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ORIGINAL RESEARCH

Forecasting Competition in the Electricity Market of Greece: a Prey-Predator Approach

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Abstract

This paper studies and forecasts the evolution of concentration of Greek energy market, expressed by market shares of operators. The evolution of liberalization process of the Greek electricity market is dynamically estimated based on concepts of population biology, according to specific data for providers' market shares. Using the Lotka–Volterra model and Integral method to determine the unknown parameters, the methodology of prey-predator model is applied to describe the competition among Greek alternative electricity providers, towards obtaining a larger market share from the common source of electrical energy of current dominant provider and future adopters. The proposed model managed to validate the available statistical data for the examined case study and is proven to be suitable for forecasting market concentration and equilibrium in electricity area. The evaluation reveals that the market share of the incumbent operator is expected to remain quite high by the year 2020 and this is why the application of a cropping strategy is proposed in order to reduce its share to 50% complied with European directions and ensure smooth coexistence of the two interacting species. The described methodology can become a powerful managerial tool for decision-makers and providers in order to drive performance and price competitiveness.

Keywords Market shares · Market competition · Lotka-Volterra model · Electricity forecasting · Prey-predator species · Cropping

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1 Introduction

Until the mid-1990s, the electricity sector in many European countries was well regulated and owned by the state. However, the low productivity of the industry along with the high level of borrowing from state-owned energy companies has gradually led governments to pursue strategies that focus on opening up the electricity markets to private investment. In addition, the developed political dissatisfaction with all these vertically integrated monopolies in combination with all the successful stories of liberalization released in other industrial networks has increased the interest in the reform of the electricity sector [1].

The evolution of energy liberalization process in Europe especially from 2000 to 2012 is depicted in Fig. 1 [2]. There is a comparison between two years (2000, 2012) and it is obvious that European retail markets are increasingly getting "liberalized." Countries which have started to open up their retail markets, without necessarily fully implementing their liberalization yet, are colored in Fig. 1.

Liberalization in Scandinavian countries, especially in Sweden, took place in te early 1990s. The transition from the traditional market structure to the liberated was successful and resulted in lower prices for both domestic and industrial consumers [3]. Regarding Britain, it is considered a pioneer in the global trend towards liberalization of the energy market. Electricity prices have dropped significantly since the activation of New Electricity Trading Arrangements (NETA) in 2001, based mainly on bilateral energy contracts [4]. These provisions provided mechanisms for real-time adjustment of the differences that may occur between pre-agreed and actual electricity generation. Since April 2005, NETA were named in Green Electricity Trading and Transmission Arrangements (BETTA) [5].

In 2000, France adopted the 2000–108 law, which motivated the liberalization of energy market and market competition. The liberalization was about production and

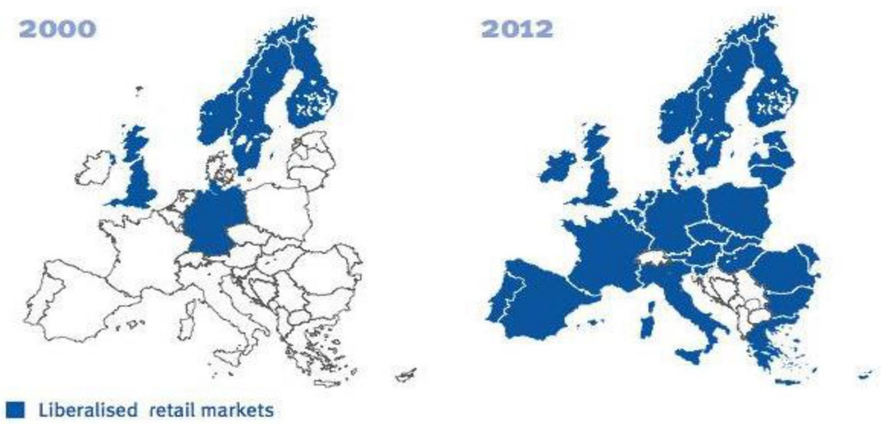

Fig. 1 A comparative figure of electricity liberalization process in Europe of 2000, 2012 (source: EURELECTRIC Innovation Action Plan Task Force Analysis)

supply activities [6]. Nowadays, most of commercial activities take place bilaterally, through direct transactions or intermediaries. In the French electricity market, a voluntary organized electricity stock exchange is now in operation [7].

Electricity trading began years ago and continues until the actual time of distribution (the moment when energy flows from production to consumption). The liberalization of the electricity market in European Union has been regulated by official regulations and directives which coordinate the prevailing conditions of competition in European energy markets, identify the problems, and set up independent regulators of electricity markets for a smooth operation of an energy market and consumer protection in EU [8, 9]. Concerning Greece, European Community directives have been incorporated into Greek Law almost since 2000. Electricity generation, transmission, distribution, and supply activities are considered to be "services of general interest" and supervised by the State, which is responsible for modernizing the industry and ensuring, under competitive conditions, the provision of electricity to consumers [10]. Even though measures for accelerating the process of liberalization of the Greek electricity market were also taken, so that the distinction between the Transmission System and the Distribution Network for electricity was clarified and all consumers could freely choose the electricity supplier [11], the Public Power of Corporation (PPC) has been almost the exclusive electricity supplier in Greece until recently (2015), accounting for more than 97% of the total energy supply [12].

As a consequence, a new European environment is being built for electricity market players, which seems to be quite appealing and challenging for new competitors and Greece should also follow up. Emphasis should be put especially on market structure, which is considered to be really important for determining market power, business behavior, and the degree of competition in different sectors of a society, especially the ones of high technology [13, 14]. Like the sector of telecommunications once was a monopolistic market and then it was liberalized [15], the market of energy as well is of great interest since it has similar characteristics. More specifically, the electricity market constitutes such a national monopoly which, after liberalization and setting important entry barriers, can become an oligopolistic market and then maybe a competitive one. As the competition among the incumbent operator and new providers increases, all of them are making an effort to grow the number of their clients by providing services and products in very attractive prices.

The electricity and energy market is very closely related to the new era of communications and the revolution of networks, data communication, Internet of Things (IoT), Industry 4.0, etc. The rapid expansion of Information and Communication Technologies (ICT) will be followed by a similar expansion of demand in energy. Thus, forecasting of the corresponding market demand and competition is of paramount importance.

There have already been some studies about electricity markets competition, which constitute important contributions to the literature. In Fehr and Harbord [16], the structure of the UK electricity market is analyzed, based on which price competition is modelled as a sealed-bid, multiple-unit auction with a random number of units. For the same country, another approach, where two dominant generators of electricity submit a supply schedule of prices for generation and receive the market-clearing price depending on the demand, is evaluated [17]. Moreover, the effect of contracts on entries and that of the threat of entries on the contract and spot markets are examined in Newbery [18]. Various ways of introducing competition in the European electricity industries considering not only the strategies of electricity providers but also their behavior in the marketplace are analyzed in Glachant and Finon [19], Haas et al. [20], and Joskow [1].

However, the majority of the aforementioned approaches refer to electricity markets where competition has already been established and they do not really apply to monopolistic markets or markets which find themselves a step before being competitive. The main contribution of this paper is to fill this gap by making use of concepts of population biology in order to examine and forecast the evolution of such electricity market's structure and concentration [21]. Using the Lotka–Volterra model and the Integral method to determine the unknown parameters [22], the methodology of the prey-predator model is applied to describe the competition among alternative electricity providers in Greece towards obtaining a larger market share from the common source of electrical energy of the current dominant provider PPC and future adopters [21, 23].

Thus, the study of the concentration of this market, as expressed by corresponding market shares, is necessary not only to describe and forecast competitors' new entries and behaviors but also to provide feedback to regulation authorities. Furthermore, the proposed model can become a powerful managerial tool for decision makers and providers in order to drive performance and price competitiveness, since it can easily estimate the "churn effect," meaning the switching of users among the electricity providers [24].

The rest of the paper is organized as follows: Sect. 2 provides information about European Union regulations and directives relating to liberalization of electricity markets in Europe and also describes the conditions of European electricity sector as reformed over the last few years. Section 3 presents the new legislative and regulatory framework of Greece according to which changes of current situation of electricity market need to be done. The model of the electricity market in Greece is used as a case study for the methodology of the prey-predator model which is presented in Sect. 4. The evolution of the Greek electricity market with the dominant player PPC as the prey and alternative providers at the place of the predator is dynamically estimated based on concepts of population biology and the results are discussed in Sect. 5. Finally, the application of a cropping strategy is described in Sect. 6, while Sect. 7 presents an overview of this study and main conclusions.

2 The Liberalization of Electricity in the EU

2.1 EU Directives and Regulations

The liberalization of electricity market was regulated in 1996 by the first directive of the European Commission 1996/92/EC about common rules for the internal market in electricity, which was repealed in 2003 from the second directive of European Commission 2003/54/EC. Following the survey of 2007 about the prevailing conditions of competition in energy markets by European Commission and also the identification of main problems that impeded the smooth operation of a single energy market in EU, the directive 2003/54/EC has been replaced by the third directive 2009/72/EC since 2009 [8].

Furthermore, the following European regulations were adopted:

- Regulation 713/2009/EC of European Parliament and Council of 13th July 2009, establishing an Agency for the Cooperation of Energy Regulators (ACER) [9]
- Regulation 714/2009/EC of European Parliament and Council of 13th July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing regulation (EC) 1228/2003 [25].

All aforementioned directives/regulations refer to the following points:

- Clear distinction between competing (i.e., electricity supply to consumers) and non-competitive (network operation) activities,
- Obligation for operators of non-competitive activities to allow third parties access to their infrastructure,
- Liberalization of the supply activity of electricity,
- Gradual lifting of supplier choice restrictions from consumers
- Setting up independent regulators of electricity markets.

2.2 European Electricity Market

In general, the electricity sector in Europe is of great interest, since it has been identified as one of its main policy priorities. The EU has considered all energy supplies as reliable and sustainable as well as that they should be provided at reasonable prices for both businesses and consumers. Since the introduction of the first directive in 1996, the progress achieved in electricity market liberalization has been enormous and has affected competitiveness, security of energy supply, and environmental sustainability in all member states. These are the main EU energy policy targets that the Energy Architecture Performance Index (EAPI), developed by the World Economic Forum, has identified in order to evaluate the success of electricity market liberalization in different countries. The applied regulatory reforms in the electricity market generally seemed to contribute to improved efficiency and welfare outcomes according to empirical studies of the era dealing with assessment of electricity market liberalization impacts and later based on the available statistical data on energy. In Table 1, the ranking according to the three dimensions of EAPI for EU member states is presented based on data provided by Eurostat for the year 2012. The industrial electricity prices, the ratio of industrial to residential prices, utilization rates, and reserve margins were used as indicators of competitiveness [26].

As one can see from information provided in Table 1, Sweden is ranked as the best-performing country according to EAPI evaluation. As aforementioned, Sweden completed the liberalization of its electricity market since 1996 and the transition from the traditional market structure to the liberated was considered a success resulting in lower prices for both household and industrial consumers [3]. Moreover,

Table 1 Ranking of EU member states according to electricity liberalization success in implementing EU energy policy targets based on EAPI (2013)

EU member states	Competitiveness	Sustainability	Security of energy supply	Overall score	Rank
Belgium	0.51	0.56	0.77	0.61	16
Denmark	0.64	0.56	0.82	0.67	4
Germany	0.6	0.58	0.79	0.66	9
Greece	0.63	0.48	0.7	0.6	18
Spain	0.71	0.55	0.75	0.67	5
France	0.58	0.76	0.8	0.7	2
Ireland	0.61	0.63	0.74	0.66	8
Italy	0.48	0.53	0.72	0.58	22
Netherlands	0.5	0.5	0.77	0.59	21
Austria	0.61	0.52	0.79	0.64	13
Portugal	0.64	0.56	0.75	0.65	12
Finland	0.58	0.47	0.81	0.6	20
Sweden	0.58	0.76	0.8	0.71	1
UK	0.59	0.63	0.78	0.67	6
Bulgaria	0.56	0.55	0.62	0.57	23
Czech Republic	0.5	0.4	0.78	0.56	24
Estonia	0.56	0.59	0.67	0.61	17
Hungary	0.53	0.67	0.76	0.65	10
Latvia	0.62	0.74	0.71	0.69	3
Lithuania	0.58	0.64	0.73	0.63	14
Poland	0.6	0.48	0.71	0.6	19
Romania	0.65	0.63	0.73	0.67	7
Slovak Republic	0.48	0.69	0.78	0.65	11
Slovenia	0.55	0.56	0.77	0.63	15

there has been a constant increase in the number of active suppliers in the market ever since. For France, which started liberalization of the energy market since 2000, there was Electricite de France (EDF), a state-owned vertical company that monopolized the generation, transmission, and distribution of electricity and today operates autonomously and has been privatized. The separation of electricity generation, transmission, and distribution has brought significant changes to the structure of the French electricity market and together with the creation of a wholesale spot market has boosted market competition. About Denmark, which is ranked as 4^{th} according to EAPI data, there has been a large number of active suppliers in the past years (over 40) for electricity but a few suppliers with more than 5% market share (6 suppliers in 2015). The UK has also a high score that comes in accordance with the information that it has been a pioneer in the global trend towards energy market liberalization. Even from the 1990s, the British government decided to privatize energy companies, which were state-owned until then. It then proceeded to the gradual liberalization of the market and, as a result, consumers gained the right to choose the energy supplier. Concerning the Czech Republic, which seems to have the lowest score according to the data of Table 1, it is reported that the total number of active electricity suppliers for both household and non-household customers has been slightly increasing over time, with 52 active suppliers in 2013 increasing to 61 in 2016. The increase in the number of suppliers is generally an indication of more competition on the electricity market for all consumers [27].

During the 15-year period from 2005 to 2020, important steps have been taken across Europe in order to liberalize the energy market at the national level of each member state with the target to create a common energy market at a European level having as main characteristics price alignment, market transparency, access of suppliers on every energy market in Europe, and consumers' choice to select the best possible offer. In theory, this has been the current situation; in other terms, every user has the right to choose their supplier, despite the fact that the level of energy market liberalization reached by the members on their attempt to deregulate their national market is different from one country to another. In practice, there are still several barriers that need to be confronted. The desired common energy market has not been fulfilled yet [26]. The most usual difficulty is that prices are not as competitive as expected and consumers cannot adapt to the new situation. Figures 2 and 3 depict the electricity prices for EU household and industrial consumers respectively according to Eurostat data for the period 2014–2015. The analysis of electricity prices for households is based on prices for the medium standard household consumption band, namely one with annual electricity consumption between 2500 and 5000 kWh, while that for industrial consumers refers to prices for the medium standard industrial consumption band, with annual electricity consumption between 500 and 2000 MWh [28].

On one hand, it is understood that electricity liberalization is not the only factor that influences the economic variables of a state, but on the other it has been proved that liberalization brings benefits to both consumers and the economic environment of a country [26]. More specifically, the price of electricity is often related to the level of taxes and levies of a state and this is why there are some important differentiations of the electricity price from one economy to another. According to Fig. 2, Denmark, Germany, and Ireland are reported to have the highest electricity prices for such medium-sized households during the second half of 2015 and by far the lowest electricity prices were found in Bulgaria, with the next lowest prices reported for Hungary. Among the reported EU Member States, the largest electricity price rise for consumers in the second half of 2015 was observed in Latvia (26.8%), where in 2014 there were five active suppliers and the next year this number increased to 10, while the share of the three largest market suppliers was more than 95%, which suggests that the newcomers were still relatively small and in fact it was observed that only one supplier on the market had more than 5% of the overall market share. In addition, price increases were found in Belgium (15.1%) due to hard competition and low margins and the UK (8.4%). The average increase for the whole of the EU-28 was 2.4%, whereas there were 12 member states where the price of electricity declined. Cyprus (−22.0%), Lithuania (−5.8%), and Ireland (−3.2%) saw the most substantial decreases in the price of electricity charged to household

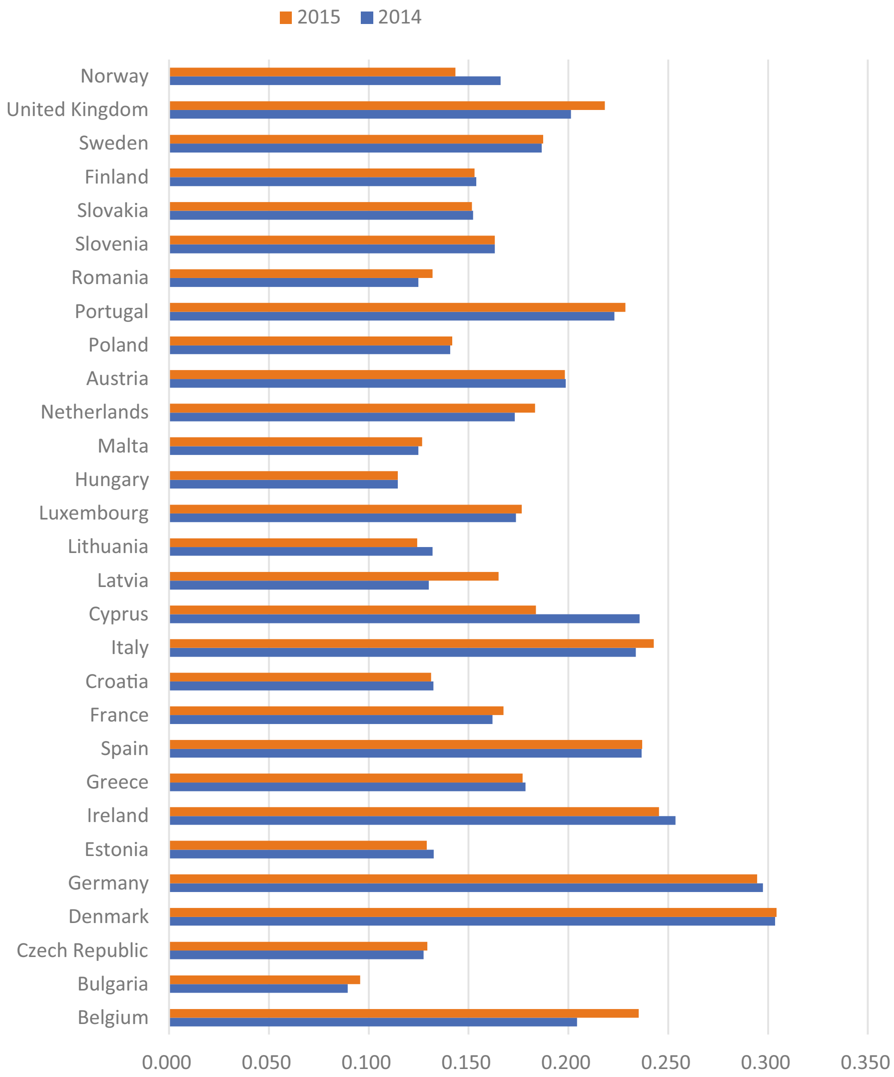

Fig. 2 Electricity prices for EU household consumers (EUR per kWh) for the period 2014–2015

consumers. Because of the limitation of the Cypriot market (geographical isolation and the small size of the market), there is only one electricity supplier but Cyprus still has energy price regulation and was obliged to decrease prices since 2012. In particular, Lithuania's electricity market price for households is still regulated but especially in the examined time period five more suppliers entered the electricity market resulting in increasing the competition in the market. At the same time, for the Irish electricity market, there has been an increase (albeit small) in the number of active suppliers, and in those with a market share of more than 5% [28, 27].

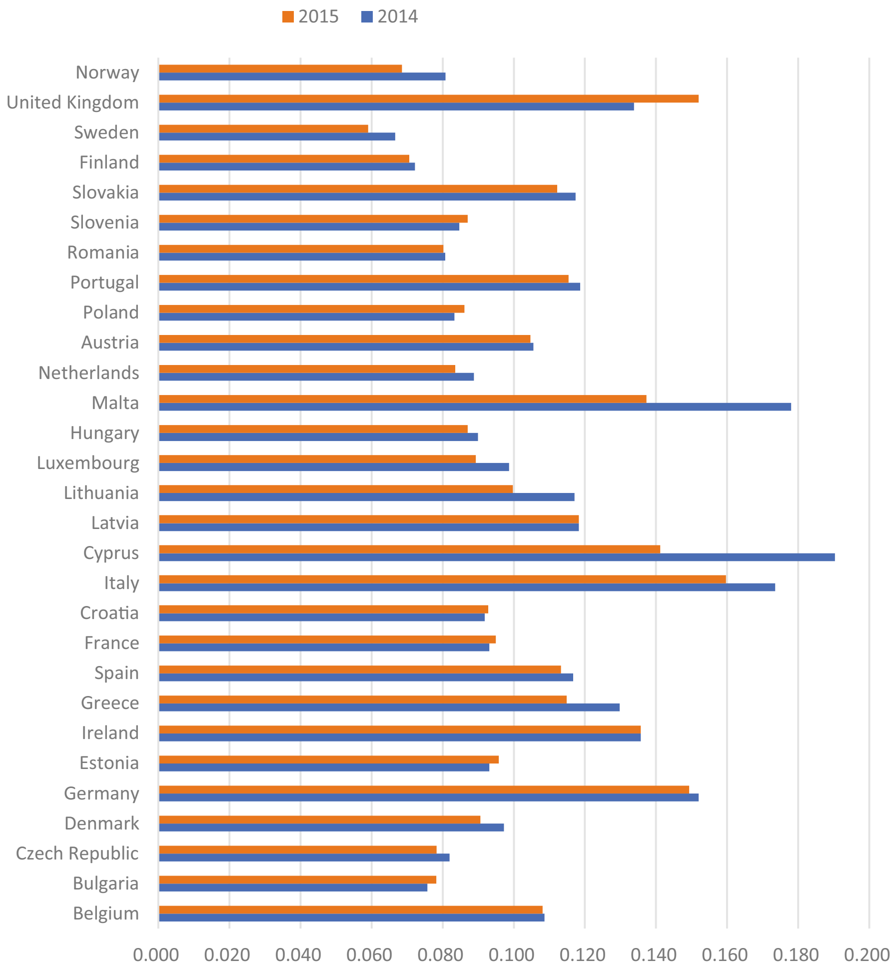

Fig. 3 Electricity prices for EU industrial consumers (EUR per kWh) for the period 2014–2015

A similar analysis is performed for industrial consumers as illustrated in Fig. 3, noting that prices correspond to the basic price and non-deductible taxes and levies and therefore exclude deductible VAT. The price of electricity for a medium-sized industrial consumer in the EU-28 decreased by 1.3% between 2014 and 2015. This reduction characterized the majority (19) of the EU Member States, while prices remain constant in two additional member states. The largest decline was recorded in Cyprus (−25.8%), Malta (−22.9%), Lithuania (−14.9%), and Sweden (−11.5%). Also here, due to the specific energy system of Cyprus, the final electricity price for non-households fell for the same reason as for the household tariffs. As far as it concerns Malta, the supplier called Enemalta holds an effective monopoly over the country's electricity market, where the energy and supply component of the retail electricity price decreased in 2015 so that it could be aligned with the wholesale prices, a situation which is an indication of an efficient electricity market. The same occurred in Lithuania as well. Once again, as aforementioned, the Swedish energy market was deregulated very soon in 1996 for electricity. Therefore, there are no non-household price regulations in Sweden. On the contrary, there were 7 EU countries where the price of electricity for industrial consumers increased during the same period; the highest price increase was recorded in the UK (13.6%), followed by Poland (3.4%). In particular, in the UK, wholesale prices for non-household consumers on the electricity market remained stable over the investigated time period, but retail prices, on the other hand, increased until 2015 in part due to increasing energy and supply component. The alignment between the energy component of industry retail prices and wholesale prices over time is also a proxy for the efficiency of retail competition. In addition, regarding Poland, polish vendors were no longer required to submit tariffs for approval to the President for industrial and commercial consumers and the number of electricity generators was also decreased in the period assessed [28, 29].

As one can realize, the procedure of transforming an energy market to a fully developed and beneficial environment so that consumers can enjoy competitive prices is a time-consuming and demanding task. Although major steps in opening the market have been successfully made by most European members, several measures still have to be taken so that consumers can enjoy the full economic benefits of a free market. One of the most important measures which is usually used to monitor the extent of electricity market liberalization is the market share of the largest generators in each country. Figure 4 presents Eurostat data for the period 2014–2015 and refers to the number of production companies in each EU Member State, which account for at least 5% of total electricity production nationwide [30].

Five EU Member States (Slovakia, Latvia, Cyprus, Malta, Estonia) have reported that only one company dominates in electricity production nationwide in 2015. There are six dominant companies in the UK and Lithuania, while in Bulgaria and Ireland there are five dominant companies. This is also an indication of the success of the liberalization of electricity in production sector in these countries. In Poland, the same number is reduced by two points in 2015 compared to 2014. In general, the number of dominants in EU-28 countries (plus Norway) ranged between 86 and 89 between 2014 and 2015 [30]. Moreover, retailers are "dominant" if they sell to final consumers at least 5% of their total national electricity consumption. As shown in Fig. 5, Slovenia has the most dominant electricity retailers, equal to eight, while there are also seven in Austria for the 2015. Countries with only one dominant company acting in electricity sales are Greece, Cyprus, and Malta, proving that in these countries there is no competition in the supply for the year 2015. Generally, in the supply as well as production sector of electricity market in EU-28 countries (plus Norway), the number of dominant companies is considered to be relatively small.

On the other hand, privatization is not considered to be necessarily correlated with increased competition in the electricity market as far as it concerns electricity prices but in some cases is related even to higher prices because of a higher cost of capital, less tax advantages, and less access to low-cost energy resources. In fact, in many countries, electricity prices are actually increased so that states could sell assets and generate revenue. Furthermore, while governments may use privatization

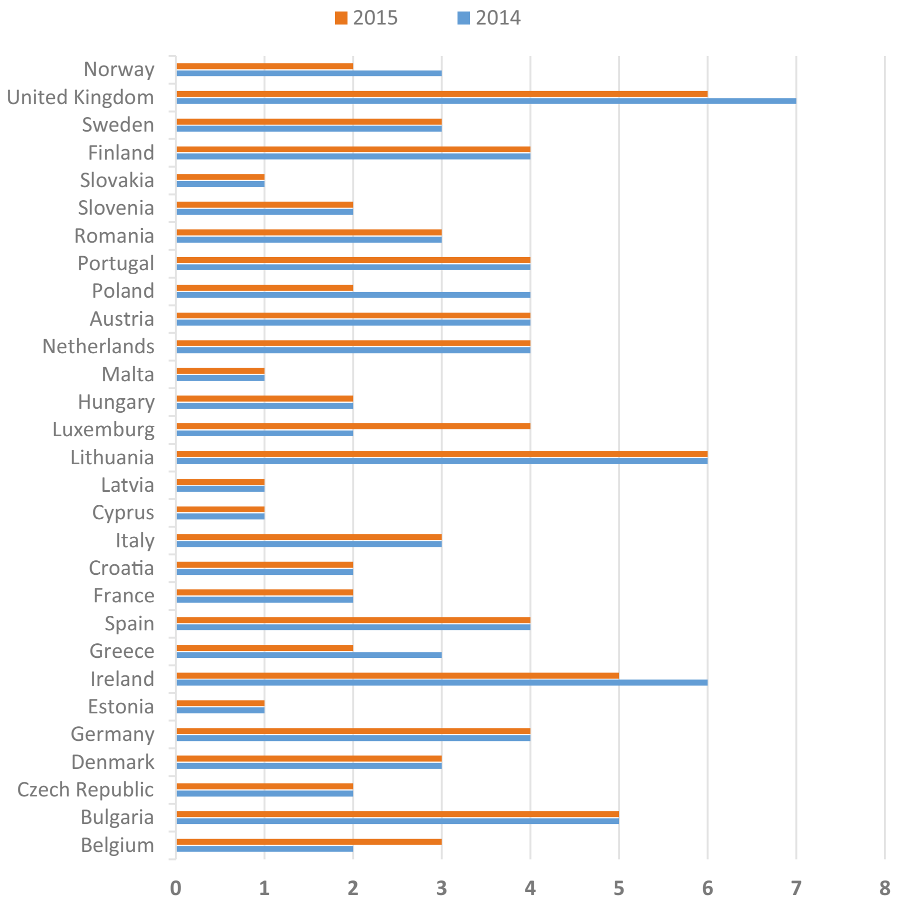

Fig. 4 Number of companies in EU Member States, whose market share ≥ 5% of total electricity production nationwide

as a platform for horizontal unbundling, if horizontal unbundling does not reach far enough, post-privatization prices may remain high [26]. However, the privatization of the electricity supply industry can dramatically change the sectors' structure of a state and make a difference in prices when it results in new entries of providers and if the incumbent does not retain practical control of the market [27].

For instance, the UK had been under complete public ownership since 1947 and it was then considered an example for the liberalization policies of the electricity sector at EU level. More specifically, the privatization of the state-owned monopolist went hand in hand with the market opening in the electricity sector and though the initial target of the privatization was to increase productive efficiency in this sector, the UK government was criticized for sacrificing liberalization objectives to promote competition. Sweden, in contrast, which also started liberalizing its electricity market early without the incentive from the European Union,

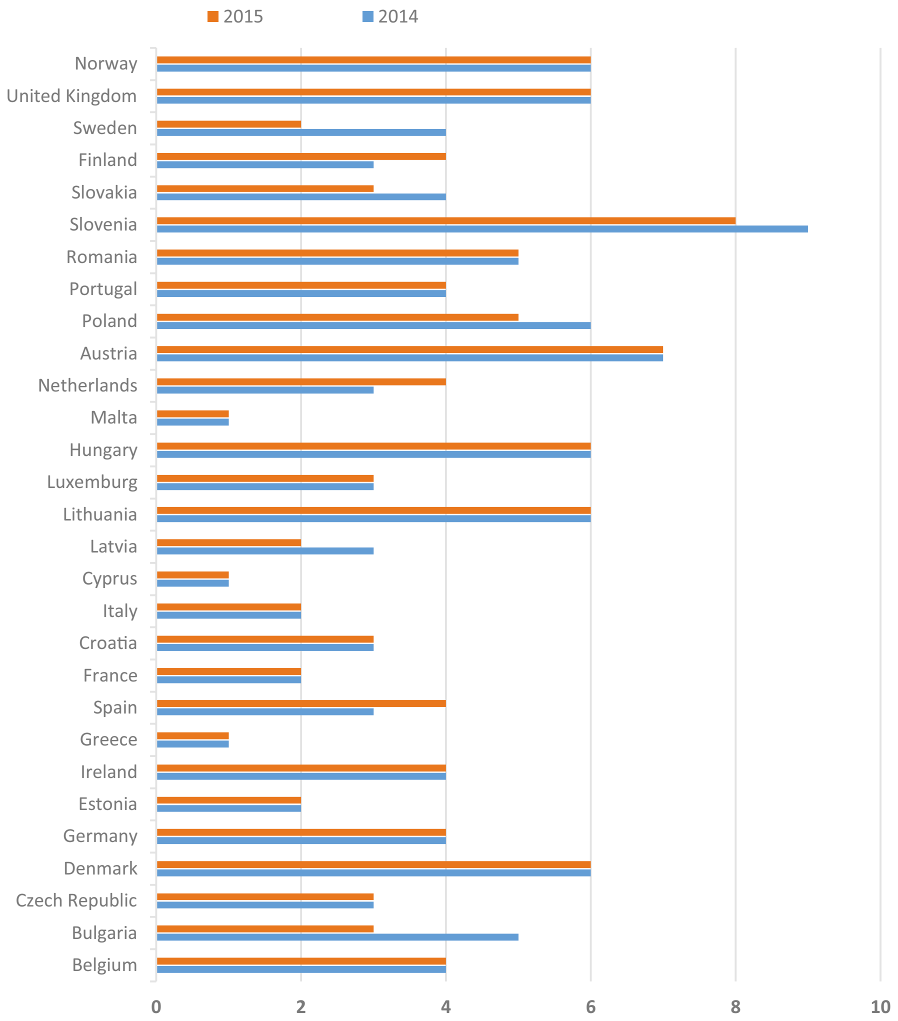

Fig. 5 Number of dominant electricity retailers per EU Member State

confined itself to a mere legal privatization while retaining full ownership control of the dominant company in the Swedish electricity market. Furthermore, the start of the liberalization process initiated at EU level may have fostered the increasing number of privatizations in the German electricity sector, but the primary driving force, which explains the retreat of the state, had been the disastrous situation of the public budgets forcing federal states and municipalities to generate extra revenue through the sale of state-owned assets in the electricity industry to the private sector. Finally, in France, which had been one of the Member States most reluctant in implementing the EU's liberalization policy for the electricity market, the conservative government had to overcome fierce domestic protest when it partially privatized the former monopolist EDF which enjoyed special status as a national utility of the "Service Public." Privatization became indispensable to finance the internationalization strategy of the company that was losing shares in its liberalized home market [31].

3 The Case Study of Greece: Reference Scenario

3.1 New Legislative/Regulatory Framework for Greek Electricity Market

The European Community directives, which officially coordinate the prevailing conditions of competition in European energy markets aiming at the same time to strengthen consumer protection in the EU by maintaining the high level of consumer trust in energy suppliers, have already been incorporated into the Greek Law almost since 2000 [10]. According to the provisions of Paragraph 4.3 (c) of the Article 3 of Law 4336/2015 about "Pension Rules—Ratification of the Draft Financial Contribution Agreement by the European Stability Mechanism and arrangements for the implementation of the Financing Agreement" [32], the Greek government has committed to design the NOME auction system, aiming at a 50% reduction in PPC's retail and wholesale market share by 2020, while the limit values will cover production costs and fully comply with EU rules [33]. More specifically, Law 4389/2016 sets out the timetable for the liberalization of the electricity market in Greece in order to redistribute the shares of PPC and alternative providers and also reduce the share of PPC, from the share it had in August 2015 to less than 50% until 2020 [34]. The regulatory measures in general aim to the:

- Equal access of eligible suppliers of electricity in the domestic energy mix,
- Development of healthy competition between suppliers,
- Improvement of the quality and the prices of electricity supply for final consumers.

The publication of the Minister Decisions 35–20/05/2016 and 38–06/06/2016 about "Approval auction application plan (NOME)" then followed and as reported there, the Authorities were committed in 2016 to start implementing the requirements of the European Consolidates Electricity Market (Target Model) [35]. The Target Model establishes the rules for the transfer of electricity between EU countries. Furthermore, in the Annex of the Minister Decision 38–06/06/2016, it is noted that the NOME mechanism should act as a special mechanism regulating the auctions of electricity [36]. Table 2 illustrates the required percentages for the reduction of PPC share in the retail market with August 2015 as a reference point.

In accordance with the Article 135 of Law 4389/2016, the annual quantity of electricity to be auctioned was equal each year to the percentage of impairment of PPC's share in the retail market of the electricity system with the time reference point of August 2015 [34]. The last Article was modified in May 2017 (Law 4472/2017) and states that the quantities to be auctioned are equal to the percentages shown in

Table 2 Annual share targets in PPC market

	Mandatory pool				EU target model	
Month/year	08/2015	12/2016	12/2017	12/2018	12/2019	2020
Annual decrease of retail market shares		– 8%	– 12%	– 13%	– 13%	
Retail market share	95.24%	87.24%	75.24%	62.24%	49.24%	

Table 3 multiplied by the total volume of the electricity that passed through the electricity system in the previous year [37].

In addition, as reported by Article 135 of Law 4389/2016, in case of the impairment of PPC's share in retail market of the electricity system falls below or exceeds by two percentage points the impairment target for the corresponding 6-month period, as determined by the division of the annual target in the corresponding semesters, the Regulator Authority of Energy proceeds to increase or decrease respectively the quantities to be auctioned for the first 6 months from the end of the reference period with an equivalent increase/impairment of the quantities to be auctioned off this semester [34].

In September 2016, Law 4425/2016 auctioned off, reorganizing the wholesale electricity market, aiming at the integration of electricity into the commodities for which financial transactions can be carried out, and LAGIE is defined as the Operator of Wholesale Electricity Market [38].

3.2 Current Situation in Greece

The Greek electricity system consists of the interconnected and non-interconnected networks (Greek islands). In the interconnected network, both production and distribution of electricity are considered as competitive activities in which both PPC and other private companies can participate. However, most islands in Greece are electrically powered by about 80% of autonomous electrical systems with electricity production coming from local thermal power stations of PPC, which operate on petroleum fuel, and about 20% from renewable energy sources, wind and photovoltaic plants [11, 39]. In this study, only the interconnected network is taken into account, since the electricity market operation and management of non-interconnected islands are not accessible to third parties.

Even though measures for accelerating the process of liberalization of the Greek electricity market were taken with a series of regulations and laws, as aforementioned, the alternative operators that emerged did not have their own network infrastructure, so they were completely depended on the incumbent provider [40]. Public Power of Corporation (PPC) still remains the largest electricity generation and supply company in Greece with about 7.4 million customers until the end of 2018. It possesses a large infrastructure in lignite mining, power generation, transmission, and distribution facilities [41]. Especially, in the retail electricity supply market, Greek private companies that emerged since the mid-2000s, had a vigorous

Table 3 Updated annual quantities of electricity to be auctioned

	Mandatory pool				**EU target model**		
Month/year	08/2015	12/2016	12/2017	12/2018		12/2019	2020
Annual quantities of electricity to be auctioned		8%	16%	19%		22%	

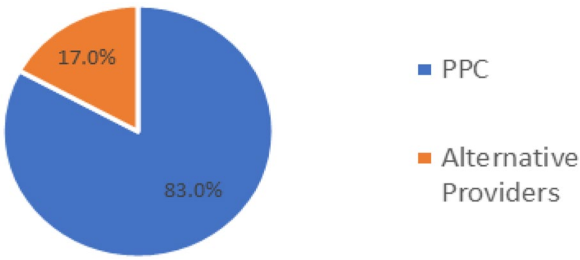

Fig. 6 Percentage contribution to total electricity supply of Greece

activation in 2011, but at the beginning of 2012, after the suspension of almost all alternative suppliers, PPC regained its oldest rates. As depicted in Fig. 6, it is obvious that PPC holds a truly monopolistic position in the electricity supply sector of Greece accounting for more than 83% of the total energy supply [42]. It also accounts for 60% of the country's total electricity generation, as shown in Fig. 7 [43].

This is the reason why the Greek government continues to reform the legislation and corresponding regulations for the liberalization of the Greek market and the supply of electricity, also limited by the Memorandum of Understanding that was signed in 2015, according to which the objective of lowering by 25% the retail and wholesale market shares of PPC and bringing them below 50% by 2020 must be fulfilled [44].

Studying the concentration of the Greek electricity market, expressed by corresponding market shares of providers, is important not only to describe and forecast competitors' new entries and behaviors, but also to provide feedback to the regulation authorities of Greece.

4 Methodology

The proposed methodology emphasizes especially on market structure, which is very important for determining market equilibrium and power, business behavior, and the degree of competition in a mainly monopolistic market [14]. The aim is to develop a model that is based on the theories of population dynamics [21] in order

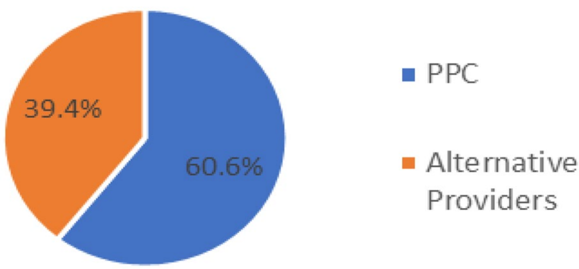

Fig. 7 Percentage contribution to total electricity generation of Greece

to both analyze and forecast market competition for high-technology markets [45] and provide useful information to decision makers and providers for making their environment more efficient and competitive.

The electricity supply market of Greece is selected as the case study to evaluate the methodology over a set of statistical data from January 2015 until March 2018, on a monthly basis, which represent providers' market shares. The approach of the prey-predator model [23, 46] is considered to be the most appropriate to describe the competition among alternative providers towards obtaining a larger market share from the electricity market of the current dominant provider PPC and future adopters.

4.1 The Prey-Predator Approach

According to the evolutionary theory approach related to population biology and population dynamics, when more than one species coexist in the same environment, these biological species are expected to interact between each other in many different ways [21, 47]. In Murray [48], it is clearly described that there are three types of interaction:

If the growth rate of one population is decreased and the other increased, the populations are in a "prey-predator" situation.
If the growth rate of each population is decreased, then it is called "competition."
If each population's growth rate is increased, then the term "mutualism" or "symbiosis" is used.

Since the evolution of market concentration in high-technology saturated markets with a dominant player is examined, this paper applies the prey-predator approach. The evolution of energy and in particular electricity market concentration in Greece is based on the evolution of the corresponding market shares of both the incumbent, the PPC here, and the alternative providers. The methodology makes use of the prey-predator approach constructing a model of two species that interact by competing for a common electricity supply. In this situation, the alternative providers represent the first species with the role of the predator that preys on the other species—the prey -PPC in an effort to survive or increase its market share by consuming PPC's market share.

The application of the Lotka–Volterra model is selected as the mathematical model to describe the competitive interaction of species, alternative electricity providers in this case, towards obtaining a greater market share from the common source of present and future adopters. The approach includes suitable parameters based on which a corresponding system of differential equations is constructed [22, 49].

The generic form of the Lotka-Volterra model for *n* species, as described in Kloppers and Greeff [22], according to which the proposed methodology of this work is designed, is the following:

$$\frac{dx_i}{dt} = x_i\left(\alpha_{i0} + \sum \alpha_{ij}x_j\right), i,j = 1,2,\ldots,n \quad (1)$$

In Eq. (1), dx_i/dt represents the rate of population change for each species i and the parameters α_{ij} stand for the growth or reduction rate (depending on their sign, positive or negative respectively) of population x, whereas α_{i0} denotes the intrinsic population increase or extinction (whether the corresponding parameter is positive or negative) in the absence of the other species.

The proposed methodology aims to identify the possible features and characteristics of the electricity market, capture the measure of competition, and provide useful feedback to regulation authorities and the Greek state about future predictions for the new market schema, concerning both the reduction of the PPC market dominance and the increase of the entry of new providers. The purpose of the model is to enhance decision making by aggregating data, which are used to quantify the indicator of market shares, into a different form of indices representing environment, energy, and economy [50].

4.2 The Proposed Model—Estimation of the Unknown Parameters

The proposed model of this paper tries to describe and forecast the competition of the Greek electricity market by using a two-competing-species Lotka–Volterra model. The species are represented by populations of the prey and the predator symbolized as x and y respectively at time t, according to the prey-predator methodology. The approach makes use of the available set of data per month that describe the electricity market shares in Greece from January 2015 until March 2018 [43].

The indicator of market shares is selected in this case as an index that represents not only the level of concentration in a market, but also the degree of competition. Market shares are identical to species that compete with each other for the market potential and are also considered the result of the underlying, usually noncooperative, game of the participating players-service providers that includes managerial and strategic activities, such as marketing, pricing, and quality of services [18, 19].

The proposed Lotka-Volterra model is mainly based on estimating the parameter values and then incorporating them into a system of non-linear differential equations. Detailed analysis can be found in literature in [23, 46, 51]. According to Eq. (1), the non-linear dynamical system consisting of two first-order differential equations, each containing linear and quadratic terms, for the two competing species, denoting by x and y the populations of the prey-PPC and the predator-alternative providers respectively, is represented by:

$$\left.\begin{aligned} \frac{dx}{dt} &= x\left(a_0 + a_1x + a_2y\right) \\ \frac{dx}{dt} &= x\left(a_0 + a_1x + a_2y\right) \end{aligned}\right\} \quad (2)$$

In System (2), *dx/dt* and *dy/dt* are the rates of population change for the prey and the predator respectively and x and y are functions of time, t. The parameters α_0

and α_3 represent the intrinsic population growth (in which case their signs would be positive) or death rate (their signs would be negative) in the absence of the other species, while the parameters α_1, α_2, α_4, and α_5 could be positive, negative, or zero, and describe whether the two species interact in terms of predation, competition, or mutualism, or not at all [22].

The evaluation of the effectiveness of the proposed model as described by the equations of System (2) requires first the estimation of the unknown parameters. There have already been many different ways to calculate these parameters in literature from basic mathematical approaches to more advanced techniques. The mathematical description of the current model is performed using a statistical method which can be solved with any linear regression software tool, since any other more complicated technique would be more expensive and often not accessible to scientists.

More specifically, the method of the numerical integration is applied in combination with the statistical linear least squares regression technique in order to determine the unknown parameters [47]. The numerical integration is performed for integrating both sides of the equations of System (2) with respect to t over the time interval $[t_0, t_n]$ that can be divided into n sub-intervals, each with unit length, following thoroughly the procedure described in Kloppers and Greeff [22], called Integral method, which yields:

$$\left.\begin{array}{l} \int_{t_0}^{t_n} \frac{dx}{dt} dt = x(t)\Big|_{t_0}^{t_n} = \int_{t_0}^{t_n} x(t)\big(a_0 + a_1 x(t) + a_2 y(t)\big) dt \\ \int_{t_0}^{t_n} \frac{dy}{dt} dt = y(t)\Big|_{t_0}^{t_n} = \int_{t_0}^{t_n} y(t)\big(a_3 + a_4 x(t) + a_5 y(t)\big) dt \end{array}\right\} \quad (3)$$

for the prey x and the predator y, respectively.

The evaluation of the proposed technique is applied using monthly data for 39 months from January 2015 until March 2018, reflecting real market shares for the Greek electricity market being represented by two species, the PPC and the alternative operators. Data were extracted from LAGIE's database and its Day Ahead Scheduling monthly reports, as shown in Table 4. The month (starting from January 2015) is referred at the second column of the table, while the third and the fourth columns describe the PPC's and the alternative operators' market share respectively. The total monthly size of the electricity market in Greece for the same period is illustrated in Fig. 8, which also shows the contribution of the PPC and alternative providers to the overall electricity supply.

The available set of data is used in combination with the Integral method to transform the initial problem into a typical statistical non-intercept multiple regression problem, so that the unknown parameters can be estimated by the approach of least squares. Any available statistical software package, such as Microsoft Excel, can be used to find these values; however, a Matlab program was implemented in the context of this work. Consequently, the set of linear equations of System (2) is represented by the following system:

$$\left.\begin{array}{l} \frac{dx}{dt} = x(1.47 - 1.47x - 1.48y) \\ \frac{dy}{dt} = y(2.44 - 2.35x - 2.74y) \end{array}\right\} \quad (4)$$

Table 4 Market shares of Greek electricity providers for January 2015–March 2018

No.	Month	PPC	Alternative providers
1	Jan 15	96.93%	3.07%
2	Feb 15	96.80%	3.20%
3	Mar 15	96.65%	3.35%
4	Apr 15	96.25%	3.75%
5	May 15	95.80%	4.20%
6	Jun 15	95.59%	4.41%
7	Jul 15	95.90%	4.10%
8	Aug 15	95.49%	4.51%
9	Sep 15	94.39%	5.61%
10	Oct 15	94.28%	5.72%
11	Nov 15	94.29%	5.71%
12	Dec 15	94.85%	5.15%
13	Jan 16	94.59%	5.41%
14	Feb 16	93.47%	6.53%
15	Mar 16	92.96%	7.04%
16	Apr 16	91.58%	8.42%
17	May 16	90.74%	9.26%
18	Jun 16	90.45%	9.55%
19	Jul 16	90.41%	9.59%
20	Aug 16	89.99%	10.01%
21	Sep 16	88.26%	11.74%
22	Oct 16	88.18%	11.82%
23	Nov 16	88.78%	11.22%
24	Dec 16	89.93%	10.07%
25	Jan 17	89.68%	10.32%
26	Feb 17	88.58%	11.42%
27	Mar 17	87.78%	12.22%
28	Apr 17	86.66%	13.34%
29	May 17	85.70%	14.30%
30	Jun 17	85.62%	14.38%
31	Jul 17	85.82%	14.18%
32	Aug 17	85.66%	14.34%
33	Sep 17	83.70%	16.30%
34	Oct 17	83.31%	16.69%
35	Nov 17	84.21%	15.79%
36	Dec 17	85.47%	14.53%
37	Jan 18	84.68%	15.32%
38	Feb 18	84.23%	15.77%
39	Mar 18	82.97%	17.03%

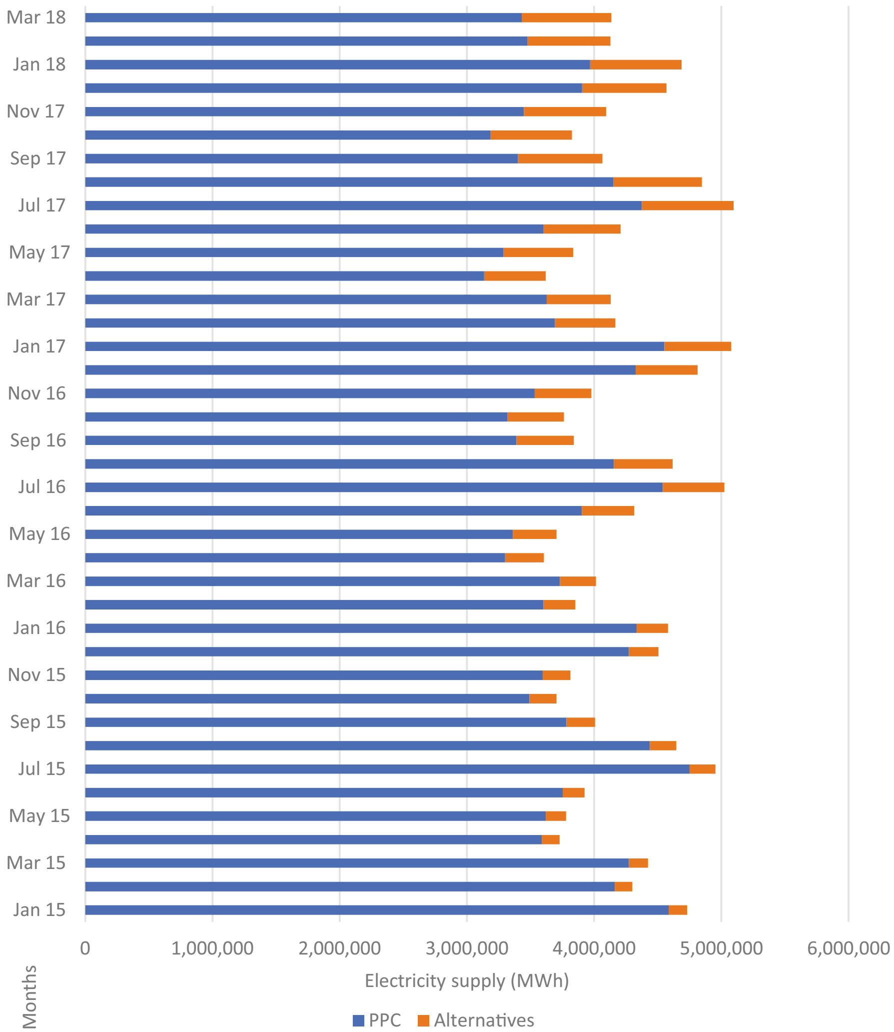

Fig. 8 Total size of Greek electricity supply market per month and contribution of PPC and alternative providers over the period from January 2015 to March 2018

where *x* and *y* represent the market shares of the PPC and the alternative electricity suppliers in Greece respectively.

5 Results and Evaluation

The estimation of the parameters in the equations of System (4) was derived using the available statistical data of Table 4. The values of the unknown coefficients indicate the dynamics and penetration of the existing electricity market in Greece.

More specifically, the alternative electricity suppliers seem to have a higher value for both the growth rate (2.44) and the intraspecies competition parameter (2.74) denoted by y than the PPC, meaning that they have entered into the Greek electricity market and have started to increase their market share at a good rate. This is found to be sufficiently close to the set of statistical data of Table 4, which shows that even though the PPC is still dominant, it has suffered losses.

Moreover, it is observed that the rate at which the PPC grows is almost as high as the rate of its decrease due to predation. The provided information as far as the "churn effect" is concerned [24], in other terms the movement of customers among different providers, is reflected by the corresponding parameters of interspecies interaction. After market liberalization, consumers have the right to switch to new entrants in the market, but several important issues may complicate this decision and this is why a return back to the former monopolist is observed. The estimated values of the parameters in the equations of System (4) show that the alternative suppliers' market share decreases more due to PPC (2.35) than PPC's share is reduced because of their presence (1.48). This describes that a number of PPC's customers have switched to alternative providers since the liberalization of electricity in Greece and it is expected that PPC will continue to suffer a market share reduction due to them. Nonetheless, it is also predicted that some of the alternatives' customers will return back to PPC and in fact at a higher rate than those that will move to the new suppliers. This is justified by the fact that customers generally are familiar only with the former monopolist with which they have built long-term relationships which foster commitment and trust. In addition, less customer knowledge about new competing suppliers has a direct negative effect on switching electricity provider [52]. However, the incumbent firm PPC still has to face the new competitors and must address customer switching since the alternative operators will keep growing, a fact which ensures that liberalization succeeds. This finding is validated as well by the results of the corresponding stability analysis [53] conducted in this paper and explained later in this section, which shows that the alternative suppliers have a certain rate of growth but not satisfying enough so that the two species reach a stable balance point at a short period of time, as required by the Memorandum of Understanding [44].

The value of the coefficient of determination (R^2) is 0.99 and this means that the estimated values fit quite accurately the model, while the mean squared error (MSE) is calculated at a value of 1.87E-17 and the mean absolute percentage error (MAPE) at 0.07. The estimated values of the market shares of PPC and the alternatives are clearly depicted in Figs. 9 and 10 respectively in comparison with their real (observed) values.

The critical points of the System (4) or equilibrium solutions can be calculated as the values of x and y for which the derivatives of this system become equal to 0. Consequently, there are four (4) critical points, all located in the nonnegative octet: (0, 0), (0, 0.891), (1, 0), and (0.789, 0.211). Even though the System (4) is a nonlinear system, all of its participating functions are proved to be twice differentiable; therefore, linearization is possible near a critical point (x_0, y_0) and the system can be represented by a corresponding linear system by taking into consideration the following transformation that moves the critical point to the origin [53]:

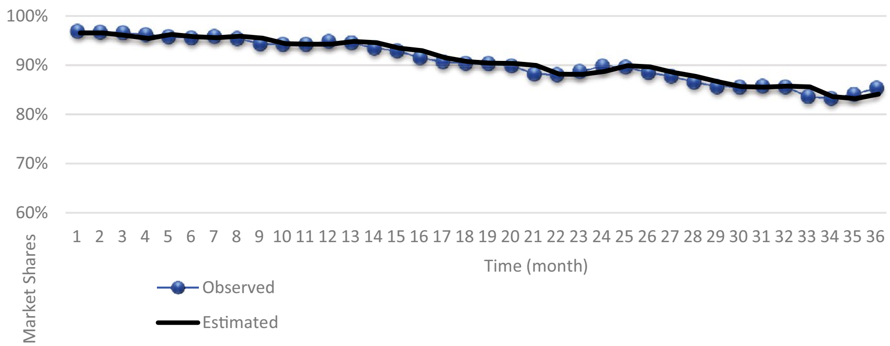

Fig. 9 Estimated market shares for PPC in comparison with observed values

$$X = x - x_0, Y = y - y_0 \tag{5}$$

According to the aforementioned transformation and after performing a Taylor series expansion, the linear system that approximates the nonlinear System (4) in the neighborhood of the critical point (x_0, y_0) is derived using the Jacobian matrix of the partial derivatives, which is given by:

$$\frac{d}{dt}\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} F_x(x_0, y_0)F_y(x_0, y_0) \\ G_x(x_0, y_0)G_y(x_0, y_0) \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} \tag{6}$$

where:

$$\left.\begin{array}{l} F(x, y) = x(a_0 + a_1 x + a_2 y) \\ G(x, y) = y(a_3 + a_4 x + a_5 y) \end{array}\right\} \tag{7}$$

Consequently, the corresponding Jacobian matrix is the following:

$$\frac{d}{dt}\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} a_0 + 2a_1 x_0 + a_2 y_0 & a_2 x_0 \\ a_4 y_0 & a_3 + a_4 x_0 + 2a_5 y_0 \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} \tag{8}$$

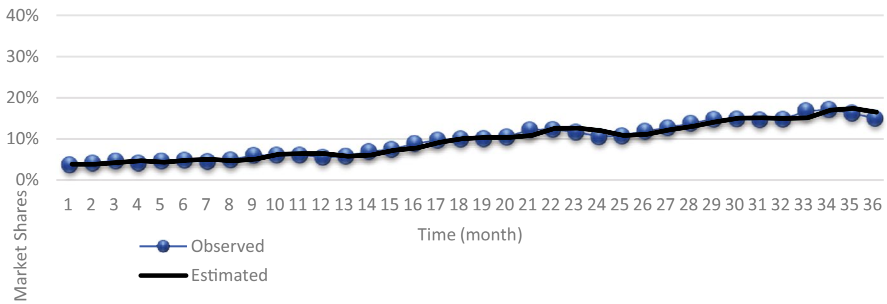

Fig. 10 Estimated market shares for alternative providers in comparison with observed values

which, after substitution of the parameter estimated values of a_0, a_1, a_2, a_3, a_4, and a_5 becomes:

$$\frac{d}{dt}\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} 1.47 - 2.94x_0 - 1.48y_0 & -1.48x_0 \\ -2.35y_0 & 2.44 - 2.35x_0 - 5.48y_0 \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} \tag{9}$$

All of the critical points of the examined system are located at the positive quadrant. For each estimated critical point, an analysis of the corresponding eigenvalues and eigenvectors is performed [47]. More specifically, the trajectory of each solution deriving from the system is examined based on the corresponding eigenvalue, since it is quite usual to investigate the behavior of the solutions without actually finding the solutions in question.

From a more geometrical viewpoint, a direction field or a slope field is constructed, as shown in Fig. 11, in order to plot the tangent vectors of the solutions of the system of differential equations being evaluated at a large number of points. The importance of this graph is that qualitative conclusions about the behavior of the solutions can be easily drawn [53]. As illustrated in Fig. 11, the trajectories of the first three solutions depart from the corresponding critical point as the time variable t increases, thus resulting in unstable solutions, while all trajectories approach the fourth critical point (0.789, 0.211) identifying it as a stable node of the system.

Substituting the corresponding values of the last critical point into the equations of System (9), it results in:

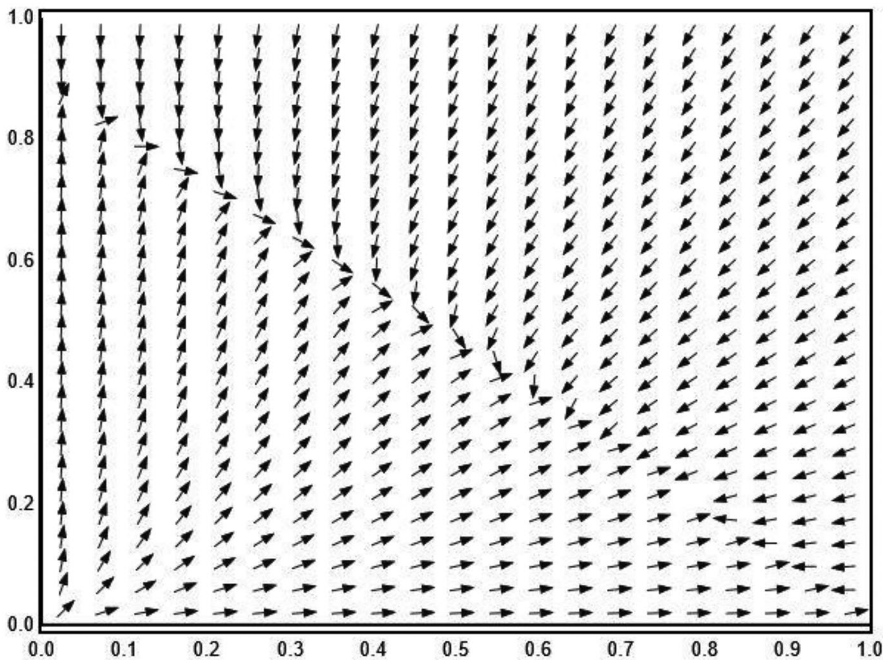

Fig. 11 Slope field for prey-predator system of Greek electricity market

$$\frac{d}{dt}\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} -1.16 & -1.17 \\ -0.50 & -0.57 \end{pmatrix}\begin{pmatrix} X \\ Y \end{pmatrix} \tag{10}$$

In this section, some results from linear algebra that are important for the solution of the examined system can be easily proved and others are not; since the purpose of this work is to summarize some useful information in compact form, there is no explicit indication of mathematical proofs in either case. All the results depend on basic facts about the solution of systems of linear algebraic equations [47, 53]. Thus, according to the theorems of second-order linear equations, the general solution of System (10) is constructed as:

$$\begin{pmatrix} X \\ Y \end{pmatrix} = c_1\begin{pmatrix} 0.975 \\ 0.438 \end{pmatrix}e^{-1.685t} + c_2\begin{pmatrix} 0.66 \\ -0.629 \end{pmatrix}e^{-0.045t} \tag{11}$$

This also comes in complete accordance with the eigenvalue analysis results which indicate that the eigenvalues of the matrices of the first three critical points are of opposite sign, one of the species dominates and causes the system to become unbounded and unstable. On the contrary, the last critical point is stable, since the eigenvalues are all negative and of multiplicity one [53].

In the equations of System (11) c_1 and c_2 constitute arbitrary constants. However, the final solution can be found by estimating these constants upon imposing the initial conditions, meaning the initially recorded market shares, into the general solution since the examined problem is an initial value problem. The final solution is estimated as:

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} -0.02 \\ -0.01 \end{pmatrix}e^{-1.685t} + \begin{pmatrix} 0.191 \\ -0.18 \end{pmatrix}e^{-0.045t} \tag{12}$$

As observed, the constructed model estimates that, for the last critical point, the two interacting species—the market shares of energy providers—will reach a stable balance of about 78.9% for PPC and 21.1% for the alternative providers and finally coexist. In this situation, no population achieves its own initial goals of spatial capacity and any species prevents its population from growing more than it prevents the growth of the population of the other species.

The proposed Lotka-Volterra model captures the measure of competition in the Greek electricity market and provides a way to calculate the rate of customers switching between the incumbent provider and the alternatives by estimating the expected market shares evolution, as shown in Fig. 12. According to the corresponding equations of System (9), the critical point is expected to be met in August 2019, but it is still obvious that PPC continues to dominate, meaning that its subscribers seem to prefer the certainty and quality of service of the incumbent supplier and are reluctant to switch to a different operator. This is also justified by the prevailing conditions of competition in the electricity market of Greece, as described in Sect. 3.2, about the fact that liberalization of the energy market has not substantially taken place in Greece. The shaded part of Fig. 12 is based on the set of statistical data for the time period from January 2015 until March 2018, which was used for the evaluation, and the white area denotes the forecasted values of market shares.

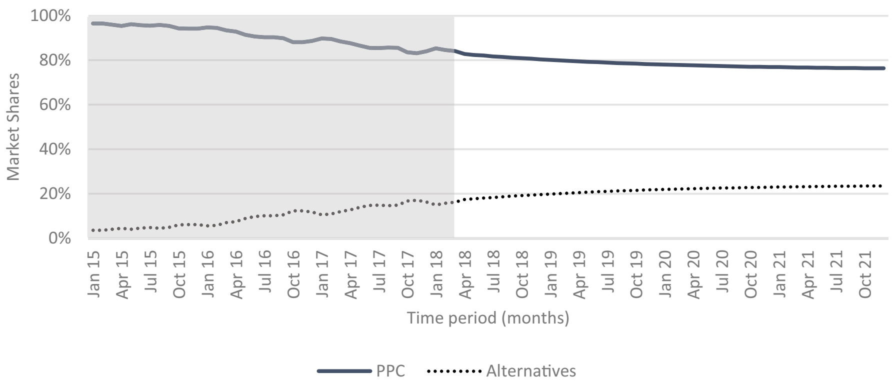

Fig. 12 Estimated evolution of Greek electricity market according to the proposed Lotka-Volterra model

6 Application of a Cropping Strategy to the Electricity Market

The estimated system dynamics, based on the available data, reveals that the market share of the dominant provider PPC is expected to remain fairly high and this is why additional measures should be taken into account by the Authorities in order to reduce PPC's share to 50% by 2020 in line with the country's memorandum obligations. Based on the results of the examined initial model, the application of a cropping strategy [54] is proposed as a necessary way to decrease PPC's market share and motivate at the same time the entry of new providers in an attempt to comply with the European directions and ensure the smooth coexistence of the two species.

PPC started with a share of 96.93% in January 2015 and in March 2018 ($t=39$) its share reached 82.97% corresponding to 3,431,823 MWh [43]. According to the forecasting methodology of prey-predator system examined in Sect. 5, the percentage of PPC's market share in December 2019 ($t=60$) is expected to be around 78.17%, while it is required to reach almost 50%, in other terms 2,068,110 MWh.

Studying the application of different cropping approaches, such as constant and linear cropping to the electricity market, is indispensable, so that the most suitable strategy is found depending on the market conditions.

Cropping at a constant rate for the proposed model of the two interacting species described by the equations of System (4) is mathematically represented by the following system:

$$\left.\begin{aligned} \frac{dx}{dt} &= x(1.47 - 1.47x - 1.48y) - r \\ \frac{dy}{dt} &= y(2.44 - 2.35x - 2.74y) + s \end{aligned}\right\} \tag{13}$$

where r is the constant cropping term of PPC's market share and s represents the rate of subscribers that move from PPC to alternatives that may offer solutions that better fit to their requirements either economic or not, as well as new subscribers. Since all the parameters of the second equation of System (13), which describes the behavior of the alternative operators, are essentially "twice as high" as these of the first equation, then s is calculated as the double value of r. During the period of

21 months taking into consideration March 2018 as a reference point, on average, 33% of the PPC's market share must be removed in total. Based on the equations of System (13), with a fixed rate of reduction of the monthly PPC's market share, r would be equal to 0.0158 (1.58%) corresponding to 65,352 MWh per month, while s accounts for 0.0316 (3.16%) reflecting the constant rate of customers who select one of the alternative providers to cover their electricity needs. The expected market shares of PPC, whose subscribers are cropped, and the alternatives, who are encouraged to grow due to the implementation of a constant cropping strategy, are depicted in Fig. 13, in comparison with the estimated values of market shares deriving from the initial Lotka-Volterra-model without cropping.

Constant cropping can be implemented in the electricity market of Greece, where the cropped species dominates the other species and is already in a major development [54], while there is a specific time period during which the cropping will take place, until the desired goal of market share is achieved. Otherwise, the strategy is quite unsound to be put into practice for a general forecasting period of the ensuing years, since the critical points of the System (13), after substituting the new terms with their estimated values, are either zero or unsuitable for the case study, meaning 97.08% for PPC and 1.36% for the alternatives.

In addition, another effective cropping method is the linear one, meaning cropping is proportional to the size of the population, which is described in the case of Greek energy market by the following equations:

$$\left.\begin{aligned}\frac{dx}{dt} &= x(1.47 - 1.47x - 1.48y) - rx\\ \frac{dy}{dt} &= y(2.44 - 2.35x - 2.74y) + sy\end{aligned}\right\} \tag{14}$$

where r is the cropping term and proportional to PPC's market share and s reflects the linear rate of growth of the alternatives' market share per month. According to

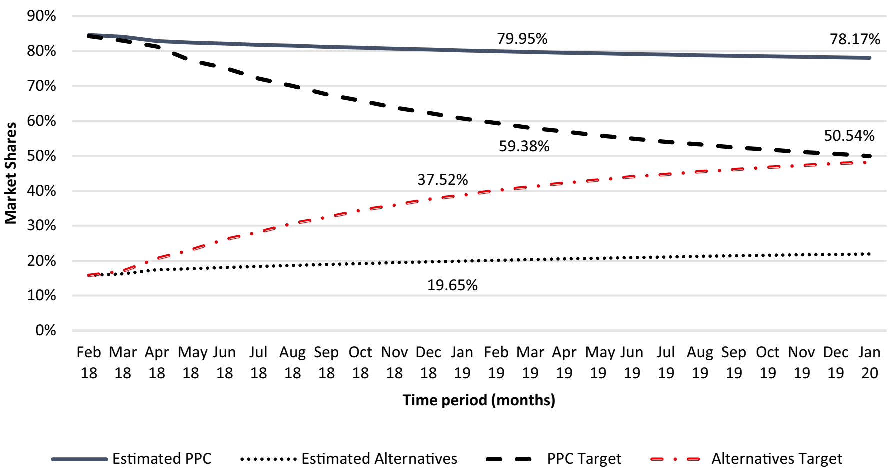

Fig. 13 Estimated market shares of PPC and alternatives after a constant cropping strategy applied from March 2018 to December 2019

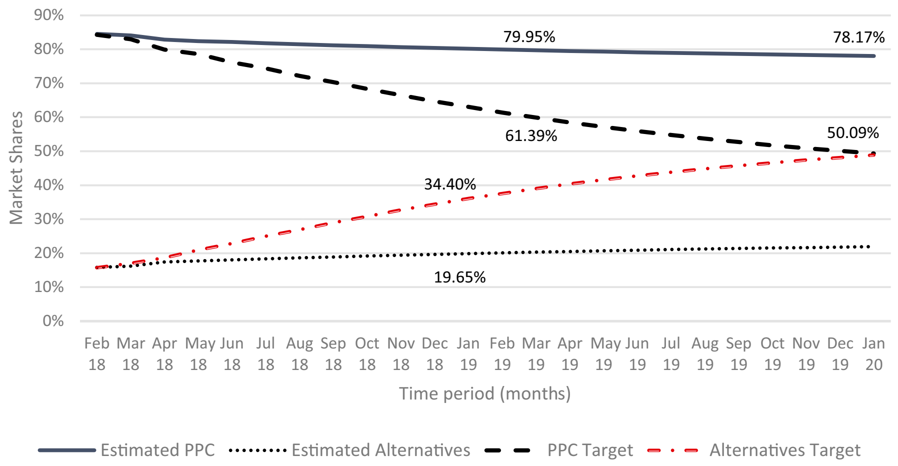

Fig. 14 Estimated market shares of PPC and alternatives after a linear cropping strategy applied from March 2018 to December 2019

(14) and given March 2018 as the time reference point, a linear rate of reduction of monthly PPC's market share results in calculating r as 0.0356 (3.56%) and the corresponding increase of alternative providers' customers due to the application of the linear cropping method estimates s as 0.0712 (7.12%). The corresponding estimated market shares are shown in Fig. 14.

Linear cropping can be used in this case not only for the requested period of 21 months, like constant cropping, but also in an attempt to stabilize the populations at an acceptable equilibrium point for the future. When solving System (14), a suitable critical point is found predicting reduction of PPC's market share to 25.26% and growth of the alternatives' share to 71.89% resulting in global stability of the proposed model.

7 Conclusions

This paper studies and forecasts the evolution of concentration of Greek energy market, expressed by market shares of operators. The results are very important for the decision-making in the market of electricity. More specifically, the evolution of the liberalization process of the Greek electricity market is dynamically estimated by making use of concepts of population biology. Using the Lotka–Volterra model and the Integral method to determine the unknown parameters, the methodology of the prey-predator model is applied to describe the competition among alternative electricity providers—at the place of the predator—towards obtaining a larger market share from the common source of electrical energy of the current dominant provider—representing the prey. Based on the results, the market share of the incumbent operator is expected to remain quite high until the end of 2019 and this is why the application of cropping strategies, constant and linear cropping, are proposed in order to reduce its share to 50% both to comply with the European directions and to ensure the smooth coexistence of the two interacting species.

The proposed methodology aims to identify the possible features and characteristics of an electricity market, capture the measure of competition, and provide useful feedback to regulation authorities about future predictions and policies for the new market schema. The purpose of the model is to enhance decision making by aggregating data, which are used to quantify the indicator of market shares, into a different form of indices representing environment, energy, and economy.

The electricity supply market of Greece considered the case study to evaluate the methodology of this paper shows the closeness of the respective solutions of the model to the real statistical data proving that the Lotka-Volterra model is suitable for forecasting energy market concentration and equilibrium. Such kind of information can be a really useful input in proceeding to critical managerial decisions; therefore, it may be possible to design more effective policy interventions and to explain their rationale to the public. Furthermore, the proposed model may be considered a powerful tool for the estimation of the level of customers' switching among providers driving at the same time performance and price competitiveness in the electricity market. Finally, the described methodology can be easily customized to include various models and parameters used to describe interaction of species in various fields of science.

Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Ethics Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare no competing interests.

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