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Arguments for a Community-Based Approach to Geothermal Energy Development

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Abstract: This paper investigates the theoretical foundation for developing renewable geothermal resources locally. For this reason, we pay attention to the role of communities in geothermal development. We derive it from the integral characteristics of geothermal energy next to the shift in the energy transition policies to focus on managing green resources locally. This study presents arguments for a framework that approaches geothermal resources as an endogenous factor of community development. To analyse it, we create a model that explains the local economic characteristics of geothermal exploitation beyond its geological conditions. It aims to conceptualise a community-based geothermal development standard referring to the endogeneity principle. Geothermal energy is given attention since the characteristics of this resource determine its use locally. This induces the internalisation of labour and technology in the local economic system, a specific condition for local geothermal projects where a community remains a prime beneficiary. We argue that the role of communities in geothermal exploitation is pivotal in the process of green growth for further expansion of geothermal energy use.

Keywords: geothermal energy; endogenous growth; green transition; energy-based local economic system; geothermal community

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1. Introduction to the Geothermal Communities Concept

This paper investigates the specifics of geothermal resources, among other renewables, because of their particular provision of both heat and power for the growing green energy demand worldwide. Opposite to popular renewable resources like solar and wind, geothermal is specified as local exploitation [1]. The underground processes happening in geothermal reservoirs limit the use of geothermal resources to the area of access [2]. This condition indicates the endogenous character of geothermal resources [3,4]. A concept of endogeneity in relation to natural resources refers to a structuring factor of a location. Open sources define endogenous as *having an internal origin* or *confined within a group or society* [5]. This reference is very popular in the study of development in, for example, African countries, where endogenous resources (i.e., human resources and natural or physical resources) are considered to be economically linked to communities or localities. The idea of Endogenous Development (ED) that is often used in African studies points to the coupled relation called *development from within*, where communities are primarily the producers and consumers of locally available resources [6,7]. Importantly, the methodological framework of endogenous development communities is centric. They are encouraged to use local resources and distribute the benefits. On the other hand, the role of natural resources is evidenced in the endogenous-driven growth [8]. This endogenous defined approach corresponds to changes initiated within a given economic system, changes ascribed to innovation using internal transactions and own resources, including energy ones.

This paper looks into the degree of the community's role in the development of geothermal resources. As a follow-up to a dedicated geothermal study [9], we pay here particular attention to the community-ownership model, which is discussed widely in geothermal exploitation practices [10–13]. A representation of local geothermal resource use is the Lindal Diagram [14] (Appendix A), a model of a cascade application of direct geothermal resources. It illustrates a wide range of geothermal fluid deployments depending on their temperature. Discussing the variety of temperatures from high (>150 °C) to medium-low (<150 °C), the diagram emphasises two important aspects of geothermal resources: cascade use to enhance the feasibility of geothermal projects and exhibiting a variety of solutions to design the geothermal system according to the local climate, quality of resources and market demand. All these characteristics of geothermal energy indicate the benefits of its local utilisation.

The community ownership model in the energy transition context is defined as a form of decentralisation of energy production and management. It results in energy empowerment for many communities, including affordability that was absent before [15,16]. This concept is found particularly suitable for geothermal resources applied in heating, cooling and energy production [17–21]. Although, as much as the relevance of technology in geothermal community formation is discussed [22–24], an interpretation throughout a local economic system is still missing. The role of communities in the process of developing geothermal infrastructure is present in the public discourse in a major part as the social acceptance condition [25,26]. Furthermore, the economic feasibility of geothermal technology is a topic brought up in the literature, yet too little is discussed about the general function of geothermal technology in the economic system—especially in the local context [27]. A community framework is useful for the viability of geothermal projects, mainly those of direct use since they usually require local recipients. Economic feasibility is best obtained when local conditions of geothermal exploitation are exploited [28]. This requires adaptation to the local economic system. From the perspective of local use of resources, including environmental ones, the internalisation effect is discussed. As much as the classical internalisation theorem of R. Coase (1960) is exampled for accommodating the negative effects of natural resources use, particular interpretations discuss a domestic context in technology transfer, flow of labour and organising a production system [29]. In the energy resources discussion, the development argument as an outcome of internalising practices of raw material flows and capacities of a created economic system is yet unexplored [30]. The legacy of the Coase theorem looks at the angle of economic uses of energy resources created because of their ownership advantage, a condition of growth. Internalisation theory demonstrates interactions between market, culture and environment, considering specific local factors. Such a factor is, for instance, geothermal energy with its endogenous features. However, a link between the endogenous economic system and the resources function in a location with an internalisation perspective is still to be followed up [29]. In this discussion paper, we identify a research gap about a limited view of the community-based approach in geothermal studies. A research novelty here is to propose references to the fundamental local development theories that seek either external or internal factors of growth to understand if geothermal energy is either of them.

Our research problem is oriented toward finding more dependencies between the development of geothermal resources in a community framework and the project's feasibility relevance. We base this work on the assumption of an endogenous character of geothermal energy, and therefore, we assume communities play a role in its development. For this reason, we ask what characterises a local economic system to develop the exploitation of its geothermal resources. The purpose of this study is to provide arguments to broaden a societal discussion on community involvement in geothermal energy development.

After an introduction to the research problem, Section 2 reviews a theoretical and socio-political context that places communities' role as a focal point of geothermal development, leading to the formation of geothermal communities in the EU policies discourse. Furthermore, to investigate what characterises a local economic system to develop the exploitation of its geothermal resources, in Section 3, we present two development frameworks based on exogenous and endogenous energy types. This section aims to illustrate the principles of endogenous and exogenous factor-driven economic growth in the context of green energy transition. An in-depth analysis of endogenous geothermal potential is presented in Section 4. There, we specify an energy-based local economic system model depending on the endogeneity or exogeneity of energy resources using a purposely developed model to visualise these relations. Finally, Section 5 summarises the research conclusions and attempts some policy recommendations for fostering the green transition.

2. Community Context to the Geothermal Resources Development

The research question of this study comes from looking into the development theories that focus on communities' roles in natural resources management. This, in the long term, results in facilitating green growth and energy transformation as described in the EU policies.

2.1. Green Growth and Geothermal Technology for Communities

International organisations argue that renewable energy resources are a part of the economic system [31–33]. Therefore, the renewable-based economy is discussed to create new, green market sectors [34–36]. In the case of geothermal energy, the resource is considered an integral part of the environmental system [37–39]. The expansion of renewable energies is driven by the concept of green growth. It is associated with economic growth and development based on the sustainable use of natural resources. Green growth, in particular, addresses renewable energy's driver role in the economy. A positive relationship with the development of renewable energies is affirmed by enhancing technological innovation and green growth [40]. Renewables are considered to help decouple economic growth and the GDP from energy overuse and environmental impacts, thereby creating a new economic value [41,42]. The principles of green growth pay attention to the energy end users [43]. They are considered enablers of the sustainable energy transition. It refers to the expansion of energy that prosumers practice as well as to joint community projects. A similar approach is represented in the studies of communities' role in energy decarbonisation processes [44]. Communities absorb new technologies and often take economic advantage of new opportunities created by renewables. In the case of geothermal energy, the technology sector has observed the fastest adaptation to the extraction of resources by upgrading the existing infrastructure of oil and gas [45–47]. Therefore, the expansion of technology is expected to facilitate geothermal energy development.

Unlike solar or wind energy, the community has historically been a pivotal point for geothermal energy use. The primary recipients of geothermal resources are communities located around geothermal reservoirs [48]. The local production of geothermal energy fits into the concept of J. Rifkin's zero-emission economy. His visionary work discusses geothermal technology as one of the future paths of producing energy [49]. He also points to job creation and local economic benefits following the transition towards green energies like geothermal. Moreover, geothermal energy development is as reflected in Rifkin's pillars of the Third Industrial Revolution [50]. They address the demand for the non-intermittent renewable energy shift, securing energy production at the micro-level (local) and providing the technologies for hydrogen generation and individual energy storage. Rifkin's analysis highlights the need for the expansion of geothermal power production, which is yet limited by current technologies and geothermal exploitation costs.

2.2. Geothermal Communities in the EU Energy Policies Discourse

Attention to local resources and local ownership, including energy resources, as part of a local resilience strategy, is the latest direction of the EU policies [51]. A message is developed that a strong communitarian approach should define problems and develop policies and policy implementation that includes local resources. The efficient use of local resources is indicated to be a part of national stability strategies and EU challenges such as political and economic instability. Furthermore, local resilience is introduced as a part of endogenous capacities, especially for addressing climate-related technology issues [51]. Renewable Energy Directive II [52] promotes decentralised and demonopolised energy production. Communities as beneficiaries of the energy transition are specifically underlined (Article 1 § 65). The community-owned energy project incentives are discussed in Article 1 (§ 71) of the document. Article 2 (§ 16) introduces the renewable community concept, where energy production and distribution is recognised as an endogenous development factor. Geothermal energy is listed as one of the renewable resources applicable to renewable community resources. Furthermore, the shift into a decentralised energy supply is one of the European Green Deal pillars, empowering the local use of renewables [53]. Decentralised energy systems lead towards more affordable and reliable energy provision. This approach interlinks the regionalisation of energy production and the sustainability of energy provision. The Green Deal refers to the capacities of communities as the main inductors of such an efficient energy multi-governance scenario. The concept of endogenous capacities corresponds with adapting technologies to local conditions [54]. The focus of endogenous capacities and endogenous technologies should be the identification of local assets to develop technologies in order to respond to local needs and conditions.

Recent years' energy policies put more emphasis on communities as an important element in the expansion of renewables. In the European Union arena, the Renewable Energy Communities were first defined by the Renewable Energy Directive I and then by the 2019 Internal Electricity Market Directive [51]. The documents set the overarching European target for energy from renewable sources and contain provisions ensuring the use of RES in the transport sector and in heating and cooling, as well as rules and regulations regarding the rights to produce and use renewable energy locally by establishing renewable energy communities. The strong element of the decentralisation of energy production that appears with renewable energy communities is primarily an opportunity to use local resources.

The concept of geothermal communities aligns with the EU's broader objectives of fostering sustainable energy practices and promoting community engagement. Areas where geothermal energy is harnessed to meet the heating and cooling needs of residential, commercial, or industrial buildings are already recognised in the European Green Deal [53] and referred to as community-based solutions for sustainable development. These communities often involve the establishment of district heating and cooling systems that utilise geothermal heat pumps or direct use of geothermal resources. Similarly, the Clean Energy for All Europeans Package [55], adopted by the European Parliament and the Council in 2018, includes directives and regulations aimed at accelerating the transition to renewable energy, increasing energy efficiency, and empowering consumers. Although this package does not specifically address geothermal communities, its provisions on renewable energy deployment and support for local energy initiatives can indirectly benefit the development of such communities.

By facilitating the emergence of geothermal communities, the EU aims to achieve several objectives using documents like the 2024 resolution about the European strategy on geothermal energy [56]. It emphasises energy security as energy production is local, but it also highlights the economic growth in local communities that geothermal energy supports and, importantly, community empowerment. It is understood that geothermal communities empower local residents and businesses by providing them with access to clean, reliable, and affordable energy sources. Overall, the concept of geothermal communities represents a key component of the EU's efforts to transition towards a sustainable and resilient energy system.

2.3. Cultural Ecology and Geothermal Community Culture

The cultural ecology concept examines the specifics of local resources that create local identification and, so, local culture. It is argued that a cultural framework plays a major role in geothermal project development [57]. So, relying on the endogenous character of the environment and resources available, cultural ecology explains the range of policy- and decision-making, economy, technology and social integrations regarding transitions. The relationship between the form of environment and society was coined by J. Steward [58], who attempted to describe the adaptation of culture to the environmental factors associated with the territory. Although his concept of cultural ecology is rooted in an anthropological paradigm, it reminds us that humans rely on natural resources and ecosystems. Steward recognised the interaction of social organisation with the local resource utilisation processes. As far as the trend of cultural adaptation to the environment was already known by anthropologists, he formulated rules under which people organise themselves to adapt to the local environment and use technology. This process of adaptation evolves into a local culture, determined by how the local resources are exploited. The evolution of Steward's concept of cultural ecology initiates discussions about cultural identification with the local environment [59,60]. Local communities grow new cultural habits while stewarding the available resources. This manifests in ways of nature conservation and new environmental practices [61].

The assumptions of Steward's work [62–64] continue the consideration of cultural ecology in the context of the relationship between man and energy resources. A positive function of culture in the process of accepting a transition into a renewable resources economy is evidenced [65]. Cultural ecology is reasoned for dialogue facilitation between local community energy use and environmental protection, and the acceptance of renewables is not always related to a country's high GDP or technological advancement [66]. A cultural impact on the choice of household heating sources is discovered [62]; household energy use is given as an example, resulting from a local socio-cultural system developed to use the materials and new technologies. On the other hand, local communities manage to develop an internal culture of energy resource use through local knowledge and experience [67]. The socio-ecological system that emerges between a community and local energy resources is considered an indicator of adaptation to ecology. The specifics of geothermal energy allow us to embed it in the concept of cultural ecology. The endogenous character of geothermal resources not only forms the landscape (e.g., geysers, hot springs, creeks) but is also a characteristic of the community that lives around the reservoir. Geothermal resources are already known to link local communities with the environment since the communities' practice is to actively use the forms of geothermal resources. The identification of geothermal energy constituting a part of local culture is already discussed for Indonesia [68], Kenya [69], New Zealand [70] and Peru [71]. The role of a community culture is also a crucial element for geothermal infrastructure development. One of the concerns related to geothermal projects is, e.g., social acceptance. It is practically a prerequisite for the promotion and successful implementation of geothermal energy plans. The majority of geothermal projects, due to the hazardous processes of development, require consultations and acceptance by a local community. Next to accepting the geothermal project as a green technology solution for a community, social acceptance is better achieved by the established culture of co-habiting with the geothermal landscape. This phenomenon is further explained in [72–75], where communities exposed to natural geothermal occurrences, e.g., in Kenya or Indonesia, have an increased acceptance of geothermal projects and infrastructure. The spiritual and cultural significance of geothermal resources for the Maori community in New Zealand [75] is evidence that communing with these resources has a collective value for them. It is also likely to impact the acceptance of potential externalities linked with geothermal exploitation. These are better internalised since geothermal energy represents cultural sustainability for this community. Geothermal resources are also placed within the concept of a "green energy landscape" [76–78]. This means that, e.g., for communities in Kenya or Iceland, geothermal infrastructure becomes a strong local value. Moreover, with consideration of the limited land availability for energy projects, where there is intense energy use on the land, e.g., agriculture, geothermal resources unlock local energy potential when using energy landscapes for decentralised energy provision.

Geothermal resources hold significant cultural significance, contributing to the development of geothermal use culture and influencing community formation. Scholars argue that the presence of geothermal resources has played a pivotal role in the establishment of human settlements since ancient times [79]. Areas with geothermal features, such as fertile volcanic soil and hot water sources, have attracted early forms of urbanisation. It is well observed in countries where geothermal energy manifests in the volcanic creations and processes of hot water extraction that have been familiar to the public for decades. Such geographic determinants add to the cultural ecology aspect of studying geothermal energy. These anthropologically derived features of geothermal energy are to be considered an advantage for the resource's development; furthermore, it is an argument for adapting geothermal policies to the needs of local communities. On the other hand, the exogenous energy resources are less integrated into the cultural ecosystem of a community. This also refers as well to renewables with imported technologies. The evolution of Steward's concept indicates that local environmental conditions determine the community's economy and culture. It is based on the use of local resources that create local identification, introducing ecological culture. Contemporary interpretations of cultural ecology lay the foundations for local energy clusters and cultural ecology principles, which were looked at during the construction of the United Nations 17 Sustainable Development Goals [80–83]. Regarding Steward's idea of adaptation, environmental problems can be addressed by the transfer of knowledge from science to culture, i.e., society and integration of new knowledge, technologies, norms and ideas into culture. For this reason, the transformation of environmental practices does not lie solely in technology. Communities that adapt to ecological factors belonging to their location and, by doing so, use water and land resources develop the ecological culture in Steward's paradigm.

3. Exogenous vs. Endogenous Energy Development Framework for Communities

Economic development is controlled by many ecological and environmental factors, energy among them. This section motivates the classification of geothermal resources as endogenous factors of growth. It compares the two frameworks of community development when energy resources are of a determinant function. Such an approach serves to address the research question in this study: what characterises a local economic system to develop the exploitation of its geothermal resources, which are assumed to be of an endogenous characteristic?

3.1. Exogenous Factors of Energy Development

In terms of economic growth, the role of energy is irreplaceable. The exogenous growth model stresses the role of technology as an independent factor for sustaining economic growth. It associates external factors to the economic system with national growth. This theory interprets exogenous factors as technological progress, government policies, and well-functioning institutions to drive economic growth [84]. An exogenous factor is considered to be independent of factors within a specific economic system. For instance, advancements in technology (in general terms) lead to savings and investment and therefore induce economic growth. Grounded in neoclassical theory, the Solow–Swan model connects economic growth with macroeconomic variables of an exogenous nature. Since it is rooted in macroeconomic theories, it omits a local context of economic growth, assuming the dominant role of national productivity outputs to the growth. Exogenous change originates outside of the economic systems [85].

The context of energy supply is traditionally analysed in the framework of exogenous growth approaches. Energy resources usually represent stochastic trends in development caused by seasonal demand. Stochasticity in energy consumption is a widely known phenomenon related to seasonality and forecasting methods. It is a recognisable element of analysing conventional energy resources, especially for power production. Energy itself is constituted as a derived demand in the exogenous models, meaning that it is demanded for the output it produces [86]. An entire argument about the exogenous function of technology in relation to imports of energy and energy consumption is built [87], with an example of the derived demand for energy imports and related imported technologies contributing to the emergence of, e.g., industrial clusters [88].

According to the exogenous economic theories, growth is determined by factors external to the economic system. A relationship between economic growth and factors of green growth technologies is established [89], where the exogenous nature of energy technology is considered. Exogenous growth drivers include technological advancements introduced to the economy, diminishing returns of capital, saving rates and sectoral production with labour growth parameters. Conventional energy resources like oil or gas are primarily considered exogenous factors of economic growth inducing technological imports and productivity—a GDP relationship [90]. In the renewable energy context, imported technology for the cases of wind, sun, and hydro energy is considered an exogenous factor for both economic growth and CO_2 reduction [91–93]. These renewable technologies introduce a radical change to the energy industry, itself manifesting as a factor of economic growth. Thus, technology developments paired with energy imports are considered the main drivers of exogenous-induced growth. This phenomenon is related to globalisation and energy trade, both considered fundamental for shaping national policies [90,94]. National-level discussions regarding energy development usually refer to obtaining and distributing resources. They result in a series of policies that are placed for energy systems. Nevertheless, exogenous energy systems depend on the global trends of trade and are also vulnerable to energy supply shocks [95]. Exogenous factors stay behind energy reforms aimed at preventing energy shortages, especially in developing countries [96–98]. The impact of exogenous factors is also perceived as limited control of energy resource management, for instance, dependency on foreign energy labour and, therefore, a lack of local human capital [98]. Personnel imports characterise exogenous factors of growth, as does the export of local raw resources to be refined elsewhere. This impacts the access of local communities to local energy resources [99], at the same time limiting local workforce involvement. Externally controlled energy technologies, as typical for exogenous systems, although responding to the increasing mass energy demand, have less impact on the local community's energy security [100]. In the context of technological growth, selected renewables are considered exogenous growth model characteristics. Wind or photovoltaic renewables represent technical exogeneity, in addition to the seasonality of the weather conditions they depend on. This risk, related to the economic feasibility of externally controlled resources and technological immaturity, is one of the major barriers to the development of imported green energies [38]. Nevertheless, in the resources discourse, the exogeneity form is rather associated with *growth* rather than a *development* concept. It implies the macroscale nature of this approach, with reference to the growth of national economic indicators. This is opposite to the development process, which uses natural resources and usually refers to a region, locality, or community as its beneficiary [101,102]. In a specific context of exogenous development using resources, the process is oriented toward market forces and institutions rather than local economic systems [103]. It focuses on trade and transactions that involve imported technologies or knowledge. These patterns lead to modernising economic and market strategies according to the exogenous development principle.

3.2. Endogenous Energy Development

The endogenous growth theory posits that internal forces play a pivotal role in driving economic growth. Originating in the 1980s within development economics, this theory emphasises the significance of endogenous factors such as innovation, knowledge and human capital [104]. According to P. Romer, these intrinsic elements are the primary drivers of technological change [105]. Conversely, R. Lucas [106] contends that market specialisation and labour productivity are the key determinants of endogenous growth. This perspective contrasts with neoclassical economics, which centres on the interplay between market supply and demand for economic growth. Neoclassical models, exemplified by the Solow–Swan model [84,107], typically treat technological progress as exogenous to the economy.

In contrast, the endogenous growth theory argues that productivity enhancements result directly from accelerated innovation and increased investments in human capital, both from the governmental and private sectors. Endogenous growth models consider essential economic factors specific to particular groups, businesses or industries [108]. According to this theory, technological advancements are industry-specific and are evaluated based on their anticipated impact within a given sector. One aspect of the endogenous growth model addresses concerns related to resources and the environment, viewing resources as endogenous public goods. As asserted in [109–112], endogenous resources play a central role in regional specialisation and can catalyse growth in smaller economies.

Endogenous growth theories consider the internal factors of growth, i.e., resources. Reflecting on the specifics of geothermal energy and its local potential for replacing fossil fuels at a cost-efficient level [113], next to a stimulating role of local development [9], this renewable is a considerable internal factor of local growth, fitting into the endogenous growth model. The endogenous growth model states, in simple words, that economic development is a function of human capital, knowledge and innovation (including technology), of which none of these forces is of foreign origin to the economic system. The importance of renewable energy sources to the endogenous growth model equilibrium is already measured [114,115]; however, the energy type is not specified.

Following the principles of endogenous growth infrastructure enhancement is particularly sought for sustaining growth. This relation is described in detail in [116], where endogenously provisioned energy is the main growth factor for an economic system. Geothermal energy emerges from the local geological conditions and, therefore, not from imported resources. Its know-how is also built locally since geothermal technology is often based on already locally practised gas or coal mining infrastructure and science (geothermal exploitation occurs on territories previously exploited for their fossil fuels [117]). Geothermal resources combine the aspects of natural and human-defined endogenous factors. This twofold endogeneity approach [118] indicates the character of a phenomenon, relating it either to a place itself or a human intervention. The natural endogenous factors representing geothermal energy are the geological conditions, including geothermal water springs and terrain topography, that allow for resource exploitation; human-induced endogenous factors related to the infrastructure are land use, emerging economic activities and community engagement and communication as a part of local geothermal development.

Endogenous resources are said to play a role in regional specialisation and in kick-starting growth in smaller economies [109,110,119,120]. This applies not only to natural resources but also to energy resources, including geothermal ones. Several comprehensive studies [39,121–123] demonstrate that the development of renewable resources can rejuvenate and boost the economic potential of a region. Geothermal energy, when classified as locally produced and utilised, is argued to bring added value to local communities [3,124–126]. Furthermore, in-depth investigations [9] spark a discussion about the endogeneity of geothermal resources and the structural changes they instigate in local economies.

The following Section 4 conceptualises the exogenous and endogenous energy development frameworks for communities. A visualisation of the dynamics between a local economic system and energy function depending on its origin is developed.

4. Conceptualising Endogenous and Exogenous Energy-Based Local Economic Systems

The deployment of renewable resources is one of the main local economic development factors [127]. Local and small-scale energy systems are said to reduce community energy dependencies and stimulate new business. In addition, they potentially reduce energy consumption, increasing energy self-sufficiency for communities [128,129]. Relatively small-scale energy systems provide integrated and sustainable energy use, especially practical for communities challenged with energy imports. The OECD [127] underlines the role of local ownership in a community's energy system. In this section, a simplified model of a community energy-based local economic system is proposed, conceptualised from the perspective of endogenous and exogenous energy resources. The central point of this modelling is the community as a beneficiary of the energy-based local economic system. The OECD [127] proposed strategies for local development points for the embedment of energy systems into the local economy, where local economic initiatives are based on local (renewable) energy systems. This approach evolves into the energy community concept, which is considered fundamental for energy policy reforms in the EU [130]. The basis for interpreting the energy-based local economic system is also referring to the energy as commons. In such cases, community ownership provides a balance between private and public energy provision [131].

The two simplified models in Figures 1 and 2 display the role of energy in the local economic system, assuming the endogeneity or exogeneity of resources. They serve to display the function of energy in a local economic system where the dynamics of the local economy, labour and technology depend on the origin of energy resources. For the endogenous resources, geothermal energy is analysed (Figure 1).

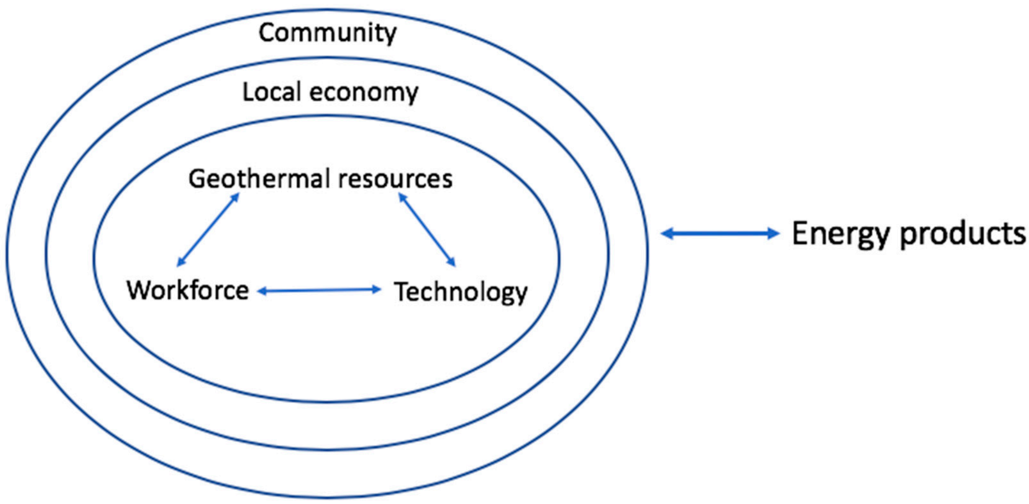

Figure 1. Endogenous geothermal energy-based local economic system (own elaboration).

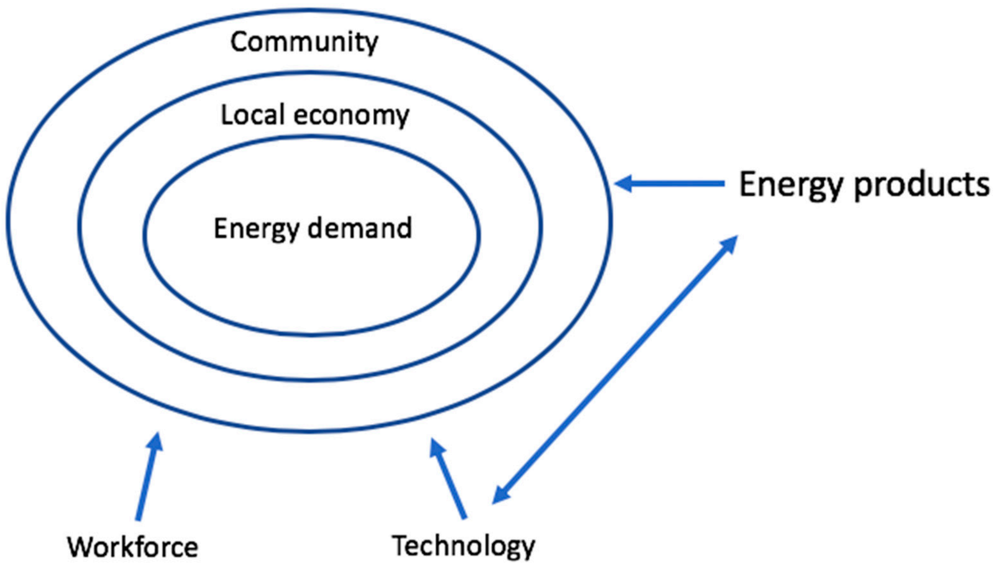

Figure 2. Exogenous energy-based local economic system (own elaboration).

Geothermal energy-based economic growth refers to the community activities of energy production and consumption. In the case of an endogenous energy source that is harnessed within a local economic system, a community becomes the prime user. As Figure 1 illustrates, an endogenous energy source is a part of the local economic system. This local economic system relies on energy production from endogenous resources, here geothermal. There is an interrelationship between geothermal resources, technology and workforce. The characteristics of geothermal exploitation imply the use of local land. Further endogeneity of exploitation concerns the employment of local labour that, in the case of localities with previous fossil deployment, provides a workforce already experienced in drilling and exploitation. Basing geothermal operations on locally existing technologies (like gas or coal) limits the need for technology imports. This situation is particularly relevant for the energy transition in regions and locations where the costs of phasing out fossil fuels and introducing renewables are instead a public concern. The utilisation of an experienced labour pool and technological know-how increases sustainable resource use (since experienced labour is there, and mining know-how is to be replaced with geothermal). The endogenic character of geothermal energy is, therefore, a solid argument in favour of its development. Moreover, the variability of direct local use (see the Lindal Diagram, Appendix A) provides the local economic system with geothermal-based activities. This also includes energy products that can be interchanged outside of the local economic system. Therefore, this exchange of energy products represents a form of a certain system of self-dependence and self-growth. As evidenced in [9], such geothermal dynamics cause a structural change within the local economic system and contribute to community development. Since geothermal energy becomes a part of the economic system, energy and energy products are locally consumed. The structural change in the local system is caused by an internal factor, e.g., the exploitation of geothermal resources. They get internalised into a labour market and related technologies, creating an economic symbiosis within the local system and resource self-reliance in a community.

In the exogenous energy-based economic system, energy imports are a basic economic activity (see Figure 2); they supply the local economy and industries while depending on external energy products in order to be generated. Fossil fuels well-characterise such a system [132]. Nevertheless, renewable sun and wind solutions rely heavily on imported technologies in order to yield energy output (e.g., PV installations or wind turbines). The community energy demand is therefore met by imported elements to the system. In the scenario of energy transition locations, specialised labour to maintain the energy sources requires importing it along with the technology. This is also related to the character of the renewable enterprises that are not local but lease or supply the technologies at any location. Therefore, outside of the system, no internalisation of resources, labour or technology takes place. This results in the emergence of a new economic system in which communities participate to some degree. Activities where a relationship between production and technology generates added value happen out of the system. Therefore, community energy demand is supplied by external resources and imports. The exogenous energy characteristic, in this context, is the relationship to external system factors, and these factors determine economic growth.

The two concepts of endogenous and exogenous energy-based local economic systems present a community development model. The reference to an energy-based local economic system is inspired by the OECD [133] generic concept of a green growth framework, where a natural resource-based growth model explains productivity through resources with economic outputs for the society. For the purpose of this study and to answer the research question, we ask what characterises a local economic system to develop the exploitation of its geothermal resources. The endogenous energy economic system refers specifically to geothermal resources. Table 1 illustrates some central differences in both systems, complementary to Figures 1 and 2, which show visualisations of the systems' dynamics.

Table 1. Energy-based economic system according to the exogeneity and endogeneity of energy resources (own elaboration).

	Subject	Endogenous System	Exogenous System
a	System	Internalisation-based	Transformation-based
b	Structure	Existing infrastructure	Adding infrastructure
c	Scale	Small-scale	Large-scale
d	Energy source	Renewables/Geothermal	Fossil/Renewables
e	Energy demand	Internal (local, regional)	External (national)
f	System beneficiary	Community	Market
g	Factors	Capital accumulation	Foreign investment
h	Labour	Domestic	Imported
i	Sustainable development	Development with controlled depletion	Depletion in scale
j	Expected benefit	Self-sufficient system	Economic returns of energy projects
k	Ownership	Royalties	Land use regulations (licences, permits)
l	Policy intervention	Fiscal instruments	Regulatory instruments (price component)
m	Economic theory relevance	Schumpeter's Theory of Innovation, Ostrom's Theory of Self-Governance	Solow–Swan exogenous growth model, Theory of Production

Legend: The categories (a–m) in which the systems are analysed are sourced from the OECD model of local green growth indicators [133].

Table 1 summarises two economic systems determined by the type of energy production. In the case of endogenous energy resources, they are considered a part of a system since they are produced inside one; resources that are import-dependent display an exogenous character. Endogeneity in reference to energy production is determined by the self-sufficiency of the local system to generate energy for the economy, whereas, in the exogeneity scenario of energy production, the resources are not domestic. This is illustrated by the exogenous nature of, e.g., fossil fuels, which are depleted in nature and are a global trade commodity. Renewable resources are identified by constant replenishment processes, and in the case of geothermal energy, replenishment is a fully local process.

(a) System: For these reasons, the effects of endogenous energy resource use, such as geothermal, in the economy are internalised by the system. This manifests in direct and indirect establishments that use the resources, i.e., internalisation into the local economy. Geothermal energy is best internalised by the various forms of local use represented by the Lindal Diagram (Appendix A [14]). This diagram shows the temperature range suitable for various direct-use activities. Typically, agricultural uses require the lowest temperatures, with values from 25 to 90C. The geothermal water application for bathing and health involves low to mid temperatures (40 to 80C). Space heating requires temperatures in the range of 40 to 100C (including ground-source heat pumps). Cooling and industrial processing normally require temperatures of 100C and higher. This scale activates geothermal resources into various sectors of the local economy, as well as internally developed channels of producing and using the energy. An economic system that expands around the possibilities of geothermal resource use internalises the direct benefits and commercial applications beyond energy provision. The internalisation of geothermal resources is observed, as well as the market possibilities for local labour. The local workforce is absorbed by the new employment that is directly or indirectly related to the exploitation of geothermal energy. The internalisation of energy production, especially in the bottom-up approach, helps to eliminate the related externalities. In the endogenous energy system (such as geothermal-based), this translates to uncertainties of supply and a shortage of workforce. In the case of the exogenous system, energy products transform the local economic system upon the introduced factors of change. These factors refer to the intensive technologies that are implemented, creating new consumption. Especially in the case of the shift from carbon to green sources, energy consumption faces the cost of the new energy technologies. The cost of the energy from transitioning to renewables is charged to the final energy system element—i.e., the individual consumer. Therefore, a consumer bears the social cost of the energy transition in the exogenous energy system. The exogeneity of energy also introduces the narrative of energy consumption savings and a savings discourse since it often refers to fossil fuel systems.

(b) Structure: Endogenous systems use foundational structures for energy resources since they focus on the spatial concentration of industrial sectors. Structural transformation takes place in the exogenous type of economic system. An industry that develops by the exogenous factors of growth, such as, for instance, imported energy resources, requires dedicated infrastructure that is usually absent in the first place. However, energy resources applied within the endogenous economic system are based on the existing infrastructure. As an example, geothermal energy can develop from fossil fuel technologies, while wind or solar energy demands its own structure of supply.

(c) Scale: Since the endogenous system refers to a local market, the scale of energy supplies is mostly community needs. For this purpose, it can be referred to as small-scale since domestic energy needs are addressed. The scale of energy provision in the exogenous systems usually corresponds with feeding the power grids and, therefore, can be referred to as a large-scale supply. It refers to both fossil fuels and the renewable resources commonly applied for power generation.

(d) Energy source: Endogenous systems look into the locally available energy sources. They focus on the accessibility of the domestic energy supply chain and, therefore, locally harnessed resources are the pillars of the endogenous economic system. Moreover, the implementation of the water–energy–food nexus using endogenous energy-saving technologies impacts an economic system. The nexus is often used in the context of sustainable development based on the application of renewables. Endogenous systems address the types of energy resources that are specific to a location or community, such as geothermal energy, the harnessing of which depends on the geologic characteristics of a location. Another endogenous energy type is, for instance, hydropower since this energy generation takes place at a fixed location, and the technology is specific to geographical conditions. The exogeneity of energy refers to the resources that are subject to transportation in bulk form as fossil fuels or as a final energy product, i.e., power via the grid. Therefore, they are importable energy sources since they are widely produced, with no special local conditions needed. For this reason, some renewable resources that are independent of local conditions and not limited by efficient transportation go under the edge of the exogenous energy category, such as biomass, solar or wind energies. The technologies developed to transport these resources and process them into green power are a little space-dependent.

(e) Energy demand: In accordance with the systematic characteristics they represent, energy resources address energy demand on a territorial scale. Resources of an endogenous nature occur locally and are, therefore, locally used. For this purpose, they serve the domestic, small-scale demand in the first place. Depending on the kind of resource, they can be sufficient for a community (e.g., geothermal) or a region (e.g., hydropower). Exogenous energy resources, while relying on imports, provide large-scale energy opportunities. Mainly, fossil fuels are traditionally used to satisfy the national energy demand.

(f) System beneficiary: Following the assumptions of the endogenous factors of growth that result from internal system processes, the beneficiaries of such an economic structure are the local recipients. In the case of exogenous energy types, they serve a broad societal interest. Hence, they are usually categorised as tradable commodities. The development of an economic system based on exogenous energy resources feeds the market and national economy. The beneficiaries are, therefore, macroeconomic structures, e.g., related industries or a banking system. It is also reflected in macroeconomic measures such as the GDP or financial statements. However, an economic system that incorporates endogenous resources is beneficial to the communities. Specific cases of geothermal resources impacting the local economic system illustrate that the beneficiaries are, firstly, the communities.

(g) Factors: Endogenous factors that originate internally include location, topography, physical geography, built environment, infrastructure and socioeconomic characteristics. An endogenous economic system relies on decisions on local economic growth and investment in local markets. Investment in local energy infrastructure is an example, especially if public investment takes place. It creates a measure of local capital accumulation, which is a sign of local economic stability. In the case of geothermal energy, capital accumulation is displayed in local infrastructure investment since energy and geothermal infrastructure are not transportable. Geothermal energy investment costs are susceptible to specific local characteristics, and the accumulation process includes a locally adjusted technology. Moreover, considering the cascading use of geothermal resources, the accumulation of capital is determined by the broad use of geothermal resources in various economic activities at a location.

Exogenous energy types are dependent on national and foreign investment. They are observed by the size of infrastructure investment and raw material imports into an economic system. One of the specifics of the exogenous system factors is a high dependency on the presence of trade tariffs—a factor absent in endogenous energy systems. Exogenous factors are also responsive to the state regulations regarding foreign investment since international funds and capital enter the economic system. Conventional energy sources are elements of the neoclassical factors of production and returns of capital. These, on the other hand, are proven to be highly related to the national GDP rates and energy consumption per capita. The size of the economy is also a factor in exogenous energy systems. Usually, national scales are the representative measures of exogenous growth interpretation. A factor leading to the development of exogenous economic systems is foreign investment. It commonly requires a large-scale economy since small-scale markets are usually disadvantaged from the perspective of investors.

(h) Labour: An important element of an economic system is access to labour. Endogenous growth factors include a growing population and a local workforce. Labour is related to human capital, which is a core element in the endogenous growth theory. In the case of energy resources, they require qualified labour, which has to be ensured within the system. For this purpose, the energy sector workforce is trained and invested in since sectoral growth depends on human capital productivity. The productivity of labour is the domain of endogenous market structures. It is related to cost reductions but, moreover, to the performance of an economic sector. The role of energy resources in the endogenous economic system is the human link between technical infrastructures and capital accumulation. Next to the added value of the energy materials, human capital is being generated. This is revealed in the specific know-how of the workforce, usually of local energy characteristics. Green growth that is based on the exploitation of renewables is commonly associated with labour-intensive practices. In the case of geothermal energy, skilled labour is related to the structure of the employment market. Because of the mining character of geothermal exploitation, it offers an easy solution for the replacement of workers from the 'brown' economic sector into the 'green' one, especially if the coal mining sector labour is to be replaced. In parallel, it facilitates the knock-on effect on employment in other sectors (considering the variety of local geothermal applications explained by, e.g., the Lindal Diagram (see Appendix A). A labour market with geothermal energy use reintegrates these workers who may lose their jobs because of the energy transition. Such a form of labour continuity is a representation of an endogenous economic growth-enhancing variable.

Labour in the exogenous energy-supplied economic system characterises economies associated with the business cycle. Labour productivity in the exogenous energy market greatly depends on the specialised labour supply. It is measured in the exogenous ratio of output and capital per worker. International (private) capital is usually found to be the external factor of the exogenously stimulated economic system. The rate of investment in the energy infrastructure corresponds with the labour force growth. It attracts an influx of labour to a location that is to be employed in the energy sector. An illustration of such a process is the fossil fuel industry. Highly capitalised and dependent on international supply chains, the coal, oil and gas businesses are known for a labour structure adapted to the type of energy source. Workforce productivity in this scenario is also sensitive to resource supply shocks. Lower productivity in the case of fossil fuel energies is assigned to climate deficiencies or costs of abatements. In the exogeneity of the labour situation, the role of governmental policies for employment is rather limited because of the energy supply volatility and wage dispersion reasons for worker migrations.

(i) Sustainable development: The UN Sustainable Development Goals (SDGs) [43] represent the global development strategy with the principle of economic growth convergence and the preservation of natural resources. Renewable resources are given significant importance within the SDGs. Dedicated sustainable goals (e.g., SDG no 7, no 9) address the role of renewable energies in setting off the principles of sustainable development and climate protection. The SDGs aim to pursue sustainable energy development from the lowest local level. Therefore, they refer to local knowledge, local resources or local markets. One of the main strategies for sustaining energy resources for the next generations is to practice controlled depletion, thereby preventing the overuse of natural resources. Controlled depletion is, for instance, a technical characteristic of geothermal energy exploitation. Its exploitation takes place under the conditions of fluid control systems—securing minimal damage to the ecosystem. The efficient deployment of geothermal resources is based on the activities controlled under existing regulations developed for petroleum exploration or water resource use and protection. Since geothermal energy is considered a mining resource, this approach is generally regarded by regulators as being adequate for managing potential environmental and operational impacts.

With externally provided energy resources like fossil fuels or importable renewable technologies, depletion is considered in the development strategies. Sustainable practices to preserve renewables from potential depletion are industrial and technical development in the exogenous context. It refers, for instance, to maintaining the infrastructure or assuring the technological durability of solar panels or windmills. Characteristics of energy efficiency for these renewable resources imply economics of scale, i.e., price element and energy supply are more favourable with an increased number of installations. These specialised practices correspond to the exogenous technological component of an energy system. For fossil fuels, depletion in scale translates into dedicated policies to preserve the environment and manage the externalities that result from fossil fuel depletion. Such policies are particularly demanded to address the energy needs of people without access to modern energy carriers, including renewables, to accelerate the development of clean and safe advanced fossil fuel technologies. Energy policies constitute the framework of exogenously stimulated sustainable development.

(j) Expected benefit: When setting up an energy-based economic system, market principles prevail. Benefits are sought in the advantages of the system that are related to the type of energy introduced. The introduction of an endogenous energy type, e.g., geothermal, is expected to revitalise the local energy resource potential. Considering the cascade character of geothermal resources, an investment in geothermal resources provides green heat and power generation possibilities. Cascade use refers to comprehensive scenarios for integrating low-temperature sub-networks in existing district heating networks. Furthermore, opportunities from geothermal cascade use go beyond the energy supply. Water provision and food production, being a part of geothermal cascade use, contribute to water resilience practices locally. This form of circularity of geothermal waters creates a critical input for resource-intensive industries like, for instance, agriculture or energy production. As a representation of the water–energy–food nexus, local geothermal use contributes to self-sustaining system creation. On the other hand, the energy resources that are less available for cascade use are driven by economic goals. The benefits are expected to address the returns from energy infrastructure investment. This refers to both renewable and fossil resources of an exogenous nature, usually observed as an imported infrastructure system and an international, large-scale investment type.

(k) Ownership: The investment type of energy resource is related to the status of its ownership. Policy planning for endogenously defined geothermal resources needs to consider aspects of mining sectors (petroleum and mining) as well as (regulated) electricity markets. Such ownership construction has to be acknowledged in energy policies and sustainable development plans. Regulating the ownership status is especially important for geothermal developers since projects consist of two large stages: exploration and exploitation. Each one includes particular risks related to the geological conditions of the geothermal reservoir, the technologies used and the social acceptance of potential externalities. The ownership of endogenous types of energies concerns local, regional or national rights, which, in this case, apply to the mining resource regulations (since geothermal resources are underground). A specific condition of geothermal ownership that distinguishes this energy from others is the relationship with the indigenous communities. Since geothermal resources are often located on indigenous territories, such as mountains, creeks or volcanos, these areas have special economic and emotional significance for these groups of residents (e.g., see Section 2). For this purpose, geothermal projects on indigenous territories are compensated in the form of royalty share or even geothermal co-ownership of geothermal infrastructure. This form of preferential arrangements for the indigenous people is found for both heating and power geothermal installations—another particularity of geothermal ownership. Furthermore, a system of geothermal royalties suggests that fairer access and broader stakeholder participation can enhance the legitimacy of resource management regimes and stimulate local energy transitions. A community-owned geothermal structure is nevertheless limited to the national regulations that classify geothermal as renewable energy with the adherent regulations for environmental tax incentives. Co-ownership or royalties depend on whether the land with geothermal resources belongs to the communities or a state. The indigenous communities are, in such cases, involved in decision-making for licensing, for instance, the use of private companies to operate the geothermal infrastructure.

Energy investment decisions in an exogenously stimulated economic system aim to minimise related risks. The trajectory of such investment is based on the ownership structure. As per the universal rule, the state regulates the transmission of heat and power at the national level. Depending on the preferred form, both public and private corporate governance structures comply. Ownership refers to the rights of transmission of the energy products assigned to those who comply with obtaining licences or permits of operation. Licences and permit systems are being transformed to reach the targets of the decarbonisation of energy. Energy-based communities are placed among others for permits (or licences to operate) that are granted with no preferences. Nevertheless, in the case of energy communities looking at green energy generation, the EU laws exclude them from gaining profit for energy transmission and commercialised energy sales.

(l) Policy intervention: Policy instruments play a major role in supporting the development of endogenously characterised local energy resources. Among the group of renewables, geothermal energy requires additional policymaking activities to successfully compete with popular solar and wind resources that lead the energy policies. Policy interventions for geothermal energy aim to correct the barriers to increasing the renewables market share. Most of them are identified as risks of technical (exploration and drilling) and economic (capital) failure in the phases of setting up the infrastructure. These types of risks are specific to local geothermal development. For this purpose, the role of dedicated policies is to attempt to mitigate the risks, especially from the perspective of the most vulnerable to the geothermal risks—the local stakeholders. As far as power generation from geothermal resources is addressed in renewable energy policies, geothermal heat production still requires more policymaking actions. The EU energy policies recognise geothermal resources as a fossil equivalent, especially for heating purposes; nevertheless, they do not yet fully take into account the specifics of complex geothermal technologies and the corresponding risks. The policy challenge lies in finding a balance between supporting geothermal as the renewable baseload, acknowledging its endogeneity and, at the same time, attracting private and public investment. The most practised form of policy support is, in this case, a range of fiscal instruments. Direct and indirect subsidies define governments' geothermal development plans. Complementary policies and tax incentives aim to encourage investment in geothermal energy, mainly for the local developers who will have to manage the varying degrees of project success. Public geothermal development funds are the tools most commonly used for geothermal projects. With this solution, the state takes over the risks associated with local geothermal systems, such as geophysical exploration and drilling, which are the major financial constraints on the success of geothermal development.

Exogenous types of energies are subject to feed-in tariff policies and carbon market transactions. Since this type of energy is rather represented by corporate structures, risks are concentrated on the operational side. Transmission to peripheral areas is one of them, regardless of the renewable power type. What jeopardises fossil fuels are the burdens of CO_2 emission trading and shocks of the connected global energy financial systems. That is why the price-sensitive element is one of the main subjects of policies and regulations. However, in the case of the exogeneity of energy resources, effective regulatory measures establish closer ties between multilateral trade and environmental protection and more effective international cooperation. Regulations on fuel prices and trade are the main underlying principles of state interventions. Moreover, the exogenous types of energy resource policies focus on greenhouse gas emissions and environmental incentives for introducing solar, biogas or wind installations. Usually, national energy policies comply with the exogenous policies that set the CO_2 thresholds on an international scale.

(m) Economic theory relevance: Examples of economic theories are given that associate the type of energy with economic development. Endogenous growth theories and their modern interpretations (e.g., Ostrom's theory of self-governance and common pool resources) place communities as a focal element of economic development and relate local resource use to development dynamics. Ostrom's concepts are well suited for managing naturally occurring resources and promoting community-based approaches to renewable energy development [134]. The democratisation of geothermal resource exploitation through Ostrom's schemes involves decentralised socio-technical networks and collective actions [135]. Considering the characteristics of geothermal resources, the theoretical foundation of Schumpeter's Theory of Innovation can interpret the role of geothermal energy in local economic systems. Due to its mining character and broad application (see Appendix A), innovation does not mean invention, but it refers to the commercial applications of associated technology, new material, new methods and new sources of energy. These arguments provide references to the organisation of economic activity according to the Coase internalisation approach. Both theories recognise the importance of innovation in economic activity. While Schumpeter focuses on the entrepreneur as the agent of innovation, Coase's theory considers how a market internalises innovative activities to capture the benefits within the economic system. Using the Coase argument, internalising transaction costs by using endogenous geothermal characteristics is preferred for a local economic system that would otherwise be too costly to conduct through market exchange (in a regular exogenous type of economic circumstances).

Following the specifics of the exogenous types of energy, they correspond better with economic theories focused on exogenous factors of growth as the resources of production/commodities (e.g., Solow–Swan exogenous growth model, Theory of Production). These theories often assume that certain factors influencing growth, such as technological advancements or changes in labour productivity, occur independently of the economic system being analysed. The Solow–Swan exogenous growth model, for example, posits that technological progress is exogenous, meaning it arises from factors outside the economic system and contributes to sustained economic growth over time [85]. With respect to exogenous energy sources, like fossil fuels, they are better suited to economic theories that emphasise external factors driving growth, as these energy sources are subject to external influences and do not arise directly from within the economic system itself [136].

5. Conclusions and Recommendations

This paper attempts to present a selection of development concepts that place local communities in the centre of energy transition using geothermal energy. We approach the research question of what characterises a local economic system to develop the exploitation of its geothermal resources, assuming the endogenous character of geothermal development, by studying the endogenous and exogenous energy factors of local economic growth. Throughout the paper, it is argued that geothermal development should be referred to as community discourse. This approach is not yet sufficiently scientifically discussed, regardless of the broad availability of technical literature on the endogenous and local character of this resource. In this paper, we search for a suitable theoretical interpretation of the role of communities in geothermal development. We have zoomed into a selection of social theories that establish an understanding of energy resource development in a community framework. We have used this analogy for the analysis of geothermal energy, finding relevance to endogenous growth concepts and local development. We argue that a community setting is necessary for geothermal resource utilisation, not only from a technical perspective but also from a resource management view. This is also an indication for dedicated green energy policies that have been documented to focus not only on localities as prime carters of energy supply but also as prime users.

After an overview of the role of energy in local economic systems, we reverse this framework and propose one: local energy development based on endogenous resources (such as geothermal energy). We select development concepts in which the local exploitation of geothermal resources can be explained. This approach fits into the concept of several theoretical threads that put the local community at the centre of socioeconomic development based on locally available energy resources. We build an endogenous character argument for geothermal resources with a proposed model of energy-based economic growth. The two models of endogenous and exogenous energy-based local economic systems are elaborated in order to establish a relationship between specific communities and geothermal resource management. We observe the phenomenon of community transformation into a self-sustained system when geothermal resources are deployed locally.

This study delivers a series of arguments for a local community's involvement in the development of geothermal energy. From the observations of its endogenous character, it is argued that the role of communities is centric. When geothermal resources are introduced to the local economic system, they activate interdependencies between the local workforce and technology use. This can result in generating energy and its products for the community's own purposes. This is an example of a self-sufficient local economic system, one of the main characteristics of a local economic system that is dependent on geothermal exploitation. Further features refer to a degree of community involvement in various local geothermal activities (presented by the Lindal Diagram [14], Appendix A), described as internalisation. Moreover, this study aims to support the argument for energy democratisation, taking the example of geothermal energy, and further encourages its technological expansion. An argument for geothermal culture is given, explaining the important role of communities in geothermal development. Moreover, a framework of geothermal resources as a commons is applied, with reference to the role of communities in managing and liberating local energy markets from centralised systems. The analysed case of geothermal energy provides some new contributions to the concept of the community's role in energy transformation in general. The proposed model encompasses internalisation practices for optimising geothermal use following the Coase principle or Ostrom's energy norms based on endogenous growth and the sustainable economics of regional resources. In general, it can be argued that the ownership and location of renewable energy plants are interdependent. Ownership influences location, so a location influences ownership, which, in the case of geothermal resources, is the latter. We attempted to explain this interdependency through the role of communities in geothermal development.

Since local geothermal development displays the potential risks of technical challenges (exploration and drilling) and economic challenges (capital), the role of dedicated policies is to attempt to mitigate these risks, especially from the perspective of the most vulnerable to the geothermal risk—the local stakeholders. The findings of this study suggest involving communities further in renewable policy design. Following the geothermal endogenous character analysis, we argue that this renewable resource is a considerable answer to energy transformation policies. Because of its local character, it creates resource independence and incorporates local economic conditions for energy system change (such as the discussed internalisation of resources, restructuring of a local system and local ownership). Furthermore, geothermal energy—more than other renewable resources—impacts communities' engagement and emotional connection. Geothermal energy, as an endogenous resource, unlike other renewables, contributes to the redefinition of energy-based development. Communities and a local economic system are to be central beneficiaries of this development dynamic. We argue that the local economic system benefits from geothermal energy exploitation, not only in terms of the environment and climate but also, importantly, from gains that the geothermal sector is able to provide to a local economic system. We give the geothermal example to underline the importance of communities in sustaining local sources of energy. Using geothermal energy as a local economic system element helps with internalising existing infrastructure in addition to creating a local identification, i.e., green energy culture. Implementation of geothermal technology has, therefore, a high chance of economically enabling local communities first. This is to be encouraged by adequate policies on the national and international levels.

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Appendix A

The Lindal Diagram is a graphical representation used in geothermal exploration and development to illustrate the relationships between temperature, depth and pressure within the Earth's crust. It serves as a valuable tool in geothermal exploration and resource assessment, providing insights into the thermal characteristics of the local geological conditions and guiding decision-making in geothermal energy development projects.

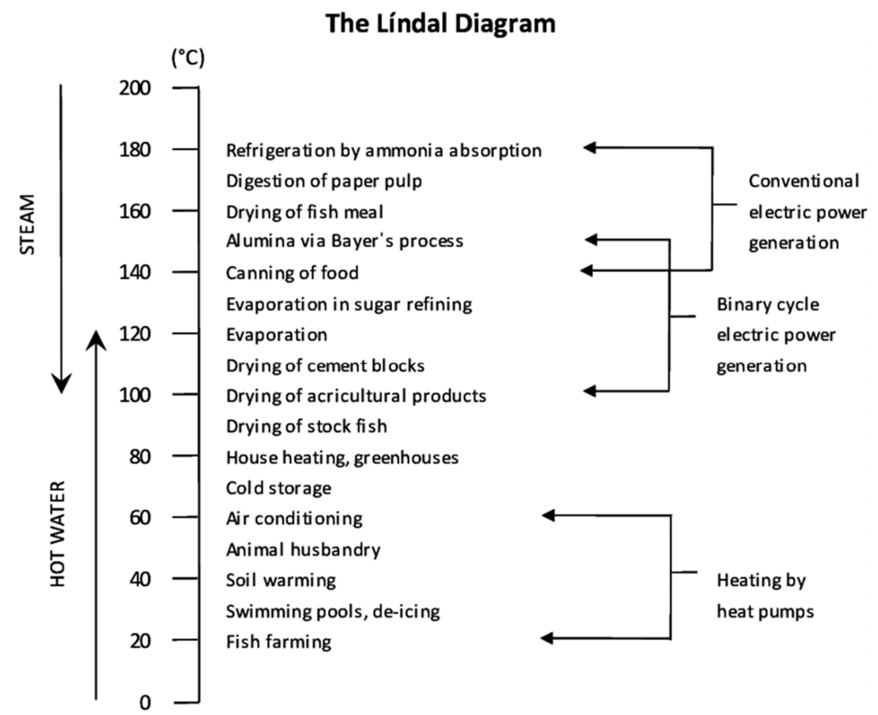

Figure A1. The Lindal Diagram of geothermal energy utilisation; source: [14].

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