Integrated Strategic Action for Facilitating the Electrification Process

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***Abstract* - Energy sector is at crossroads facing fundamental changes across its entire supply chain. The surge of new technological solutions revolutionizes the way we generate, transmit and consume energy. One of the major driving factors of transformation is the process of electrification. In order to foster and facilitate the electrification process, a multi-level strategy needs to be implemented. The aim of this paper is twofold. First, we aim to identify the forces of disruption and key areas of technological innovation in the energy sector. Second, we center on the process of electrification. In this context, five key focus areas that should be the center of a national strategic action plan aimed at reaching a sustainable energy future are determined. In order to reap all the potential benefits of the electrification process it is crucial to adopt e-mobility, improve energy efficiency, create synergy between corporate and research networks, invest in research and development to strengthen national capabilities in electric frontier technologies and raise awareness regarding the benefits of electrification. We argue that utility providers and distribution system operators act a key role in enabling the deployment of new solutions and the development of the sector as a whole.**

Keywords – energy transformation; sustainability; electrification; action plan; power sector

I. INTRODUCTION

Numerous disparate trends facilitated by raised environmental concerns are remolding energy systems across the globe. Climate change has become a global issue with a profound effect on socio-economic systems across the world [1]. The negative impact of the energy sector on the environment has the potential to cause a significant degradation of the quality of life [2]. This realization caused a stir among energy producers and policy makers. New policies aimed at mitigating climate change facilitated the surge of renewables and the proliferation of various new technological solutions aimed at achieving a low-carbon energy system [3]. In order to make further progress, additional policy action is needed. Energy sector has traditionally been highly regulated and characterized by relatively stable returns, but in recent years it is experiencing numerous changes deeply affecting the industry [4]. So far there have been three eras of transformation that had (and continue to have) a critical impact on the energy sector as a whole.

First large transformation came with the liberalization of the energy markets. Liberalization entails the restructuring of vertically integrated companies dividing their business into 4 separate entities in line with the 4 main parts of the energy supply chain: production, transmission, distribution and supply [5]. This enabled production and supply to become market-viable business areas, while distribution and transmission remained natural monopolies regulated by an energy authority. Second transformational process regards the on-going decarbonization of the energy system. Raised awareness regarding the harmful impact of the energy sector on the environment resulted in an endeavor towards achieving a sustainable, low-carbon system of the future [6]. Today, we are at the dawn of a third significant transformation – digitalization of the energy supply chain. As technology evolves, the world becomes more digital. Digitalization facilitates the optimization of processes opening countless opportunities in all segments of the supply chain [7]. In the future it will enable consumers to become more involved in the operation of the grid, potentially enabling a sting of service-orientated approaches to capturing and creating value in the energy ecosystem [8].

The paper aims to identify key drivers of change in the energy sector, pointing out some of the main issues and potentials of the transitional period. In this context, six forces of disruption and six areas of technological innovation are identified. Second part of the paper discusses electrification as an important segment of the transformation towards sustainability. Up until recently, few mitigation scenarios paid attention to electrification, but recent research shows an increasing focus on demand-side technologies [9]. Companies in the power sector are only beginning to see electrification as an opportunity for revitalizing sales and revenues [10]. Level of electrification increases with stringency of climate policy. At present, apart from the topic of rural electrification [11], there are not a lot of papers that focus on policies that would facilitate the electrification of different processes [12]. However, changing circumstances regarding the energy sector and its effects on the environment are causing policy makers and researchers to focus on facilitating end-use of electricity in different applications. This paper tries to bring some clarity on the importance of beneficial electrification as a tool in reducing carbon emissions. Furthermore, it outlines key focus areas that should be the center of a national strategic action plan aimed at reaping the benefits of electrification.

The text is organized as follows. After the introduction to the subject, six forces of disruption in the energy sector have been outlined. In section 3, six key areas of technological innovation are identified. Section 4 presents an overview of the electrification process along with its main characteristics and facilitators, while section 5 draws a final conclusion on the topic.

II. FORCES OF DISRUPTION

We identified six forces of disruption that drive change in the energy sectors of today: electrification, digitalization, implementation of renewable energy sources (RES), technological and business innovation, evolution of consumers and the emergence of disruptors. For an easier overview, these forces are represented in Figure 1.

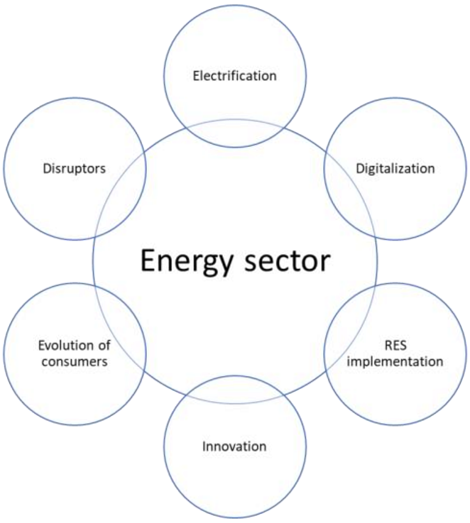

Figure 1 Six forces of disruption in the energy sector

Electrification is an on-going process that increases consumption, improves efficiency and facilitates the decarbonization of the energy system [13]. At present, electricity only makes 19% of overall final energy consumption, growing from 15% in 2000 [14]. However, a number of analysts assume this share can more than double by 2050 [15]. Companies have started to electrify numerous processes in an effort to reduce emissions and improve efficiency. Electricity is an easily available and reliable source of energy while electric systems are often more controllable and lighter than fluid or mechanical systems. In order to be able to reap the benefits of electrification, decarbonizing the generation portfolio is crucial. Electrification of processes, buildings, heat systems and the general shift from heavy to lighter industries are all factors increasing consumption [16].

Digitalization accompanied by the use of big data, Industrial Internet of Things (IIoT) and Artificial Intelligence (AI) will prove to be essential in taking the energy sector to the next level. After decades of silence, data is now starting to flow between providers and consumers. This is in many ways revolutionary, as it allows energy to flow between the two sides of the equation, as well. Traditional one-way energy traffic is starting to be obsolete, while bi-directional flow of current is a thing of the future. Data is one of the key enablers of the implementation of distributed energy sources and a key enabler for consumers to start acting as prosumers on the electricity market [17]. The increased complexity of electricity systems will have to rely on various machine learning (ML) algorithms that will predict when and where energy will be needed and how to optimize the supply chain flow in order to achieve maximum efficiency of the system [18]. In this context, ML is already being implemented for predicting intermittent outputs of renewables such as wind and solar power plants [19]. Moving forward, a considerable amount of literature predicts that AI-based techniques will form the basis of the future power sector with applications ranging from energy efficiency [20], power generation [21] and transmission [22], to utilities of the future [23]. This is a radical change of the existing top-down supply structure that characterized electricity systems for the past several decades. Digital transformation in progress will provide a foundation for disruptive innovation necessary to enable these processes.

Boosted by the support of government policies technologies regarding wind farms, photovoltaics, various distributed resources, battery storage systems, smart grid solutions and energy efficiency recorded significant improvements [24]. After years of falling costs, renewables are now reaching a stage where they are competitive to traditional sources. Only one issue remains in order to break the last barrier towards an even more significant implementation of renewables – the issue of flexibility. Most renewables being deployed utilize solar or wind energy and these sources are quite volatile. Balancing out the variations in production patterns is essential in enabling a system based on renewable energy. As a number of reports forecast, energy demand is likely to increase by around one quarter to what it is now, in large part due to population growth and urbanization [25]. These reports also forecast renewables to make up around 40% of global generation (as compared to their current 25% share) [14]. This all means that the energy sector will become virtually unrecognizable in the next 20-30 years.

During this process of change, innovation is a crucial front on which the battle for the energy market share is taking place. As the grid gradually gets “smarter”, new solutions offer new possibilities unimaginable before. These technological advances paired with the global process of digitalization are revolutionizing the way energy systems operate and how their participants interact [26]. At the same time, these changes present a great challenge for standard energy planning and practices [27]. Companies stuck within a surpassed traditional model of operation will soon face insurmountable obstacles on the market. Electricity and gas, once low-engagement products, are now increasingly visible to consumers. Markets that operated with only a handful of players are now packed with dozens of energy providers offering numerous service packages. Innovation is immensely important for companies operating in any area. Incumbents operating in the energy sector will need to focus on facilitating innovation of both their business models and technological solutions.

As the energy supply chain gets digitalized, new players appear disrupting the delicate balance of the energy market and opposing traditional businesses. The implementation of smart meters enables the collection of data regarding customers' consumption patterns. Various new business models and a range of pricing structures emerged leveraging this very data. Apart from aiding customers in finding a tariff that best suits their needs, data collected is also used in various other ways, mostly aimed at gaining insights into consumers' habits and then using those insights to tailor offerings and perhaps help in optimizing energy demand through various demand-response (DR) mechanisms [28]. Most companies are familiar with innovation, but they generally look for opportunities to improve their existing products, services or processes. This kind of innovation is branded as linear. Disruptors are among the rare companies that don't just look to gradually improve a certain business segment. They look for new ways of solving customers' needs. At present, innovation start-ups in the energy industry mostly focus on technologies regarding renewable energy sources. However, it is only a matter of time until disruptors that found ways to offer completely new services enter the market.

New technologies offer an immense number of new possibilities enabling consumers to gradually start being an active part of the system. Up until recently, consumers had virtually no insight into their respective consumption patterns. The introduction of smart meters is now enabling them to raise their awareness and allows them to modify the way they use energy at their workplace or at home. Thanks to data analytics, an increasing number of commercial, industrial and household consumers are finding ways to be more energy efficient in their daily processes [29]. With the aid of sensors, they are able to predict heating or cooling requirements and limit the variations in energy demand. Additionally, large companies such as Google, Wal-Mart, Samsung, Facebook etc., have all set various targets regarding the improvement of energy efficiency, purchasing green energy credits and supplying themselves with renewable energy. Finding ways to optimize consumption and purchasing renewable energy is not the only thing companies and households do. In order to reduce their energy bills, more and more users are starting to install energy sources of their own, and this is only the beginning. It should be noted that the transitional phase towards a zero-carbon energy system will not be as swift as one would hope. It will be an enduring march during which a combination of policies and technologies will have to implemented. It will also be a time during which the power sector will have to rely on traditional thermal power plants to guarantee stable and reliable supply [30].

III. AREAS OF TECHNOLOGICAL INNOVATION

Regardless of the sector in question, innovation is immensely important for any business endeavor and is at the heart of the global energy sector transformation we are currently witnessing. Technological innovations paired with globalization and evolved customer behavior create a window of opportunity for a second type of innovation – one that focuses on creating new business models. We identified six areas of technological innovation that will drive change in the energy sector: artificial intelligence and big data, blockchain, battery storage, smart grid and internet of things, renewables and electric vehicles and their accommodating infrastructure. For a better overview, these areas of innovation are presented in Figure 2.

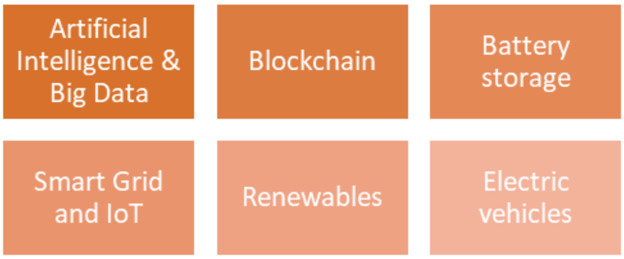

Figure 2 Areas of technological innovation

Despite receiving an increased amount of attention, artificial intelligence not utilized enough in the energy system of today. It seems that the vast majority of utility companies view artificial intelligence primarily through the scope of customer service [31]. It is therefore mostly applied to digital marketing and various customer orientated applications. Utilities mostly use mature applications of AI, but invest far too little effort in developing novel, bespoke solutions. In most cases, they focus on enabling superior data processing and analytics for improved customer experience. This is why utilities have so far applied AI to automate specific tasks related to the repetitive nature of customer inquiries. In this context, AI's perceived investment risk is low and it can potentially deliver a considerable return on investment during a relatively short time horizon. However, there are multiple existing processes within the utility that can be enhanced by using AI. Improvements in areas such as invoicing, paying, but also reporting planned or unscheduled outages have enabled a much more efficient communication between utilities and consumers [32]. Opening up a channel of communication is one of the first steps towards providing a service, not just a commodity and this is the basis of modern business models across the world.

Energy storage has always been an essential part of the energy system, but with falling prices of batteries it is destined to play a major role in the energy system [33]. The role of battery storage is even more emphasized with the increased use of renewable energy sources. The majority of renewable energy comes from either wind or solar power. These two energy sources are characterized by variable production. In other words, their production is dependent on outside conditions. Consumption, on the other hand, has a different modus operandi resulting in a potential system imbalance. Energy storage thus becomes a key player providing the necessary balancing service between real-time production and consumption of electricity. Apart from balancing out the shortcomings of the renewable generation portfolio, their role is also aimed at smoothing out the demand curve and thus lowering operational costs that arise from peak consumption.

With the surge of distributed sources and an increased occurrence of two-way flows of both data and power in the electricity grid, a whole string of smart grid (SG) solutions emerge [34]. Digitalizing the energy supply chain enables generating enormous amounts of data able to describe the details of system operation [35]. This new structure of the power system allows consumers to gain a more active role in the electricity market permitting them to contribute to the dynamic energy management system [36]. In this context, the largest challenge becomes the question of how to take advantage of consumers' participation in order to improve efficiency and reduce costs. Solving this challenge requires the application of various methods for the exploitation of vast volumes of data generated by countless smart meters and sensors [37]. Therefore, robust data analytics, high performance computing, efficient data network management, and cloud computing techniques are crucial in effectively managing smart grids [38]. This is where Big data comes in play. Big data represents an array of complex data sets. Given their large size, these data sets are unmanageable by traditional data processing software [39]. Data can be processed and analyzed in order to draw insights on how to optimize the system, but can also be used to increase transparency, coordination and information sharing. There are several business areas in which big data can be of particular aid to the energy industry: consumption forecasting [40], predictive maintenance [41], operation (proactively analyzing processes leads to insights on how to improve efficiency), customer experience [42] and security [43].

Apart from a number of positive outcomes, digitalization raises fundamental security and trust issues which are the prerequisites for doing business – this is where blockchain technology comes in play. Blockchain is a powerful peer-to-peer (P2P) network technology. It utilizes advanced computer science techniques in enabling trustworthy interactions. Blockchain technology is being increasingly adopted in platforms dealing with P2P transactions. At present, blockchain technology is mostly applied in the financial sector. However, the network infrastructure of the energy system makes it suitable for blockchain applications [44]. Particularly when it comes to distributed power grids. Together with internet of things (IoT), blockchain will soon transform operations in the energy sector connecting a vast array of devices with platforms that record and share data in real time. In the future, we are likely to witness a transformation of existing transaction models from a centralized to a decentralized structure. Decentralized data storage and automated validation would make transactions more transparent and easier to monitor and record. By incorporating blockchain technology in transaction models of the energy sector, the need for intermediaries would be eradicated opening up space for more efficient asset management systems and improved emission unit allowance (EUA) trading. Blockchain technology can also be incorporated into other aspects of business of a utility such as metering, billing and clearing. These processes will also involve the use of advanced artificial intelligence algorithms.

Microgrids consisting of distributed, interconnected elements that supply local energy needs in a sustainable manner are is the future of the energy system. The centralized approach used in solving the energy puzzle envisioned a one-way flow of energy from producers to consumers with the power grid acting as a backbone of the system. Microgrids offer a different perspective. They envision a decentralized approach where instead of large production stations we have smaller distributed sources of energy [45]. The system is now being designed to enable a bidirectional flow of energy and enable everyone to contribute in the power generation process. Smart meters are being extensively implemented across Europe and are now considered standard equipment. Smart home devices are entering an increasing number of houses enabling consumers to monitor, for the first time, the energy consumption of their appliances. Soon enough, machine learning algorithms will be incorporated in the majority of these devices enabling computer aided optimization of household processes [46]. In this context, the Internet of Things (IoT) will play a crucial role facilitating a more efficient use of energy. It can allow device optimization and the correction of demand, but it can also enable buying and selling energy.

IV. ELECTRIFICATION

In parallel to the implementation of renewable sources, the process of electrification creates additional benefits for the environment shifting a number of end-uses from fossil-based sources. Creating an energy policy that would promote electrification is difficult task. Effectively implementing an energy policy is often challenging as policies rely on consumers to make certain choices. Therefore, policymakers often provide consumers with tools and incentives in order to make their choices more aligned with policy goals [16]. In order to successfully facilitate the electrification process, having a multilayer strategy acting across different sectors is required. In particular, looking from a national perspective, five focus areas with a strong potential in facilitating the electrification process are identified as: (1) enhancing energy efficiency, (2) adopting e-mobility solutions, (3) improving collaboration between academic and commercial sectors, (4) strengthening national research and development (R&D) capabilities regarding new technologies and (5) diffusing awareness regarding the benefits of new energy solutions.

In essence, electrification facilitates the increase of energy efficiency. In developing countries, electrification offers significant opportunities in segments that are oftentimes largest polluters. In developed countries, perhaps the largest potential of electrification can be realized through the transportation sector. Apart from transportation, electrification is directed towards residential heating, various commercial, industrial and household processes and manufacturing. As the light-duty vehicles segment accounts for the majority of the transportation segment, it has been identified as a critical area of the decarbonization process. According to a recent study, transportation accounts for almost a third of all emissions in the UK [47]. The majority of these emissions come from light-duty vehicles. There are four areas with considerable electrification potential: transportation, renewable generation, residential buildings and industry. Consequently, these areas have a significant potential when it comes to decarbonization efforts.

According to recent studies, there are over 60 electrification technologies being applied. Out of these technologies, six were identifies for having the highest deployment potential [48]: battery systems, heat pumps, LED lamps, electric drives, power electronics and energy management systems (EMS). Heat pumps can provide more heating energy than they consume electricity. They extract heat from a cold space and transfer it to a warmer one. They are utilized for space and water heating and are as much as 50% more efficient than traditional condensing boilers [49]. Power electronics refer to wide band-gap-devices that employ semi-conductors in controlling and converting electric power. Energy management systems are automation systems that utilize energy-related data to optimize processes. In electrification processes, presently they are mostly applied in various heating, ventilation and air conditioning (HVAC) processes [50]. In order to fully reap the benefits of electrification, a systematic, integrated action is needed involving all these areas.

The electrification of transport has been a rapidly evolving field during the past couple of years [51]. Vehicle range on a single charge has improved from less than 160 km to over 500 km [52]. This was one of primary concerns for potential electric vehicle (EV) owners. Second, the cost of batteries recorded a decline from 1000 $/kWh in 2010 to below 300 $/kWh [48]. The reduction in battery prices significantly lowered the cost of EVs enabling the production of a few models with prices acceptable for a wider array of buyers. As prices of EVs record further reduction, we witness the gap between traditional internal combustion engine (ICE) vehicles and electric-based models become even more narrow [53]. As a result, an increasing number of EVs are present on the roads. With the increasing use of electric vehicles, there is a growing interest in researching their potential, but also possible limitations in reducing harmful emissions. Although they do not directly emit CO_2 into the environment, EVs use energy that is deeply tied to the very structure of the power system. In other words, if EVs are powered by fossil-based generation, their potential in reducing carbon emissions will inevitably be limited [54]. Therefore, the increase in electricity consumption caused by the surge of EVs should be accompanied with the increase of renewables in the power generation segment [55]. At present, EVs benefit from direct government subsidies that partially offset their high purchase costs. The key is to ensure their economic viability without subsidies. Additional problems for widespread adoption of EVs are also the accompanying charging infrastructure and the prolonged time it takes for them to charge. The next step is to shift subsidies from vehicle purchases to charging stations. This would enable equal opportunities for EVs as ICE vehicles now have. As far as the charging process goes, in this fast-paced world, people are somewhat unwilling to wait for their vehicle to charge. In order to mitigate this issue, charging techniques need to be improved. In the meantime, people need to accustom to the different pace their EVs dictate [56]. This is a difficult task as it requires people to change their habits. An additional problem lies in the fact that high-power charging infrastructure and a larger number of EVs would have a profound effect on the entire power grid. If vehicles would be charged during peak hours it would significantly increase load. This would, in turn, cause prices of electricity to surge and would potentially have a negative impact on the stability of the power system. To mitigate this issue, charging schedules would need to be optimized and additional investments in both generation capacities and battery storage would be needed. On the other hand, the adoption of EVs could also be an opportunity if the vast potential of newly deployed battery storage is to be taken advantage of. In this scenario, EV owners would charge their vehicles during off-peak hours and might even provide additional power in peak times. Vehicle-to-grid (V2G) technology could, in such a way, reduce peak loads and aid to grid flexibility. In order to accommodate EV adoption and all the parameters it entails, a comprehensive nation-wide strategy should be made. The strategy should encompass regulatory and legal issues that potential EV owners and charging infrastructure operators would encounter [57].

Research & Development (R&D) is of strategic importance as it facilitates the creation of new technologies and innovative solutions to meet sustainability goals. In order to strengthen e-mobility adoption and improve energy efficiency programs, there should be no lack of coordination between research and business sectors. Progress is often slowed down due to personnel under-sizing, scarcity of financial resources and poor sensitivity to patenting activity [48]. That is why it is important to incentivize research regarding strategic areas of innovation and enhance the knowledge sharing process between academic and business networks. Finally, promoting the benefits of electrification should be directed to both the public and the business community and should be the final step towards a wider adoption of electrification in end-uses.

V. CONCLUSION

Fundamental changes are occurring across the energy sector’s value chain. Sustainable, low-carbon technologies are now an essential part of the generation portfolio as they slowly replace traditional fossil-based central stations [58]. Customers are becoming increasingly involved in the electricity system serving as active participants in the generation segment [59]. By producing and consuming electricity, they act as prosumers on the market. Additionally, as people become more involved and more informed they consequently become more demanding. As if these changes are not enough of a challenge, major trends such as electrification, digitalization and the penetration of electric vehicles present additional forces disrupting the delicate balance of the energy system. As the energy transformation progresses, new opportunities arise offering potential benefits for all the participants of the energy supply system. This is primarily facilitated by technological innovation, as grid operators are now able to receive information, process data and act upon events in real-time. In addition, consumers are increasingly becoming producers thus becoming bi-directional participants on the electricity market. New innovative technologies such as smart meters, sensors, smart appliances and optimization algorithms enable a stronger than ever connection between all elements of the electricity supply chain, from generators to consumers. With the aid of digital platforms, sensors can indicate occurrences of peak loads or disturbances in the grid.

In this paper, six forces of disruption and six key areas of technological innovation have been identified as crucial drivers of change in the energy sector of today. The paper argues that businesses, policy makers and the general public need to work together for truly reaping the benefits of this transitional period. As already mentioned the transition towards achieving a zero-carbon energy system is composed of multiple layers and numerous focus areas. Apart from having a strategic action plan regarding e-mobility, special attention should be paid to areas such as energy efficiency, collaboration between academic and commercial sectors, strengthening national research and development capabilities in new technologies, but also diffusing awareness regarding the benefits of new energy solutions towards policy makers, businesses and the general public. The changing nature of the energy system offers unique opportunities for economic growth as well as the chance to improve the quality of life.

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