THE IMPACT OF DISRUPTIVE TECHNOLOGIES ON THE FUTURE ENERGY DEMAND IN ROMANIA, AT THE HORIZON OF 2050

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Abstract

The prediction of future energy demand is a very important element of the strategic development. It is based on models considering a multitude of parameters characterizing the evolution of the demographics, socio-economic development, technological evolutions. The paper discusses the sources of some important uncertainties in such predictions, grouped in the influence of the disruptive technologies on the future energy demand. Based on the classical modelling, an estimation of the energy demand for Romania by 2050 is performed. Considering the existing knowledge on the impact of the disruptive technologies and using expert judgement approach an estimation of these impacts is obtained and discussed.

Keywords: *Energy demand, Disruptive technologies, Sustainability, Strategic development*

Introduction

Despite the amazing development of the computational power and the increasing of available data and algorithms, the prediction of the future energy demand remains very difficult. The existing models are based on the description of the possible evolutions resulted from the analysis of multiple set of data such as the gross domestic product (GDP), demographics, energy intensity for different sectors, structure of the economy, consumers' behavior, etc. Such data are significantly affected by uncertainties. Even the description of the past and current situations is affected by the lack of enough accuracy.

Looking to the future, even in the case of short-term perspective, the predictions are rarely confirmed in practice. The main motivation is the unexpected changes produced by a set of influencing factors, difficult to be quantified and realistically handled in the models.

In the category of influencing factors, the development of the disruptive technologies is of crucial interest. According to [1] there are twelve areas with high potential to produce disruptive impacts on energy demand by 2025: mobile Internet, automation of knowledge work (artificial intelligence, AI), the Internet of Things, cloud technology, advanced robotics, autonomous and near autonomous vehicles, next generation genomics, energy storage, 3-D printing, advanced materials, advanced oil and gas explorations, and renewable energy.

The paper discusses the possible influences of the disruptive technologies on the energy market, in terms of energy generation, transport and consumption, intending to offer an idea about the necessary corrections on the simplified models used by the computer codes such as Model for Analysis of Energy Demand (MAED), a tool developed by IAEA [2]. For the purpose of the energy market predictions the following disruptive technologies are considered: (1) Artificial intelligence (AI), (2) Internet of Things (IoT), (3) Biotechnology (Bt), (4) Additive manufacturing (3Dp), (5) Material science (Ms), (6) Energy storage (Es), (7) Advanced Robotics (AR), (8) Big data (Bd), (9) Blockchain (Bch), and (10) Drones (D).

These impacts on the final energy demand for Romania are discussed. It is good to note that most of the influences are mediated through economic growth, labor market, consumption patterns, and daily behavior.

Methodology

The analysis is structured in three steps:

(1) the estimation of energy demand for Romania at the level of 2050 based on the MAED computer simulation and using a set of assumptions,
(2) the discussion of current status of the disruptive technologies use, based on literature review,
(3) the estimation of possible impacts of the disruptive technologies on the Romanian energy market, at the level of 2050, based on expert judgement assessment and using the information collected in previous steps. In the assessment process, ten experts were involved.

A general view of the possible evolutions of the energy sector in Romania

In the last 3 decades, the Romanian economy has undergone profound structural changes. In the first decade after 1990, the economic decline was accompanied by the closure of some industrial "giants", large consumers of energy. A decrease of the energy per capita from about 2.8 MWh (1990) to 1.8 MWh in 1999, has occurred.

After 2000, the economy recovered and led to a gradual increase in energy consumption, except for some oscillations induced by the economic crisis (2009-2012). In 2020, the consumption reached 2.7 MWh/capita, very closed to the 1990 level (it should be noted the decreasing of the population from 22 million to around 19.5 million).

From the point of view of the energy production structure, over the last three decades a progressive decrease of the coal contribution occurred, together with a gradual increase of contribution from variable renewables (wind and solar).

In terms of the sectorial consumption, a decline of the industry energy consumption was produced due to the shift from large consumers to a more flexible and energy efficient economy. At the same time, an increase of the residential, commercial and public services energy consumption occurred.

The choice of fast systems relies on the fact that all fission systems are driven by a source of fast fission neutrons emitted by nucleus fissions. Such a choice doesn't exclude the extension of this type of benchmarking to intermediate and/or thermal spectrum systems.

Looking to the next 3 decades (until 2050), the following assumptions seem to be reasonable as a basis for the energy demand forecast:
(1) a demographic decline of Romania's population is very likely (due to aging of the population, reduced birth rates, and continued emigration). According to the simulations the decrease is about 1 million people per decade. The model considered an average life expectancy of 76.2 years in 2020 (with an increase to 80.4 years in 2050), a birth rate of 1.68 children (in 2020) per woman of childbearing age (1.73 in 2050), as well as a ratio of new-born boys / girls of 51.4% / 48.6%;
(2) an increase of the GDP per capita from 12,920 USD in 2020 [3] to 20,900 USD in 2050; the estimation is based on the strategic estimation [4] characterized by an economic growth of 2.7 % (2020-2025), 2.1 % (2025-2030), and the previous decline of the population;
(3) introduction of measures to increase energy efficiency [4] with a clear impact in the decrease of total energy consumption by 37.5% (in 2030 compared to 2007). It is estimated that the measures will have a major impact especially in the industrial sector, but it will be acting also by reducing losses in the energy transmission networks, by reducing energy losses in buildings and by changing consumption habits, including stimulating some changes by switching to smart local area networks;
(4) an increase of the consumption generated by measures to extend electrification of the transport (electric vehicles) and heating & cooling. At the level of 2030, an increase of the annual electricity consumption is estimated due to the electrification of the transport by 7.5 TWh, i.e. 10% increase of the electricity demand [5];
(5) a total phase out of coal-based energy generation will be implemented by 2050 (with an intermediate target, 50% in 2030);
(6) a great support for the development of intermittent renewables (iRES) will remain in the EU and national policies, expecting to have a share of 40-50% in 2050;
(7) an increase of the interconnection of the national and neighbouring country grids from 10% (2020) to 15% (2030) and 20% (2050), respectively.

Based on these assumptions and MAED simulations, an estimation of the energy demand for Romania at the level of 2050 was obtained, in the frame of the IAEA INPRO ASENES SMR project [6]. In Table 1, the results obtained for three developed scenarios are presented. A summary description of the three scenarios is also included.

Table 1. Energy demand for Romania in 2050, simulations by MAED

	Parameter	**Scenario 1 (Optimistic)**	**Scenario 2 (Moderate)**	**Scenario 3 (Pessimistic)**
Assumptions	GDP increase	High	Moderate	Low
	Electrification rate (Electric Vehicles, Heating and Cooling)	High	Moderate	Low
	Impact of energy efficiency measures	Low	Moderate	High
	Interconnectivity	High	Moderate	Low
	Immigration	High	Moderate	Low
	Demographics	-0.5% per year	-0.5% per year	-0.5% per year
Predictions for 2050	Increase of energy demand (vs 2020)	**+52%**	**+27%**	**+12%**

The variations of the main parameters (GDP increase, electrification impact, etc.) were restricted to three possibilities: High, Moderate and Low. "High" means 100% of the predictions of the national and EU strategies, "Moderate" means 50%, and "Low" means 15%.

Scenario 1 prediction is comparable with the estimation of national Energy Strategy [7] where a value of 43% was obtained, whereas the estimation of Scenario 2 is similar with the prediction of SEERMAP (South East European Roadmap) project estimation (26%) [8].

Beyond the previous assumptions considered in MAED tool, there are some influencing factors that may affect drastically the predictions on the future energy demand. In this category, the influence of the disruptive technologies development has to be discussed for a better understanding on the possible challenges and changes in the energy demand and on the energy sector.

The analysis of possible impacts of disruptive technologies on the energy demand

In this section the influence on the energy demand of the development and implementation of some disruptive technologies (AI, IoT, Bt, 3Dp, Ms, Es, AR, Bd, Bch, D) is discussed.

Artificial intelligence (AI)

From the point of view of energy consumption, the following major effects of AI are expected:

(1) high contribution to optimize the energy use, based on automatic and more effective measures to implement energy efficiency,
(2) creating valuable solutions for load following and demand response flexibility in a market characterized by a high penetration of the intermittent renewables (iRES),
(3) produce a wide spreading of electrical appliances and applications for most human activities,
(4) contribute to a better use of the existing natural resources, including the discovering of new reserves,
(5) stimulate major changes in the occupational structure.

Currently, AI is used in the energy sector of many countries to enable communication between smart grids, smart meters and IoT devices [9]. An optimistic vision of the future imagines a world with all devices connected to the internet, consumers and manufacturers, smart meters, consumer programming, including large consumers, creating an intelligent and optimal system with low energy intensity. Such kind of broad interconnection will produce large amount of data and will create appropriate conditions to use machine learning to optimize the energy system operation. In this manner, it is possible to reduce energy consumption, costs paid by users, to have a better management of variable energy resources, planning, operation, and control of power systems [10].

Large companies tend to make the most of new technologies (AI, IoT, blockchain, cloud databases) to increase the efficiency of various processes. Other initiatives have a more global focus, e.g. Microsoft's IA Azure platform is already providing scientists with new tools for monitoring the environment in order to mitigate climate changes [10]. DeepMind, a subsidiary of Google, applied the algorithms through neural networks machine learning, for a 700 MW wind farm in order to predict production 36 hours in advance [9].

Therefore, the use of AI and other connected technologies will create a tendency to reduce the consumption of electricity. It should be noted, at least in the initial phase of the optimization process, any exploitation of a huge amount of data collected from the real world and its transformation into algorithms necessary to optimize the targeted processes based on learning, is an activity with high energy consumption.

The dominant element in the energy consumption of AI is the deep learning process based on the processing of very large amounts of data. This type of machine learning uses very large mathematical models (the neural network method) with a huge number of parameters (from hundreds of millions to billions). Based on neural networks, complicated tasks can be performed such as classifying images, recognizing faces and voices, generating coherent and convincing texts.

Behind these solutions there is a huge number of repeated attempts and trainings of the system which, by using a large number of examples (generated by adjusting the parameters), seeking a better solution and, finally, reaching the one considered as the optimal. The pace of learning can be considered fast over time, but slow in terms of the number of examples needed to generate the solution and consolidate the learning. The electricity consumed for these activities is generally associated with CO_2 emissions. Significant emissions associated with the machine learning process are mentioned, for example 192t of CO_2 during the Google AI learning process of the game of chess [11].

Fortunately, after being trained, a deep learning model requires much less power. Many learning models can be implemented on smaller devices after being trained on large servers [11], including mobile devices, drones, laptops, and IoT devices. However, even small deep learning models consume a lot of energy compared to other software programs.

A pessimistic estimation [11] predicts that by 2030, more than 6% of the world's energy could be consumed by data centres. On the other hand, AI developers believe that the main cause of this consumption is generated by use of general processors, which are not adapted to the specific requirements of AI. The CS-1 processor development (1.2 trillion transistors, 18 gigabytes of on-chip memory and 400,000 processing cores [11]) allows running the entire deep learning model without the need to communicate with other components, reducing in this way consumption. Major companies, such as IBM, are developing so-called green supercomputers (the Satori system) with low power consumption. Intense activity, over a period of one year, generates an amount of CO_2 that can be absorbed by 5 mature maples [11], i.e., a reduction of 50-60 times compared to the current computers.

Another important possible impact of AI is on the management of an energy system dominated by the iRES. AI systems can be trained to work in tandem with renewable resources. When the production of solar or wind energy is low, data centres can automatically reduce consumption by slowing down computing tasks and delaying low-priority AI tasks.

It is expected that AI will have important effects on the traditional oil, gas and electricity industries [12], by profoundly transforming the way they operate.

At the same time, AI will help analysts and energy market participants to understand extremely complex phenomena, from the behaviour of electricity networks to climate change effects [13]. AI will help to build a better understanding of how energy is supplied and distributed, which will allow better predictions and decisions, with positive consequences in reducing the costs.

Some examples for a better understanding are as follows: (1) machine learning can improve the ability to map and understand the value of underground oil and gas reserves, (2) dynamic regulation of the operation of the renewable energy systems, for example the automatic regulation of the relative position of the propeller to optimize the capture of the wind energy, (3) improvement of the quality of solar energy forecasting.

From the point of view of the occupational structure, it is estimated that, by 2030, AI will influence more than a third of jobs in the European countries [14]. Some jobs will disappear, but new ones will be created. Between 40% and 50% of existing jobs could be partially of fully automated. For Romania, the potential for job automation is about 50-60% of the total jobs [15]. The most affected jobs are those with low complexity tasks, standardized and repeatable, as for example: assembly line workers, drivers, mining workers, cleaning workers. Employment will largely increase for occupations requiring higher education and Information, Technology and Communication (IT&C) knowledge.

Some futurists believe that AI will have a drastic influence on the possibility of finding a job, "an important segment of society not being qualified for any activity on the market, automation and robots taking over these repetitive activities" [16].

From a structural point of view, the society will consist of some classes, depending on the relationship with AI: (1) AI developers, manufacturers, owners; (2) users of AI and robots; (3) providers of maintenance services for robots and AI; (4) other providers of service and activities, as well as (5) a relatively large class of "irrelevant persons" [16].

According to [16], there is a radical change "from a society based on the exploitation of labour to a society with a majority of irrelevant persons". For this category, the vision for a future society advances the idea of paying a guaranteed minimum universal income, based on taxes for the use of AI. The occupation of this large class will be that of "pure consumers", a large part of their lives being filled with recreational activities, such as video games.

Undoubtedly, systems that incorporate AI have the ability to update quickly in the context of real-world conditions and are, in all probability, much more efficient systems. For this reason, after an initial period of consumption to transform data into learning, there will be a decrease in energy consumption based on the use of AI and related technologies. Efficiency will reduce energy demand and consequently, the emissions. However, the level of energy consumption cannot be exactly known. The reduction is estimated at "a few percent" in [13]. A much larger effect can take place at the level of reducing emissions, an emissions reduction of 60% to 100% being advanced [13].

Internet of Things (IoT)

The most important impact of IoT in energy sector is connected with the introduction of a diversity of sensors that are monitoring in real-time the operational parameters, creating the possibility of remote control over the energy consumption patterns. Advanced solutions using IoT sensors and AI algorithms were developed to make the energy sector better and more agile.

The following areas [17] of energy systems are targeted by the IoT development:

(1) process monitoring and resource optimization (installing sensors devices in the plants to create the automated execution of processes),
(2) proactive maintenance,
(3) advanced analytics (optimize the processes based on data analytics),
(4) smart grid integration (get control over the energy consumption in order to create the targeted balance),
(5) cost savings and data management,
(6) sustainability (reduce the wasting of energy),
(7) integrated control of electric vehicles, including vehicle to grid (V2G) approach.

The use of IoT systems in the energy sector creates sustainable solutions to improve the efficiency and produce savings. IoT has a great potential to significantly change the way of consuming, from the classical pattern to a real-time informed consumer assisted by technology, to create the optimal balance.

Biotechnology (Bt)

The development of biotechnologies will have important effects in: (1) demographic changes (which may influence global and local energy consumption), (2) technical developments (new solutions for energy generation and product development).

According to United Nations estimates, the world's population is constantly growing. It will reach 9.7 billion inhabitants in 2050, and about 11.2 billion in 2100 [18].

Meantime, for most of the European countries there is a general tendency of decreasing of population, for the analyzed period, due to the progressive aging of the population and a decrease of the birth rate. The same effect is present in Romania, with an estimated decrease of 1 million per decade.

The increase of the life expectancy is boosted by biotechnology, by increasing of the capabilities to monitor the health (including the use of AI, IoT) and reduce the risks and consequences of the diseases by creating better conditions for transplantation, including the creation of artificial organs.

Regarding the duration of life, there are specialists' opinions who support the idea of a biological determination of the maximum duration. There is a limitation of life expectancy to 115 years [19], the probability of exceeding this age being extremely low. More generally, there are three visions of longevity called "futuristic", "optimistic" and "realistic", [20]. Futurists believe in a continuous extension of life expectancy, as biotechnological progress, towards immortality and eternal youth. Optimists support the increase in life expectancy, a process started in the last century, with a linear increase of 2.5 years per decade. They are convinced of medical and biotechnological progress and do not consider an upper limit for life. Realists, on the other hand, are convinced of a bio-determination of the limits, and the continuous increase of life expectancy is implausible for them. Based on studies on the role of renewed neuro-stem cells (NSCs) and experiments performed on mice, the hypothesis of the possibility of extending the limit to values over 125 years is stated [21].

An extremely important aspect, namely the use of medicine and biotechnology to increase life expectancy, has raised many discussions and concerns in recent years. Through synergistic effects, AI and Bt can restructure society and the economy, offering a totally different perspective from that of the industrial age. In accordance with [16], IA and Bt give mankind "the power to reshape and redesign life". If the industrial revolution has brought to humanity the power to change the nature, Bt gives solutions to alleviate the aging of the body, including the creation of "a-mortality" (the individual is not yet immortal, because some serious accidents can lead to death before medical intervention). The idea of the possibility of "brain design", "continuous upgrading", "life creation", as well as "control over our inner world" is discussed in [16] as very probable options. The author is extremely pessimistic about the consequences, because "people have always been much better at inventing tools than using them wisely".

Such a perspective will lead to important demographic changes, especially regarding the age structure, to polarizations that may accentuate the migration phenomenon. On the other hand, the fusion of AI and Bt can quickly take billion people out of the labor market, "undermining both freedom and equality" [16].

The population decreasing at the level of demographic declining states will lead to a reduction in household electricity consumption and a possible contraction of their economy. On the other hand, global population growth will raise the issue of food security and global energy consumption. From the point of view of social concerns, conventional production techniques alone cannot meet the increasing food demand for the population in the future. For this reason, research on plant growth techniques tends to focus on finding methods with maximum yield, in ever-changing climatic conditions. Specialists are convinced that food security can be improved by diversifying agriculture, using more species for cultivation, and especially by developing biotechnologies [22].

An important direction for the energy market analysis is the cultivation of species favorable to the production of biofuels, in order to produce more efficient energy. Moreover, certain biotechnologies can contribute to improving access to hard-to-exploit resources. By using these technologies, oil that is difficult to exploit from depleted deposits (they contain about 60% of the initial amount of oil) can be converted to natural gas, which is easier to exploit [23]. At the same time, coal gasification techniques, as well as those for recycling organic waste are already available. Currently, industrial biotechnology uses enzymes and microorganisms to produce chemicals, food and feed, detergents, paper and pulp, textiles and energy with a direct impact in avoiding the fossil resources use as a raw material, but in some cases competing with resources that could be used for food. This issue, especially in the case of biofuels, can be solved by using inedible biomass as a single raw material.

From the point of view of the energy sector, a plausible decrease of the population for the period 2020-2050 (e.g. in Romania's case, a decrease of about 16%) will generate a decreasing trend of consumption that will add to the decreasing effects generated by the efforts to increase energy efficiency, as well as those of optimization based on AI (these having as direct effect the decrease of consumption per capita).

Additive manufacturing (3Dp)

Additive manufacturing produces the objects by adding successive layers of materials. The technique referred also as 3D printing is based on computer-aided-design (CAD) software or 3D object scanners to control the deposition of the layers and obtain a precise geometric shape. In the classical approach, the object is obtained by successive removal of layers of materials, by milling, machining, shaping, and curving or by casting. The technique impact consists of a great simplification of the manufacturing process, a high ability to produce complex geometries, wastes reduction, high efficiency and reduction of errors.

An extensive development of additive manufacturing may dramatically change the supply chain, including the manufacturing nuclear industry. Many components can be produced at the destination or locally by additive manufacturing, reducing the transport efforts, duration and possible the costs. In few decades is expected that the most of the components of a Small Modular Reactor or even Large Reactor may be additive manufactured. The process is dependent only on the preparing appropriate alloys for the 3D printing of different parts/components. An important advantage will be the elimination of some constraints in the design due to the classical manufacturing process.

The designer may approach the systems outside of the existing traditional structures. A great opportunity is open by the additive printing for the instrumentation and control. Sensors for real-time monitoring may be easily integrated into the components. Based on them, valuable information on the components'/systems' performance may be collected, including data for preventive operation or even autonomous operation.

Material science (Ms)

The amazing development of Ms will influence the energy consumption especially by the new possibilities to reduce the energy losses. For example, the heat produced by large plants will be transported easily at high distance to be used by the existing or new clusters of consumers.

The development of energy-storage materials [24] will open broad possibilities for the energy storage as a key factor for the use of iRES.

The development of energy efficient materials can support the reduction of the emissions in the construction sector by two factors [25]: (1) reduction of the energy loss due to their various thermal properties (like heat storage, heat retention), (2) production of the materials by using processes with less energy consumption.

The key importance of the advanced materials for the development and deployment of low-carbon energy technologies is clearly stated in the EU policies [26]: "without continuous innovation in advanced materials, it would not be possible to increase the performance, reduce the cost and extend lifetime of low-carbon energy technologies".

On the other hand, the raw materials availability is a limitation factor for the development of the energy technologies based on existing technologies. Currently, eight metals were classified as "critical" (Dy, Eu, Tb, Y, Pr, Nd, Ga, and Te), and six materials were classified as "near critical" (graphite, Re, Hf, Ge, Pt, and In) [26]; they should be monitored closely. Most of them are connected with iRES development, electric cars lighting, and fuel cell technology. For the nuclear industry, concerns are generated by the "near critical" materials Hf and In.

Based on the Ms' objective to develop such material and technologies, the total consumption decreasing is expected.

Energy storage (Es)

Energy storage is based on batteries, thermal storage, or mechanical systems. Currently, the storage capacities are very limited, the most used and promising being the hydro pumping, but this approach is limited to countries with appropriate landscape and rainy climate.

Thermal storage seems to be practicable for the classical power plants (coal, gas, nuclear) where more than 60% of the heat is wasted due to the physical laws. The energy storage in batteries is very limited today, being less by an order of magnitude than that of the largest pumped storage power plants. However, the Ms development is promising for a new development in the batteries, with effect in costs, reliability, and impact on the use of special materials.

If the energy storage will be developed at large scale, the dream of high penetration of iRES on the energy markets will be transformed into reality. Important expectations are connected with the development of electric vehicles (EVs) and the use of their batteries as storage systems to balance the variability of electricity production and consumption.

Advanced Robotics (AR)

The development of AR is linked with the evolution of AI and IoT (sensors). AR is oriented to develop systems replacing the human actions (e.g. in difficult environment conditions, but also in all repetitive processes). In this manner, the main effects of AR are connected with: (1) changing the structure of jobs, (2) increasing the productivity, (3) decreasing the energy consumption by automation and optimization of the activities, (4) creating new needs for maintenance and services.

There is a high transformation potential of the economy, especially of industry, by robot use in tasks previously performed only by humans. This transformation can lead to strong effects in the consumption of energy. Robots do not need the human comfort in terms of heating, cooling and lighting. A great reduction of the consumption is possible by adapting the factories to the relaxed needs of the operation of robots.

The AR use will greatly impact on the cost of maintaining offshore windfarms. Currently, about 80% of the cost of maintenance is spent by sending people for "inspections and repairs via helicopter, maintaining support vehicles, such as boats, and building offshore renewable energy platforms to house turbine workers" [27].

The development and implementation of autonomous mobile robots in the industry may improve a lot the innovation in intralogistics, reducing the costs in the transportation of material and components, with effect in the total energy consumption.

Big data (Bd)

In the last decade, an increasing number of energy users and vendors have recognized the great potential of the big data to improve the economics and the safety of a plant. One of the most attractive areas is the use of Bd in combination with the engineering knowledge to obtain safer and more resilient energy systems. The optimization of the maintenance and the component inventory are some of the direct applications of Bd in the energy sector due to the volume and diversity of the components. Collecting the data from a multitude of sensors all-together will be useful for the diagnostics and prognosis of the operational performances of a plant.

Such development may have influence on the plant life management allowing a better use of the components, avoiding the burdening states. At the same time, safety and security performances may be significantly improved.

Blockchain

The blockchain technology may increase cyber security for the data recorded. Moreover, it may create a more effective and efficient interface with regulators. It is acting as a trusted platform to record transactions and to distribute information among the parties without the control of a central entity. No files are used to store the digital records; instead, they are represented by transactions written on a cryptographic hash.

Some important applications are already identified in the nuclear sector such as: (1) the fuel supply chain, involving many stakeholders including mining, processing, purchasing, operation, spent fuel storage etc; (2) effective management of the nuclear materials used in construction, operation and post-operation of a NPP, even after decommissioning; (3) recording events within a single facility or company (security access, safety events, etc.). These will contribute to a better transparency, also reducing the risks of fraud.

Drones

The commercial unmanned aerial systems, or drones, may be used for aerial monitoring including the critical infrastructure facilities, such as NPPs. The use of drones may be extended for the inspection of different nuclear facilities (e.g. looking for leaks in boilers, steam isolation valve rooms, radioactive waste or fuel recycling areas). Moreover, drones equipped with adequate sensors may collect the dose data on contaminated areas, even in case of difficulty to access indoor areas.

Assessment of the impacts of the disruptive technologies

Based on the literature data (the elements summarized in the previous section) and the own expertise in the field, ten experts in the energy were asked to assess the possible impact of each disruptive technology on the energy demand in Romania for 2050, versus the reported consumption in 2019 (the year just before the pandemics). The answer was retained in the percentage form with a scale between -100% and +100%, with a step of 5%.

Table 2 presents the range of the answers, in the form of minimum and maximum (algebraic) values. Based on these ranges, three scenarios were formulated in order to introduce a correction of the predicted demand for 2050 (Optimistic, Moderate and Pessimistic scenarios). It worth mentioning that the Optimistic scenario is associated with the increase of the energy demand.

Table 2. The perceived impact of the disruptive technologies on the energy demand in Romania by 2050

	Disruptive technology	**Perceived impact (increase vs 2019 level)**		**Scenarios**		
		Min	*Max*	*Pessimistic*	*Moderate*	*Optimistic*
1	Artificial Intelligence	-20%	+5%	-20%	-10%	+5%
2	Internet of Things	-10%	+5%	-10%	0%	+5%
3	Biotechnologies	-15%	-5%	-15%	-10%	-5%
4	Additive manufacturing	-30%	-5%	-30%	-12.5%	-5%
5	Material Sciences	-10%	+5%	-10%	0%	+5%
6	Energy storage	-20%	-10%	-20%	-5%	+10%
7	Advanced Robotics	-10%	+5%	-10%	0%	+5%
8	Big Data	-20%	+5%	-20%	-8%	+5%
9	Blockchain	-5%	0%	-5%	-2.5%	0%
10	Drones	-5%	+5%	-5%	0%	+5%

The results presented in Table 2 may be translated into the following elements:

(1) there is a tendency of experts to credit all the disruptive technologies to decrease the energy consumption by energy efficiency, optimization, and new operational management; there are some exceptions (assessing a small increase) due to the transition phase of such technologies;

(2) the largest impacts in decreasing of the energy demand are attributed to the additive manufacturing, artificial intelligence, energy storage, and big data, whereas the impact of blockchain and drones are considered small;

(3) even if the appreciations are produced by a small number of experts and are based on a limited understanding of the possible evolutions, the values are important to understand the level of uncertainties of the predictions given by using classical computer tool, such as MAED;

(4) the future of energy demand is difficult to be realistically predicted for long term and, therefore, the results of the simulation tools should be treated with prudence in the strategic documents.

Conclusions

A moderate increase of the energy demand is expected in Romania for the next three decades. An increase of the quality of life and economic activity is expected to stimulate the increase of energy demand, but energy efficiency measures, together with the improvements in the management will temperate the potential increase. The optimistic scenario shows an increase with +52% (in 2050 vs 2019), whereas the pessimistic scenario estimates an increase of only +12%.

The simulations performed by using classical energy demand tools, such as MAED, are affected by the uncertainties of the basic parameters characterized by limited knowledge on future socio-economic development and technological evolutions.

In this respect, the results should be doubled by additional analysis such as expert judgement to create more credibility on the input data.

The paper presents a set of considerations regarding the evolutions of the disruptive technologies and their impact on the energy demand in Romania, for the next three decades. Based on expert judgement, a credibility range of the impacts has been obtained. As a general trend, the disruptive technologies are acting towards the reduction of the energy demand; therefore, the optimistic increase should be amended by such estimated influence.

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