marketing and attractive financing. Now it wants to transform solar manufacturing. Whether SolarCity succeeds or fails, it is once again pushing the possibilities of solar power. Efficiency matters because the panels themselves represent only 15 to 20 percent of the cost of the full installation. Much of the rest comes in what’s known as balance-of-system costs: inverters to connect to the grid, materials to house the array, nuts and bolts to attach it to the roof, the labor to install it, and so on. SolarCity’s installation will require one-third fewer panels to produce the same amount of electricity as conventional installations. “Fewer panels means fewer bits and pieces, less wire, less days on the roof to install.” (Francis, 2017).

3 Problem and objectives

One of the reasons why we focus on micro-grid is that it will play a great role in a demand-led energy system. The power markets are very complex, and the supply has to meet demand, everywhere in the system, at every moment. However, its complexity can be broken down into sub-problems and we just need to focus on the fundamental issue across the renewable energy generation flows. The second key design principle of the power market of the future is suitably matching supply and demand, to a large extent, placed on power retailers, as they are near the end-consumers, they hold customers’ consumption and transaction data, which are more valuable than the one owned by generators, transmission, distribution system operators, and also regulations or policy-makers (Michael, 2017).

In terms of the micro-grid performance and its sustainability goals, we need more research on them. In this innovation paper, we will focus on the micro-grid, through analyzing identified case studies, comparing and contrasting the two different business models in the power industry: Tesla (2017) and Brookyln Microgrid (BMG) in U.S.A, Himin and Global Energy Interconnection Development and Cooperation Organization (GEIDCO) in China (2017). The goal is to conduct a research initiative and investigate on the renewable energy production in a decentralized way, and have extended research based on the hyper-connected modular and mobile production (Marcotte and Montreuil, 2016), to set up the link between Physical Internet and Energy Internet towards a hyper-connected Physical Internet era.

With the expansion of sustainable renewable energy, it is gradually shifting its position as an alternative choice into the main stream energy sources, and the requirements for an intelligent, flexible power grid are increasing. The climate-friendly production of electricity will only fully pay off if the grid is able to handle all of the electricity that is generated. This requires the role of the distribution system operator to change from a reactive to a proactive one. The 'Proactive Distribution Grid' needs to assess how exactly that proactive, formative role will look. Table 1 illustrates the main constraints across the renewable energy service supply chain, from perspectives of input, goals (indirect and direct), to give clear direction for research and development. We have identified as direct goals the ones pursued in our research, while the indirect goals are expected to be indirect improvements achieved through the direct goals.

Table 1: The key identified constraints across the RE service supply chain, adjusted from Wee and Yang (2012).

	Supply	**Production**	**Distribution**	**Demand**
Input (constraints and characteristics)	• Technology limits • Intermittency • Variability • Maneuverability	• O & M costs • High investment • Cost too high • Technology limits		• Government policy • Substitution effect
Indirect goals	• Land usage • Water consumption	• Employment	• Employment	• Social impacts
Direct goals		• Location • Conversion efficiency	• Distribution efficiency • Storage	• Environment impacts

The main objective is to make grid operation flexible. A key principle in this context is the 'traffic light concept' for describing the interaction between market and grid. Therefore, ideas for optimally fleshing out the traffic light concept in terms of the technology and organization need to be developed. Network optimization will be important to dynamically design and flow the value in an efficient and effective way.

4 Analysis and solutions

4.1 Analysis

In this innovation paper, the concept of "supplying electricity in a decentralized way" has already attracted ample attention from the academic and industrial stakeholders. We are now at the singularity in the self-sustained energy disruption times. More impressive disruptions taking place in energy storage, electrical vehicles (EVs), digitalization and smart energy demand, will facilitate and accelerate the self-sustained disruptive nature of solar.

Since solar and wind power are energy technologies, not energy resources, their growth offers increasing opportunities, not challenges, when compared to conventional resources. But we should be mindfully optimistic about its future when rethinking the renewable energies (RE) manufacturing process and their respective value propositions in this particular energy market, to have the decentralized energy network with a large pool of prosumers (producers & consumers). We will compare and contrast the macro and micro grid projects between China and U.S., with specific measurements in terms of its performance and carbon emissions; than we propose a future that energy mix will be a way out for the sustainable lifestyle. Table 2 shows a preliminary comparison between the actual proposed projects.

Table 2: E-macro vs E-micro vs E-mix

China	China	USA	USA
Geidco	Himin	Tesla	Brooklyn MicroGird
High voltage transmission	Sustainable lifestyle on solar	Giga-factory within solar industry	Co-op business model across micro-community
NGO	Private	Private	Private
One Belt One Road	Micro emission earth strategy	Solar energy with EV and Smart home	DRE practice based on bottom-up approach
Macro-grid	Micro-grid	Macro-grid	Micro-grid

4.2 Proposed solution

Microgrid Prosumers Dashboard (MPD)

In the demand-led RE landscape, prosumers can identify the core data from their own dashboard, which give them a clear and transparent view on the energy generation, consumption and transaction flows.

As micro-grid gives prosumers more free choices concerning energy self-usage or trade in the micro-community, they can monitor the dashboard to make decisions on the quantity that they will sell and to whom, this is in the case that the prosumers produce sufficient energy in their own RE sources. On the opposite case, if it works as well, the Microgrid Dashboard can decide how much will be used and which neighbor to send his/her excess energy to.

The Dashboard also allow prosumers to store power in their own batteries to provide energy when the sun does not shine and the wind does not blow, as well as to set the interface to sell the excess energy to the existing major transmission and distribution network in case of extra energy. Figure 3 gives a view on an example of a dashboard.

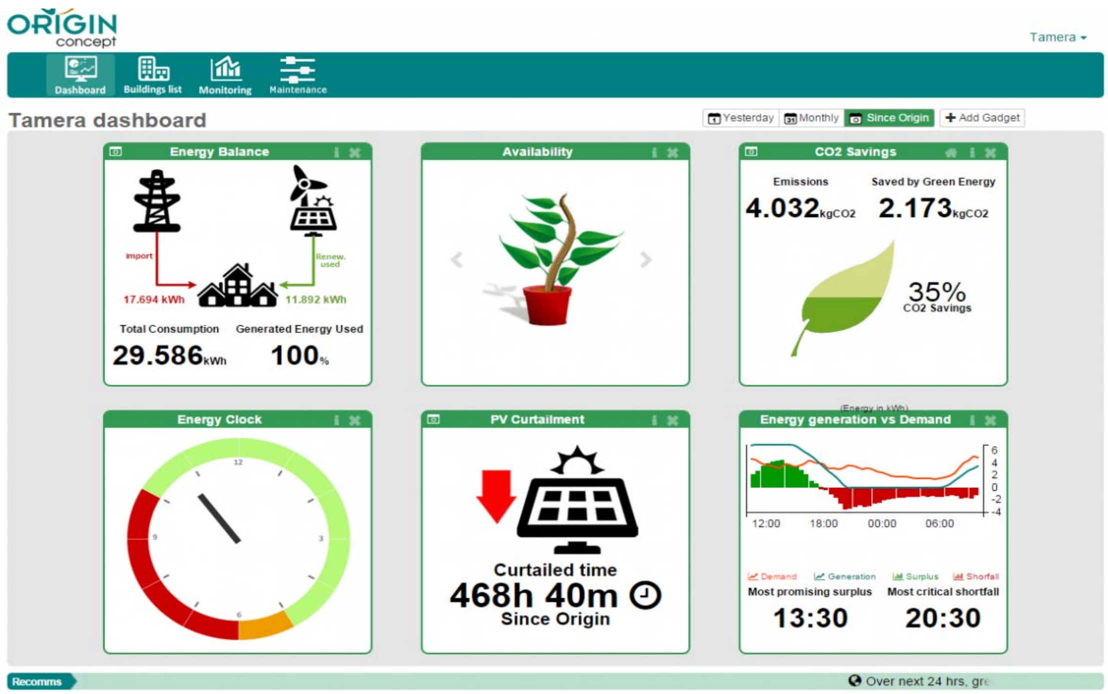

Figure 3: Dashboard, adjusted from Origin concept, adjusted from Peacock et al. (2017)

5 Next steps

5.1 Artificial Intelligence

The challenges remain in the following three aspects: Firstly, the mindset shift from the ownership to access in the coming zero marginal society, the emerging Realization Web and Supply Web will be the first enablers during the critical transformation; Secondly, Artificial Intelligence Management (AIM) in the energy service supply chain, for organizations in traditional energy industry, the question is no longer whether they should consider adopting AI in their business and strategy processes, the question is what their AI strategy should be and how to implement that strategy. For example, the solar panel system, battery storage and artificial intelligence tool can be integrated as a service for residential and industrial use, which will be transparent and cost-effective in the coming decades. Last but not least, as mentioned in the context above, the upgraded energy policy will be critical when the technology innovation is moving faster than regulations in the 21st century. It will have significant impact on the redefined market and enabling collaborative commons mindset.

5.2 Co-optimization & Mobile and Modular Logistics Unit Innovation

In the foreseeable future, with the introduction of cutting edge analytics, smart meters and software solutions, the prosumers will be more productive, as they have the potential tools to combine and process energy usage, on-site rooftop generation, thermal and electric storage, and even electric vehicle charging. They analytics can help aggregate the demand requests from the different layers and respond in an intelligent and cost-effective way. They will be able to co-optimize all resources against forecast weather conditions, basic usage demand, market reliability information and capacity market prices, in order to help them minimize the impact of reliability events and leverage excess capacity.

"Mobility as a service" is emerging in the open and sharing transportation market, with the Physical Internet prototype containers also emerging, the potential integration between PI trailer (equipped with mobile) PI-box and solar PV on the top is appearing as a further research avenue.

6 Conclusion

One of the biggest utility trends is the migration from centralized distribution to a distributed grid where more generation is pushed to the network edge. To effectively interface with the electric grid, energy storage and visibility into generation and demand are required. Strategically, the integrated and distributed grid is the foundation of the global economy for both service and manufacturing industries. The distributed grid is also required to improve national security from intrusion and manipulation of the grid. Building decentralized manufacturing networks, empowered by Industry 4.0 and technological enablers such as 3D printing, that could collaborate (vertically and horizontally) in order to increase efficiency of transport, could support this process and provide the hub with a higher role in the whole network, the modular renewable energy production unit will be the challenges related to the realization web, which opens the ample space for research and development for academics and industry stakeholders.

References

Bithas and Kalimeri (2016), A brief history of energy use in human societies, Springer.

BNEF (2017), New Energy Outlook 2017, https://data.bloomberglp.com/bnef/sites/14/2017/05/Liebreich-Six-Design-Principles-for-the-Power-Markets-of-the-Future.pdf?from=timeline&isappinstalled=0, accessed on 15th, June, 2017.

Demand Energy(2017), http://www.demand-energy.com/, accessed on 13th, June, 2017.

Economist (2002), Building the energy internet, accessed on 16th, June, 2017.

Edison, Thomas. (1883), Electrifying New York and Abroad, April 1881–March 1883 (Volume 6).

Francis, S. (2017), http://energy.mit.edu/area/power-distribution-energy-storage/, MIT Energy Initiative. Global Energy Interconnection Development and Cooperation Organization (GEIDCO), http://www.geidco.org/html/qqnycoen/index.html, accessed on 12th, June, 2017.

Himin (2017), http://china-solarcollector.com/, accessed on 12th, June, 2017.

Marcotte, S., Montreuil, B. (2016), Introducing the concepts of hyper-connected mobile production, IPIC 2016, Atlanta, U.S.A.

Michael. L, (2017), Six design principles for the power markets of the future-a personal view, Bloomberg New Energy Finance.

Montreuil, B. (2011): Towards a Physical Internet: Meeting the Global Logistics Sustainability Grand Challenge, Logistics Research, v3, no2-3, 71-87.

Peacock, Andrew., Chaney, Joel., Goldbach, Kristin. and Edward, H. (2017), Co-designing the next generation of home energy management systems with lead-users, Applied Ergonomics 60: 194-206. April, 2017.

Rifkin, J. (2015), The Zero Marginal Cost Society: The Internet of Things, the Collaborative Commons, and the Eclipse of Capitalism, Palgrave Macmillan, 120-156.

Wee, Hui-Ming. and Yang, Wen-Hsiung. (2012), Renewable energy supply chains, performance, application barriers and strategies for further development, Renewable and Sustainable Energy Reviews 16 (2012) 5451-5465.

SolarCity (2017), http://www.solarcity.com/residential, accessed on 12th, June, 2017.