Received April 1, 2020, accepted April 21, 2020, date of publication April 23, 2020, date of current version May 8, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2990123

Artificial Intelligence for Smart Renewable Energy Sector in Europe–Smart Energy Infrastructures for Next Generation Smart Cities

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ABSTRACT One of the most challenging areas of Future Smart Cities Research is the Smart Energy domain. Critical issues related to optimization, provision of smart customizable networks and sophisticated computational techniques and methods enabled by artificial intelligence and machine learning need further investigation. The renewable energy (RE) is a powerful resource for the future global development in the context of climate change and resources depletion. Artificial intelligence (AI) implies new rules of organizing the activities in order to respond to these new requirements. It is necessary to improve the design of the energy infrastructure, the deployment and production of RE in order to face the multiple challenges that will affect the sector's growth and resilience.. In this research work we exploit the recent developments on the AI adoption for RE sector in European Union (EU). In this respect, we analysed (i) the efficiency of the transformation processes of the RE within the energy chain from Gross Inland Consumption to Final Energy Consumption, (ii) its implications on the structure of renewable energy by source (solar, wind, biomass etc.), (iii) the labour productivity in RE sector compared to the economy as a whole and its correlation with investments level, (iv) the implication of the adoption of AI for RE towards Future Smart Cities Research. The main contribution of this research is the development of a framework for understanding the contribution of AI in the RE sector in Europe. Another bold contribution of this work is the discussion of the implications for Future Smart Cities Research and future research directions.

INDEX TERMS Future smart cities research, smart grids, optimization, machine learning, artificial intelligence, renewable energy, energy sector, innovation, energy grid.

I. INTRODUCTION

The issues related to the integration of sophisticated artificial intelligence technology to Smart Energy systems and grids, requires a multi-fold understanding of computational, economic and social issues. This kind of socio-technical platform and integration needs an initial definition of the domain and a well-grounded specification of the research problem.

The quest of sustainable development has involved the society, academia and industry in finding tangible solutions for the world development, beyond the post-industrial society and its implications. Consequently, not only the new processes associated with the changes, but also the literature describing the resulted challenges were enriched.

The evolution of Smart Cities research integrates multidisciplinary contributions. Sophisticated disruptive technologies set new challenges for the investigation of sustainable models of economic development. The research issue of Energy management is one of the core application areas for both smart cities research and disruptive technologies adoption. In our research study this investigation is a key research objective.

The global energy industry records important changes related to the generation, distribution, storage and methods of selling the energy as result of challenged to increase its flexibility and to reduce both the costs and the pressure on

The associate editor coordinating the review of this manuscript and approving it for publication was Kuan Chee.

the environment (resource consumption and reduction of CO_2 emissions).

The renewable energy (RE) started to be attractive during the energy crisis of the mid 70's when it was understood the risk of running out conventional fuels that leads to developing RE and conservation of natural resources. In the 80s, the pollution, global warming, resource depletion raised questions related to the need to avoid or fix the environment damage [1]. More recently, the energy consumption moved attention to the renewable energy sources with low carbon emissions and highlights the need of continuous protection of the environment and the human health [2], [3]. Integrating renewables into energy sector is playing a major role in reducing the greenhouse gas emissions and import dependency. Compared to fossil fuels, renewable energy has the capacity to be naturally regenerated which generates efforts to make it as tangible as possible.

As environment is adding more pressure on the energy sources, is not surprisingly that RE become the star of the energy grids as result of the human need to control the energy supply. The energy from renewables increase and the challenge is to find methods to manage it as to respond to global demand of clean and cheap energy. Cost and environment concerns are important both for consumers, producers and governments. Under these circumstances, solutions should be found. Artificial Intelligence (AI) represents a major opportunity to meet these needs of today's societies. The advantages of its large deployment include the possibility of performing prediction and generalization at high speed, flexibility, explanation capabilities and symbolic reasoning [4].

The artificial intelligence represents a new era in the knowledge society and in the global development based on information and knowledge. It implies new way of using the traditional production factors, as well as new rules of organizing the activities in order to respond to the current challenges. While the historical evolution of AI has to show significant milestones, the recent developments of neural networks research, cognitive computing and machine learning, promote new unforeseen capabilities for energy management, monitoring and optimization. The integration of AI with 5G networks and sensors networks, can set a fertile new ground for future generation smart cities services.

Focusing on the creation of intelligent machines that work and react more like humans, the AI is an area of computer science that add intelligence to applications, is the next technological development that gives computers human-like abilities. It is increasingly used in the last period as result of the large availability of processing power and of the remarkable increase in data volumes. Internet of Things is the engine of AI growth because the data could be managed through the cloud once the devices are connected to the internet [5], allowing efficient and timely decisions.

A key question related to the adoption of AI in the Energy sector is related to the capacity of AI to enable optimization systems as well as personalization and parametrization of consumption and production. Visioning smart agents powered by Smart Grid technologies and AI algorithms in the Energy sectors requires the analysis of social and economic factors beyond the technical capabilities.

Different AI approaches including management of structured data, data mining capabilities and machine learning techniques, can support an AI eco-system or a system of systems within the energy sector promoting an AI enabled Smart Energy Grid.

AI needs to be added to all levels in the energy grids, in order to conduct to their development. It is necessary to improve the design of the energy infrastructure, the deployment and production of renewable energy [6].

The logical flow of argumentation of this research is summarized as follows:

In European Union level, there is an increasing interest for renewable energy sector. The analysis of economic facts can lead to significant conclusions related to the necessity to support further the RE sector with incentives and additional allocation of funding. Furthermore, the direct connection of RE sector with Sustainability and Economic Development, requires an analysis of factors that promote the efficiency and the social impact, especially in the context of Smart Cities Research.

From the other side, the Artificial intelligence domain, with advanced machine learning and cognitive computing capabilities, seems to be a key enabler of unforeseen efficiency capabilities in the context of smart energy grids.

The investigation of this multidimensional connection is the key purpose of this research study. We intend to contribute with a novel approach for the development of a theoretical framework for a scientific debate on how AI can enhance the efficiency of RE sector towards economic efficiency and sustainability. In the context of this special issue who is related to Future Smart Cities research we contribute a new significant item in the research agenda: AI driven RE services for bold social impact and economic efficiency. We recognize from the beginning that within this complicated and multifaced research context our research study is a first effort to initiate a future research dialogue.

The main contribution of this work is the integration of social sciences research with advanced information systems research. The analysis of the implications on Economy of the adoption of Renewable energy in Europe, and its enhancement with the exploitation of sophisticated artificial intelligence technologies set challenges for the design of future smart cities. Various aspects of this research study contribute to a framework for the study of the contribution of AI research to RE smart energy systems.

At the theoretical context, this research performs a thorough literature review on the integrative aspects RE, AI and Smart cities. This approach informs our research model which targets to the justification of the value adding components of a methodological framework for the exploitation of AI for progressive RE adoption in Europe towards Smart Cities implementation.

Another key contribution of our approach is the interpretive approach of key facts for the evolution of RE in Europe energy sectors, towards the new AI-driven era of RE.

Last but not least our research study contributes to a qualitative approach of using the AI as disruptive technology that facilitate and enable the development of the new domain of smart energy infrastructure as a service in RE sector.

The paper is structured as follows. The next section includes the literature review. The third section presents the data, research model and the outcomes of the research. The last part presents the conclusions and further research directions. Last but not least an interpretation of the key findings of this research for future smart cities research is provided.

II. INTEGRATING ARTIFICAL INTELLIGENCE INTO RENEWABLE ENERGY – STATE OF THE ART

A. RENEWABLE ENERGY AND ARTIFICIAL INTELLIGENCE - AN OVERVIEW

The energy sector is facing many changes that will affect its growth and resilience and the RE is a powerful resource for the future global development. In the context of climate change, traditional resource's depletion and increased pollution, world cannot afford to waste the potential of RE. The energy sector major transformations are conducted by the increasing use of RE technologies with variable energy supply, large volume data, bidirectional flow of energy and the need to increase the use of energy storage. The increasing trend towards renewable energy requires higher power and process quality in the generation, transmission and distribution system [7].

RE is available in remote areas instead of burning fossil fuels in old fashion factories, which determine the challenge to develop technologies to produce, integrate, control the energy flows from isolated grids, to increase the conversion efficiency [8]. Their major advantage is the independence from fossil fuels whose prices could be very variable. Also, the variability of renewable energy sources could be a challenge, which implies the need to use methods to produce and stock the energy when conditions are favourable and to use it when they are not, but also to accurate predict data to avoid inefficient and unreliable results [9]. Whether they are isolated or not, the major challenge for renewable energy grids is intermittent power generation. If it not properly managed, it can bring us back to consumption of backup fossil fuels.

The production of energy using renewable sources is uncertain, depending on natural environment which cannot be forecasted perfectly. The increasing penetration of RE in the energy sector emphasis the need for accurate forecasting of variable resources [10], [11]. The objective is to reduce the forecast error, so that the deviations do not strongly affect the stability, in terms of dispatching requested quantities and to achieve power grid balance [12]. Supply interruptions can determine supplementary cost for the producer [13]. The demand is highly inflexible in responding to changing in power supply: the consumers adjust their demand to their needs and activities, not to current supply or environment conditions. Correspondingly, the solutions for balancing the variable and uncertain supply of RE are on the one hand, other power generators, more controllable in terms of inputs (but not in terms of prices, availability or environment pressure) such as coal, gas etc. and, on the other hand, integrating AI [14], [15]. The cost of using one of these solutions should be understood as part of the total (opportunity) cost of using RE [16].

Notable progresses in AI appeared in the 1990s, even the term was used since 1956 within the Dartmouth Summer Research Project and the intelligence of the machines was questioned since 1950 by Alan Turing and Claude Shannon [17]. After the IBM's computer beats a chess champion, the AlphaGo beats a champion of the Asian game, Go, a robotic surgeon worked better than a doctor, it is not surprisingly that AI gain confidence and it is used in many domains. It can be characterised by 3 features: learning (continuous and automatically improve the knowledge and algorithms based on collected data, features usually referred as machine learning), recognizing (the capacity to identify situations and processes based on similarity with the previous periods), acting (take autonomous actions) [18].

Some authors consider that artificial intelligence is the activity devoted to making machines intelligent, and intelligence is the quality that enables an entity to function appropriately and with foresight in its environment [19]. Also, it is considered that AI refers to the study of the computations that make it possible to perceive, reason and act and it should be defined in terms of its goals. From this perspective, there are identified two goals: the engineering goal (solving real-world problems as the end point of AI) and scientific goal (identifying which ideas that solve the problems explain various sort of intelligence, as incentive for development and increasing the usage of AI) [20]. Experts consider that AI can make predictions, recommendations and decisions regarding a given set of human-defined objectives, influencing the real or virtual environment [21].

AI systems are able to change their behaviour without explicit reprogramming, relying only on experience resulted from observation, collecting and analysing large datasets. They offer an overview of the processes and the algorithms can extract valuable information. The power systems are more and more complex, the data more complex and large, and as result, AI needs to support the decision-making process [22].

The AI will start to substantially change the energy grid all over the world. The variability of wind conditions or solar irradiation started to worried grid operators as RE counts a higher share in their energy systems [22]. As result, they need forecasts for weather conditions (wind and solar) in order to know in advance the amount of energy they feed into the grid in the next period [23]. The probabilistic load forecasting has become more and more important to energy systems planning and operations [24], being required for the good operation of the power grid and for the optimal management of the energy fluxes occurring into the renewable energy systems [25]. The efficient energy management depends critically on load and renewable energy forecast [26]. The actual energy grid was not designed to manage with variable energy sources or with fluctuation in loading capacity as is the case of RE. Currently, it is changing because it increasingly incorporate renewable energy and new intelligent algorithms of controlling, producing, transmitting and using the RE. The new algorithms require less computation time and have better accuracy. It is even suggests to use the hybridization of two or more algorithms to overcome the limitations of a single algorithm [27]–[29].

The complexity of the grids is constantly increasing and AI should explore data and use automatic algorithms combined with weather forecasting to exploit the full potential of the investment in RE and to forecast the energy generated by all the production components of the grid. Even the initial investments in RE are high, the mass production of RE has a very low marginal costs. Using AI, the systems will collect and analyse large volumes of data received from all the smart components of the grid and will be endowed with timely decision making algorithms for the best allocation of the resources, in and out the grid.

Prediction, simulation and management decisions based on deep analyze of large data sets enable AI to identify recurring, cyclical models and patterns, to detect inconsistencies in processes stages, to forecast the trends both for energy production and for energy demand, to reduce or remove the imbalances in demand and supply caused by the variation in RE, to prevent power outages by optimizing the demand and supply within the smart grids, to increase energy efficiency and help the power grid optimization in a cost effective way. Also, it could be able to make decisions autonomously based on previous experience or based on previous human decisions (integrated into available data) in the comparable or new contexts.

As result of their potential to analyze historical data and make prediction, to supervise and control operations, to make timely decisions, to store energy, the technologies using AI in RE sector determine the increasing of the investment return rates, simultaneously with decreasing the cost of AI and the increasing ease of use [30]. Benefits imply associated risks and costs, that refer to system safety and negative effects on the labour force.

The use of AI will help to surpass the limits of traditional production factors, conducting to economic growth and, considering the effects on environment and on well-being, to economic development. This approach is particularly much more evident in the case of using AI into RE sector. The AI will change both the technologies used and jobs demand structure which imply the need for investments in technical capital and lifelong learning for the reshaping of the production and labour market, taking into account the new nature of processes. Considering this perspective, labour market offer a new challenge to RE sector, related to skills and labour shortages. As in the case of investments, as well as in the labour market, developed countries are advantageous because are well supplied with highly skilled population [31], [32].

Despite the changes in occupational structure, RE also offers significant scope for generating new employment opportunities, a current policy concern in many countries [33]. Even AI implies increasing complexity and speed of decision-making that surpass the human operator, human remains in the center of the processes, being able to reconfigure, program, supervise, impose regulations and safety operation rules etc. (Figure 1).

FIGURE 1. **The importance of human in AI processes.**

New generated jobs could be created in construction (production), operation, supervision, distribution of renewable energy which can provide increased opportunities for using human capital and generate higher incomes for the population.

B. INTEGRATING ARTIFICIAL INTELLIGENCE INTO RENEWABLE ENERGY SECTOR

AI is highly needed in the energy sector, as it operates with a large amount of data and increasingly complex systems. Particularly, the RE sector can be stimulated by AI especially through a better monitoring, operation, maintenance and storage of renewable energy and a timely system operations and control. The integration of RE into power systems refers to the following major applications of AI [22]:

- RE generation, considering the variability of renewable sources and the supply volatility;
- grid stability and reliability, safety operations;
- accurate demand forecast and weather forecast;
- efficient demand-side management;
- energy storage operations;
- market design and operations;

- better connectivity between grids components and with microgrids.

The relations implied by AI and its applications are presented in Figure 2.

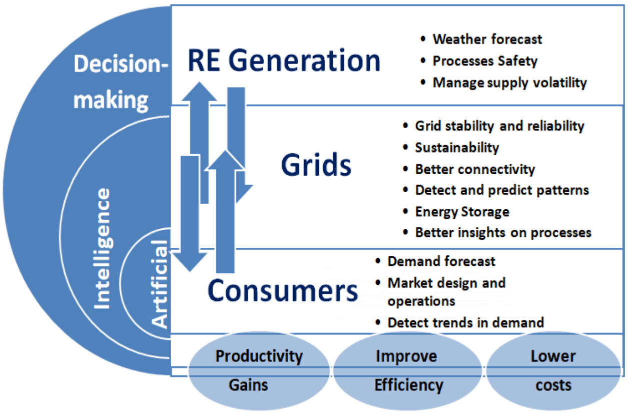

FIGURE 2. **Energy system: interactions based on AI application.**

In RE sector important applications of AI are smart match of supply with demand, intelligent storage, centralized control system, smart microgrids.

1) SMART MATCH OF SUPPLY WITH DEMAND

Even the increasing use of RE represents a great opportunity for the current societies in fighting against climate change and resource scarcity, there is a threat in achieving the role of the leader of energy sector by RE that consists in its intermittency [34]. As the RE are whether dependent, the possibility to not relying on traditional power sources, like fossil fuels, resides in the AI, that could provide accurate forecasting in terms of RE power supply, in order to respond to natural fluctuations, to adjust the operations as the plans not be affected and to respond to assumed current customers demand. It is expected to increase the efficiency of RE by using automation of the processes, activity that imply large-scale use of AI.

The final objective for RE grids is the maximisation of infeed from a production capacity considering the volatility and related uncertainty cost. AI is used to forecast the energy demand for a better adjustment to peaks. It is also important for managing the energy demand and supply from decentralised production systems (private users that produce energy from renewable sources) which request energy from the grid when the production is lower than their needs and send back into the grid the supplementary energy when they produce more than they consume. It would enable continuous energy exchange between consumers and providers.

2) INTELLIGENT STORAGE

Renewable energy systems could be unreliable in itself without sufficient storage capacity in the context of future changes in the complexity of markets, fluctuations in demands, virtual customers etc. Recent trends shows that their optimization may be provided by AI, even without extensive long term weather data [35]. Adding intelligent storage to RE project maximize the return on investment and increase flexibility for fluctuant demand and changing renewable inputs due to climate conditions. RE needs to be used at full potential and intelligent storage enable the creation of intelligent renewable energy systems. The result will affect both the producers from the energy system and the consumers as they can have access to energy at low costs.

The increasing quality of the transmission network and storage technologies are a great advantage for integration of renewables (the usage of the output from RE in the power system) [16]. Also, the ability to shift between power sources is an useful adjustment mechanism.

Storage technologies can help to solve the problems of volatility of renewable sources (mostly wind or solar) and of cyclical evolution of demand. It is possible to be produced more energy when it is not demanded.

3) CENTRALIZED CONTROL SYSTEM

AI incorporated in centralized control systems will proactive avoid shortages in energy production by early problem identification and will help to reduce the time needed for repairs. To be effective in these directions, it should include alarms based on statistics, reporting, using user-friendly and web-based interface, back-up server for recovery in unexpected cases, security keys for authentication for users form different locations etc.

Using AI in RE is a necessity, considering increasing interconnections between grids as a result of large volume of data and information. Centralized intelligent control refers to the platforms needed for managing the supervised sites. AI could manage this exponential growing data, providing methods to cope with the fluctuations of RE based on practice and forecasting. These will help the RE to be better integrated into the energy chain and will better exploit the potential of these sources irrespective of their variability.

Many assets have different energy capacity, different technologies and ages. They should be linked and brought to the same denominator in order to ensure their efficiency. The efficiency should be certified by the changing market conditions which hardly require a centralised intelligent unit to respond and to adjust to the new conditions (Figure 3).

4) SMART MICROGRIDS

Microgrids and their intelligent integration within the grid increase as their energy shares a larger part of total energy production. A microgrid is able to operate both as ''island'' and grid connected. As result of increasing interconnection between grids, the microgrids evolve from island or independent systems to centralized and regulated systems. Sometimes microgrids are the only technical solution when the connections with major grid are limited, their efficiency depending on the storage scheduling process [36]. Also, they could represents a cost-effective solution in those cases. RE can be used in microgrids not only as primary energy source, but also as emergency backup in case of energy

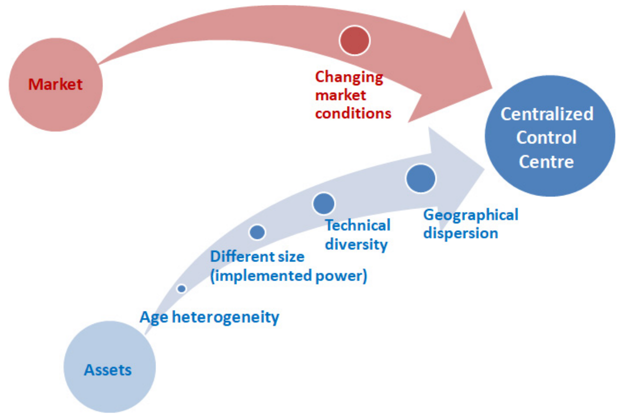

FIGURE 3. The necessity of centralized control center.

shortages in order to reduce the disturbance. Due to the increasing cost and emissions of fossil fuels, there is a growing trend to use standalone hybrid renewable energy systems, hybrid systems with solar and wind energy becoming popular choice in such applications [37].

The RE, increasing storage capacities and communication links determine the need to develop the control and protection of grids much more than before [38]–[40] which also provide more flexibility and reliability to the energy system. As they become more complex, the traditional control and protection is outdated by the variability and dynamism of modern smart grids [41], [42].

Adding 'intelligence' to renewable energy sources will increase the value of the microgrids through:

- performing predictive analysis;
- helping to better match supply with demand;
- increasing revenue for producer and reducing the storage cost and time in case of rapid reorientation towards an unexpected high demand sector;
- real time storage dispatch.

Smart microgrid technology represents a transition from the traditional centralized production and distribution energy system to a new and modern network that incorporates decentralized management of generation, transmission and distribution of the energy.

As fluctuations (in renewable energy and in demand) do not synchronize, the key to solve the problem is not only the control of the production, distribution, storage but the use of the intelligence under the form of Artificial Intelligence in all stages of the production and distribution RE chain. Successfully linking RE to AI is the fundamental change for the future smart grids with long-term impact in the industry.

Using storage capacities will help to adjust to the demand peaks. Under these circumstances, switching from providing energy to consumers from storage to providing energy to consumers from production should be made very quickly in order to reduce the cost of using back-up alternatives.

The applications of AI in RE sector have the role of reducing the risk of variability in terms of energy capacity and, finally, to raise the RE at the level of conventional sources and to exceed them.

III. RESEARCH METHODOLOGY, EMPIRICAL ANALYSIS AND KEY FINDINGS

The critical literature review of the previous section leads to the justification of our research model. Given the multidisciplinary nature of this research and our key objective to integrate advanced computer science research with economics and smart cities research the key aspects of our research methodology are as follows:

1) The understanding of macro-economic contribution to the debate on Smart Girds and Renewable Energy domain
2) The integration of advanced Artificial Intelligence components to the research model, recognizing AI as a research domain with key impact on efficiency and performance on Smart grids and RE.
3) The combined impact of Macro-Economic factors and AI value propositions to resilient Smart Cities research.

In the next three sub-sections we elaborate on the above stated aspects of our research methodology. We recognize from the beginning that the complexity of the phenomenon sets various limitations to our work but from the other side, this research is a first effort to provide a combined discussion on the integration of the three domains, namely, Economics, AI and Smart Cities research.

A. RESEARCH MODEL

The literature on RE sector and the role of AI lead to concerns related to these fields which were included in the objectives of our research. In this paper, we aim to identify (Figure 4):

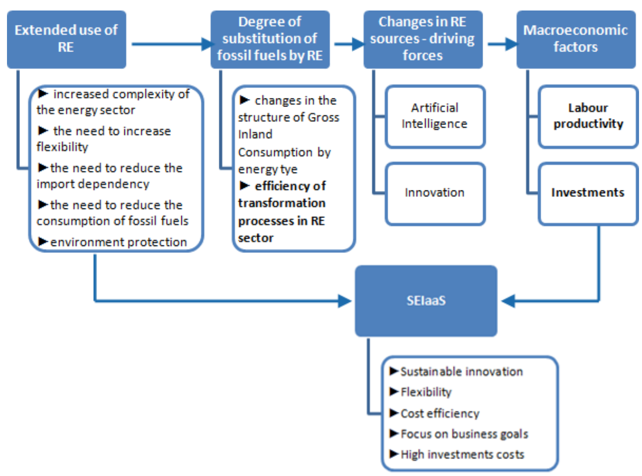

FIGURE 4. The research model.

1. The evolutions and macroeconomic factors that disclose the use of AI into the RE sector in the EU.

2. The implications for energy management and Future Smart Cities Research of the adoption of AI into RE (towards Smart Energy Infrastructure as a Service - SEIaaS).

To address the first objective of our research and to identify implications on energy management, we identify the following questions:

1) What are the changes in Gross Inland Consumption, how extended is the use of RE and how has evolved the efficiency of the transformation processes of the RE within the energy chain from Gross Inland Consumption to Final Energy Consumption?

2) Which are the changes in the structure of renewable energy by source (solar, wind, biomass etc.)?

3) Focusing on macroeconomic factors that drive the changes in RE sector: how is labour productivity in RE compared to the labour productivity in the economy as a whole and how labour productivity in RE sector is related to investment level in EU.

In order to address the questions of our research we have used data provided by international organizations (United Nations and European Union: Eurostat and European Commission-DG Energy) focusing on the following indicators:

- indicators from energy balance provided by DG Energy of European Commission: Gross Inland Consumption, Transformation Input, Transformation Output, Final Energy Consumption. They are expressed in MtoE and include energy consumption for all energy sources (Oils and petroleum products, Natural Gas, Solid fossil fuels, Nuclear, Renewables and biofuels). Renewable energy is also divided by types of energy, including: wind, solar, hydro, geothermal, biofuels and renewable waste.

- indicators provided by Eurostat, official statistics of European Union: GDP per capita, Gross Value Added, total employment and labour productivity at national level.

- data provided by United Nations - Environment Programme Centre: investments in RE sector.

Based on official statistics we have calculated:

- the efficiency of transformation processes in energy sector and in RE sector, as ratio between transformation output and transformation input;

- labour productivity in RE sector, as ratio between Gross Value Added (as measure of economic activity in the sector) and total employment.

The analysis refers to the period 2006 (starting point for counting progresses in EU, considering the level of 2005 as reference value for EU targets for 2020 [43]) - 2017 (the last available data provided by DG Energy - European Commission).

B. ARTIFICIAL INTELLIGENCE AS DRIVING FORCE FOR RENEWABLE ENERGY DEPLOYMENT. EUROPEAN UNION IN A GLOBAL CONTEXT

The evolution of AI as a new powerful technology and strategy has significant impact on the domain of Smart Energy. The wide range of application domains of AI in Smart energy include and are not limited to the following:

- Sophisticated profiling and understanding of consumers
- Advanced modelling of consumption patterns and demand monitoring
- Computational neural networks for machine learning techniques in the Energy optimization and management
- Evolutionary algorithms for the relocation of smart grids
- Progressive smart grids and dynamic re-structuring of cloud energy services
- Integration with Internet of Things and 5G networks
- Modelling of patterns and recommendation systems for Energy and RE systems
- Provision of interoperability and standardization over distributed energy networks

European Union is one of the leaders of the global energy sector, particularly of the RE sector. Promoting renewable energy is one of the goals of the energy policy in EU. Renewable energy represents a high priority for EU due to its contribution to improving energetic security, environment protection and diversification of energy supply. The RE Directive [44] set up a policy for control the energy consumption and for increased used of energy from renewable sources. It recognizes the importance of the opportunity of establishing economic growth through innovation and a sustainable energy policy and sets general objectives: achieving a 20% share of total Gross Final Energy Consumption from renewable sources and a 10% share of energy from renewable sources in transport energy consumption by 2020.

In 2010, EU adopts a Strategy for smart, sustainable and inclusive growth which recognise the importance of innovation and knowledge in growth processes (smart), greener and resource efficient economy (sustainable) and social cohesion (inclusive). These three priorities are mutually reinforcing, as the Strategy links objectives of investments in research and development, employment, education and reducing poverty with climate/energy targets [43]. The objective of promoting a more efficient and greener economy is sustained by 3 specific targets: reduce the greenhouse gas emission by 20% compared to 1990, increase the share of energy from renewable sources in final energy consumption to 20% by 2020 and a 20% increase in energy efficiency by 2020.

The objective of increasing the energy from renewables in final energy consumption of 20% by 2020 at the Community level was reflected in national targets for each EU Member State. The targets for countries range from 11% (Luxembourg) or 13% (Belgium, Czech Republic, Cyprus, Hungary) to 49% (Sweden), 40% (Latvia) or 38% (Finland). As the energy markets and the availability of resources differ between EU Member States, the individual targets were calculated as to encourage development and to be met, based on the level recorded in 2005 by each country. For example, in 2005, Sweden recorded a share of 39.8% from final energy consumption from renewable sources and Latvia 32.6%. As result, their targets were higher than the Community target as they already exceeded the 20% level in 2005.

In order to accelerate the deployment of energy infrastructure and to deliver secure, clean and affordable energy across EU, starting from 2013, there are supported Projects of common interest, representing major energy infrastructure projects. They contribute to the modernization of the energy grid and increasing integration of renewable energy [45].

The objective of The European Council that endorsed a binding EU target of at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990 [46] show also an increasing interest in renewable energy and increasing need to adopt measures to support renewable energy sources.

In 2018 a new Directive [47] entered into force and establishes a new renewable energy target of at least 32% of energy consumption for 2030, including clause of a possible upwards revision under the circumstances of the substantial cost reduction in the production of renewable energy. This new target encourage the investments in (and the development of) the clean and flexible technologies associated with renewable energy.

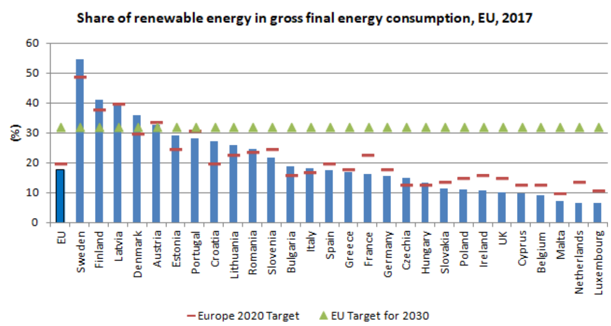

FIGURE 5. Share of RE sector, EU, 2017 [48].

The progresses made by EU countries in terms of RE are evaluated using the share of renewable energy in Gross Inland Consumption, indicator considered by European authorities for targets of Europe 2020 Strategy. As it shown in Figure 5, there are many countries that exceeded the target for 2020 (Lithuania, Bulgaria, Romania) and few others that already exceeded the Community target for 2030 (Sweden, Finland, Latvia, Denmark, Austria). Also, there are countries that are far from the national level agreed for 2020 (France, Netherlands, Ireland).

By analysing the relationship between the share of renewable energy and the real GDP per capita, we found that there is no direct correlation as we could expected. There are countries with high levels of development reflected by high levels of GDP per capita that have low RE shares in Gross Inland Consumption and have not reached the renewable energy targets set by the Europe 2020 Strategy: UK, Germany, France, Netherlands, Belgium, Ireland, France (the right-down corner, Figure 6).

This aspect shows the postponement of considering the importance of the renewable energy sector for the country's development. Countries like UK or Belgium were challenged by the Europe 2020 Strategy targets to increase the share of renewable energy two or three times. Currently they are below

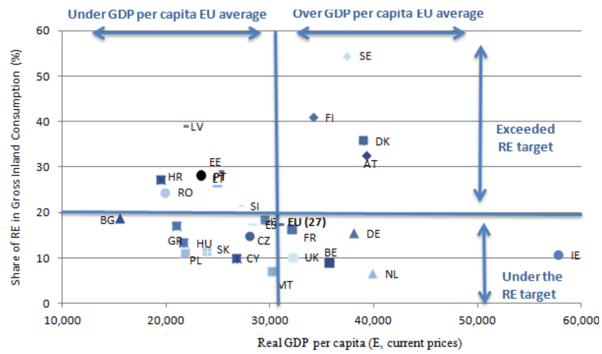

FIGURE 6. Share of RE sector and GDP per capita, EU, 2017 [47], [42].

the agreed level, but with the possibility of achieving it if they continue the efforts made so far.

Developed countries have the capacity to invest in technologies, which are the main driving forces of RE deployment. In addition, modern technologies imply the increased overall efficiency of the economic activity, due to the increasing degree of automation and integration of AI.

C. EFFICIENCY GAINS IN RENEWABLE ENERGY SECTOR IN EU - A MACROECONOMIC APPROACH

The evolution of the RE sector in the European Union, was analyzed focusing on identifying the factors, at macroeconomic level, that favour and disclose the integration of AI into this sector.

The most important aggregate in the energy balance is Gross Inland Consumption referring to supply which covers production. It represents the total quantity of energy necessary to satisfy inland consumption and it covers: consumption by the energy sector itself, distribution and transformation loses, final energy consumption by end users (the indicator considered as target for Europe 2020 Strategy) [49].

Gross Inland Consumption decreases between 2006 and 2017, the level from 2017 representing 91% compared to the level from 2006. Analyzing the energy from renewable sources, within the same period, we found that it constantly increases in accordance with the EU requirements (excepting 2011, as result of internal EU financial conditions). The renewable energy in Gross Inland Consumption increased by 180% in 2017 compared to 2006 (Figure 7). At the EU level, the structure of Gross inland consumption by energy type has changes in last decade. The RE is the only energy sector that increases both as volume (MtOe) and as share in total Gross Inland Consumption, between 2006 and 2017. It almost doubled the share, increasing from 7.02% in 2006 to 13.94% in 2017. The increase of share of RE in Gross Inland Consumption show the degree of substitution of conventional fossil or nuclear fuels by renewable energy.

The energy balance of a country shows the relationship between supply, input and output into the energy transformation processes and the Final Energy Consumption by all forms of energy. We have used the energy balance to analyze

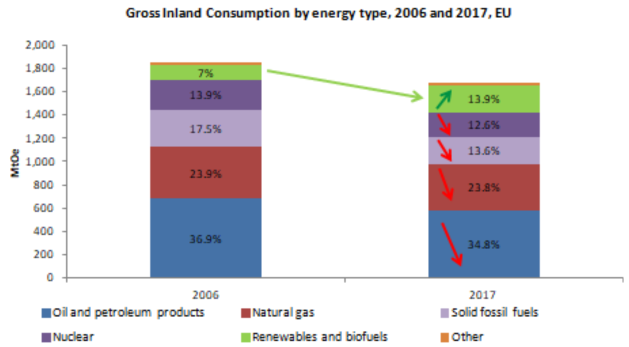

FIGURE 7. Trends in gross inland consumption - total and renewable energy, 2016-2017, compared to 2016 [50].

the energy chain from Gross Inland Consumption to Final Energy Consumption in order to identify gains in efficiency of RE deployment as result of increasing incorporation of innovation and AI in the field.

Table 1 shows the balance for energy sector (all resources) compared to RE sector. Between 2006 and 2017, the RE increased its share both in Gross Inland Consumption and Final Energy Consumption. Being a relatively new industry, RE is much more based on advanced technologies and technological innovations associated with artificial intelligence, compared to fossil fuel energy which, although it includes technological innovations, is largely based on traditional processes such as coke ovens, blast furnales, etc. In RE sector the accelerated use of AI is the driving factor of increasing RE sector.

TABLE 1. Energy sector (all resources) and RE sector - energy, 2006-2017 [50].

	Energy Sector			RE Sector		
	2006	2017	Change (%)	2006	2017	Change (%)
Gross Inland Consumption	1845.5	1674.9	-9.2%	129.6	233.5	80.1%
Transformation Input	1678.9	1528.4	-9.0%	69.0	144.6	109.4%
Transformation Output	1235.8	1175.6	-4.9%	3.1	14.3	361.5%
Efficiency of tranformation processes (Transformation output/transformation input)	74%	77%	4.5%	4%	10%	120.4%
Final energy consumption	1123.4	1060	-6%	63.6	102.4	61.1%

For RE sector the increase in transformation output far exceeds the increase in transformation input. Transformation output is the result of the transformation process of energy products and it refers to gross production of derived products. Within the energy balance, the products can pass several cycles of transformation. Several products (e.g. electricity, motor gasoline), are available only as transformation output [49].

The efficiency of transformation processes (calculated as share of transformation output in transformation input) increased in the analyzed period in RE sector by 120.4% compared to an increase of 4.5% in energy sector as a whole. This is the result of new performing energy devices and systems that transform the energy provided by the nature. These systems are complex and imply a series of transformation of energy through intermediate forms. Even there are limitation imposed by principles of physics or chemistry, for example, the transformation processing integrating smart technologies bypass some intermediate steps of conversion increasing the results.

The increase in efficiency of transformation processes is reflected in the change in the structure of RE by source. Traditional forms of bioenergy are still widely used, even modern technologies are also available: the energy from biomass and waste, still the more abundant (62% of total RE in 2017) decreases. Moreover, associated technologies to traditional biomass processes that involve direct or indirect combustion of wood and charcoal, are not considered clean [51]. Hydro and geothermal energy also decrease. The major change was recorded for RE sources considered to incorporate at a large scale systems and devices associated with AI: solar and wind energy. They increase their share from 1% to 25.51% and, respectively from 7.1% to 31.2%, in total renewable energy between 2006 and 2017 (Figure 8).

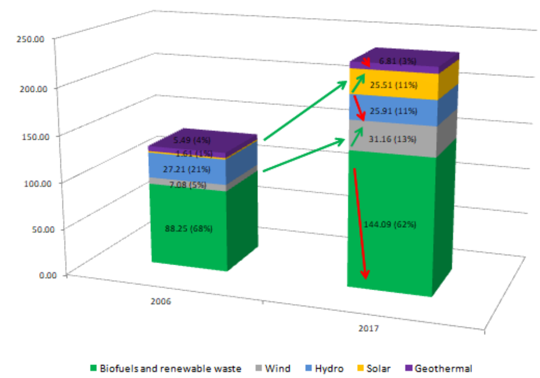

FIGURE 8. RE structure, 2006 and 2017, EU [50].

The resource productivity in RE sector as indicator that disclose the integration of artificial intelligence into processes and jobs is described by the RE production structure and by the elasticity of substitution between input factor (nature, labour and technologies) [52].

Particularly, labour productivity is an important indicator for assessing progress made by all sectors of the national economy. High labour productivity is found in sectors that are both technology and labour intensive, which generates high gross value added (GVA) per employed person. The new RE sector tends to be more labour-intensive than conventional energy sectors and even than economic processes of the national economy as a whole [53].

We calculated and analyzed labour productivity in RE sector compared to labour productivity at the level of the entire national economy in EU countries. The results showed (Figure 9) that in the RE sector, labour productivity is higher than labour productivity at national economy level (except Ireland), which supports the hypothesis that this sector uses modern technologies and skilled labour force. Also, countries that register relatively low shares of renewable energy in Gross Inland Consumption (Figure 6, right-down corner)

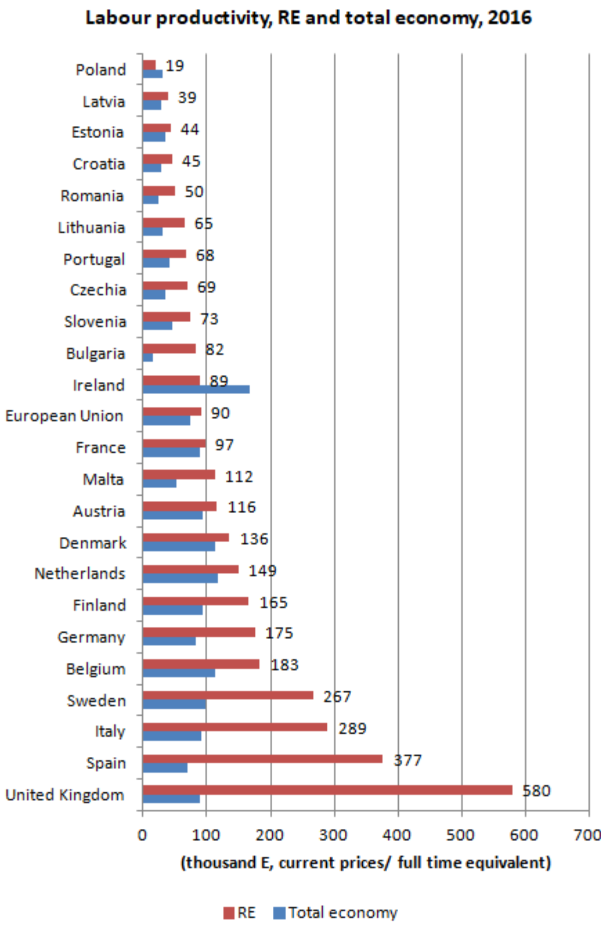

FIGURE 9. Labour productivity in RE sector and total economy, EU, 2016, [48].

have a higher labour productivity in RE sector, compared to national economy and to EU average.

Innovation is very important in a domain like RE. It is useful for accelerating deployment of RE technologies. The more innovative a sector is, the more likely it is to exploit existing resources under conditions of increased efficiency.

Innovation in the field has contributed to the increased use of artificial intelligence in RE. In the knowledge society, innovations increasingly involve intelligence, meant to improve the exploitation of existing technologies.

Investments in RE are needed not only to implement the new innovation, but also to increase the technological base in a sector that is in full ascension.

UN Environment shows the new investments in RE capacity by top 30 countries in 2018. Ten of these countries are EU member states [54]. Moreover, 5 of these are countries shown in Figure 6 in the right-down corner, respectively countries with high level of development, but low performance in RE. We have analysed the correlation between the level of investments in top 10 investments countries and labour productivity in RE sector and we found, as expected, the existence of a direct correlation (Figure 10). Therefore, investments are a driving factor of increasing the efficiency in the RE sector,

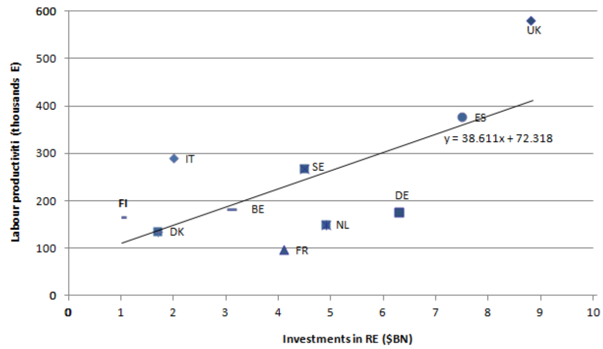

FIGURE 10. Correlation between investments and labour productivity in RE in EU countries [48], [55].

aspect that must be understood by both private and public sector agents.

The use of AI in RE requires investments in modern technologies based on innovations in the field that will generate new jobs with high level of education. Often, investments in this sector combine new technologies with capital intensity [56]. These investments can be supported by both the public and private sectors. Accelerated technological maturity creates the possibility that projects can be financed by private investors, not only by public sector which can assume higher costs and risks of investing in less mature technologies [57]. However, over 90% of investments in RE technologies belong to the private sector, even the public sector plays a key enabling role by covering the early risks and getting new technology markets to maturity [58]. The global energy transformation makes economic sense considering the savings from decreased pollution, increased human health etc. caused by the use of fossil fuel use or of other types of energy deployment such as carbon capture of nuclear power. These benefits would far outweigh the transition costs [59], [60].

The changes analyzed in EU countries referring to the use of RE (higher efficiency of transformation processes for RE compared to energy sector as a whole, changes in the share of different types of renewable energy in total renewable energy in favour of sectors that require modern technologies like wind and solar, higher labour productivity in RE compared to national economy as a whole) are macroeconomic factors indicating an increasingly smart and developed sector, based on the accelerated incorporation of AI.

Even if progress is still needed in terms of AI assimilation in the RE sector, the progress made so far shows that the EU has understood the need that energy consumption to be met more on internal market and from renewable sources in order to remove the burden on the environment. Thus, the import dependency is reduced, and national market development involves the use of renewable sources that can be exploited recurrently, with no potential for exhaustion.

For few countries with geologic advantages in terms of RE, the objective of RE supply seems to be effective. For others, in particular situation with favourable wind, sun conditions or heavy rains, the energy production exceed the demand for short period of time (day or months). For many other countries, this remains a great challenge for the near future.

D. ARTIFICIAL INTELLIGENCE AS DISRUPTIVE INNOVATION CHALLENGE. TOWARDS SMART ENERGY INFRASTRUCTURE AS A SERVICE (SEIaaS) IN RENEWABLE ENERGY SECTOR

The emerging technologies characterized by increased incorporation of AI as new market dominators in RE sector can be explained by the disruptive innovation theory as a powerful factor of innovation-driven growth.

Disruptive innovation, as management theory, explains the decisions of leading players when confronted by different types of market and technological change. The disruptive innovation are initially inferior on accepted or traditional dimensions, but its novelty consists in introducing a new set of unique attributes [61]. Even if disruptive technologies are considered to take root initially as simple application at the bottom of the established markets, they have the capacity to move up, displacing the competitors or to compete on the entirely new markets. The flexibility of producers in adopting disruptive technologies depends on the management approach on new technological innovation: opportunity or threat. If considered as threat the resource allocation to disruptive innovation is greater. Producers that prove disruptive are those that do not ignore the overlooked segments of the markets or the needs of low-demanding customers segments [62]–[64]. The disruption appears when new entrants begin to attract mainstream customers as result of the strategy of the establish producers to focus on their most profitable segments of demand.

As in other industries, in RE sector the disruptive technologies are characterized by lower marginal gross revenue, smaller targeted segments of market, provided services not as attractive as the existing implemented solutions compared to traditional performance trajectory.

Conventional energy technologies are still dominating RE markets. As initial efficiency/performance of emergent technologies incorporating AI will rise, their diffusion rate will increase and they will dominate the RE sector as it is observed in various industries. In competition between conventional and emerging technologies in RE sector, the order of entering the market is the most important factor for the technology's success. This is an disadvantage of emerging technologies in RE sectors as latecomers. It will be balanced by the increased consistency with customers' preferences, the price level and their performance rates [65].

Technological innovation and much more, disruptive innovation, has the capacity to transform the RE sector, by increasing productivity and improving the way in which the societies produce and consume energy. The producers in RE industry benefit from innovations in the area, being constrained by the ecological goals, resource depletion and, last but not least, by the prices of oil and other commodities (in terms of price level or volatility). For a country as a whole, these achievements are also important for reducing the reliance on conventional fuel and to reduce import dependency. The competition between technologies, e.g. wind versus natural gases or solar versus coal, raises the standards in the domain and accelerate innovation.

The applications of AI play the role of disruptive technologies for RE sector. Artificial intelligence refers to a combination of machine learning techniques, robotics and algorithms and automated decision-making systems which can have major economic and social benefits, being used in many areas including the renewable energy sector. AI systems is used to encourage sustainability and environment responsibility in EU [55]. It represents the next level in RE sector, a level that have already attempted in EU. Increasing energy from renewable sources, both absolutely and relatively as presented above, could not have been possible without many of the AI applications in RE sector:

- collect and analyze large amount of data from smart devices;
- accurate forecasting of the renewable sources conditions, addressing this way their intermittency;
- indentify demand patterns, based on analyzing data collected from grids or provided from human operators;
- smart grids which imply highly autonomous decisions;
- timely changes between renewables and fossil fuels in case of variation in renewable sources and demands peaks;
- smart storage systems, able to adapt in real time to changes in demand;
- timely identify and manage supply and demand peaks;
- proactively repair errors in production, storage systems, energy infrastructure.

The energy management strategy should enhance energy reliability and identify new opportunities for improve efficiency through technology used. These will refer mainly to cost savings and flexibility to adapt to changes. For enrolling in this direction, the efforts will include the increasing consolidation of the infrastructure and/or provisioning it as a service.

Like other industries, the energy industry and particularly the RE industry is facing a major transformation in terms of its transition from the traditional product-based to a service business model [66]. The As-A-Service model refers to the possibility of a firm to use applications without the burden of deploying, configuring or maintenance the equipments on which the application run, giving users high flexibility and control. Infrastructure as a service provide storage, networking equipments, computer capabilities, database management as standardized services (over the network).

The technological interdependence can affect firms performance in new technology generations, the success of an innovation being dependent on the efforts of other firms in the environment. As an innovation does not stand alone, the generated effects depend both on its magnitude and its location in the ecosystem relative to the focal firms. The external challenges require innovation from other actors, embed the local firm within a system of interdependent innovation [67].

Under this chain of interdependences, providing smart energy infrastructure as a service (SEIaaS) become a new and successful renewable energy management strategy, especially when the infrastructure incorporate artificial intelligence, new technologies and the domain is facing rapid changes. RE infrastructure includes infrastructure for deployment, storage, transmission, distribution of the energy.

SEIaaS in RE sector will become a mechanism of delivering (renting) of the energy infrastructure, both hardware (storage, grids, servers) and associated software (operating systems) to the end users, as a service, e.g. for using it, without implementing it. This does not require a long term commitment and allows firms to use resources on demand. The providers are responsible for housing, running and maintaining the infrastructure operational and the customers deploy their own software, in applicable, on the infrastructure [68], [69]. The most important benefits of SEIaaS in RE sector are (Figure 11): costs (initial cost and also maintenance cost are reduced as infrastructure is not purchased), flexibility (increase as result of: invoicing by usage, increasing the speed of adaptation to the changing economic conditions, increasing the speed of getting the appropriate infrastructure, helping the user to concentrate on the business goals being able at the same time to control the system, application, storage), storage (automation on demand and flexibility in usage).

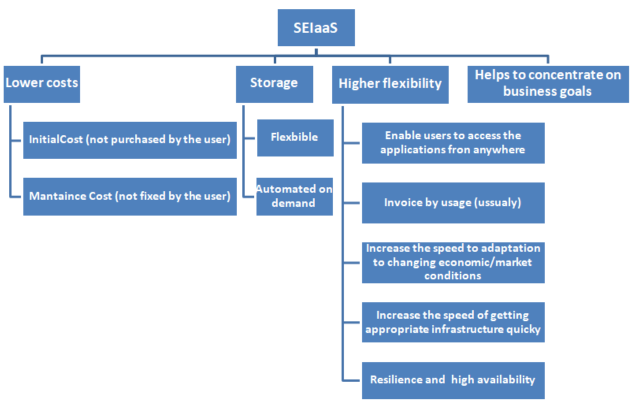

FIGURE 11. **Benefits of SEIaaS in RE sector.**

SEIaaS can be used with a contract or on a pay-as-you-use basis. Usually the final users consider the benefit of the flexibility in term of price to be very important and, as result, they consider to be more efficient the payment for the resources that the application delivery requires. This price flexibility, along with the other benefits associated to SEIaaS make this model of delivering infrastructure a management strategy for integrating disruptive innovation into RE sector.

IV. CONCLUSION

The use of renewable energies is increasing worldwide as result of the need to reduce the impact of climate change and global warming. RE represents not only an important research-development sector, but also an effective solution of today's economies in the context of resource depletion and imperative of environment protection. Increasingly, AI is increasingly integrated into this sector, contributing to better results both in terms of efficiency and accessibility to RE.

AI helps to manage the energy production and consumption in a changing environment and market context. The variability of renewable sources is one of the key challenges of this sector, with increasing importance as the RE share in the total energy production is growing. AI is the solution that should be integrated at microeconomic level, for reducing the risk of variability of RE sources, by performing predictive analysis, identifying patterns, reducing the storage cost, better connectivity between grids and users, thus conducting to grid stability, reliability and sustainability.

The synergy between RE and AI will change the energy sector and improve sustainability at national and global level. Using AI could increase the efficiency of the RE sector by detecting and predicting patterns, by performing specific tasks without explicit instruction from human, by optimising the supply and enhancing decision-making. It will provide better insights on processes due to speed forecasting and smart links between vital components as result of rapid development of technologies incorporating AI.

EU is one of the major player in RE industry at global level. Environmental concerns were transposed into specific regulations both at the Union level and at the level of each member state. The use of AI is important in this sector in order to win the fight against the degradation and depletion of internal resources but also to successfully face competition on a global basis (China and USA). Even at the microeconomic level, the use of AI could be easily identified (for example by the existence of intelligent storage, micrograds, centralized control systems), from a macroeconomic perspective, the degree of AI use and the generated effects are difficult to be identified as result of the multiple factors affecting the final results of economic processes, decomposition of effect being difficult to achieve.

Considering the evolution and the current efficiency of the analysed indicators and processes, we conclude that AI is largely used in EU within the RE processes, from technology to labour force. Modern technology endowment showed by the efficiency of transformation processes and by the changes in structure of RE by sources associated with highly skilled labour forced revealed by the high labour productivity levels in RE are prerequisites and requirements of AI. But even there have been made progresses and EU, as a whole, is effective meeting the renewable energy target as it was set by internal regulation in terms of the share of RE sector in Gross Final Energy Consumption, further progress based on increasing development of artificial intelligence needs to be made in order to make this sector the leader of the energy industry in all of EU member states. Towards Future Smart Cities Research [70]–[72] the integration of AI for RE efficiency will require significant considerations including:

- The development of sophisticated machine learning optimization algorithms for all the workflow of RE from production to consumption

- The integration of AI for RE at micro and macro level. From applications for smart home applications to integrated platforms for optimizing Energy Smart Grids
- The integration of sustainability consideration in the design, execution and management of integrated distributed Energy systems worldwide
- The development of an AI ecosystem of energy Big Data for the provision of flexible, integrated services and applications
- The development of cloud-based energy sophistication. Energy Infrastructures as a Service (EIaaS), or Energy Smart Grids as a Service (Energy Smart Grids as a Service) will be the next big milestones
- Personalized Smart Monitoring services at local level
- AI enabled international energy networks for on demand consumption
- The development of advanced Analytics and Big Data based KPIs for the Smart Energy Grids

The usage of RE still face persistent barriers in the process of its wide implementation. These are not related only to the technology needed but also to the policy making, aspects that should be debated in further studies.

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