A Demand-Supply Equilibrium Model – Study Case on the Electricity Market for Households from the Perspective of Prices Liberalization

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Abstract

Energy production and consumption exert considerable environmental pressure on climate change, deterioration of natural ecosystems and adverse health impacts. Our paper/scientific approach starts from the premise that in the near future the Romanian Electricity Market will be completely liberalized in order to be integrated in the Single Market Electricity. These profound changes will have a strong impact on the household behaviour. In this regard, we develop a dynamic model for the electricity market, based on the principle of supply and demand equilibrium. At the same time, by means of extrapolation methods we are deducing the expressions of demand and supply functions for electricity. These expressions are entered in a demand-supply model given by a dynamical system. The aim of this study is to investigate the equilibrium and the evolution of this system based on data sets from 1999 to 2021, in order to determine the evolution of electricity consumption and to establish competitive advantages for sustainable consumption.

Keywords	***DOI***	***JEL code***
Consumption, energy, environment, equilibrium model, prices liberalization, Romania	*https://doi.org/10.54694/stat.2021.30*	*C6, C62, D1, E21, H31, P18, P48*

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INTRODUCTION

Electricity is perceived as a public service to the population and, at the same time and equally, as a necessity for the economy. Citizens (consumers), when provided with this service, have not only the right to be served, but also an obligation to use energy rationally, under the conditions of energy efficiency. Distribution companies can be carriers of this message in a transparent way through appropriate price corrections.

Energy sources can have a major impact on the environment, on the atmosphere, such as acid rain and global warming. This is due to the widespread use of fossil fuels. The impact on water, soil and landscape must also be mentioned.

In recent years, the European Union has had to reach a balance between protecting the environment, and the political interests on the one hand, and meeting the energy needs of individual economies on the other hand. The European Union (EU) has identified the energy sector as one of its main policy priorities. Reliable and sustainable energy supplies at reasonable prices for businesses and consumers are crucial for the European economy. In the past, the energy industries were organized as vertically integrated monopolies and they were generally belonged to the state. The growing ideological and political disaffection with vertically integrated monopolies and the liberalization successes of other network industries have led to liberalization initiatives in the energy industries (Streimikiene, Bruneckiene and Cibinskiene, 2013).

The liberalization of the energy market became obligatory in Romania, once the country joined the European Union. The liberalization of energy prices in our country was a difficult process. The leaders of the Union have imposed a schedule for the liberalization of prices on the government, mentioning that the failure to comply with it would result in certain penalties to be paid. At European level, the liberalization of the energy market was set up in July 2009 with the adoption of the third legislative package on domestic electricity and gas markets, which was to be completed in 2011 (Eberlein, 2008). Romania did not comply with the European deadlines; the new energy law was adopted with delay by the Chamber of Deputies and promulgated by the President of Romania in the first half of July 2012. Although this liberalization was to be applied from 2012, it seems that for last year, 2021, it would only be applied to household consumers, because so far there are no implementation rules. At the same time, this year, very few competitors entered the market, therefore the change is not significant.

The major distortions (subsidies/cross-subsidies) present on the Romanian electricity and natural gas markets stem from the fact that energy prices have been artificially maintained at very low levels and used as a short-term fix for pervasive social problems. Therefore, in contrast to other European countries where timely deregulation has led to bigger competition, resulting in lower prices (both in wholesale and retail markets), in Romania the expectation is that deregulation will result in higher prices, particularly because the measure is long overdue and has, in the meantime, created series of other problems: mainly, the low energy prices have de-capitalized the energy companies that were thus unable to invest in energy efficiency measures and other modernization projects – all this driving further up the real costs of energy supply. The social problem is composed of the renewable support scheme and the cogeneration bonus. District heating is an energy sub sector with its own set of problems producing a significant social impact. All these different problems accrue in the energy bill (Leca et al., 2014).

However, the liberalization of the energy prices is conducted amidst a grossly unsustainable energy sector which incurs huge losses. Due to its great delay, price deregulation will put a significant strain on all the consumers. Measures aimed to soften this shock will have to target a reduction of both energy consumption (through energy efficiency) and energy loss (through modernization of the antiquated infrastructure). Studies show that energy efficiency can be improved by 16–24% (Leca, 2012).

Before and after Romania's accession, the privatization process in the energy sector unfolded haphazardly, no investments were made to modernize the thermal power plants and the district heating system that is now in a very precarious situation, threatening the heat supply in 32 cities. Before 1989, Romania had and continues to have a very high-energy intensity, which results in a wasteful use of resources (Leca et al., 2014).

Leaving aside the big negative effect of liberalization of the energy market in our country – increasing the mass of vulnerable consumers – theoretically, liberalization should have beneficial effects on energy efficiency, so the impact on the environment should decrease. But the increase in energy consumption will lead to extra pressure on the environment, by over-exploitation of natural, non-renewable deposits. This involves new investments in the field of natural gas exploitation, in the development, rehabilitation and dispatching of natural gas pipelines, in the increase of the natural gas storage capacity. Furthermore, this involves additional costs for a country already not rich enough.

A report of the National Regulatory Authority in the Field of Energy shows that the power prices in Romania went up by nearly 20% in 2017 compared to 2016, while there is also an increase of over 3% in domestic electric energy consumption compared to 2016, which strengthens the result of our analysis. One of the reasons for the rise in prices is the liberalization of electricity prices. On the other hand, suppliers are still obliged to buy a certain amount of import and a certain amount of domestic production by 2021. And last but not least, energy bills are higher than they need be because homes are energy inefficient.

In the first part of the article, we made a brief introduction to what energy means in economics, in the life of today's man. In the first part, we have shown the impact on the environment of the production of energy from renewable sources and we have made a foray into the legislation of Europe and Romania related to green energy and the liberalization of energy prices. In the second part, we described the mathematical model itself, and then, some conclusions about what we were looking for.

The purpose of the article is to make an analysis of the influence of price liberalization on the energy market for household consumers in Romania. To this end, we have considered a mathematical model and realized the graphic interpretation of the results obtained using the considered model.

1 THE ELECTRICITY MARKET AND THE IMPACT OF THE ENERGY SECTOR ON THE ENVIRONMENT

One of the major challenges for the European Union is how to ensure energy security with competitive and "clean" energy, taking into account the limitation of climate change, the escalation of global energy demand and the uncertain future of access to energy resources. The energy sector comprises the following activities: the extraction and preparation of coal; oil and natural gas extraction; the extraction and preparation of radioactive ores; oil processing industry; the production, transport and distribution of electric and thermal energy, gas and hot water.

The production units in Romania are thermal power plants, hydropower plants and the Cernavoda nuclear power plant.

A country traditionally rich in energy resources, Romania has a very poor understanding of the concept of energy saving and no culture in this respect at all. Energy efficiency was recognized as a priority only in 2000, through Law 199/2000, itself adopted with great delay. While the discussions about price are endless, there is little to no focus on the other component of the energy bill: quantity. Thus, energy efficiency should become the government's number one priority over the next period, more so since Romania's potential in this respect is quite untapped (Leca et al., 2014).

But burning solid fuel is not only unsustainable (in the case of peat and coal), but it also generates a wide spectrum of particulate and gaseous air pollutants such as respirable particles (PM10) and non-respirable particles, carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), and polycyclic aromatic hydrocarbons 210 (PAH) (Guo, Lewis and Mclaughlin, 2008).

Industrial competitiveness is at the forefront of the EU's energy policies, along with the following aspects: liberalization of energy markets, energy security, environmental protection and climate change.

In consensus with the Kyoto commitments of the European Union, the liberalization of the electricity markets has been announced to reduce prices, increase efficiency, guarantee security of supply and develop renewable energy sources (National Regulatory Authority in the Field of Energy, 2017). Some solutions, of course in agreement with other researchers, would be the use of bio-energy, for the generation of electricity, and heat using modern conversion technologies (Al Asfar et al., 2018).Thus, biomass may be used as an alternative fuel which may save 40% of fuel cost (Demirbas and Demirbas, 2016).

The 2009/28/EC Directive on renewable energy, implemented by Member States by December 2010, sets ambitious targets for all Member States, such as that the EU will reach a 20% share of energy resulted from renewable sources by 2020 and a 10% share of renewable energy specifically in the transport sector.

The 2009/28/EC Directive was approved for the regulation and the promotion of renewable energy, and established a mandatory methodology to assess the sustainability of biofuels in terms of greenhouse gas emissions (Lapuerta, Ruiz and Lechon, 2014).

In order to reduce the impact of the energy sector on the environment, Romania has transposed into Romanian legislation, in 2003, the 2001/80/EC Directive on the limitation of air emissions of certain pollutants by large combustion plants. This legislative act aims at limiting emissions of sulphur dioxide, nitrogen oxides and dust from large combustion plants, i.e. plants with a thermal output of more than 50 MW thermal (The energy strategy of Romania for the period 2007–2020 updated for the period 2011–2020).

2 DYNAMIC MODELING OF SUPPLY–DEMAND MODELS, METHODS – RESULTS – DISCUSSION

The market price of goods is determined by both the supply and demand. In 1890, English economist Alfred Marshall published his work, Principles of Economics (Marshall, 1890) which was one of the earliest writings on how both supply and demand interacted to determine price. Today, the suply – demand model is one of the fundamental concepts of economics. The point at which the quantity supplied equals the quantity demanded essentially determines the price level of a product.

This is a model studied by Beckmann and Ryder (Beckmann and Ryder, 1969) and Mas-Collel (Mas-Collel, 1986).

A demand supply model in which price (p) reacts to quantity (q) and vice versa was given in (Tu, 1992) by adding constants k and μ to Beckmann and Ryder model:

$$\begin{cases} \dot{p} = k\left[F(p) - q\right] \\ \dot{q} = \mu\left[p - C(q)\right] \end{cases}. \tag{1}$$

In the model, (p) represents the price and (q) represents the quantity. $F(p)$ represents the quantity demanded at price (p) and $C(q)$ represents the marginal cost. Price rises in response to the excess demand $F(p)$ over supply (q) and the quantity increases in response to the excess of price over cost $C(q)$.

In the considered demand supply model $\dot{p}$ and $\dot{q}$ denotes the derivates of price and quantity with respect to time.

Let us take $k = 1$ and concentrate on the speed of adjustment $\mu > 0$ treated as a single parameter on the model. The system becomes:

$$\begin{cases} \dot{p} = F(p) - q \\ \dot{q} = \mu\left[p - C(q)\right] \end{cases}.$$

We note: $f_1(p,q) = F(p) - q$; $f_2(p,q) = \mu\left[p - C(q)\right]$.

In order to solve the system, first we need to compute de Jacobian matrix:

$$\frac{\partial f_1}{\partial p}=\frac{\partial F}{\partial p}\ ;\ \frac{\partial f_1}{\partial q}=-1$$

$$\frac{\partial f_2}{\partial p}=\mu*1=\mu\ ;\frac{\partial f_2}{\partial q}=-\mu*\frac{\partial C}{\partial q}\ .$$

Let us consider:

$$a=\frac{dF}{dp}\text{ and }c=\frac{dC}{dq}>0\cdot$$

The Jacobian matrix is:

$$A(\mu)=\begin{pmatrix}\frac{\partial f_1}{\partial p} & \frac{\partial f_1}{\partial q}\\ \frac{\partial f_2}{\partial p} & \frac{\partial f_2}{\partial q}\end{pmatrix}=\begin{pmatrix}a & -1\\ \mu & -\mu c\end{pmatrix}. \tag{2}$$

We study the eigen values, determined from the Jacobian matrix, in order to determine the type of equilibrium. The eigen values λ_1 and λ_2 are the solutions of the characteristic equation:

$$\lambda^2-tr(A)\lambda+\det A=0\,.$$

So, the eigen values satisfy the following relations (Viète relations):

$$\lambda_1+\lambda_2=tr(A)=a-\mu c\,,$$

$$\lambda_1*\lambda_2=det(A)=\mu(1-ac)\,.$$

The sign of the eigen values influences the equilibrium point of the system and we analyze the relations between the sign of the eigen values of the system matrix and the equilibrium point.

If $Re\lambda_1 > 0$ and $Re\lambda_2 > 0$, then the system solution is getting closer to the point of unstable equilibrium.

The characteristic equation is obtained by replacing *tr*(*A*) and *det*(*A*) in the characteristic equation:

$$\lambda^2+(\mu c-a)\lambda-\mu-\mu ac=0\,.$$

We consider the following notation:

$$r(\mu)=tr(A)=a-\mu c\,,$$

and so, if an equilibrium point exists, we have:

$$r(\mu_0)=a-\mu_0 c\,.$$

A complete analyse of the model stability was made by to Beckmann and Ryder in their paper (Beckmann and Ryder, 1969). We used their complete evaluation and adapted it to this particular model. We can comment the behaviour of the systems as follows:

- If $a < 0$, $r < 0$, the model is instable.
- If $a > 0$, r > 0, we have:
  - For $\mu < \mu_0$ and $r(\mu_0) < 0$ the model is stable.
  - For $\mu > \mu_0$ and $r(\mu_0) = 0$ for $\mu_0 = \frac{a}{c}$ and det $A > 0$ we obtain the equilibrium point.

The bifurcation takes place when the determinant of the Jacobian matrix is different to zero or when the eigen values of the matrix are both different to zero.

In order to analyse the demand-supply equilibrium model we consider the available data from the Eurostat. Eurostat is the Commission's department responsible for publishing comparable statistics across the EU. For our study, we consider the consumption and the price for householders' energy. All data from the Eurostat database are included in Table 1 and we further use them to determinate and to visual represent the relation between price and consumption.

Table 1 Numerical application, Romania case (the data corresponds to each year)

Year	Consumption (TWh)	Price (EUR/kwh)
2000	7.652	0.0541
2001	7.724	0.0561
2002	7.771	0.0419
2003	8.243	0.067
2004	8.043	0.0921
2005	9.234	0.0655
2006	9.999	0.0792
2007	10.389	0.0855
2008	10.400	0.0885
2009	11.021	0.0814
2010	11.329	0.0856
2011	11.577	0.0848
2012	12.035	0.0795
2013	11.896	0.089
2014	11.910	0.091
2015	12.095	0.0927
2016	12.067	0.0914
2017	12.596	0.0871
2018	12.779	0.099
2019	12.984	0.0983
2020	data not yet available	0.1045
2021	data not yet available	0.1115

Source: Eurostat

For the evolution of the price we initially obtained a linear trend, but since 2015, it has reached a maximum, after which the price lowered slightly.

To apply the proposed demand supply in the study about electricity prices liberalization we consider the reference year 2008. We note $t = 0$ for the year 2008, and this parameter increases or decreases in concordance with the considered year.

In terms of price evolution, calculations were made both for a linear function of function and for a parabolic function.

Thus, for the price, we will stop at the second degree expression of:

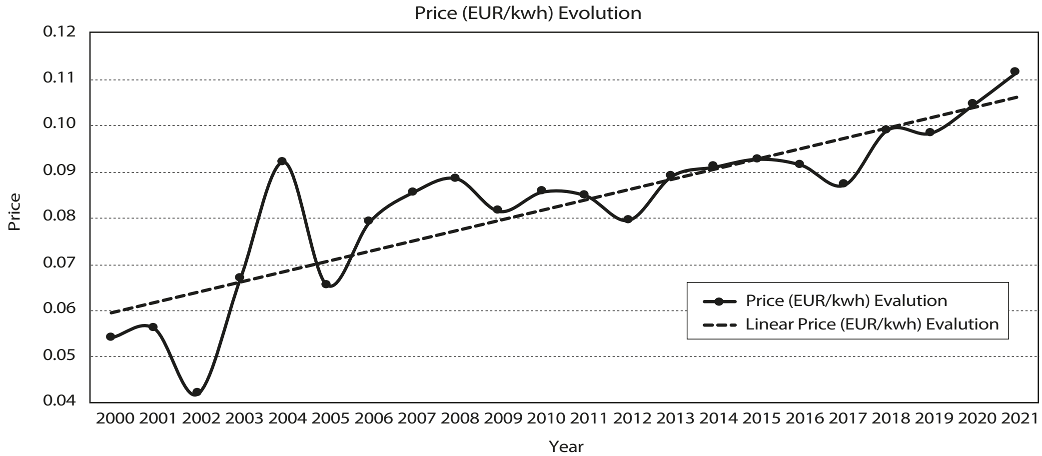
$$P_t = -0.0002t^2 + 0.6434t - 649.57.$$

If we take into account a linear trend, that is, a continuous price increase, it will have the expression:

$P_t = 0.0037t - 7.3637.$

Graphical representations of the linear expression for the price evolution in time are given in Figure 1.

Figure 1 Study of price evolution using a linear expression



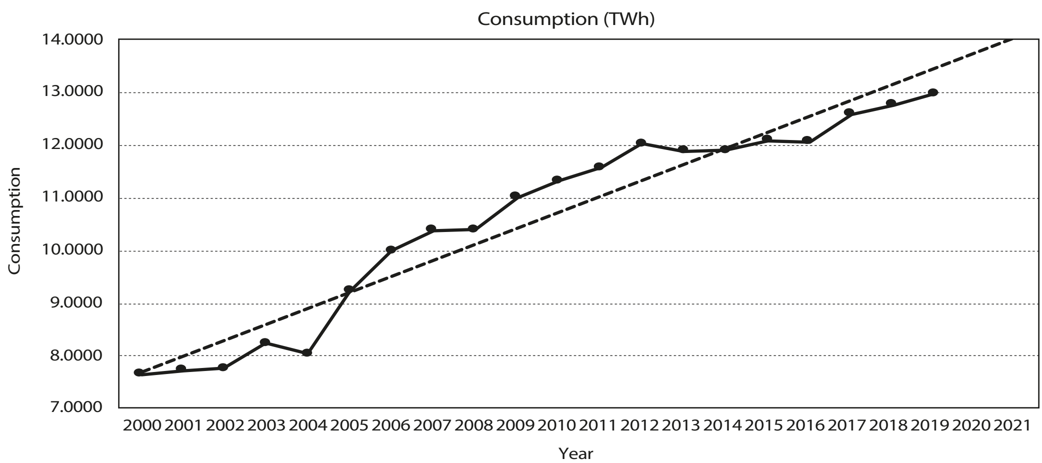
Source: Eurostat

Further, using the same program, we find a linear evolution of consumption, given by expression:

$C_t = 0.0037t + 10.15$.

Graphical representation of the linear expression for the consumption evolution in time is given in Figure 2.

Figure 2 Graphical representation of the linear evolution of consumption



Source: Eurostat

Figure 3 Price – consumption relationship

Source: Eurostat

In Figures 1–3, the blue line represents the actual value of price or consumption and the red line represents the linear trending of the dependency between price, consumption and time.

Analyzing the actual data on consumption and price data for households during the period 2000–2021, using the graphical representation, we determined, using the method of extrapolation and using the least squares method, both the evolution of the consumption and the price in time and the functional relationship between the two variables (consumption and price).

Thus, for the evolution of consumption, we determined a linear relation obtained from the relations between the consumption values and their evolutions in time, whose expression is:

$C_t = 0.0037t + 10.15.$

At the same time, the dependence of the consumer price is given by:

$P(q) = 0.0037q + 0.0507.$

By replacing these functions in the initial system and considering that $\dot{q} = 0$, we deduce that:

$C(q) = -1/\mu + 0.0037q + 0.0507.$

If we consider that $\dot{p} = 0$ we obtain the following relation:

$F(p) = p/0.0037 + 0.0470.$

Returning to the system in (1) we find as:

$$\begin{cases} \dot{p} = k\left[F(p) - q\right] \\ \dot{q} = \mu\left[p - C(q)\right] \end{cases},$$

$$a = \frac{dF}{dp} = \frac{1}{0.0037} = 270.270 > 0,$$

$$c = \frac{dC}{dq} = 0.0037 > 0,$$

$$r(\mu) = a - \mu c = \frac{1}{0.0037} - 0.0037\mu = 270.270 - 0.0037\mu .$$

Therefore,

$$\mu_0 = \frac{a}{c} = \frac{270.270}{0.0037} = 73045.95.$$

The bifurcation takes place because the determinant of the Jacobian matrix is different than zero.

Replacing the values computed above in the system we obtain a dynamic system that is conducting to an unstable system.

$$\begin{cases} \dot{p} = 270.270p - q + 0.0470 \\ \dot{q} = \mu(p - 0.0037q) - 0.9493. \end{cases}$$

The equilibrium point of the system is determined by solving the system and considering that $\dot{q} = 0$ and $\dot{p} = 0$:

$$\begin{cases} 270.270p - q + 0.0470 = 0 \\ \mu(p - 0.0037q) - 0.9493 = 0. \end{cases}$$

This system admits a single equilibrium point ($p \cong 1.00463$, $q \cong 272.47$) and this is an unstable equilibrium point, a repulsive node. The value of this point depends on the parameter μ.

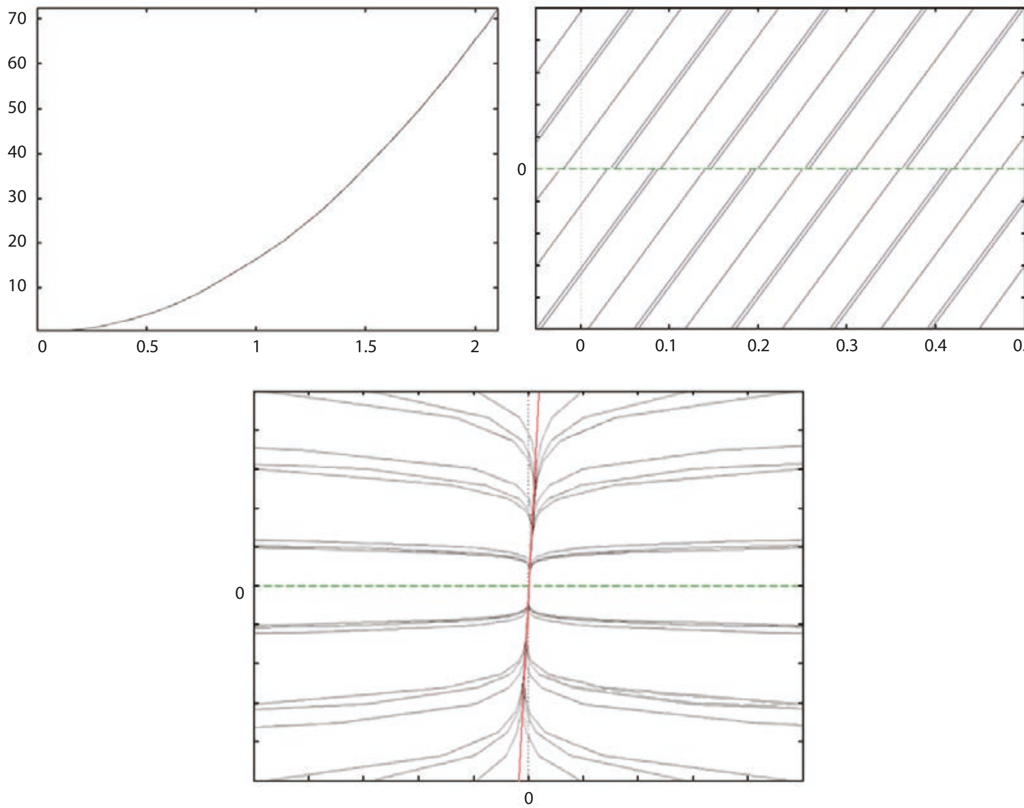
By computing the determinant of the Jacobian matrix, we observe that, for the value $\mu = 73045.95$, a bifurcation appears. We have illustrated the evolution of the system according to some parameter values in the following figures. The equilibrium point of the system is a repulsive and unstable node.

The following figure gives a visual representation of the described model for the data considered in Table 1. In the first part of the figure the axes are time (year) and price (a similar representation is if we represent consumption). Second part of the figure represents the relation between price and consumption in time (axes are price and consumption). And the last part of the figure represents the visual interpretation of the equilibrium point.

In a free market such the one considered in this article, energy market, the demand and supply tend to achieve an equilibrium. If the consumption tends to increase more than the availability then the price will go up. If the consumption decreases then the price will do down. Based on the relation between price and consumption, the model will determine an equilibrium between these two components. If we analyse the graphical representations in Figure 4, we can observe that in all cases the system tends to find its own equilibrium point (to balance the price and consumption).

While the price rises, the consumption decreases, but as we can observe from the considered example, these changes are not proportional. The same observation can be done when the price decreases and the consumption increases. As we can observe in the Figure 4, the equilibrium point is obtained but the lines that represent the price and the consumption are not symmetrical. This equilibrium point is obtained based on the interaction of the supply and demand.

Figure 4 Visual representation for the model: price/consumption evolution over time, the evolution of consumption by price, the equilibrium point (repulsive node)



Source: Own construction

CONCLUSION

Romania is the European country with the largest rural population. Slowly but surely certain areas start growing; people buy computers, television sets, home appliances. Consumption increases from one year to another, and the trend will continue in the coming period.

Bucharest is the European capital where the price paid by the household consumers was, in February 2021, 18% higher than the price paid one year ago. It is, by far, the biggest increase from all European capitals analysed in the latest statistics of the European Commission. In the second and third positions there are Kiev with a 16% increase and Belgrade with about 9% increase. Within the European Union states, 13 out of 27 capitals maintained the same prices or lowered them, while the increase of prices in all the other European capitals was moderate, generally by 5%, with the exception of Stockholm and Warsaw, but here the increase is much lower in comparison with Bucharest (Vaasaett, 2021).

From the forecasted model, it can be concluded that the liberalization of energy prices in Romania will lead to higher prices. The analysis was extended until 2021. Both the model and the tables show that, in order to maintain a balance (called equilibrium point in the model), as consumption increases, the prices must also increase.

The mathematical model allows us to study and to analyze the equilibrium point in the electrical market considering aspects like price and consumption. Using this model, we can analyze the evolution of the relation between the price and the consumption. The results obtained using the mathematical model are in accordance with the electrical market evolution.

We can notice that the bigger the price has become, the lower the consumption has dropper. The demand supply model allows us to sum up, when the demand is higher than the supply, the price will rise, and, when the demand decreases below the value of supply, the price will go down.

During the pandemic and as a result of rising prices or because a number of raw materials were not found, a large part of the Romanian industry was shut down. As a result, the energy required by the industry has decreased. In contrast, energy consumption has increased in household consumers. When the industry restarts, Romania will need more energy. For now, the production of energy is sufficient, even part of it is distributed abroad. It is expected that at the level of 2030, the Cernavoda Power Plant will start reactors 3 and 4. Until then, Romania must stimulate the production of energy from renewable sources, in the southeast, the production of energy from wind sources, due to the fact that the winds are stronger, then throughout the country the production of energy from photovoltaic cells and other renewable sources and non-polluting will be supported.

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