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A peer-to-peer approach to energy production

Chris Giotitsas [a], Alex Pazaitis [b], Vasilis Kostakis [c,*]

[a] School of Management, University of Leicester, University Road, Leicester LE1 7RH, United Kingdom
[b] P2P Lab, Kougkiou 3A, 45221 Ioannina, Greece
[c] Ragnar Nurkse School of Innovation and Governance, Tallinn University of Technology, Akadeemia Street 3, 12618 Tallinn, Estonia

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A B S T R A C T

This paper strives to provide a theoretical study for energy production and distribution. We thus examine and discuss the evolution of energy systems technologies and their impact on the global socio-economic structure. We critically analyze the evolution of the energy production infrastructure and then review the renewable and decentralized energy production technologies, while focusing on the concept of microgrids. Ultimately, we propose an alternative model, inspired by the commons-oriented practices, currently observed in the production of information, that utilizes microgrids in order to create a peer-to-peer energy grid and then discuss the conditions necessary for the "energy commons" to emerge.

1. Introduction

Since their ancestors gained the ability to control fire, humans have striven to harness energy to satisfy their needs. In the quest for efficient energy sources we have been through several periods of development. Up to this point, what energy production sources had in common was that it made sense, economically and efficiency-wise, to be centrally controlled, distributed and produced in big plants, in a system whose driving force was fossil fuels [65], a logic densely codependent with capital accumulation and scale economies.

The advancement of Information and Communication Technologies (ICT) have arguably provided the opportunity for a "paradigm" shift in the way energy is produced and distributed. An increasing number of people have been experimenting through a variety of participatory networks allowing them to manage, share and produce in a collaborative manner. The foundations of a new social order have been set, based on meaningful cooperation and active participation [8,10,45], intensifying the intellectual discussions that explore its applicable political and economic range. The emergence of a new mode of social production, named commons-based peer production (CBPP), has signified an alternative way to create information, i.e., software, design, culture and content [10]. In the CBPP, openness and collaboration are embraced to create common value. Prominent examples of this new mode of production are the Free/Open Source Software (FOSS) projects, the free encyclopedia Wikipedia, but also open hardware projects like the Open Source Ecology or the Wikispeed car. People have been exploiting these interconnected spaces to actively shape and reproduce technological advancements according to their needs, in a paradigm where profit, power and control seem to deteriorate in significance in the shade of values like openness, sharing, cooperation and participatory production.

* Corresponding author.
E-mail addresses: cg255@leicester.ac.uk (C. Giotitsas), paz_alexis@hotmail.com (A. Pazaitis), vasileios.kostakis@ttu.ee, kostakis.b@gmail.com (V. Kostakis).

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Growing concern about global environmental and social issues has stimulated a pursuit of a more sustainable approach of how energy is being produced, valued and consumed and more environmentally friendly, socially responsible innovations have been gaining ground. Yet the transition to a distributed, recourse-efficient approach in the energy sector seems to be stalled by the still prevalent logic of the past [65]. Following this logic, some of the most promising technologies are pushed into the wealth-creating centrally controlled pit of industrial production and large solar energy fields are created in the desert and big wind farms are set up, having a negative impact on the environment instead. A revolutionary alternative of a decentralized, smart energy grid where producers and consumers merge via small-scale energy production is necessitated, not only for the feasibility of the CBPP model, but more importantly for the formation of a more feasible, sustainable future of human societies.

This paper is using the experience gained by the CBPP as a point of departure to explore its potential within the energy sector, mainly focusing on electricity production and distribution, valorizing practical evidence from the implementation of existent microgrod projects (a form of decentralized, small-scale energy production). The focus on the electricity sector is not only based on the practices documented, but more importantly in an attempt to develop a socio-economic approach, emerging from a significant milestone in the evolution of the energy sector, energy transmission in the form of electricity. A revolution closely bound with some of the main dynamics of the current dominant mode of production and growth, which is large scale manufacturing and domestic consumption. Other energy sectors in society, such as transportation, should not be underestimated however. This paper is only narrowing down to this specific sector in order to emphasize its main approach to the theoretical discussion towards a commons-based energy production and management as opposed to the centralized energy production and transmission in the form of commodity or service, in the sense of contrasting the centralized, one-to-many structure to a P2P (peer-to-peer) network. The characteristics determining the operation of highly decentralized energy networks (like the transportation system), which transcend the operational and productive range of society exceed the limitations of the current study.

Hence, our aim is to develop a critical look on the evolution of the energy system until today and then attempt to tentatively propose a theoretical application of the mode of production currently utilized in the information commons towards the creation of energy commons. Specifically, the structure of the paper is as follows: First the methodological approach is explained. Then a historical account is provided of how energy has evolved and how the industry took shape till the current ICT-driven techno-economic paradigm. Further, we provide the context in which our theoretical proposal takes place, so renewable and distributed energy are explained. Next, the P2P networks and the CBPP are introduced with a description of the proposed model to follow. Then, we discuss the possibilities of a different energy paradigm. Last, the concluding remarks of the paper are presented.

2. Methodology approach

This work strives to provide a theoretical study for energy production and distribution. We aim to critically analyze the evolution of the energy production infrastructure and ultimately propose an alternative path, inspired by the commons-oriented practices that have been observed, up to this point, in the production of information. In other words, the goal of this study, as a theoretical attempt to enrich the current literature and understanding of the phenomenon in question, is to tentatively explore the possibility of the currently evolving market-driven energy production system into one that is promoting the decommodification of energy in the vein of the commons-oriented practices. Hence the following questions can be generated by the research goal: i) How are the new technologies revolutionizing the energy system? ii) What role could the CBPP acquire in this context? iii) What are the strengths and weaknesses of a proposed approach system?

The sources of information relevant to this study include interviews with experts on the field; academic literature; exemplary cases that support our theoretical claim; and press and other media sources. The research strategy of choice in this project is literature review, enriched with interviews and data from relevant practices. It would be important to emphasize that there is a lack of extensive research and literature on the subject, since it is an emerging phenomenon-structure. What should be expected from such a study is to develop our partial answers to our questions, which would be "input to the ongoing social dialogue about the problems and risks we face and how things may be done differently" [[23], p. 61]. Therefore, significant contribution to the formation of the proposed model is provided by semi-structured interviews (see Appendix for the list of interviewees), conducted with Eric Hunting, a sustainable architecture and renewable energy activist and technical writer as well as with four engineers-researchers (Ioannis Margaris, Panos Kotsampoulos, Kostas Latoufis and Iasonas Kouveliotis-Lysikatos) from the research unit behind the Kythnos microgrid (one of the first and most innovative microgrid implementations).

3. Evolution of energy production

3.1. Energy in history

Energy flows define and determine life itself, so it makes sense that they also influence human societies greatly. For the largest part of the human species' history, energy surpluses were minimal. According to Ref. [75] approximately 250,000 years ago began what could be described as the first energy era, with two consecutive transitions to follow and the last one still running its course. During that first era, energy transformed from the simple process of metabolizing food procured with foraging, to the utilization of domesticated animals and a scarce use of fire. This shift from foraging to cultivation assisted with energy harnessed from animals could increase productivity in agriculture and transportation up to 15 times to that of a farmer [74]. Innovations like the wheel, metallurgy, the plough and the sail increased efficiency [44]. Water contraptions were also utilized to provide energy but it was not until the next transition that they became prominent [75].

The second transition commences in the Middle Ages and extends to the early modern ages, with the increasing use of wind and water converters but also with more efficient man-powered machines [75]. First was the vertical waterwheel, which had been around for a long time but was now widely utilized [66]. Innovations like the cam and crankshaft offered the opportunity for more advanced hydropower applications [58] and watermills spread all over Europe, reaching culmination with large mills like Arkwright's in the 1770s. Then wind powered devices appeared, first post mills for water pumping and grain milling and after, larger more advanced tower mills [31]. Sail ships became more efficient at utilizing wind, thus enabling a boom of commerce and the transfer of these innovations beyond Europe [75]. Coal was introduced in energy production with Newcomen's steam engine, which was mainly used to pump water from coal mines, and later made efficient through Watt's improvements [32]. After Watt's patent expired, steam engines were developed greatly powering, along with further innovations in traditional energy sources like the water turbine and improved windmills, the industrial revolution [74]. The increasing demand for fossil fuels in energy production was solidified by the replacement of coal with oil, as the internal combustion engine emerged [6].

The third transition, according to [75]; begins with the invention and implementation of systems for the generation, the distribution and the use of electricity. This transition is what fuels, and one might say shapes, the capitalist industrial production. By the beginning of the 1900s, the electric system had reached its final state which is still largely unchanged today. The reciprocal motion that powered the inefficient engines up to this point with the assistance of belts and shafts was no longer necessary. Electric engines revolutionized not only industrial production but also households since energy could now be transferred [13]. Energy consumption skyrocketed, and power plants became larger and more efficient. Huge hydroelectric and nuclear plants appeared since electricity could be transmitted over long distances. However by 2000, only 10% of all commercial energy supply came from these sources, with the rest 90% provided by fossil fuels [75]. Peak unit capacities have risen 15 million times in the last 10,000 years, yet only people in affluent societies (about 15% of the total population is 2000) have the opportunity to enjoy (and take for granted) this much energy surplus [75].

As was mentioned in the introduction, what all energy production sources had in common was that it seemed preferable, given the technological capabilities, to be centrally produced, controlled, and distributed and in big plants, in a paradigm formed by cheap fossil fuels [65]. In fact, the reliance on fossil fuels is so great, that electricity generation emits 26% of global greenhouse gas emissions and 41% of all carbon dioxide [40]. Next we look into the fossil-fuel driven energy production industry that, arguably, shaped (and was shaped, in a dynamic relationship, by) the capitalist mode of production.

3.2. Energy industry and the centralized system

The electricity industry traces its roots back into the 1880s with the introduction of inventions of pioneers like Thomas Edison, Nicola Tesla, Elihu Thomson and William Stanley [35]. Edison founded several companies to manufacture his inventions and introduce the lighting system he devised, with the first steam powered production stations launched in 1882 and by 1888, spread in several cities in the US and a few European ones [36]. The method of supply for these first stations was direct current (DC), so the system had to be of relative small-scale, since it was not possible to transmit far from the production site. The transfer of this technology in Europe was received with varied degrees of adoption and enthusiasm. While in England, after the failure of the Edison station that was established in 1882 and the obstacles presented by conflicting interests, the adoption rate was relatively slow, in Germany, after the establishment of three stations by 1885, the domestic industry quickly took off and became quite powerful on its own account [36]. The alternating current (AC) technology, following several years of “battle”, eventually displaced the DC system in the early 1890s [54] with the introduction of the AC motor (mostly attributed to Tesla), since this system made possible the transmission of electricity in larger distances with smaller costs.

The potential of the AC system did not go unnoticed, and soon entrepreneurs jumped into the opportunity to merge small firms and create large scale production plants [33]. Samuel Insull became a leading figure in this process after taking over the Chicago Edison firm in 1892 [59]. He quickly seized the control of smaller firms by building large production stations that produced energy at lower costs than was possible for smaller producers, while through AC technology he was able to distribute over large distances, increasing his clientele greatly [36]. Implementing incremental innovations on the process for the conversion of fossil fuels (such as coal) to electricity as well as the utilizing the steam turbine to produce power more efficiently (culminating to the creation of the Fisk street station in 1903) allowed Insull's company to reach a near monopolistic state by the early 1900s [33]. This has been supported by his taking advantage of government regulation to legitimize the monopoly and to secure investment funds. It had to be ensured, after all, that energy companies were turning enough profit to be able to pay bond interest and stock dividends [33]. These tactics were emulated elsewhere creating a circle of ever growing power plants to compensate for the similarly growing energy needs of the expanding capitalist mode of production. This mode of industrial production is dependent on constant growth after all, with an almost 5% annual compound growth in the period 1944–1973 [28].

Over the next years, the structure was geared towards the centralization of generation in ever greater stations and distances in the same network. Depending on the government form of each individual country this could either be a state facilitated industry, companies run by corporate giants or an ownership amalgam. Yet in, almost, all cases the organizations dealing with energy production approached the issue of energy distribution as a “natural monopoly" and all technological advancement efforts were focused in specific technologies that best served the integration in a single, large-scale system [57]. The Tennessee Valley Authority (established in 1933) is a prime example of mixed ownership in energy production in the USA, which traditionally refrains from such tactics [21]. Meanwhile, the demand for power kept rising as more and more energy demanding products flooded the markets and even more individuals grew accustomed to the consumer lifestyle promoted by the capitalist system. Large generators were built to support national grids and new methods were implemented to improve efficiency in both thermal and hydro-power stations [68]. By the 1950s, nuclear power plants appeared in the UK, USA and France and in the following years several other countries [25]. Non-western type countries started acquired substantial power grid after the second world war with each forming its own unique power infrastructure, yet the poorest ones faced (and are still facing) many difficulties with the inequality rift widening instead of being reduced as was expected [57].

The insatiable demand for more energy that pushed for the expansion of the infrastructure reached a turning point at the end of the 1960s with the hike in prices of fossil fuels, the extremely high costs of nuclear plants but also the ever growing concerns for the impact of these technologies on the environment [33]. In order to overcome these issues the following decades, energy conservation was promoted as well as the deregulation of the industry. Research for alternative energy sources was now funded and an alternative production system that was already employed in underdeveloped countries came to the fore [57]. That of the small-scale, non-networked, energy production since, in these countries, large scale production stations were not economically feasible. In fact, it should be noted that what has been presented up to this point could be characterized as the "industrialized type" of centralized stations and mass distribution, and that does not necessarily mean that it is suitable for all countries. In other words, it can be claimed that this fossil fuel driven system is inextricably connected to the entire socio-economic mode of capitalist production and all its inherent contradictions [34]. It should be noted that more than 56% of the global energy consumption today is for industrial use and transportation [41]. So it seems reasonable to assume that the current form of the energy production system has evolved in such a way so as to accommodate the expansion of industrial capitalism, which in turn was shaped according to the energy paradigm of fossil fuels.

In the face of the current energy crisis and the ominous predictions for a future where fossil fuels will be less and less accessible, many scholars have predicted several outcomes. [43]; for instance, warns for a slow development of alternative energy technologies along with an escalation of competition between countries that emerge as energy bountiful and the traditional great powers, leading possibly even to military conflict. Ref. [15] predicts that the end of the abundant supply of fossil fuels that drives the current extreme form of capitalism will signal the deterioration of the large political structures and the return to smaller structures that could resemble the feudal form of the past. Yet he hopes for simpler, more sustainable communities that live in harmony with the environment. Ref. [30] claims that no matter how much technological innovation we produce, perpetual growth cannot be sustained, even more so in times when economic and political turmoils stifle major government-lead advancements. So, it would seem reasonable that non-industrialized developing countries might not choose to adopt this system and it is questionable whether in the future it will still be the dominant one [19].

Next renewable energy sources are introduced and the distributed mode of production is presented. Solar and wind power, besides hydro, emerged as the most viable of alternative sources. Solar energy technology had already been utilized up this point by countries like Chile and India, while wind energy was mostly harvested in Scandinavia, Holland and the Soviet Union initially [57]. By the 1990s the interest for all sorts of green, sustainable energy sources was evident all over the world.

4. Renewable energy and the distributed system

4.1. Renewable energy

Currently almost 80% of the world energy is still provided by fossil fuels while energy demand is increasing in all regions of the world [40]. In the face of climate change, environmental destruction and the rising costs for fossil resources, societies are driven to adapt and achieve sustainability. Further, a great percentage (more than 1.3 billion) of the world population still lacks access to electricity at home [39]. Technologies like carbon capture do alleviate some of the harmful effects on the environment but, in essence, only pose a temporary solution since, while it is not certain when the deposits will be exhausted, fossil fuel extraction is becoming more expensive and depletion is inevitable [38]. Renewable sources along with high energy efficiency seem like a compelling alternative. For the most part, these technologies have been government-supported and are, considering the potential payoffs, significantly underfunded [69]. Also, in spite of the unfavorable conditions, fossil fuels are still cheaper but it is expected that with further research on renewables this condition will change [69]. According to [67]; renewable energy technologies can be divided into four broad categories based on the availability status. These are: 1) technologically mature with market penetration in several countries: large and small hydro, woody biomass combustion, geothermal, landfill gas, crystalline silicon photovoltaic (PV) solar water heating, onshore wind, bioethanol from sugars and starch; 2) technologically mature but with small markets in less countries: municipal solid waste-to-energy, anaerobic digestion, biodiesel, co-firing of biomass, concentrating solar dishes and troughs, solar-assisted air conditioning, mini and micro-hydro and offshore wind; 3) technologies that are being developed and have been commercialized in a small-scale: thin-film PV, concentrating PV, tidal range and currents, wave power, biomass gasification and pyrolysis, bioethanol from ligno-cellulose and solar thermal towers; and 4) still being researched: organic and inorganic nanotechnology solar cell, artificial photosynpaper, biological hydrogen production involving biomass, algae and bacteria, biorefineries, ocean thermal and saline gradients, and ocean currents.

There is, undoubtedly, a lot of research being conducted on these technologies. After their emergence in the 1970s, these alternative energy sources were viewed as capable to herald a new sustainable and democratized energy regime that would be rid of the issues that plague the current one (see Ref. [51]. However, with the passing of the years, and especially after the liberalization of the energy market, we can arguably witness a shift towards research for large-scale implementation of these technologies as result of corporate interest for profits. By the 1990s big energy companies and energy trading companies (such as Enron with their speculation scandal) had been greatly “financialized” and today major investment banks are also energy traders leading to short term investments in renewable technology companies for speculative purposes. Thus leaving the future of energy developments on the hands of profit-maximizing financial speculators aiming towards resource extraction [77]. So, instead of creating a new energy regime, renewable energy sources are considered as substitute for conventional ones in the same system [24], leading to efforts for renewable energy production that are, like their predecessors, detrimental to the environment (see Refs. [42,72] and may cause severe problems to local communities (see Ref. [12].

4.2. The decentralized system

Meanwhile, the emergence of another set of technologies that has brought about a new technological revolution [61], has also enabled the introduction of a different model of energy production. Terms like ICT and the “Internet of Things” signal the capacity for inter-connectivity of objects beyond computers in a network. This has enabled a transition from the traditional socio-economic structures to networked-based ones driven by information production [16]. Thus, due to the wide availability and affordability of ICT, increasing cooperation is possible in the social, political and productive aspects of society [8,10]. Similarly other terms like “Smart Grid” have emerged to describe the way ICT is revolutionizing the way energy is produced and distributed. This term entails several applications like the monitoring and automation of energy distribution systems, the intelligent monitoring of the high voltage network, the usage of smart meters that provide real-time data and other innovations that can improve the efficiency of the centralized system discussed above [56].

But, these technologies, along with the deregulation of the energy industry [37], have also facilitated the promotion of a different kind of energy system, the distributed one. There are several definitions of what constitutes a distributed generation (DG) network, depending on issues like the purpose; the location; the rating of distributed generation; the power delivery area; the technology; the environmental impact; the mode of operation; the ownership, and the penetration of distributed generation [2]. A broad definition would entail a small source of electric power generation separate from a large central power source and placed close to the load that is usually comprised of biomass based generators, combustion turbines, solar power and PV systems, fuel cells, wind turbines, micro-turbines, engines/generator sets, small hydro plants, and storage technologies and can be either connected to the grid or independent [20].

For the premise of this paper, renewable energy technology and DG technology are viewed as invariably connected, since DG through conventional means can, like centralized production, have a detrimental effect on the environment [73] and cannot offer long term sustainability and autonomy. Further, the same can be said for renewable energy when implemented according to the old paradigm. Out of all the distributed energy structures we are focusing on that of the “microgrids”, as modules for the formation of a large smart grid. A microgrid is a network, in essence a smaller version of the smart grid that was previously described, of small-scale energy generation units [53]. Microgrids can function autonomously (islanded) or connected to a larger grid. In this context, DG in microgrids has several advantages:

- Microgrids can be installed in remote areas with much less cost than building infrastructure to connect them to the central grid, they offer more reliability through the diversification of energy sources but also are more economically viable due to reduced transmission and distribution costs [62,70].
- They have the potential to greatly reduce greenhouse gas emissions, but also health hazards tied to high voltage power lines [3].
- They improve energy efficiency through cogeneration, meaning the utilization of the heat generated from localized electricity production instead of doing it separately [81].
- Their capacity to operate autonomously, provides security against failures of the main grid.

A better insight on the potential of microgrids for a revolutionary distributed network, albeit in a rural environment, as well as its feasibility in our context is provided by the installation in Kythnos, a small Greek island in the Aegean see, one of the several islands outside the main national electricity grid. Designed and installed in 2001 by the National Technical University of Athens (NTUA) and the Centre for Renewable Energy Sources and Saving, 4 km away from the nearest medium voltage line, the facility consists provides power for 12 houses [64], having as a goal to be entirely supplied by solar energy produced by the PV or stored and the diesel generator to be used only as a back-up. Intelligent load control systems are implemented in each house to measure voltage, current and frequency and coordinate remotely power line communication load switches [78]. The monitoring and communication hardware of the microgrid is able to detect component malfunctions, enhances the performance and safety of the power supply and collects performance data. This particular element is one that is of significant interest within the context of the study, providing a good example of a self-sufficient, cost reducing and environmentally sustainable system, implementing a distributed management system, involving each house as a node providing information for successful coordination, performance optimization and network safety.

Another illustrative project for this paper's premise is the ESUSCON (Electrificación Sustentable Cóndor) microgrid that was developed for Huatacondo, a small village at the foothills of the Andes in Chile [50]. A central Energy Management System (EMS) manages the components and sends signals for optimizing their operation according to load and resources forecasts [4]. Consumption data are gathered and sent back to the EMS through smart meters. For the communication between devices, the microgrid uses a SCADA system (Supervisory Control And Data Acquisition). Traditionally, SCADA systems gather data, monitor and control equipment. In order to ensure the long term success and sustainability of the project, the ESUSCON team integrated a social aspect into their SCADA in order to enable the community (who lacks technical expertise) to perform the management and maintenance of the microgrid, monitor consumption and generation, and engage in decision making processes [60]. So, by acknowledging the ideas and criticism of the people in the area, organizing workshops and other educational activities and promoting engagement in the operation and maintenance of the system this social SCADA system is an important tool for the adaptability of the microgrid [4], illustrating that through participatory procedures, discussion and knowledge diffusion it is possible for a community to produce and manage a common energy pool, while maintaining the infrastructure to do so. In the next chapter the proposed model will be presented after a brief discussion about the commons and the CBPP.

5. The peer-to-peer energy grid

5.1. The principles of commons-based peer production

Increasing attention has been placed upon the concept of the "commons", stimulating the intellectual debate on how future societies will be determined by the way resources and productive forces are defined. Initially, the struggle of the commons had been concentrated on the process of expropriation and commodification of land and natural resources, with local conflicts being generalized through an emerging interconnected global community [80]. Questions and conflicts rose over access, control, of course, property and its defense as "the foundation of every modern political constitution" [[27], p. 15]. Ref. [27] in *Commonwealth* conceptualize the commons in two notions: one referring to natural resources as Mother Nature's gifts to humanity and the second, a dynamic notion of abundant knowledge and practices, as well as social relationships, exploited and expropriated by capital for the creation of surplus value.

This notion of the commons as source and outcome of social reproduction, is intensified on energy, conceived as "vital means of subsistence, as well as means of production" [1], with a potential change on energy production, distribution and consumption having a crucial effect on productive relations. Changes on social structures and processes define to a great extend the eventual conception of energy either as a common, resource and outcome, or commodity determined by market relations. Social struggles, in turn, are defined not only by the separation from the means of production, but also from the means of existence, and specifically in the field of energy by the degree of community participation in energy production and administration.

Ref. [18] puts emphasis on this separation, posing a political question that "any discussion of alternatives within the growing global anti-capitalist movement must pose: the direct access to the means of existence, production and communication, the issue of *commons*". In that context, the commons become object of social struggles, striving upon the openness and access, with neoliberal regimes, like recent strict copyright enforcing legislations of ACTA/SOPA/PIPA, acting as enclosures of the post-war capitalism. This struggle necessitates a "constitutional perspective" [55], in the context of a constitution of the commons, i.e., the rules that a society sets on how the commons are shared and managed. The commons emerge in a non-commodified space shared by the community and the participation of its members is intensified on local level, with "local" referring to the proximity, or better, interconnection, of those involved.

Through the previous analysis, we have seen that microgrids enable remote communities to employ sustainable energy production in a cost-effective way, and that this technology has been available for e few years now. We have also seen that by actively informing a community about energy technologies and building a community spirit, it is possible to enable cooperation and common administration of the productive capabilities. But is this concept applicable in a wider context, as an alternative energy system beside isolated areas? Using the experience from implemented practices and respective feedback as a starting point, this paper presents a theoretical model that utilizes the principles behind the P2P networks of information production, codified within a social context by the theory of CBPP.

But first, a brief introduction on P2P networks and CBPP is in order. P2P is a network whose members (peers) share a part of their own hardware resources and information in order to facilitate certain applications, like for instance file sharing or project collaboration [71]. Each peer is both a provider and receiver of resources and can directly communicate with the rest without the mediation of an intermediary node, thus enabling the network to continue operations if one or more peers seize to function. There are three types of P2P networks. Unstructured ones, where peers randomly form connections with each other. Structured ones, where peers are organized into a specific structure and hybrid ones, which are a combination of P2P and server/client models.

CBPP is a term coined by Ref. [10] to describe a new form of social production made possible by ICT technologies and first observed in P2P networks. Communities of peers are enabled to cooperate in order to produce and share information, cultural artifacts, knowledge [8]. CBPP arguably presents the opportunity of a possible alternative for the dichotomy of market versus state. These communities are not structured like a corporate hierarchy or through market allocation, but are usually coordinated via flexible hierarchies and merit-based structures, and their production is neither private nor state/public [8]. New property licenses have been institutionalized, such as Creative commons, the General Public Licenses, and the now emerging Peer Production Licenses, to enable and facilitate the creation of an information commons and to allow the social reproduction of peer projects. Contrary to the capitalist mode of production, CBPP is not driven by profit maximization. Meaning that instead of producing profit it produces use value. Instead of promoting antagonistic behaviors and consumerism, it thrives on collaborative effort and supports sustainability. A prime example of CBBP is that of Internet-coordinated communities producing free/open source software (FOSS). The peers in these projects contribute to the creation of software for reasons that transcend profit-making, like expanding their knowledge and skills, producing innovative and reliable software and simply for the joy of engaging in cooperative work [10,47]. FOSS has been successful in antagonizing (or even surpassing) proprietary software, due to this mode of production. Further, [45] have utilized the practices evident in FOSS and other CBPP projects to produce a wind turbine, thus illustrating that CBPP can successfully transcend information production and be expanded into hardware design and manufacturing.

Our theoretical model will attempt to apply these principles in conjunction with the concept of microgrids, to the field of energy production while keeping in mind the limitations and inconsistencies of such an application. This proposal is, of course, far from a complete one. It is merely a point of departure for research towards an alternative mode of energy production. One that is inspired by CBPP. It takes into account the inefficiencies of the current fossil-fuel capitalist system but also the growing environmental concerns and offers an alternative regarding energy production that could be incorporated in the growing “ecosystem” of CBPP.

5.2. The proposed peer-to-peer energy model

There is a general lack of extensive research on the subject of P2P infrastructure implementation on energy production. Ref. [5] suggests the use of P2P networks in order for peers (assuming they are both produces and consumers) to easily buy or sell, in this case, hydrogen. Ref. [11] propose the implementation of different types of P2P architectures in power grids and discuss their general advantages and disadvantages. Our theoretical microgrid, being a P2P network, can operate without a central control node and the loss of any of its modules will not result in the collapse of the whole system. Thus, new units can be added or old ones replaced without having to alter the control system. Each energy consumer of the grid is also a producer. This can be achieved by various forms of microgeneration, but as was previously discussed, we focus on renewable energy sources like PV, small wind turbines and others. This, of course, depends on the available renewable energy sources of each area. Production takes places within the house or close by in order to reduce transmission losses and possibly utilize cogeneration (see Ref. [81]. Further, the houses can be retrofitted in order to become more energy efficient [17]. When a producer has surplus power, it can be stored using various methods [79] but, since this procedure is still quite costly and the current technological level does not offer completely efficient storage, losses will occur. The excess power can be distributed amongst the peers of the microgrid, in order to avoid having wasted energy. Now, instead of attempting to employ complex algorithms and technological equipment to negotiate prices (as is usually the case for DG research projects) for the buying and selling of energy, the system could be engineered to allocate excess energy according to where it might be needed. Creating, in essence, a common energy pool within the microgrid.

As mentioned before, a microgrid can operate both autonomously and as a part of a grid. A second P2P network is proposed on another level. One comprised of microgrids in that are in close proximity from one another (in the context of urban landscapes). This larger network may obey the same rules as its component networks. Excess energy from each individual microgrid can be distributed in the rest according to their needs, basically creating an even greater common energy pool. Similarly, if for any reason one the microgrids collapses it would not compromise the operation of the whole system. If there is still an energy surplus, then the network can sell it to the central utility grid, if possible (Fig. 1). The funds could be diverted to the maintenance of the connectivity among the peers. There appear to be two levels of common ownership possible. One is that of the infrastructure for energy production (PV, wind turbines, meters) and second is that of the energy itself. So in our case, we are discussing the latter. Each producer-consumer is able to join or leave the grid at will, though within the grid the collective behavior is defined by the community itself. Thus, the specific rules that will define the form and the fine-tuning of the microgrid will be shaped according to the goals and the desires of the “commoners”. The main difference between information and energy is that the former is abundant in that it can be reproduced in nearly zero marginal cost. So peer produced information (like FOSS) can be distributed freely to anyone,

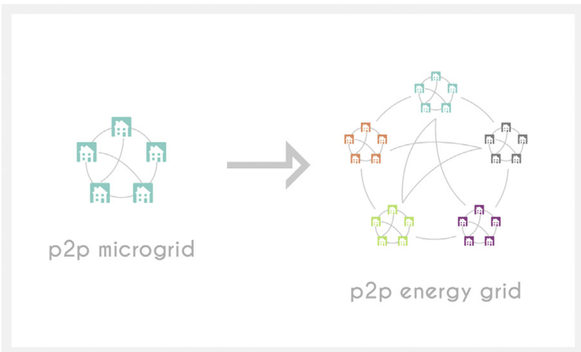

Fig. 1. The P2P energy grid in two levels.

whether they contribute to its creation on not, forming a true information commons. Energy, on the other hand, might be abundant (solar energy for instance) but it is not possible, at least for the time being, to efficiently harness, store and transmit it. Therefore, energy produced in our model might be considered a commons only for those participating in the production.

Since there is no research conducted to provide hard data regarding the feasibility of this model, interviews were conducted with four energy grid experts and a P2P-oriented hacktivist in order to obtain feedback regarding the matter. These semi-structured interviews were guided by the following questions: How are new technologies revolutionizing the energy system? What role could the CBPP and open technologies acquire in this context? Do they think this proposed model is possible? If not, what would they suggest could make it possible? What advantages and disadvantages can they locate on the theoretical model? What is your view on the idea of decommodification of energy and the establishment of energy commons? Based on the combined feedback from the interviewees the following remarks can be made. Regarding the theoretical model all interviewees feel that it is consistent with the current trends for distributed energy and they agree that, technically speaking, it is entirely possible, with the technology necessary fully developed and new options available in the near-term. Open technologies can be implemented in the ICT aspect of the microgrid but also, to some degree, on the production itself thus reducing costs and providing modularity and flexibility. Economically and logistically the model does present challenges. Lack of research on the specific model is mostly attributed to the focus of the market demand on the dominant model. They point out however, that this model presents similarities to multi-agent microgrids. Though, besides the structural differences, what this model presents is a different socio-economic approach.

The following advantages have been noted about the model:

1. It decommodifies energy, i.e., it removes the effect of speculation through market mechanisms and eliminates the economic-political power coming from centralized, private production and management of an important resource for society.
2. Small-scale producers/consumers develop an environmental conscience due to the fact that they experience first-hand the energy production process with its limitations and side-effects.
3. It offers far greater resilience and security than the current centralized system since the collapse of one of its components does not influence the entire network.
4. It minimizes energy losses and the use of methods that are harmful for the environment and it promotes sustainability.
5. New technological options are being made available in energy production and storage that could diversify possible solutions for different geographic locations, but also reduce the costs.

There are certainly challenges to this model according to the interviewees. These are summarized as follows:

1. The main disadvantage is the high-cost investment, especially in the case where only renewable sources are used for production (for instance avoiding to use a diesel generator). In this case the cost for energy storage, since renewables cannot produce constantly, can be very high (at least for the time being).
2. Another weakness is the relative inefficiency of small-scale production in comparison with large-scale. Although the interviewees agree that this inefficiency is partly covered by the smaller loses due to the near distance consumption compared to the great losses in large distances. This difference is difficult to measure without any hard data.
3. Another limitation of this model is its inability to include technologies that are not possible to be deployed in small scale. Hunting mentions ocean thermal energy conversion, which despite being a technology with many advantages and is actually carbon-negative, has been shunned by renewable energy activists because it does not fit the grass-roots alternative energy rhetoric.
4. They also point out that while this model would be suitable for a suburban landscape, it could present a difficult deployment in a dense urban space whose energy needs are far greater and the capacity for renewable energy production is limited, though this could potentially be weighted out by more efficient use of energy and space due to proximity.
5. Despite the deregulation in the energy industry, there is not a clear legal framework or incentives that can facilitate such a model (for barriers see also [9]). Further, energy is highly “political”, thus there are parties that oppose such attempts for a different paradigm.

This section has provided the proposed model and then the interviewees' feedback in a codified manner. The next one attempts to present a critical view on the conditions for a shift towards a commons-oriented energy paradigm.

5.3. A new energy paradigm: towards global energy commons?

Ref. [65] in the vein of Ref. [61] claims that like each industrial revolution, ICT will constitute a new one industrial revolution when it converges with a new energy regime. In other words, this new energy regime should conform to the collaborative techno-economic model that is made possible by the whole set of ICT, but mainly the Internet and other P2P infrastructures. These infrastructures however, as is technology in general [22], are a field of social struggles. Evidence of this can be found in the proposed legislations of ACTA/SOPA/PIPA that enforce strict copyright; the attempts for surveillance, public opinion manipulation and censorship [52] but also in the most recent decision of the USA Court of Appeals against net neutrality. These can be viewed as attempts for rent seeking on this revolutionary medium. Similarly then, it makes sense that there are those who, simply put, resist changes that are imperative in the energy system. Its centralized and large-scale form has provided the blueprint for an industry that shares the same characteristics. Fossil fuels established the framework of the 20th century. Arguably today, distributed and renewable energy technologies are designed to fit into this framework. Medium and large-scale producers are favored to small ones. Communities, instead of owning their own energy production infrastructure, end up purchasing the energy produced in their vicinity. Energy is a key resource for society. Therefore, change in energy would signal change in the entire productive and economic structure.

At this point we have to acknowledge that the deregulation of the technological infrastructures will not necessarily determine the political outcome of the struggle upon their control. Even a positive political and legislative outcome commoning the energy sector alone would not determine the direction of the rest of the productive forces towards a commons-oriented economy. The aim of the current paper is to theoretically test a transformation of the energy sector based on an emerging production mode, as observed in the production and sharing of information. Therefore, the focus is being placed on the current struggle upon control of the infrastructures that made this very paradigm possible, mainly the internet and other P2P infrastructures, and consequently the possible outcomes described further on regard the social and economic forces as constructed from the application of this emerging mode of production and distribution of common value.

Ref. [46] propose four different possible outcomes for these social struggles over the P2P infrastructures, stemming from the combinations of whether control will be central or distributed along with whether the goal will be the expansion of capital or the benefit of the commons. On the one side, there can be found a new form of capitalism. One adapted to the new techno-economic paradigm brought forth by ICT [61]. This distributed capitalism takes advantage of P2P infrastructures in order to exact profits and ensure its continued survival. On the other side, we witness the new commons-oriented practices, also made possible by the same infrastructures. Within this framework, our model falls into the distributed control of commons-oriented P2P infrastructures. That of “resilient communities” according to [46]. These communities, emerging around the world, are poised against capitalist growth and strive for sustainability, energy efficiency and environmental awareness [49]. Movements like the Transition Network are akin to the presented model in this paper as they strive for a holistic shift from today's unsustainable consumer lifestyle.

For our “energy commons” to become a global reality, such communities need to develop a conscience that will accommodate such a leap. The energy system needs to attain the traits that made the Internet (and the P2P infrastructure in general) so innovative. A turn towards the spirit of sustainability and cooperation promoted by CBBP appears like a viable vehicle for change. The energy system proposed in this paper anticipates a similar shift from traditional industrial production of scale to small-scale, local production of scope enabled by desktop manufacturing technologies and CBPP [45]. So the model would aim to cover not just the domestic consumption but also energy for the production of goods. Energy that usually is outsourced to the market of goods and consequently fed by another energy production source. It could be argued that the seeds for this change are currently emerging. As was mentioned already, a step towards open hardware is being taken. Open source technology enables the unrestricted and free adoption and adjustment of hardware designs according to one's resources and needs, thus promoting knowledge diffusion, innovation and cooperation [63]. There are several examples of open designs for energy production infrastructure available. For instance, the Rural Electrification Research Group of the NTUA has developed a cost-effective and fairly easy to reproduce wind turbine [48] and a pico-hydro turbine based on designs that were already available on the Internet, while [14] make a compelling case for the advantages of open source development for PV.

6. Conclusion

The point this paper is trying to convey is that in order for energy to evolve from being a commodity into a commons we cannot simply rest until the technological level for energy production reaches a threshold where it is cheap enough for this to be possible. The conditions arguably need to be created and this study attempts to contribute to such a discussion. Research towards technology that provides everyone free access to the means for cheap, clean energy should be promoted instead of market-based mechanisms that treat energy as a means for profit-making. Distributed, renewable energy can have negative effects both on a social and an environmental level, such as dispossession of rural communities or harming wildlife, when capital accumulation is the ultimate goal. Further, it is apparent that technology cannot be expected to solve all any dimensions of the energy problem on its own. So for a realistic application of this model in a grand scale, there needs to be a shift in the entire socio-economic context. Meaning a shift towards a new and sustainable mode of production and consumption. CBPP, in conjunction with the emerging desktop manufacturing technologies, arguably presents a compelling alternative that could enable communities to strive for change. Moreover, societies need to shed their inherent indifference for the consequences of the mass consumerism that was endorsed by the ever expanding, fossil fuel powered system and embrace an environmentally conscious lifestyle, in tune with the capacities of the planet.

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Appendix

List of interviewees:

Name	Method of communication	Role
Ioannis Margaris	Voip	Senior researcher at the Smart Grids Research Unit of the Electrical and Computer Engineering School of the National Technical University of Athens
Kostas Latoufis	Voip	Researcher at the Smart Grids Research Unit of the Electrical and Computer Engineering School of the National Technical University of Athens and member of the Rural Electrification Research Group and member of the Rural Electrification Research Group
Panos Kotsampopoulos	Voip	Researcher at the Smart Grids Research Unit of the Electrical and Computer Engineering School of the National Technical University of Athens and member of the Rural Electrification Research Group
Iasonas Kouveliotis-Lisikatos	Voip	Junior researcher at the Smart Grids Research Unit of the Electrical and Computer Engineering School of the National Technical University of Athens and member of the Rural Electrification Research Group
Eric Hunting	Email	Technical writer, activist and a member of, among others, the P2P Foundation, the Lifeboat Foundation and the Living Universe Foundation

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