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Energetic communities for community energy: A Review of Key Issues and Trends Shaping Integrated Community Energy Systems[1]

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Abstract

Energy systems across the globe are going through a radical transformation as a result of technological and institutional changes, depletion of fossil fuel resources, and climate change. At the local level, increasing distributed energy resources requires that the centralized energy systems be re-organized. In this paper, the concept of Integrated Community Energy Systems (ICESs) is presented as a modern development to re-organize local energy systems to integrate distributed energy resources and engage local communities. Local energy systems such as ICESs not only ensure self-provision of energy but also provide essential system services to the larger energy system. In this regard, a comparison of different energy system integration option is provided. We review the current energy trends and the associated technological, socio-economic, environmental and institutional issues shaping the development of ICESs. These systems can be applied to both developed and developing countries, however, their objectives, business models as well as composition differs. ICESs can be accepted by different actors such as local governments, communities, energy suppliers and system operators as an effective means to achieve sustainability and thereby will have significant roles in future energy systems.

Keywords: *Distributed energy resources, Local energy systems, Energy systems integration, Self-organized energy communities, Smart grids, Flexibility*

Contents

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1 Introduction

1.1 Background

A recent surge of interest in local communities generating and supplying energy as well as the parallel development in the smart grids has attracted the attention of many in the implementation of local energy systems. Local communities in both developing and developed countries are being transformed by challenging their traditional identity as passive consumers to active prosumers who both consume and produce [1]. Local energy systems can potentially contribute to the overall energy and climate objectives, helping reverse energy consumption and emissions trends worldwide. Several energy and climate policies promote and support these systems to reach energy and climate targets (e.g., EU 2030 framework [2], UK community energy strategy [3], U.S. Intended Nationally Determined Contribution (INDC)[4]). Local communities are well-placed to identify local energy needs, take proper initiatives and bring people together to achieve common goals such as the reduction of energy costs, CO_2 emissions and dependence on the national grid. Local energy projects also lead to job creation and economic growth. These initiatives can further the transition to a low-carbon energy system, help build consumer engagement and trust as well as provide valuable flexibility in the market.

Although centralized energy systems are economically attractive, local energy systems are important for self-sufficiency and sustainability. Research on such systems has increased significantly in recent years [5][6][7][8][9]. These studies often focus on individual technologies and issues related to implementation but often lack a comprehensive and integrated approach for local energy systems. Specifically, assessment and evaluation is lacking on the role households and communities play in the existing system architecture and the resulting impact they might have in a smart grid. Numerous technologies, actors, institutions available as well as market mechanisms further complicate the implementation of integrated local energy systems. Such complexity demands new instruments and institutional arrangements to optimally integrate generation and demand at a local level. Various approaches are available for energy system integration such as Micro-grids [10], Integrated Energy Systems [11], Virtual Power Plants [12] [11], Energy Hubs [13] and Prosumer Community Groups [14]. These approaches, however, are designed to adapt to an existing blue-print of a centralized energy system. A more bottom-up solution which can capture all the benefits of distributed energy resources and increase the global welfare is still lacking. A comprehensive and integrated approach for local energy systems where communities can take complete control of their energy system and capture all the benefits of different integration options is needed.

Integrated community energy systems (ICESs) are a modern development for dealing with a changing local energy landscape. ICESs represent locally and collectively organized energy systems and combine the concept of sustainable energy communities [15], community energy systems [8], community micro-grids [16], and peer-to-peer energy [17]. ICESs are capable of effectively integrating energy systems through a variety of local generation of heat and electricity, flexible demand as well as energy storage. Cross-sector integration at the local level helps in the efficient use of available energy. Integrating smart-grid technologies and demand side management facilitate an increase in reliability and efficiency of such local energy systems.

The main purpose of ICESs is to fulfil the energy requirements of local communities through better synergies among different energy carriers. ICESs aim not only at the self-provision for the local communities but also provide system services to neighbouring systems such as balancing and ancillary services. Therefore, ICESs differ from other forms of energy system integration as a result of an integrated approach.

1.2 Research Framework

1.2.1 Research Trends

The main research trends in local energy system are identified through a keyword analysis in Scopus[2] for 2004 to 2013 [18]. Search terms ‘Community Energy Systems OR local energy systems’ and ‘community energy AND Institutions’ were used to cover technical as well as institutional dimensions, yielding a total of 1285 publications for analysis.

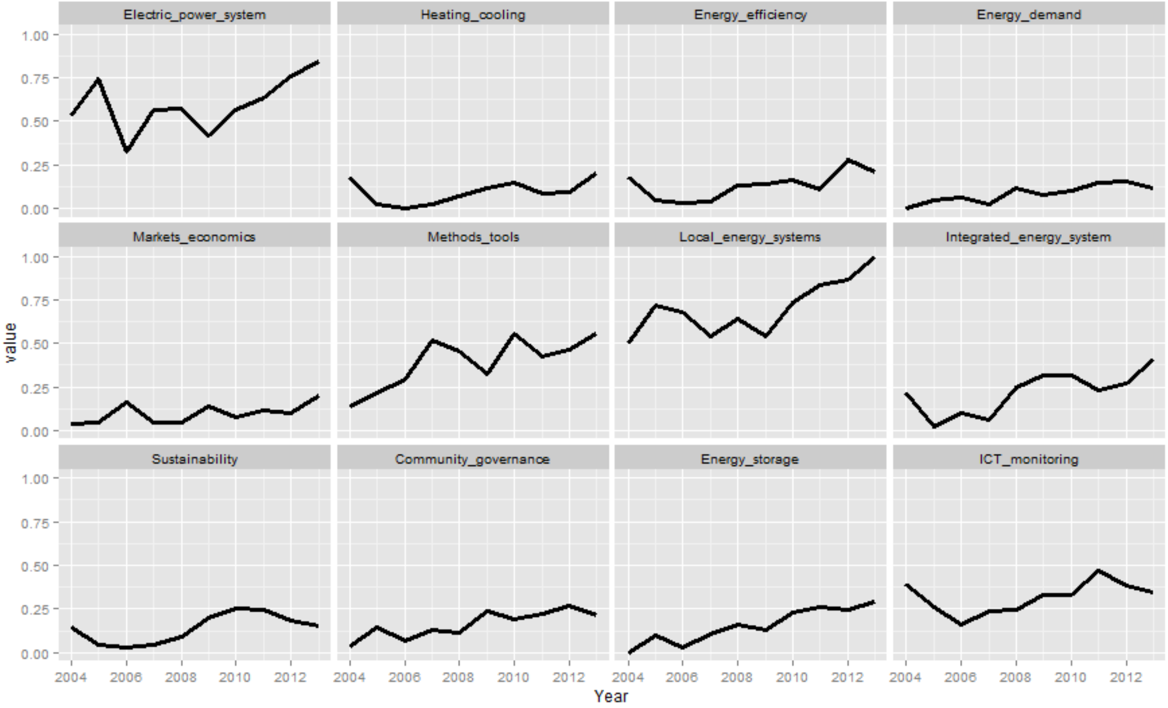

Figure 1: Research trends in local energy systems

The keywords from each article are ranked by occurrence with a script used in Friege et. al. [19]. After this, similar keywords are clustered into 12 main themes (see Figure 1). Normalized values are obtained for each theme by dividing the total number of keywords for each year by the total publications in that year. The resulting value is further divided by the maximum to get a normalized value. All identified themes have increasing research trends while some appear to receive more attention than others (see Figure 1).

1.2.2 Analytical Framework

ICESs are conceptualized as multi-source multi-product, complex socio-technical systems consisting of different decision making entities and technological artefacts governed by energy policy in a multi-level institutional space [20]. ICESs have a strong degree of complementarity that is enabled via physical and social network relationships [20]. ICESs encompass a combination of technical elements, characteristics and active links. Such characteristics consists of a pattern of social practices and thinking referred to as ‘institutions’ [21]. Current energy systems are highly institutionalized, however, these institutions did not develop with the focus on ICESs. Yet, current trends in the energy system affect these institutions. Therefore, ICESs as well as other forms of local energy systems are shaped by new trends in the energy

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[2] As the largest abstract and citation database of peer-reviewed literature, Scopus delivers a comprehensive overview of research output in various fields along with features for analysis and visualization.

landscape. Transformational energy systems such as ICESs are also influenced by technological, socio-economic, environmental and institutional issues and interactions (see figure 2) [22]. As a result, these trends and issues influence the emergence of ICESs. In the changing local energy landscape these issues and trends are considered accordingly for a comprehensive assessment of ICESs.

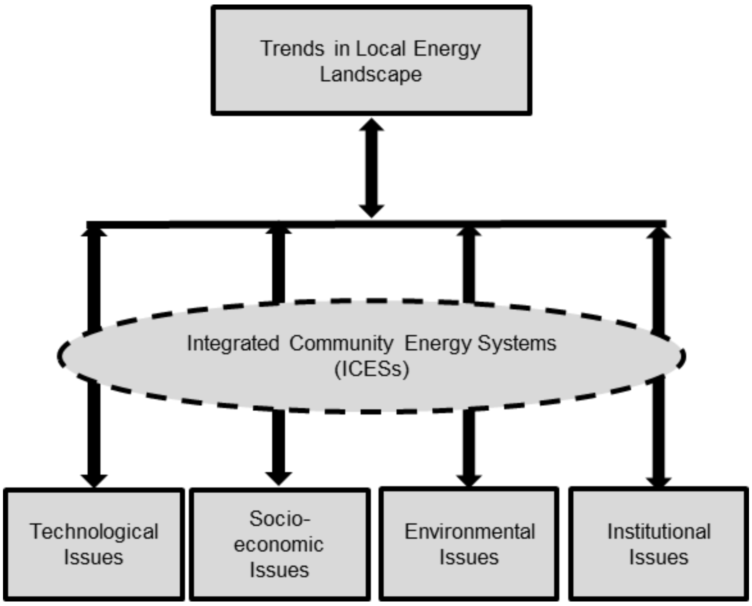

Figure 2: Analytical framework considering issues and trends in changing local energy landscape

1.2.3 Research Approach

This research assumes that ICESs are shaped by current trends and issues in the energy system. First, the trends in the current energy landscape are reviewed, followed by an elaboration on different energy system integration options. ICESs are conceptualized as a comprehensive approach towards integrated energy systems together with engagement of the local communities. Different technologies, actors, characteristics, categories as well as drivers and barriers of ICES are reviewed. Technological, socio-economic, environmental and institutional issues related to the implementation of ICESs are highlighted. A business model canvas for ICESs is also presented. Finally, the application of ICESs in developed, and developing economies are highlighted with case examples.

1.3 Research structure

This paper presents a review of keys issues and trends in the energy landscape which are shaping the development of ICESs. The work begins with an analysis of \ current trends, followed by a review of energy system integration options in section 3, which bring the focus to ICES. Specifically, the local level emphasis is elaborated in detail in section 4, which conceptualizes ICESs, presenting the technologies as well as actors involved. Section 5 examines the key technological, socio-economic, environmental and institutional issues affecting the implementation of ICESs. In Section 6, a business model canvas as well as sample cases of ICES application are presented.

2 Trends shaping the energy landscape

Restructuring and liberalization of the energy sector both in developed and developing countries is facilitating the energy transition [23]. The energy landscape is transforming towards decentralized low-carbon energy systems. Such developments are engaging a multitude of actors to deliver new and innovative solutions. Utilities are adapting their business models and new energy services are emerging. In this context, new roles for local communities are emerging, transitioning them from passive consumers to active prosumers with local generation, demand response and energy efficiency measures. Demand response refers to programs which provide incentives for consumers to modify their consumption patterns [24] [25]. The shift towards renewable-based production for energy consumption and increasing electrification of different sectors requires local generation to be integrated and coordinated.

2.1 Increasing electrification

The world energy demand is expected to increase at the rate of 2.2 % per annum between 2012 to 2035; 90 % of this growth will occur in the building and industrial sectors [26]. The energy demand growth has been stabilized for OECD countries since 2005, whereas the rest of the world is still experiencing ongoing incremental energy growth. The IEA predicts a continuation of this pattern until 2040 [26].

Evidence indicates that the built environment is responsible for most of the energy consumption and CO_2 emissions worldwide. For example, 70 % of energy demand worldwide comes from cities which will increase further with rapid urbanization. In the European Union (EU), the building sector alone is responsible for 40 % of total CO_2 emissions [27]. In order to improve overall energy efficiency as well as reduce CO_2 emissions, specific focus on cities and local communities is required.

According to the EU 2050 Roadmap, electricity will have a more predominant role on the final energy consumption by almost doubling its share by 2050 in comparison to 2005 [28]. This is due to the de-carbonization of the transportation and heating as well as cooling sectors. Residential electricity demand is expected to increase significantly with the adoption of electric vehicles and heat pumps [29]. Consequently, increasing electricity demand resulting from electrification may contribute to escalating congestion problems on local grids. Until now, the solution has been grid reinforcement, which is costly and path dependent. Distributed local generation will become more prevalent with the increasing electrification of different sectors.

2.2 Rising distributed energy resources

Distributed Energy Resources (DERs) include distributed generation, storage as well as controllable loads [10]. Distributed generation refers to electric power generation within a distribution network or on the customer side of the meter [30]. More recent definitions of distributed generation include local generation such as electricity and heat [31]. DERs are becoming increasingly common in the local energy landscape and are playing an essential role in the global energy system. Currently, one-quarter of electricity generation worldwide is attributed to distributed generation [32][33].

In smart grid systems, end-users are expected to utilize distributed generation and storage technology in their homes (e.g., TESLA Powerwall [34]) as well as at the community level (e.g., community energy storage [35]). This enables local communities to take energy-related matters into their own hands. Electric storage has also experienced significant cost reductions in the last decade and costs are also expected to further decline in the next decade. Moreover, demand side management can be stimulated as well through price based and incentive-based schemes. This is enabling bidirectional balancing in the power system i.e., both on the supply and demand side.

2.3 Towards a carbon-neutral energy mix

The Energy transition from fossil-fuel based centralized energy systems towards renewables-based decentralized energy systems is high on the energy policy agenda for a low-carbon future (e.g., EU 2030 [2], American Recovery and Reinvestment Act of 2009 [36], and Renewable Portfolio Standards [37]). Relatively inflexible conventional power plants such as coal and nuclear are being replaced by more flexible systems that can accommodate a high share of intermittent renewables [38]. Renewable energy systems are being incentivized in the form of grants for research and development, subsidy on initial capital cost as well as through direct renewable generation support schemes. This has increased the share of renewables such as solar and wind in the energy mix of several countries in Europe and elsewhere. For example, the installed solar PV capacity of 38.5 GW in Germany in 2014 exceeded all other types of power plants.

Increasing penetration of intermittent renewables in the energy systems leads to various issues and raises capacity and ancillary service costs [39][40]. Such issues are becoming increasingly common not only on the transmission systems but also on local distribution systems. Moreover, renewable generation at the local level raise new balancing and congestion challenges. This demands flexibility from all the actors in the electricity value chain including customers [39]. In other words, all the market players are expected to be ***"balance responsible"***. Balance responsibility refers to the responsibility of connected users at every node on the grid to draw up for them their programs for production, transport and consumption of electricity. Balance responsible parties are expected to act in accordance with these programs which they provide to the system operator; if connected users do not comply with their submitted schedules they face penalties [41]. The need for imbalance management will rise in the future, as it will reflect the real cost of balancing intermittent renewables. Along these lines, there is a rising demand for new flexibility sources such as storage and other innovative measures to balance the rising variability of renewable energy production.

2.4 Changing utility business models

With the rise of distributed generation, individuals and communities have higher control of generation and consumption of energy. For example, more than half of Germany´s remarkable RES installation is owned by citizens, whereas the share of the four big incumbents, namely E.ON, RWE, Vattenfall and EnBW, is only 6.5% [42]. The increasing share of RES is affecting the capacity factor and economics of large power plants. This is distorting the business case and incumbents are reporting losses to the tune of millions of euros.

Accordingly, incumbents are also starting to change roles and strategies in energy systems. In September 2013, RWE, Germany's largest power producer, decided to radically depart from its traditional business model based on large-scale thermal power production to become an energy service company [43]. Similarly, E.ON announced at the end of 2014 that it is spinning-off conventional power plants to focus on RES, distribution network and customer solutions [44]. RWE and E.ON are the representative example of undergoing transformation in the energy system.

2.5 Increasing customer engagement

Many local communities have expressed their goal to become self-sufficient and carbon-neutral in energy. For example, in the Netherlands there are more than 500 initiatives for energy neutral, zero-emission or low carbon communities [1]. Several others are engaged in local generation as a business case to sell electricity to the national grid [45]. Similarly, there are more than 900 energy co-operatives in Germany. In either case, decentralized co-ordination is an emerging phenomenon in the local energy landscape.

Household level energy conversion, storage and exchange technologies are expected to permeate future energy infrastructures [46]. The integration of distributed generation, however, is a challenge. If managed properly it brings a lot of opportunities such as local jobs and improves energy efficiency. For this to happen, the traditional system designed to fit centralized energy infrastructure and institutions has to be adapted. This will help to utilize the maximum potential of decentralized energy systems through the use of local resources and wider engagement of local communities. The energy system becomes more flexible and decentralized if different energy sectors such as electricity, heating, cooling and transportation are increasingly integrated at the local level. Such integrated approaches bring energy generation closer to consumers, thereby reducing all the complexity, cost and inefficiencies associated with a centralized energy system [16]. Hence, decentralized co-ordination is required for both engaging customers and integrating sectors.

3 State of the art energy system integration options

The key challenge of future energy systems is the integration of increasing levels of distributed energy resources. Several energy system integration options are designed to meet this challenge such as virtual power plants, energy hubs, community micro-grids, prosumers community groups, community energy systems and integrated community energy systems.

3.1 Energy system integration

These options to energy system integration differ in their objectives. For example, the aim of community micro-grids is to optimize electricity generation and demand for resiliency whereas virtual power plants aim at aggregation and operation of DERs. See table 1 for a summary of the objectives of each energy system integration option.

Table 1: overview of energy system integration options

Options	Objective	Reference(s)
Community Micro-grids	Optimize electricity generation and demand for autarky and resiliency in community	[47]
Virtual power plants (VPPs)	Aggregate and manage (operate and dispatch) DERs	[48]
Energy Hubs	Multi-carrier optimization of electricity, gas, heat and cooling within a district	[13]
Prosumer Community Groups	Energy exchange among prosumers having similar goals	[14]
Community Energy Systems	Invest and operate local energy system	[49][50][8][6]
Integrated Community Energy Systems (ICES)	Multi-faceted approach for supplying local communities with its energy requirements through DERs, flexible loads and storage together with different carriers	[16] [51] [52]

Community micro-grids: Community micro-grids comprise of locally controlled clusters of DERs which are seen as single demand or supply from both electrical and market perspectives [53]. Micro-grids can detach from the national grid and operate autonomously when needed. It enables higher penetration of DERs such as solar, wind, combined heat and power, demand response as well as storage. In this way, local resources can be used to supply local demand, thereby reducing losses and increasing the efficiency of the energy delivery systems.

Virtual power plants (VPP): Consumption and production of various households can be aggregated to form flexibility capacity equivalent to that of a power plant, hence creating a type of virtual energy plant (VPP). According to Morales et al [48] , virtual power plants are " a cluster of dispersed generating units, flexible loads and storage systems that are grouped in order to operate as a single entity". A VPP can be technical or commercial [12]. A technical VPP has location specificity attached to the flexibility, mainly within a distribution system. Differently, a commercial VPP has no location specificity; flexibility from such a VPP can be distributed and aggregated from different distribution systems. The VPP allows participation of DERs into energy markets as well as system operation support; thereby helping the gradual replacement of centralized power plants.

Energy hubs: An energy hub manages the energy flows in a district through optimal dispatch of multiple energy carrier [13]. It includes storage, conversion and distribution technologies to supply electricity, heat, gas and other fuels to the end users. When the conversion technology is available, energy-carriers can be transformed to other forms.

Prosumer community Groups (PCG): According to Rathnayaka et al. [14], "PCG is defined as a network of prosumers having relatively similar energy sharing behaviour and interests, which make an effort to pursue a mutual goal and jointly compete in the energy market". In fact, PCGs are designed to overcome possible inflexibility arising from micro-grids and technical VPP such as complexity to add or remove new members. PCGs virtually interconnect prosumers and may not necessarily be connected technically.

Community energy systems: According to Walker and Simcock [8], "community energy systems refer to electricity and/or heat production on a small, local scale that may be governed by or for local people or otherwise be capable of providing them with direct beneficial outcomes".

Integrated community energy systems: ICESs capture attributes of all energy system integration option and apply them to a community level energy system. These are modern developments to re-organize local energy systems. Mendes et. al. [16] defined ICESs as a multi-faceted approach for supplying a local community with its energy requirement from high-efficiency co-generation or tri-generation as well as from renewable energy technologies coupled with innovative energy storage solutions as well as electric vehicles and demand-side measures. They aid in increasing self-consumption and matching supply and demand at the local level. ICESs are further elaborated in detail in chapter 4.

3.2 Energy Services

According to Perez-Arriaga and Burger [54], energy services refer to "activities or products with commercial value that are procured directly for, or on behalf of electricity consumers." Some of these services are internal whereas others are system services. For electricity, these services can be further categorized into energy-related services, operating reserve and network related services (see figure 3). Energy-related services include the provision of electrical energy. In addition, secondary services such as medium and long term contracts, power exchanges can be derived from these primary services. Operating reserves service consist of primary, secondary and tertiary reserve as well as firm capacity to ensure reliability of the system. Network related services include network connection, voltage control, congestion management and energy loss reduction. For more detailed elaboration on electrical energy services, see Perez-Arriaga and Burger [54]. These services differ slightly for other energy carriers such as heat and gas, and should be defined accordingly. Moreover, when multiple carriers are involved additional services emerge. For example, over-production from DERs can be balanced in heating or power to gas conversion.

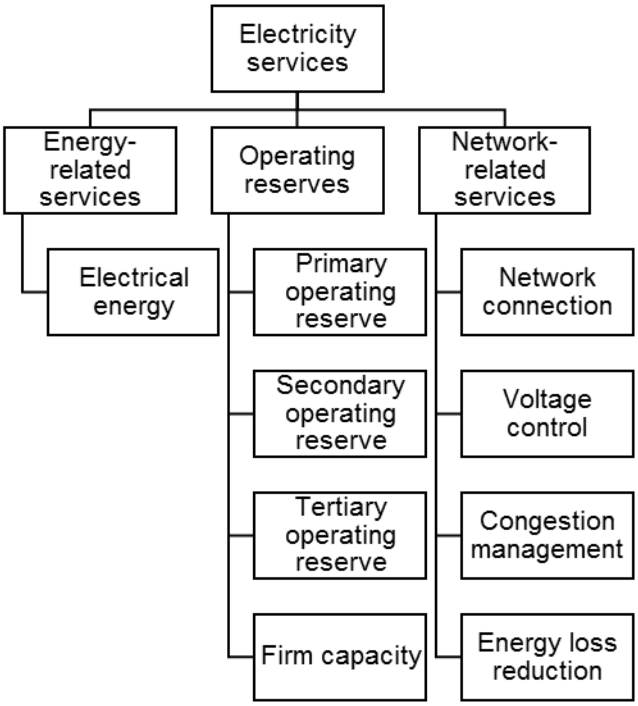

Figure 3: Electricity services

3.3 Comparative analysis

Value generation and degree of integration is analytically plotted for different energy system integration options (see figure 4). Value generation refers to the value for other energy system. It can be through collaboration and services to external systems such as other communities or larger energy system. Degree of integration refers to internal values such as self-provision and self-sufficiency. As ICESs and community micro-grids provide both energy-related services, operating reserves and network services through physical interconnection, they rank high in terms of both value generation and degree of integration. ICESs are expected to rank slightly better than community micro-grids due to superior community engagement.

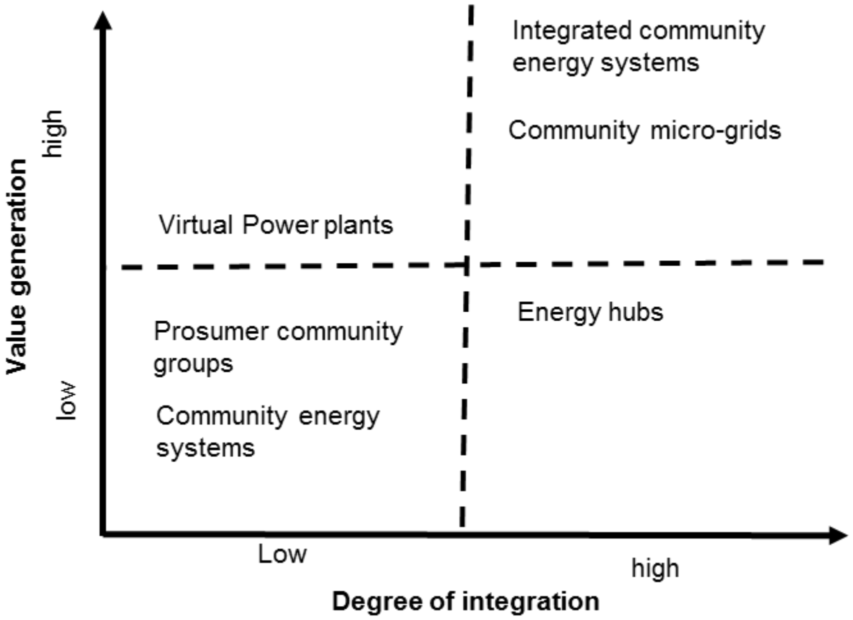

Figure 4. Interplay between value generation and degree of integration in different energy system integration options

Despite many benefits and being frequently mentioned in energy policy documentation [3], local energy systems integration options such as ICESs, however, have not gained enough momentum in Europe and elsewhere. This can be attributed to missing active engagement from local communities as well as existing regulatory barriers. This paper further analyzes the justification behind such a hindrance by plunging into the complexity associated with such systems, accordingly investigating main energy trends and key issues in the implementation of ICESs. Specifically, the work focuses on conceptualizing these multifaceted smart energy systems which optimize the use of all local distributed energy resources.

4 Conceptualizing Integrated Community Energy System (ICES)

Currently, local communities are supplied by a centralized energy system. This top-down architecture is due to the presence of economies of scale, possibilities to ship conventional fuels such as coal and gas to a desired location etc. However, technological and economic progress has shifting the energy production and consumption towards a smart grid paradigm that is increasingly concerned with climate change mitigation. We are at the cross-roads of redesigning our energy systems to integrate distributed energy resources. The energy system is transforming to a combination of top-down and bottom-up systems, being incentivized by the vulnerability and insecurities associated with centralized energy infrastructure, depletion of fossil fuels and climate change [23]. This enables communities to control generation and demand, leading to social innovation in management of energy systems.

As a result of the monotonous focus on big power plants for scale economies in the last century and recent attention on individual households, thus far local energy systems have remained in the shadows [3]. Thanks to technological advancement and socio-political acknowledgement, the potential of communities is now at the forefront of exploration with a key role in transitioning energy systems [3]. However, if a large number of households install intermittent renewables and other local generation and storage technologies, it can have adverse effects on distribution grids. These local grid issues can be solved either via network reinforcement or by encouraging smart local energy management via ICESs. Moreover, with the advents of smart grids and rising climate change concern as well as decreasing cost of distributed generation technologies, collective energy systems are receiving renewed attention. There is widespread consensus that, if the energy system as we know it has the desire to become sustainable, different energy sectors have to be integrated and, local communities engaged.

Schweizer-Ries [15] introduce the concept of sustainable communities and energy sustainable communities. Sustainable communities are communities which promote or seek to promote sustainability. However, the term “sustainable communities” is very broad and refers to all aspects of resource use and emissions reduction. Differently, energy sustainable communities are communities that use renewable energy and energy efficiency measures. On this basis, we consider ICESs as an advanced form of energy sustainable communities. Chicco and Mancarella [31], using a comprehensive distributed multi-generation framework, argue that the adoption of composite multi-generation systems through coupling of combined heat and power units with absorptions/electric chillers, heat pumps and fuel cells, can lead to higher energy efficiency, lower CO_2 emissions and enhance profitability.

We present an integrated community energy system (ICES) as a comprehensive approach for a paradigm shift in the energy sector. This approach aims at shifting the current rigid and centralized energy systems towards ones that are more flexible and decentralized. Integrated operation of distributed energy sources from the local neighborhood can lead to a flexible and robust interconnected energy system with considerable energy security benefits. ICESs are enabled through effective technical and market integration of distributed energy resources, providing a necessary platform for community engagement. The following sections focus on identifying technologies, characteristics as well as actors bringing to fruition ICESs.

4.1 Defining ICESs

Several definitions of ICES exist in literature [16] [52] [55] [56]. The initial conceptualization of ICESs is attributed to Buck [52], where a feasibility analysis of co-generation, heat and cold storage is performed for meeting the energy needs of Georgetown University in 1980, inclusive of an institutional assessment for governing interaction. Mendes et. al. [16] define ICESs as a multi-faceted approach for supplying a local community with its energy requirements from high-efficiency co-generation or tri-generation as well as from renewable energy technologies coupled with innovative energy storage solutions as well as electric vehicles and demand-side management measures. According to Harcourt et. al. [56], ICESs also exemplify planning, design, implementation and governance of energy systems at the community level to maximize energy performance while cutting costs and reducing environmental impact. Therefore, ICESs involve the assessment of existing energy infrastructure and available resources in a community. This helps to find innovative solutions for local generation, load shifting, local balancing, collective purchasing and energy conservation methods. In this sense, ICESs focus on the complementary role of energy and is capable of embracing technical and social innovation in the energy system integration as they become available**,** see Figure 5.

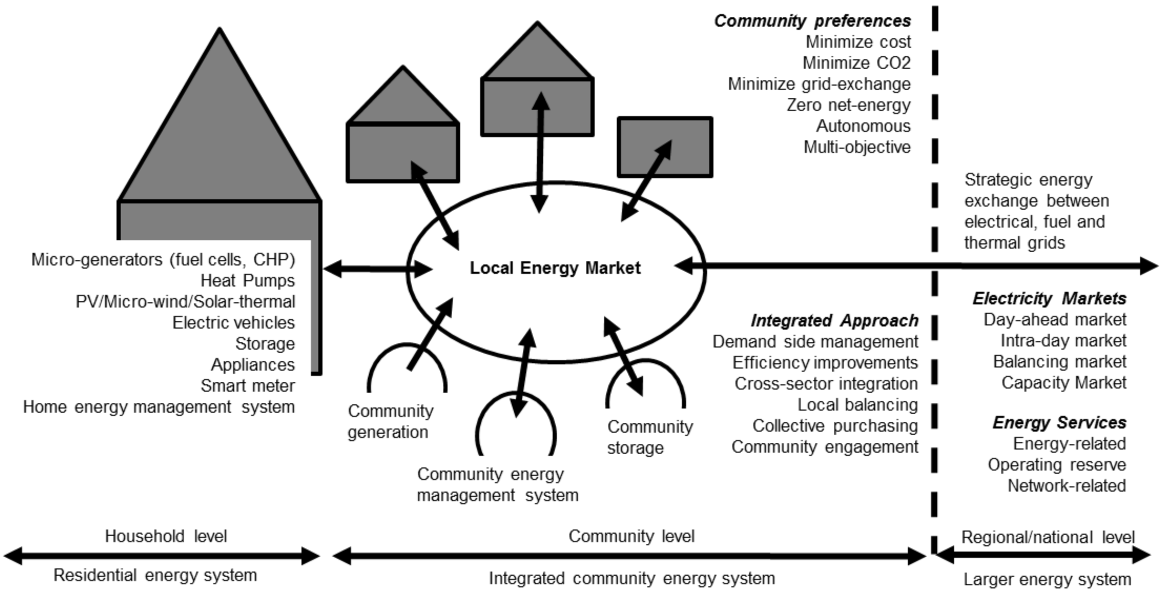

Figure 5. Functions of an integrated community energy system in the larger system

The local community is a fundamental component of ICES with varying notions [7] [9] [15] [57] [49]. For ICESs, communities can range from a block of households in a street all the way to an entire district. Furthermore, community composition differs a lot between developed and developing countries as well as between urban and rural areas. Nevertheless, a local community is the sense of place, identity, localism and shared values. Wirth [9] provides a neo-institutional definition of a community as a local geographic entity from which cultural-cognitive, normative and regulative forces originate. Walker [49] distinguishes between communities of locality and communities of interest. In this work, the focus is on the former since it provides not only economic and environmental benefits, but also a range of technical and institutional values to the local communities. Prior to delving into details of ICESs, below we discuss essential attributes to consider in such evolving systems.

4.2 Attributes of ICESs

4.2.1 Location (specificity)

ICESs on the one hand, have defined system boundaries as units of the whole energy system (see Figure 4), integrating DERs at different scales. The advantage of extending to multiple buildings lies in the variation of demand profiles and availability of multiple generation and consumption sources, in this way increasing the flexibility of the system and overall extracted value. When consumers co-operate, more energy options become feasible at a community level due to economies of scale and local balancing. On the other hand, we do not define strict boundaries as they are up to the community wishing to integrate to make that decision according to evolving needs. Typically, a cluster of households within a distribution transformer are part of ICESs. It may even be the case that all connected users, commercial and residential alike, are part of the flexible community.

Generally, integrated energy systems can be realized at the local level by combining rooftop photovoltaics, small wind turbines, district heating, and community energy storage or biogas and hydrogen production systems. An integrated energy system can also be pursued when for example waste heat from nearby industrial plants are utilized [58][59][60]. ICESs promote local balancing as well as strategic exchange with electrical, fuel and thermal grid (see figure 5). In this way, ICESs will always have interaction and therefore coordination with the other ICESs or larger energy system no matter how remote and seemingly isolated their location may be. Although ICESs will be self-sustaining as much as possible in order to meet the energy needs of the consumers in the community, they will nonetheless need access to both power and fuel from the larger systems. When connected to the larger electricity system they may receive power at times when local generation is not enough to meet the supply. Moreover, fuel (except biogas) is difficult to produce and access at a local level, therefore interaction with the larger system is unavoidable.

There are some undeniable differences in the process when considering developed and developing countries. In developed countries, the application of ICESs have increased as a result of climate change, energy autonomy motives as well as economic reasons inclusive of subsidies for local energy sources. Differently, in developing countries the main purpose is simply the provision of energy access. Moreover, the number and type of energy carriers also differ among developed and developing countries. In developed countries, electricity, gas and heat networks have existed for decades whereas in developing countries the grids are mostly electricity-only. In this section, we elaborate ICES development in both developed and developing countries. Examples for each case are presented in section 6.

ICESs have common practice and exchange with the larger system, but implementation, utilization and value will differ when considering urban and rural locations. Note, differences intensify depending on the implementation in urban and rural locations of developed versus developing countries. Below follows a short discussion on this differentiation between these communities and what the integrated systems entail.

4.2.1.1 Developed countries

Among developed economies, Canada, UK, Germany, and Denmark are already implementing concepts of ICESs. These developed countries especially in Europe have recently witnessed a new wave of development of local energy systems in the form of energy co-operatives [61]. Canada has developed a roadmap to benefit most of its communities from integrated community energy solutions by the year 2050 [62].

Initiatives for ICESs are emerging across Europe but with varying numbers, success rates and strategies [45]. The diversity in success of these community initiatives have been attributed to prevailing structural, strategic and biophysical conditions. Electricity market reforms together with favorable energy policy, such as feed-in tariffs in Germany have stimulated local initiatives promoting the production of clean energy by using local energy sources [45]. Over half of Germany's remarkable renewable energy portfolio is owned by citizens and farmers. There are more than 900 energy co-operatives operational in Germany. In the UK, there are already more than 5000 groups working to transform the way communities use energy [3]. According to the UK community energy strategy [3], these groups are organized in a wide variety of forms and sizes from collective switching schemes, generating local energy through community wind and solar farms to neighborhoods, joining forces to insulate their homes. Furthermore, it is estimated that such schemes involving local communities could supply enough electricity for 1 million households in the UK by 2020.

4.2.1.2 Developing countries

In developing countries, the main objective of ICESs is to provide affordable energy access to rural communities. For example, community micro-hydro plants in South and South East Asia are successful in providing energy to rural communities [63]. These community hydro systems are small decentralized energy systems based on locally available hydro resources and are established through joint effort of multiple-stakeholders with significant participation of local communities. Communities are involved from the start of the project conceptualization all the way to final operation. Higher coordination among local communities, social actors, governments, project developers, donor organizations, financial institutions and other stakeholders have yielded significant impacts in success of community energy systems development as observed in community micro-hydro solutions in countries such as Nepal and Afghanistan [82]. Community micro-hydro in Afghanistan (48 MW), Nepal (22 MW), Sri-Lanka (2 MW) and Indonesia (21 MW) are already providing an array of basic energy needs to thousands of households. Community energy systems are well integrated in local communities and contribute to the integral development of rural socio-economics. The tremendous opportunities associated with community energy systems for providing rural communities in developing countries with energy access should be further exploited; challenges can be solved with coordinated efforts.

4.2.1.3 Urban areas

Urban areas consist of towns and cities with dense population and limited space. Density entails close interactions and an emphasis on high living standards. Lund et al. [64] point out that smart energy system design in both developed and developing countries could aid in making locally produced renewables a mainstream part of cities' emissions mitigation strategies. For instance, the incorporation of local electrical storage can aid in increasing power share by 40% to 60% in Delhi and 25% to 30% in Helsinki [64]. ICESs can play important role in transforming urban energy systems.

4.2.1.4 Rural areas

Rural areas mainly consist of villages and even smaller areas with population that is dispersed and with ample space. In developed countries such as the EU rural electricity access is not a main issue because of European legislation mandating Third Party Access; an obligation for network companies (electricity and gas) to connect networks to third parties with available capacity for production and consumption. For Europe, the rural areas can connect their flexibility to the larger system or can consume it locally. Unfortunately, this is not the case for developing countries; rural access to energy brings about many challenges and even more benefits when reliable energy access is achieved. With more than one billion populations without energy access, ICESs has tremendous potential for provision of energy access.

4.2.2 Criteria for assessment

In assessing ICESs it is important to keep in mind that for community integration there needs to be an existing system in place, rarely (unless in rural areas of developing countries) will we be working with a 'green field' where an ideal system is designed bottom up. More often it is the evolution of existing energy systems that creates a path dependence which inhibits innovation. Hence, the authors propose the following assessment criteria for an energy system to qualify as an ICES; locality, modularity, flexibility, intelligence, synergy, customer engagement and efficiency.

> ***Locality:*** *The system should have a larger proportion of local investment and ownership. It should be operated locally. Local generation should be used for self-provision through local energy exchange.*
>
> ***Modularity:*** *The system should be able to cope with entry and exit of its members. Household and community level technologies could be added later to adapt with rising demand.*
>
> ***Flexibility:*** *One of the important criteria for ICES is flexibility, which can be achieved through local demand response, local balancing, flexible load and supply. This flexibility can be utilized to provide energy and system services.*

Intelligence: *For the co-ordination of energy and information flow to match supply and demand locally, ICESs should be intelligent.*

Synergy: *The system should allow synergies between different sectors such as electricity, heat and transport as well as between different technologies.*

Customer engagement: *The system should engage customers through different means such as investment, ownership, local energy exchange and economic incentives.*

Efficiency: *The system should be both technically as well as economically efficient.*

According to the above criteria, the categorization of ICESs becomes a focal point which we discuss in the following section.

4.2.3 Categories of ICES

ICESs can be categorized in different groups based on their activities, scale, grid connectivity, initiatives, location and topologies as summarized in table 2. ICESs activities can be categorized into local generation, storage and demand response, collective purchasing as well as energy exchange and trading. Ideal ICESs consist of all these activities, although the communities can also choose single activities. Further distinction can be made between supply side activities such as collective purchasing of solar panels or collective ownership of wind farms and demand side activities such as energy conservation, retrofitting of dwellings or energy awareness raising initiatives [65]. In terms of scale, macro, meso and micro ICESs exist, applicable for city, neighborhood and buildings level respectively. Further distinction can be made based on grid connectivity [7]. ICESs can be initiated either by leadership of citizens or by government and private enterprises [65]. ICESs also differ based on locations such as developed and developing countries or urban and rural areas. Various topologies of ICESs are possible such as state of the art integration of DERs, integration through common point of coupling and autonomous systems. The authors emphasize that such systems have to be categorized and analyzed from different lenses and perspectives in order to derive their added value.

Table 2. Categorization of ICESs

Perspective	**Categorization**	**Reference**
Activities	Local generation, storage and demand response Collective purchasing Energy exchange and trading	[3] [65]
Scale	Large/macro: city, region Medium/meso: neighborhood Small/micro : household / buildings	[56] [61] [66]
Grid Connection	Grid connected Off-grid	[7]
Initiatives	Led by citizens Led by private enterprises Led by government	[65]
Location	Developed countries – urban Developed countries – rural Developing countries – urban Developing countries – rural	Own assessment
Topologies	State of the art integration of DERs Integration through common point of coupling Autonomous	Own assessment

4.2.4 Local energy exchange

Local energy exchange is one of the most important attributes of ICES. Figure 6 illustrates the architecture for such local energy exchange. Households can exchange energy locally through local buying and selling prices. Mechanism should be developed to determine these local energy prices. Local energy exchange allows local money to remain within the local economy; an attribute that becomes increasingly important in developing countries. The grid connection to the larger energy system(s) can also have strategic exchange with different energy markets. For example, the excess energy can be sold to the wholesale market at wholesale prices. The supply to cover residual demand can be purchased at retail prices. In case of autonomous ICES, total demand should be met locally. Suitable institutional arrangements should be designed in such a way that well-defining the commodities and suppliers. Note, local energy exchange with the larger system should always ensure efficiency, fair allocation of costs, right prices for participation and prevent opportunistic behavior. It should also design mechanisms to pay back local investment and share benefits. One such mechanism for local energy exchange is PowerMatcher® concept developed in the Netherlands [80] [81]. It utilizes available electricity consuming and producing devices from households to derive system operation that optimally matches supply and demand maximizing individual household benefit [80] [81]. For such systems to prevail, appropriate technology integration is crucial.

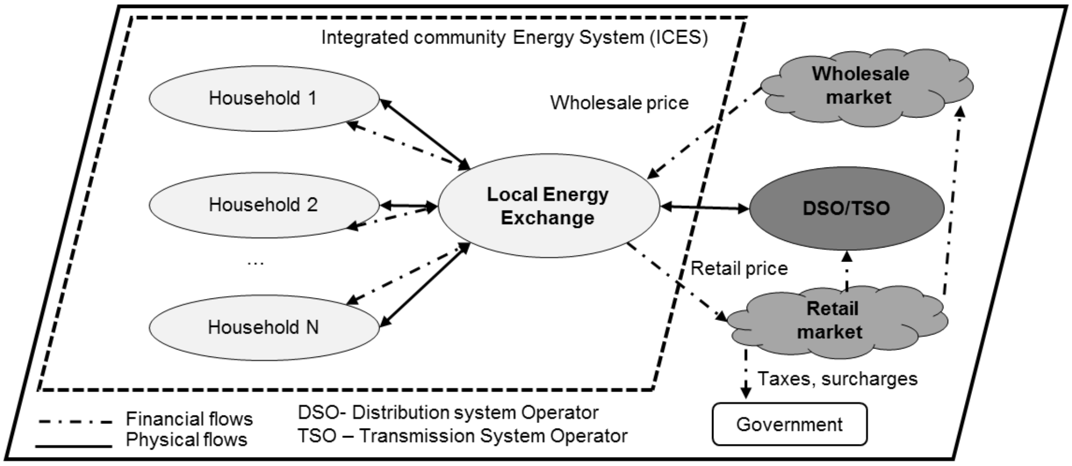

Figure 6. Local energy exchange in ICES

4.3 Technologies

Smart grid advances provide the basis for ICESs. The technologies to operate decentralized energy networks and markets have improved tremendously as a result of advancements in information and communication technologies [23]. Such technologies are required to manage ICESs, see Table 3. These systems can be characterized by active management of both information and energy flows within the context of distributed generation, storage, consumption and flexible demand [21]. Furthermore, energy management systems such as home energy management systems, building energy management systems, battery management systems and community energy management systems ensure effective control and operation of energy communities.

The architecture of ICESs depends on available technologies and the corresponding political, market and regulatory frameworks as well as technical standards adopted [69]. CHP, heat pumps, community energy storage and electric vehicles are some of the technologies which can already provide a basis for energy system integration at a community level. Recently, more decentralized technologies at affordable prices (e.g. PV, battery storage) have become available, further driving community level engagement [39]. Note, technologies will continuously be used in the future to develop energy independence through integration such as installation of heat pumps for district heating systems in combination with renewable energy systems. At given circumstances, local communities can utilize waste heat from nearby industries in local heating networks. This has been successfully implemented in places such as Sweden, Denmark, Germany and Finland with for decades, bringing about both environmental and monetary benefits [58][59][60].

Table 3. Technologies in ICESs

Categories	**Technologies**	
	Household Level	**Community Level**
Local generation	Micro-CHP Reciprocating engines Internal combustion engines Fuel cells Heat pumps Pico-hydro Solar PV (rooftop) Solar thermal Micro-wind	Community CHP Reciprocating engines Internal combustion engines Fuel cells Heat pumps Biomass Geothermal Micro-hydro Community PV Solar thermal Community wind
Demand side flexibility	Flexible appliances (e.g. dishwasher, washing machine) Electric vehicles Electric and heat storage Battery energy management system (BEMS) Home/building energy management system (HEMS)	Community electric and heat storage Community BEMS Community energy management system (CEMS)

4.3.1 Local generation

The local generation can be further categorized into intermittent and flexible generation. Renewable generation such as solar and wind are intermittent [70]. Spatial and temporal variation of solar irradiance and wind speed makes the forecasting of such generation a challenge. Although in recent years there has been a significant improvement in prediction and forecasting [71], nevertheless output still remains stochastic at times. As a result it is difficult to have a system that solely depends on such production sources. Hence, ICESs consider multi-source and multi-fuel options for 'keeping the lights on'.

Fluctuations in supply as well as demand can be absorbed through flexible generation, providing the ideal basis for local balancing. Most flexible generation technologies to date use conventional fuels. Flexible renewable technologies such as hydropower and geothermal are also becoming increasingly common. ICESs help these technologies to minimize emissions and maintain the system integrity. Balancing heating or cooling demand requires an integrated approach for cost and performance. For example, ground source heat pump systems are renewable and highly efficient technologies with high energy and environmental performance. They are being widely used for covering cooling and heating demand of well-insulated buildings with low supply temperatures. Research and application of ground source heat pump integration with different cooling and heating technologies pose several challenges inclusive of climate conditions, building functionality, ground thermal balance and thermodynamics [72] [73] [74].

Thanks to high efficiency, zero or low emissions, and modular structure, fuel cells have proven merits as a flexible generation technology [75][76]. Fuel cell performance is continuously improving in terms of reliability and cost. For instance, Sulphur-oxide fuel cells can already provide very high efficiencies (close to 70 % for electricity generation with possibility for heat recovery) in the context of combined heat and power applications [76][77].

4.3.2 Demand side flexibility

Effective integration of end users can be achieved through the adoption of home energy management systems and community energy management systems. Demand and supply side management system allow for effective integration of supply and demand at the local level. Electric vehicles, storage and flexible appliances can be programmed to match the local generation profiles. The availability of flexible demand varies significantly on a diurnal and seasonal basis [78]. The importance of flexible demand increases with higher fraction of non-dispatchable generation in future energy mix.

A wide range of state of the art studies have focused on demand side management [25][79][80]. On the one hand ageing assets, increasing penetration of renewables and other low-carbon generation technologies as well as advancing information and communication technologies are major drivers for wider applications of demand side management. On the other hand, several factors inhibit the widespread adoption: lack of metering as well as information and communication infrastructures; lacking insight into the potential benefits; inapt market incentives, increased complexity in system operations; and distorted competition. Furthermore, application of demand side load modification might disturb natural diversity of loads and create some undesirable and maybe even perverse effects.

4.4 Actors and their interests in integrated systems at the local level

Delivering energy to end users requires multiple processes both competitive and regulated for the procurement, production, conversion, and transformation of energy [81]. Actors in the energy sector are inter-dependent in the realization of their goals. Different actors of ICESs have varied interests from ICESs. For instance, households want low cost hassle free energy at their disposal while aggregators seek to maximize the value of flexibility in the various markets and policymakers want to ensure sustainable energy supply in the transition to low-carbon energy systems. Table 4 provides a detailed summary of the actors' interests, categorizing them into private and system interests. Note, interests can also change and evolve over time; as new developments take place, new technologies become available or new market mechanisms get established. Below follows a discussion of the critical facets that make up ICESs as discussed in this work.

Table 4. Interest of different actors in ICES

	Actors	**Interests**	
		Private interests	**System interests**
Competitive parties	*Households*	Use of local, affordable and clean energy at a low cost	Sale surplus and purchase deficit energy
	Communities	Reduction in energy related costs, provision of local energy	Emission reductions, energy independence, energy supply security, resiliency
	Energy producers	Investment in local energy system (profit maximization)	Sale local generation
	Energy suppliers	Profit from deficit energy supply, portfolio optimization	Increase renewables in their portfolios, new roles and business models
	Energy service companies (ESCOs)	Profit from energy efficiency, operation and management of local generation	Role in energy efficiency improvement activities as well as operation and management of local generation
	Technology providers	Sell technologies to transform the existing energy landscape both production and consumption (e.g. circular economy)	Promotion of local generation as well as demand side management technologies
	Aggregators	Business model for generating profit, Maximize the value of flexibility in the markets (both with capacity and energy)	Role in making system more efficient
	Balance responsible parties	Portfolio optimization, balance energy procurement at lowest cost,	Provision of accurate scheduling to the system operator

Regulated parties	*Transmission system operators (TSOs)*	Maintain larger system balance of supply and demand at lowest cost to the consumers	Maintain larger system balance of supply and demand
	Distribution systems operators (DSOs)	Distribute energy to the neighborhood with safe, reliable and affordable grid,	Avoid grid congestion, defer network investments, self-balancing energy islands in smart grids
	Government, policy makers and regulators	ensure competition for affordable energy for end-users	Sustainable energy supply, transition to low-carbon energy system, energy security

5 Key issues with implementation and adaptation

ICESs are confronted with technological, socio-economic, environmental and institutional issues during implementation and adaptation [22]. Most of these issues act as driving forces to encourage such systems emerge on the premise of sustainability. Moreover, ICESs aim at maintaining energy security or striving for energy independence, tackling climate change and keeping the prices affordable.

Although ICESs are often portrayed as neutral and inherently positive solutions, there are different barriers in the process of transition. The biggest barriers of ICESs are institutions favoring centralized energy systems [23]. Government agencies, private companies and utilities are often at the top of this list. According to Swider et. al. [82], the main factors affecting the deployment of DERs are site conditions, grid connection issues, generation costs, feed-in tariffs and support schemes as well as the allocation of the costs. Furthermore, scarcity of public and/or private space needed to install the power generating units as well as the temporal availability of the resources present challenges for ICESs [79].

ICESs, on the one hand can even face resistance from local communities if they do not align with local interests. For example, the issues of coordination and split-incentives can arise when costs and benefit of ICESs do not boil down to the same actor. Coordination requires transparency in the interactions between market parties in order to ensure mitigation of unfair cost-benefit allocation [83] . On the other hand, the local communities should also be very pro-active to take control of their energy system. The drivers and barriers of ICESs will however continuously change on account of technological and institutional changes, fuel costs, economics of technologies, and incentives. In this section, we elaborate on technological, socio-economic, environmental and institutional issues in detail, see Table 5.

Table 5. Key issues related to integrated community energy systems (ICESs)

Technological Issues	Socio-economic Issues	Environmental Issues	Institutional Issues
1. Intermittency of local RES generation and demand response 2. Energy efficiency 3. Storage 4. Local balancing of supply and demand 5. Local flexibility and impact on larger energy system 6. Load and grid defection	1. Paradigm shift through community engagement 2. Economic incentives 3. Willingness to pay 4. Split-incentive problem 5. Energy poverty 6. Energy autonomy and security of supply 7. Initial costs and financing	1. Environment and climate change 2. Emission 3. Waste 4. Spatial	1. Trust, motivation, and continuity 2. Energy democracy 3. Ownership 4. Locality 5. Support schemes and targets 6. (self-) governance 7. Regulatory 8. Institutional design 9. Roles and responsibilities

5.1 Technological issues

Technology progress is essential to linking local energy services and making them accessible and affordable. At the same time, technologies should ensure environmental compatibility by continuously shaping and adapting ICESs to the local circumstances. Technology choices are often linked to laws and regulations that reflect community capabilities, social preferences and cultural backgrounds [81]. Accordingly, ICES implementation differs among communities. At the same time, technological innovations help reduce initial costs of the energy system and increase reliability, enabling citizens and communities to adopt ICESs. Walker [49] argues that ICESs may, however, be inhibited by technical obstacles such as lack of equipment, technical knowledge and expertise. Table 6 provide an overview of the different technological issues and what role ICESs can play in their mitigation.

Table 6. Overview of technological issues

Issues	Examples	Role of ICESs
Intermittency of local RES generation and demand response	Intermittent generation Fluctuation in demand	Local balancing, storage, activation of flexible generation and demand, aggregation, promote load uniformity throughout the day in order to avoid peaks
Energy efficiency	Poor implementation	Collective purchasing of insulation materials and energy-efficient appliances, provide feedback within community, community economies of scale can bring down costs
Storage	High initial cost Storage duration	Collective purchasing of household storage devices, community energy storage system, peak curtailments, efficient utilization of local generation
Local balancing of supply and demand	Matching supply and demand locally	Demand side management, storage, diversity in demand and supply
Local flexibility and impact on larger energy system	Flexibility within communities Flexibility for regional/ national grid	Provide flexibility for larger energy system (s), local balancing, trade energy with other local communities/ICESs, increase penetration of renewables
Load and grid defection	Decrease of load in general and increase in peak demand at times	Complementary role to larger energy system through local energy system services, local balancing

5.1.1 Intermittency of local RES generation and demand response

Some DERs such as local RES generation and demand response are stochastic by nature. The latter is dependent on energy demand which varies with time, weather and consumer behavior which is at times habitual and predictable but most often not. Renewable local generation varies with wind and solar irradiation but also with the choice of use by the owners. For instance, a rooftop solar PV owner may want to transfer excess production to his neighbor and not sell generation back to the grid, which in turn causes further stochasticity. The generation variability is partly due to naturally occurring weather conditions but also the mechanisms in place for exchange, e.g. net metering. Despite the intermittency, the adoption of local generation and demand response mechanisms is continuously increasing. As fluctuations in generation and demand challenge balancing on a local community level, it is up to the transparent mechanisms in place to foster the right environment which will mitigate uncertainty.

5.1.2 Energy Efficiency

Although large improvements have been made at the household level with appliances (e.g., energy star in the US [84] and Eco Label in the EU [85]), energy efficiency projects are not yet common practice in local communities. ICESs facilitate communities to take part in energy efficiency improvements programs such as buildings' insulation. Sometimes, community energy efficiency improvements also include co-generation and utilization of waste heat from nearby industries driven by ICESs [61]. They can improve efficiency of local energy systems by combining different sectors such as heat, electricity and transport. Moreover, ICES help to reduce line losses compared to a purely centralized system. Through smart local production and hence consumption, energy efficiency can be increased as well. ICESs are expected to optimize the energy as well as the exergy (i.e. energy that is available for use) of local energy systems.

5.1.3 Storage

Fluctuating renewables make the case for storage an important part of the future energy mix. Storage of electricity, heat or gas is vital for ICESs as it helps to deal with local demand and supply intermittency in the form of thermal, chemical, mechanical or in intermediate products [79]. Storage type and size differs based on daily, weekly and seasonal demand to store energy. Although short-term electricity storage technologies are available, long-term electric storage technologies are still missing.

Hadjipaschalis [76] presents an overview of current and future energy storage technologies for electric power applications inclusive of flywheel, battery, super-capacitor, hydrogen, pneumatic and pumped-hydro technologies. Among them lead-acid, lithium-ion, nickel-cadmium batteries as well as flywheels are considered most promising. Due to high discharge rate, flywheels are suitable for the provision of only short-term (yet reliable) standby power. Flywheels can be used to smooth out the generation profiles of solar and wind energy within an ICES. Lead-acid batteries are common due to high-energy efficiency, low self-discharge rate, easy installation, low maintenance and low investment cost. The limiting factor for lead-acid batteries is relatively low battery operational lifetime. Although nickel-based batteries perform better in this regard, their costs are very high compared to lead-acid batteries. Lithium-ion batteries are also becoming increasingly important and have several advantages over lead-acid batteries. Although pumped-hydro and compressed air energy storage technologies can store very high power, these technologies are less likely to be incorporated into ICES unless suitable locations are available in local communities. In addition, heat storage technologies facilitate the efficient utilization of renewable energy sources as well as energy conservation [73] .

Based on where the storage systems are installed (i.e. household level and community level or a combination of both), it might help ICESs to withstand peaks in demand as well as to achieve power balance. Additionally, storage allows flexible generation to run at rated power, thereby with higher efficiency. Moreover, distribution networks could be operated at full capacity when needed, reducing the need for reinforcement and expansion. Furthermore, Hapaschalis [76] recommends to study the network environment as well as available storage devices specifications before making decisions on storage technology. Accordingly, storage solutions are very tailored and much system specific.

Local energy systems are likely to change with the introduction of plug-in electric, hybrid and vehicle to grid technologies [21]. Rising penetration of electric vehicles will yield higher load as well as storage capacity for ICESs. Electric vehicle flexibility is expected to bring added benefits such as stability and reliability to the local grid as well as flexible back-up for intermittent renewable energy.

5.1.4 Local balancing of supply and demand

Balancing supply and demand at the household level is inefficient mainly due to the diversity in appliance usage. Most demand is largely uncontrollable and varies during the day and year. One of the strengths of ICESs is local balancing of supply and demand. ICESs, which combine different households at the community level, can have significant value if the demand has to be met locally [79]. The ratio between maximum coincident total demand of the system and the sum of maximum demand of individual consumers in the system is defined as coincidence factor [79]. Electric load profiles together with the coincidence factor are used for accurate load forecasting, network planning and scheduling generation capacity.

Local generation technologies such as renewables and combined heat and power continue to expand in our energy systems and facilitate local balancing. However, with new and heavier loads such as heat pumps and electric vehicles as well as distributed generation and home energy management systems, the future electricity consumption patterns of residential consumers will change [86]. Citizens engaged in ICESs are expected to take an active role in demand response activities as well. The role of local energy systems in demand-side management has been investigated in Ward and Phillips [80]. Demand flexibility can enable more renewable integration through localized policies such as load preference [87]. ICESs are expected to positively contribute to demand response and ultimately to local balancing through an integrated approach.

5.1.5 Local flexibility and impact on the larger system

Significant benefits are associated with an increase in the flexibility of local energy systems [38] [39]. Technologies and methods employed for increasing ICES flexibility include: co-generation, fuel cell batteries, heat pumps, electric vehicles and community energy storage as well as demand response.

Increasing flexibility allows higher penetration of intermittent renewables within local energy systems and opens new possibilities to trade energy with neighboring communities and the national grid. Wide-spread emergence of ICESs creates a new role for communities as flexibility providers. The value of flexibility from ICESs, however, can be different for different actors such as communities, energy suppliers, grid operators and aggregators. Moreover, ICESs can contribute to system services such as capacity and ancillary services needed to operate the grid [40].

Lund and Muenster [38] analyze the benefits of increasing flexibility of Danish energy system using the integrated energy systems. The advantages of combining small and large combined heat and power plants with heat pumps have been highlighted. One such advantage is the possibility to increase the share of wind energy in the Danish energy mix from 20% to 40% without causing significant imbalance issues [38].

The energy mix of a country is expected to impact the emergence of ICESs as well. Although renewables penetration is constantly rising, it still represents a very small share of the total production worldwide. The deeper the renewable energy penetration in a system, the higher the expected value of ICES flexibility. For example, in Denmark 40 % of total electricity consumption comes from wind, in turn the system is heavily dependent on balancing power from the combined heat and power of local communities as well as its strong interconnection capacity with neighboring countries [38].

5.1.6 Load and grid defection

Energy systems at their current state will have to overcome several problems in the future. Namely, a higher share of demand for intermittent renewables, higher investment in new power lines and storage. Moreover, the majority of grids today are reaching the end of their lifetime and need replacing in the coming years, consequently demanding investment for network expansion and reinforcement. In Europe alone there is a need for €600 billion in grid investments by 2020 [REF].

Investment costs are ultimately passed on to the customers. This means the fixed part of the electricity tariffs will rise in spite of a decrease in wholesale electricity prices from increasing penetration of renewables. Soon, it might be profitable to generate energy locally, all while using local resources. If this happens on a larger scale, it might lead to grid defection, which means on-site generation may become cheaper than the increase in grid tariffs resulting from investments needed for staying heavily interconnect with the larger system. Furthermore, policy cost of renewable energy support schemes and a nuclear phase out drive this phenomenon with amplified speed. Since 2011, feed-in tariffs have been kept lower than retail electricity prices in Germany to encourage self-consumption. Currently, feed in tariffs for such systems are comparable to wholesale electricity prices. With the technology learning, the cost of storage systems is also expected to decrease. Photovoltaic storage systems are expected to reach grid parity in the near future as well, which will make the case of grid defection even stronger.

The Rocky Mountain Institute in the U.S. recently published a detailed analysis of defection from the large electricity grid using storage together with solar photovoltaics [88]. This study suggests that solar photovoltaics together with storage can make the electric grid optional without compromising reliability and at lower prices.

Along these lines, CSIRO [89] foresees a future Australian energy system that will look very different than the one today; 2050 distribution systems will become even more customer-centric where customers consume, trade, generate and store electricity. Furthermore, if suitable policies for integrating local generation are not in place, then leaving the grid (i.e., grid defection) will become economically viable in 2030-40. This will give a way for a third of Australian consumers to go off-grid by 2050, a likely outcome as a result of the rich solar resources and soaring electricity prices.

5.2 Socio – economic issues

As mentioned above, technology will drive the end-user activation in energy systems, yet this also remains the trickiest part of the ICES engagement process. In the following section we present an overview of the socio-economic issues facing communities, see Table 7 for a summary.

Table 7. Overview of socio-economic issues facing ICESs

Issues	Examples	Role of ICESs
Paradigm shift through community engagement	Passive consumers	Deliberative and inclusive participation of consumers in the energy system
Economic incentives	Rising energy costs Free-riding behavior	Collective distribution of benefits, higher bargaining power, saving on energy bills, less risk to invest
Willingness to pay	Higher willingness to pay for local energy	Absorb higher willingness to pay in local energy system
Split-incentives problem	Cost and benefits do not boil down to same actor	Design mechanism to allocate benefits
Energy poverty	Lack of energy access	Bring welfare to low-income households
Energy autonomy and security of supply	Degree and scale of energy autonomy Security of supply at local level	Manage local resources, local balancing, reduce dependencies on imported fuels
Initial cost and financing	High initial cost Risk aversion of banks	Collective purchasing and financing, innovative business models

5.2.1 Paradigm shift through community engagement

In essence, local communities encourage bottom-up solutions. A growing number of state of the art literature is increasingly concerned with the importance of more deliberative and inclusive participation of consumers in the energy production process [61] [90]. In the developed world, ICESs are being motivated by increased climate awareness and willingness to become autonomous among pro-active communities. In recent years, our energy system is shifting towards more distributed generation driven mainly by techno-economic improvements and ambitious carbon and energy policy targets [7]. Communities having self-imposed and targeted local energy strategies are expected to benefit from such implementation strategies. In addition, the push from local government entities as well as local business and residents will have a larger impact and a greater probability of success [66]. Furthermore, community mobilization has a very important role in initiating and sustaining ICESs [90]. Collective community identity and the quest for autonomy play a critical role community engagement in the larger context of energy systems.

Citizen engagement is considered to be the best way to obtain public acceptance for energy systems [61]. Energy generation from ICESs is reported to have higher public acceptance compared to private or utility-based generation. The word acceptance however is misleading in the context of ICESs as it implies to something external. Hence, local support or citizen engagement is preferred [61]. Citizen engagement or local support is composed of an attitude towards technologies, inducing changes in energy consumption patterns and investment in ICESs. Community engagement is deemed essential in the transformation from existing centralized energy supply to a more distributed supply system that exploits the full potential of local generation including renewables [9]. It is expected that some of the best opportunities for reducing energy demand and carbon emissions as well as for realizing flexible and integrated energy infrastructures are through stronger engagement of local communities.

A strong sense of community is a prerequisite for ICESs [65]; such systems result from a high degree of involvement at the local level in the planning, development and administration of energy projects as well as collective distribution of benefits [50]. Local energy systems such as ICESs are open and participatory as well as local and collective [50]. An emergent and self-organized community approach is expected to change the experience and outcomes of energy technology implementation as communities become both producers and suppliers of energy [6] [22] [66].

5.2.2 Economic incentives

Community action on energy has significantly increased during the past decade due to rising energy costs [90]. Citizens in developed countries are eager to invest in local energy systems over the alternatives. For example, a large number of communities in Germany have been self-organized as energy co-operatives. The members in these co-operatives are getting average dividend of 4 % which is much higher than the interest rate given by the banks [91]. Moreover, communities willing to install solar panels on their roofs or implement energy efficiency programs together will have higher bargaining power. According to recent survey by DECC[3] [3] in the UK, 42 % of people surveyed show interest in community energy participation, if it results in energy bill savings. Still, the incentive for citizens to participate in ICESs are low because the benefits do not accrue just to those who make the investment, but rather tempt free-riding behavior among citizens [90].

In recent years, small energy projects are grabbing investors' attentions in contrast to their bigger counterparts. It may be the case that investment in local energy systems such as ICESs is less risky. Economic benefits of ICESs can be remunerated as the interplay between increasing electricity tariffs and decreasing up-front investment costs of local energy systems. Local citizens should be enticed to invest in local and collective electricity production and storage whenever possible. However, there are case specificities especially when considering energy poverty.

5.2.3 Willingness to pay

In the developed world, research has shown that for a local energy system consumers are willing to pay a higher price for sustainable energy. To illustrate, 92 % of Germans support further growth of renewables and are willing to pay higher prices for locally produced energy [42]. Differently, in the UK, despite renewable energy being highly valued by the households, the willingness to pay is not large enough for a majority of the households to adopt micro-generation [92]. Through household and community level investments, an ICES enables local generation in such a way that the responsibility and cost are shared and in this way creating a local scale economy. Hence, with locally induced economies of scale, a community level becomes more interesting and households may be better inclined to accept the surplus. This surplus can be used to further expand ICESs or in other innovative activities which the community members agree upon.

Given these observations, for ICESs a different demand curve seems to exist, with a willingness to pay that is higher than that of conventional generation. We have coined the term '*ICES surplus'* to represent the consumer willingness to pay. It refers to additional willingness to pay by the consumers in the developed world for energy which is locally produced (see figure 7 (b)). The shaded area above the equilibrium price and demand (P_e and Q_e) and below the ICES equilibrium price (higher willingness to pay) and demand (P_{ices} and $Q_e + Q_{ices}$) represent the ICES surplus. This surplus can be used to improve further the welfare of the community involved. Further, research could aim at quantification of this ICES-surplus. In developing countries, the surplus for practical reasons is zero (see figure 7 (a)).

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[3] Department of Energy and Climate Change (DECC), from the United Kingdom

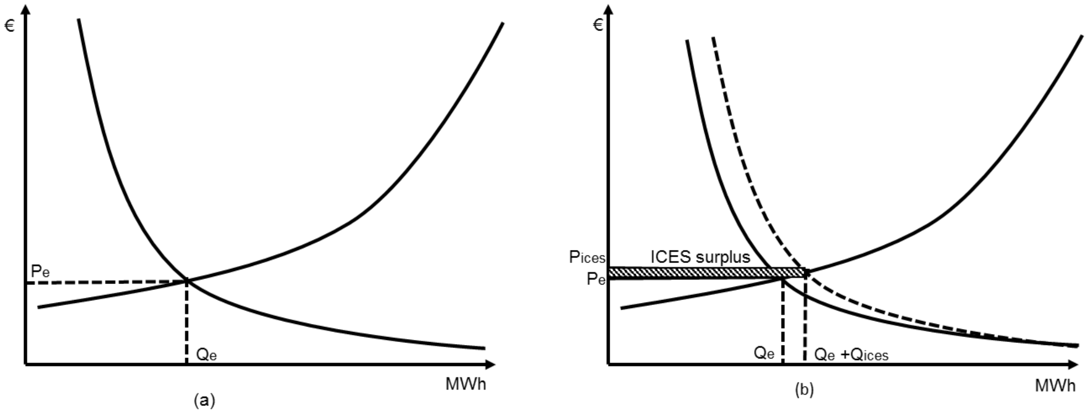


Figure 7. Willingness to pay for ICESs in developing (a) and developed countries (b)

5.2.4 Coordination and split-incentives

The value of community flexibility depends on how it is utilized, therefore the actors with access to it must communicate transparently in order to ensure the highest benefit for the community members. Co-ordination is necessary to ensure that the flexibility is not sold to more than one parties as well to ensure complementary but not opposing signals for flexibility.

Split-incentives problems are prevalent in energy efficiency projects where owners need to make investment and tenants reap the resulting benefits [93] [94]. This does not provide the right incentives for investments in energy efficiency projects. Similarly, it is important that in ICESs, costs and benefits are shared fairly amongst the stakeholders involved, making sure that those who are not involved in the costs do not rip the resulting benefits. Hence, it is critical that all interests are mapped accordingly in order to avoid issues with split and perverse incentives (see table 4).

5.2.5 Energy poverty

Energy poverty is of growing public interest in both developed and developing countries. The global definition of energy poverty considers end-users lacking access to modern energy services. Specifically, energy access is a development indicator; in the developing world over 1.6 billion people remain without access to electricity. The traditional top-down approach providing energy is clearly not working for rural areas, where access is plagued by remoteness and the resulting heavy investment needed [95] . Even in the cases where a village has access to an electricity grid, there may be a lot of problems on both the supply and demand side. On the supply side, common issues include low voltages and frequent power cuts. For the demand side problems like affordability and large difference between off-peak and peak demand are often visible. Note, utilities have always kept the rural areas in the least priority for the electricity supply [61][95].

In the context of advanced economies energy poverty often encapsulates low-income households which cannot afford enough energy to cover their basic needs [96]. ICESs are expected to be in a better position over profit-seeking traditional utilities to tackle the issues of energy poverty.

5.2.6 Energy autonomy and security of supply

Energy autonomy is one of the key drivers for local energy systems such as ICESs. Bradley and Rae [7] find that the shift towards a more distributed energy generation system presents numerous social and technical challenges. At the same time, energy autonomy at community level can deliver a host of social, financial and environmental benefits. The main issues include [7]: the degree and scale of energy autonomy; matching of demand with supply; importance of socio-economic and political factors and energy autonomy in island and remote communities.

ICESs can enhance security of supply at the local level; communities are in best positions to manage heat, cooling and electricity demand locally. This can be done through co-generation and local distribution network for heat and electricity. ICESs exploit locally available resources in a sustainable way and are expected to reduce dependencies on imported fuel which has several geo-political issues.

ICESs fit very well into the neo-liberal ideas of self-reliance and independence [65]. Many communities around the globe are concerned with security of supply and are planning to achieve energy self-sufficiency through dedicated energy efficiency and emissions reduction targets. The expansion of energy systems from residential to community level helps to achieve higher energy and power balance. With larger areas, more primary energy is locally available and generation profiles from intermittent renewables can be absorbed within the local system. However, as more communities attempt to achieve energy balance at the local level, the national energy systems might have negative rebound effects if peak demand of many ICESs coincides, in turn leading to higher electricity prices during peak hours. Moreover, it is very difficult to achieve the power balance in real time when individual technologies are considered. ICESs enable a power balance through smart local consumption, community energy storage, and flexible micro-generation units such as CHPs, fuel cells and heat-pumps as well as hydrogen or ammonia production. As heating, cooling, and transport sectors are being increasingly electrified, it remains an open question if ICESs can cover future demand. If all of this demand has to be met from the national grid, distribution grids will need substantial reinforcement to avoid local congestion. Alternatively, a significant portion of this demand could be met locally with the help of ICESs.

5.2.7 Initial costs and financing

One of the main barriers for ICESs is high up-front costs compared to existing national-grid alternatives. ICESs mobilize private capital of households, enabling investment in local generation technologies. Policy incentives to persuade local households to enable such self-financing model is necessary. Braun and Hazelroth [97] has stressed for then national, state and local policy to mobilize local money for local energy, capturing and optimizing local economic benefits.

Moreover, the cost of DER technologies are going down constantly. For instance, storage and fuel cells technologies are continuously improving in term of investment cost [76]. Furthermore, several studies attempt to understand the costs and benefits associated with the renewable energy technologies in the context of modern electricity system [98]. However, such studies do not exist for ICES. Although, there are funds available and favorable conditions in loan packages in many countries, risk aversion of banks concerning loans for communities is a major barrier to financing [22] .

5.3 Environmental issues

Similar to distributed generation, environmental policies and awareness are probably the major driving force behind the surge in implementation of ICESs [99]. Together with improvement in efficiency and reliability, ICESs are considered to be an environmental friendly alternative to the centralized power supply system [21]. Being local, these systems have higher social acceptance than their giant counterparts. Consequently, community action on energy have increased significantly during the last decade as a result of rising concerns about climate change [90]. In this section, we further elaborate environmental related issues with ICESs such as emissions, waste and space constraints.

5.3.1 Emissions

Harcourt et.al. [56] estimate that ICESs in Canada have the potential to reduce CO2 emissions by 5 to 12 percent annually by 2050. Furthermore, the role of local community engagement in reaching CO_2 emissions reductions goals is becoming increasingly evident. Moreover, using optimization based design of a district energy system for an eco-town in the UK, optimal mix of technologies to decrease the emissions and increase the resilience of supply has been identified [100]. According to Weber [100]

, it is not encouraged or desired to avoid electricity from the grid completely, however, CO_2 reductions up 20 % at no extra costs are achievable.

5.3.2 Waste

Waste management is becoming an increasingly important issue in local energy systems. Schemes of energy from waste and biomass residues are becoming increasingly common, despite the public acceptance issues. Moreover, management of decayed electric batteries are also an issue with the rising need for storage. In several countries, recycling facilities for batteries have been established in parallel to the diffusion of these technologies. ICESs contribute to reduce waste through wider use of reusable product and comprehensive recycling programs [62].

5.3.3 Spatial Issues

A fundamental change of local energy system through ICESs also requires re-organizing spatial structures. Critical aspects concerning the local energy systems and their spatial issues are elaborated in Wächter [101]. Limited availability of private and public space for the installation of energy systems at local areas challenges the emergence of ICESs. Most of the communities do not own public space. Therefore, acquisition of land or renting of land for development of community energy projects are often the first hurdle to overcome. Moreover, most renewables such as solar and wind have lower energy density, requiring more space. This affects the goal of some communities to become energy independent and to reduce CO_2 emissions.

5.4 Institutional issues

Jacobsson and Johnson [102] identified hard and soft institutions, which are equally applicable to ICESs. Hard institutions refer to legislations, capital markets, or the educational system whereas soft institutions consider cultural and social norms. These institutions are comprised of regulative, normative and cultural-cognitive elements which together with associated activities and resources can provide stability and meaning to ICESs. There are five categories of institutions for the provision of low-carbon energy such as ICESs: (i) government policies; (ii) dominant technologies; (iii) organizational routines and relations; (iv) industry routines and relations; (v) societal expectations and preferences [21]. These characteristics and links connect ICESs with the larger energy systems. ICESs experiment with current institutional arrangements, take risks and grab opportunities, and create new institutions or, even self-organize energy systems if needed [22]. Changing local energy landscape requires reconsidering roles and responsibilities of different actors. Financial and regulatory risks can be dealt with by leaving some aspects such as economic incentives to market and regulating other aspects such as co-ordination of shared infrastructure and facilities. Opportunities such as self-regulation and self-governance emerge in local energy systems. Institutional transformations must be a critical aspect for ICESs because it is the only way to effect significant and lasting social change to ensure the sustainability of the smart grid systems. In the following section, we present an overview of the institutional issues facing communities, see table 8.

Table 8. Overview of institutional issues

Issues	Example	Role of ICESs
Trust, motivation and continuity	Lack of trust and motivation	Win trust and motivate individual households and local communities, gain trust of local government, sustainable business models
Energy democracy	Enforced energy system Missing local participation	Create decentralized structures to democratize energy systems
Ownership	Ownership model	Local ownership
Co-operatives	Co-operative tradition Lack of business model	Energy co-operatives with sustainable business models
Locality and responsibility	Lack of Local and responsible energy system	Direct accountability, self-regulation

Support schemes and targets	Lack of suitable support schemes and incentives	Lobby for suitable support schemes, incentives, collective formulation of targets
(Self-) governance	Governance of local energy systems	Local governance, (self-) governance
Regulatory Issues	Design of prices for service, grid access	Local control of distribution grid, re-bundling, self-regulation
Institutional (re)design	Transforming institutions of centralized energy system	Dynamic and flexible institutions
Roles and responsibilities	Refer Table 9	Refer Table 9

5.4.1 Trust, motivation and continuity

The main themes that are essential for initiating and sustaining ICESs are trust, motivation and continuity [65]. On the one hand, increasing number of communities are not satisfied with the fact that the energy system is not yet on a sustainable track. These communities trust more on ICESs than in government or incumbent energy companies as these systems deliver on their mission and objectives and provide suitable alternatives for their energy concerns. On the other hand, governments are also expected to trust these community initiatives and provide necessary support. Motivation of citizens as well as a sustainable business models, are crucial for collective investment of time and other resources in local energy systems.

5.4.2 Energy democracy

ICESs are often linked to creating decentralized structures and democratization of energy production and supply through new organizational forms [9]. Locally and collectively owned energy systems open up new opportunities, create wider basis of support as well as mobilize participation and contributions.

5.4.3 Ownership

ICESs promote commons-based energy supply. In a liberalized market, it is possible to establish local producer/prosumer – consumer energy commons. Different actors can be enabled to co-create a smart local energy system. ICES could be 100 % community owned or may be developed together with private or public sector under co-ownership arrangement [49]. Although many communities are already involved in the ownership and financing of local energy production which is directly fed into the grid, the ICESs advocate a combination of locally owned production and consumption of energy. Following a legal and financial model of ownership, four arrangements for ICESs ownerships are observed namely co-operatives, community charities, development trusts and co-ownerships (shares owned by communities) have been observed in literature [49]. As most common ownership arrangement, we further elaborate co-operatives below.

5.4.3.1 Co-operatives

A co-operative is an organization owned and run jointly by the members who shares the profits or benefits. Energy co-operatives have been flourishing in European countries due to the environmental concerns after the oil crisis in 1973. Some examples of collective organizations of renewable energy are wind and biogas co-operatives in Denmark and photovoltaics co-operatives in Germany [9]. The numbers of energy co-operatives increased significantly in Germany between 2007 and 2013 (from 100 to 900). Similarly, in the Netherlands, there are close to 500 active energy co-operatives [61].

Differently, the electricity sector in the United States (US) presents a traditional and well-established example of co-operatives mainly driven by the objectives of rural electrification. There are 905 electric co-operatives among of which 840 are distribution and 65 are generation and transmission co-operatives serving 42 million people in 47 states [61]. Most of these energy co-operatives are also involved in renewable energy supply. Other relatively successful co-operative experiences in the context of rural electrification have been observed in Bangladesh, Costa Rica, Nepal, Bolivia, Tanzania and the Philippines [61] [63].

Energy co-operatives that enable citizens to investment in generation units and energy efficiency measures are a specific way of involving citizens in the diffusion of ICESs. Whether co-operative tradition is really a driver for ICESs is a matter of further investigation. It appears that the US model of co-operative ownership helps in market mechanisms for renewable energy supply, however, the European model where these co-operatives are well embedded in the society and part of their culture is more suited for the development of ICESs. Renewable energies and other forms of local generation are suitable for co-operative in light of high initial costs and local availability. Currently, energy co-operatives in Germany are facing difficulties to develop new business models, leading to stagnation in their growth [103]. Innovative business models such as self-consumption and energy services can be enabled through the development of ICESs.

5.4.4 Locality and responsibility

ICESs as non-profit entities are more effective and efficient in providing services to local energy consumers. Direct accountability to the customer base makes ICESs responsive to the concerns and needs of local communities. This can encourages a system of self-regulation [61].

5.4.5 Support schemes and targets

Limited political support for market based policies to price externalities such as taxes on emission or a tradable permit system leading to the creation of policies to promote renewable and local energy directly [98]. Suitable support schemes can drive the development of ICESs. These support schemes could be through subsidy on the initial cost or priority access to the grid. Collective subsidies schemes for solar PV as implemented in some of the Dutch cities help in establishing community energy systems in the neighborhood. Moreover, these support schemes and incentive programs should be updated continuously as the market dynamics change. For example, German feed-in tariffs are already encouraging self-consumption over direct feed-in of solar electricity to the grid. Furthermore, skills development training or tours to some exemplary ICESs sites helps in empowerment of local communities to manage these systems. Furthermore, incentives could be incorporated in ICESs to increase competition for improving energy performance among neighbors in local communities.

Targets set by central or local governments in collaboration with local communities could help in the emergence of ICESs. For example, the Scottish government has set a target of 500 MW community or locally owned renewable sources by 2020, which has encouraged community mobilization through grant and loan schemes [90]. The UK government has also sought to develop community renewable energy since 2000 through support schemes and funding programs [49].

5.4.6 (Self -) governance

The main barrier for incorporating local and community actors in the emerging energy governance structures and policy delivery mechanisms is the lack of understanding of how they work in the field and how best to support and develop effective local energy governance [104]. Development of ICESs challenges existing energy-structures and creates opportunities for self-governance [65]. There are good examples of common pool resources managed by communities. However, the ICESs ask for more specific skills such as technical expertise.

Avelino et. al. [65] identify four categories of challenges for self-governance of community energy: economic and financial challenges, legal issues, socio-cultural conditions, and micro-political struggles as well as conflicts. Moreover, a community energy system is largely affected by inter-personal dynamics, intellectual capacity of community members and their long-term commitment. Often, the community energy initiatives are due to enthusiastic leaders. Yet, there are often free rider problems in such initiatives.

A multi-actor perspective has been used to identify roles of different actors namely, the state, market, and the community involved in the self-governance of community energy systems [65]. Parag et.al. [104] highlight the important role of intermediary organizations in local governance structures. Likewise, Frantzeskaki et.al. [22] introduce the concept of 'beyond controlling and beyond governing' or 'invisible governance' or 'meta –governance'. These concepts can be utilized for the governance of ICESs. This type of reflexive governance diagnoses paradoxes and facilitates space for self-correction and action without neglecting the roles and responsibilities of the government. This provides higher control for local communities in shaping their energy systems.

5.4.7 Regulatory issues

With the competition between centralized and decentralized resources, the design of prices for services based on markets such as energy markets, capacity markets, balancing markets as well as ancillary services as well as charges for regulated services such as network and other energy policy costs as subsidies to renewable energy are of crucial importance to achieve a sustainable and efficient future energy system.

5.4.7.1 Grid issues

Access to a distribution grid for the local transfer of locally generated energy is of crucial importance for the emergence of ICESs. Existing and persisting problems include tax issues associated with the use of distribution grid for local consumption. Community energy labelling and different tariff design for the energy produced from ICESs might help in local consumption of the energy. Moreover, some communities have taken control of the distribution grid (e.g. Schönau EWS, Germany [65] and Feldheim, Germany (see section 6.2.1) and many other communities are considering to take control of the distribution grid. In Germany, there is emerging trends for re-municipalisation of the distribution grids [105].

5.4.7.2 Re-bundling

ICESs might cause conflicts with unbundling requirements of the European Union third energy package [106]. According to Harcourt et.al. [56], ICESs are more likely to be feasible if the regulatory system accept some re-bundling, specifically of the local energy generation and distribution, allowing experimentation to facilitate innovation.

5.4.8 Institutional (re-) design

Delivering energy by traditional means to end users requires multiple processes such as production, conversion, transformation and distribution as well as many actors from both the public and private sector [81]. Similarly, ICESs involve a diverse set of institutions and stakeholders and operate at the interface of community, policy and institutions.

Most state of the art research related to institutional design of ICESs revolves around examining existing arrangements in energy systems to see if they are satisfactory and altering them when necessary through rethinking and reshaping of formal structures as well as interventions in any of the arrangements which co-ordinates the behaviors of the individuals in the society [9] . In other words, it is not necessarily about designing new institutions but more about adapting existing institutions so that ICESs could emerge. Furthermore, Frantzeskaki et.al. [22] argues that the institutional design focus has to shift from designing diffusion instruments to designing suitable institutions that fit the operation of ICESs. Distributed strategy in both technological developments and governance is desired. Such design should also be able to link markets and grassroots initiatives such as ICESs. For this, design should be dynamic and flexible (see criteria 4.2.2). The design should also incorporate lessons from experience and evaluation obtained through feedback and monitoring [107].

Wirth [9] presents a framework for analyzing emergence of community energy projects from institutional perspective based on biogas cooperatives in South Tyrol. In this framework, a community is treated as an individual institutional order which shapes decisions. Community spirit, a co-operative tradition and the norms of locality and responsibility are presented as central drivers behind the emergence and constitution of biogas co-operatives. These institutional features influence the decision not only concerning involvements of citizens but also plant location and scale. These outcomes from the research of biogas co-operatives could also be applied to ICESs.

Institutional space available for ICESs differs among countries. Oteman et. al. [45] analyzes the available institutional space for local energy systems in the Netherlands, Germany and Denmark. This study was performed by putting the local energy systems within the institutional context of the policies, power structures and energy discourses in each country. By giving the example of traditionally civil society friendly energy sector of Denmark, market-oriented energy sector of Netherlands and state-dominant energy transitions strategy of Germany (*Energiewende* in German), it was demonstrated that evolving institutional configuration of the energy sector strongly influences the available institutional space for local energy systems development.

5.4.9 Roles and responsibilities

As the citizens and communities start to become prosumers, new actors and roles will emerge in energy systems, see table 9. ICESs imply new roles for communities as they might have to be actively involved in energy production, supply and other energy conservation measures. Roles of communities in production, further depends on institutional arrangements of ownership and control of the production units and distribution grids [61]. Industries will contribute by local generation and demand response as well as via the provision of waste heat to the local communities. Commercial as well as residential end-users will also play a role in local generation and demand response. In addition, residential end-users can collectively purchase energy systems or energy efficient technologies. The community will have collective responsibilities in formalizing business models as well as local balancing arrangements. Distribution system operators have to adapt the system operation as per system needs. These developments challenge the governance and traditional business structures [65].

However, as energy infrastructures are extremely complex, it would be impossible for communities to manage the entire energy systems. Therefore, the traditional companies need to be adapted accordingly with the emergence of ICESs. In this respect, a growing numbers of literature has advocated the adaptation of roles and responsibilities of different actors in the context of ICESs [61][65][22]. The existing energy companies could assume the role of aggregators or could even establish partnership with the local communities for the management and operation of integrated community energy systems. Furthermore, accountability and beneficiary issues of community owned projects also need to be specified. Moreover, for the success of ICESs, national and local government should play the role of facilitator.

The establishment of a mediating organizations will make a significant difference enabling communities to undertake initiatives and succeed as indicated by the example of such endeavor, Community Energy Scotland initiative [22]. Similarly, establishing knowledge exchange platform could also be beneficial for these initiatives as they can learn from each other. One such example is Hydro Empowerment Network which is knowledge exchange platform for community micro-hydro in South and South East Asia [63].

Table 9. Changing roles and responsibilities in ICESs

	Actors	**Roles and Responsibilities**	
Competitive parties		*Current system*	*ICES*
	Households	Consumption, payments	Consumption, payment investment, generation, energy management
	Communities	Passive and inactive individual consumption	Local energy exchange platform, accounting and billing, flexibility
	Energy suppliers	Electricity, gas and heat supply, billing, energy procurement	Supply the deficit, management of local energy systems, flexibility and energy procurement
	ESCOs	Financing, supply and installation of energy efficient equipment, building refurbishment	Management of local generation fleets; financing, supply and installation of energy efficient equipment, building refurbishment
	Technology providers	Provide energy efficient and Distributed generation technologies	Technologies for local generation, energy efficiency, energy management system
	Aggregators	-	Aggregate the flexibility from the local community
Regulated parties	*DSOs*	Grid operation, reinforcement	Grid operation, local congestion management
	TSOs	System balance	Use flexibility for system balance
	Government, policy makers and regulators	Ensure sustainable energy supply, subsidies	Investment and subsidies for ICES, policies, Reduce barriers, shape local markets
	Balance responsible parties	Balance responsibility	Incorporate flexibility in portfolio

6 Application of ICESs

6.1 ICESs business model canvas

The success of local energy systems such as ICESs largely depends on the business model adopted. Business models differ significantly between developed and developing countries. In developed countries these system could provide different energy services for the members as well as to the neighboring ICESs or larger energy systems. The same is not possible for ICES implemented in the rural areas of developing countries. Therefore, ICESs in developing countries have to solely depend on revenue from self-provision. Therefore, the business case for ICESs is not always straightforward. In this section, we fill this gap using the framework of the business model canvas [108]. This framework is extensively used to develop new business models for smart energy systems [109].

Taking developed countries case as reference, examples for each building-block is provided in figure 8. Below we define the 9 building-blocks used in the ICES business model canvas.

Key partners: *Anyone who help ICES to leverage the business.*

Key activities: *main activities in ICES to create values.*

Value propositions: *product and services of ICES that create value for customer segments.*

Customer relations*: the type of relationships established by ICES with customer segments.*

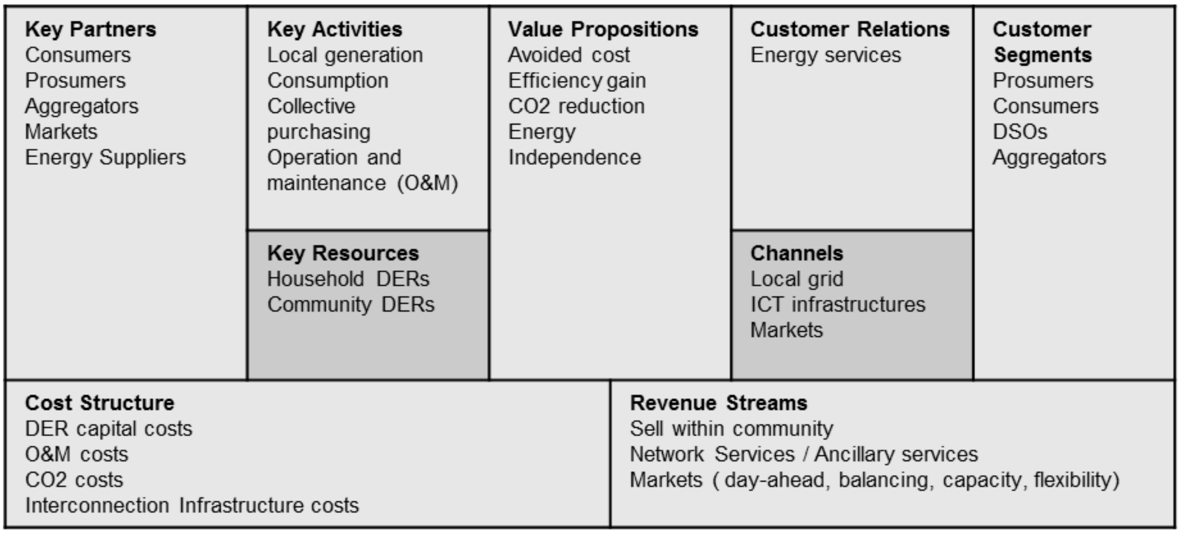
Customer segments: *households and organization ICES aim to serve and create value.*

Key resources: *infrastructures to create, deliver and capture value.*

Channels: *ICES platform for delivering value and interacting with customers*

Cost structure: *cost to realize the business model*

Revenue structure*: the pricing mechanism with which the business model is capturing values*



Key Partners
Consumers
Prosumers
Aggregators
Markets
Energy Suppliers

Key Activities
Local generation
Consumption
Collective purchasing
Operation and maintenance (O&M)

Key Resources
Household DERs
Community DERs

Value Propositions
Avoided cost
Efficiency gain
CO2 reduction
Energy Independence

Customer Relations
Energy services

Channels
Local grid
ICT infrastructures
Markets

Customer Segments
Prosumers
Consumers
DSOs
Aggregators

Cost Structure
DER capital costs
O&M costs
CO2 costs
Interconnection Infrastructure costs

Revenue Streams
Sell within community
Network Services / Ancillary services
Markets (day-ahead, balancing, capacity, flexibility)

Figure 8. ICES Business model canvas for developed countries

6.2 ICES examples in developed and developing countries

6.2.1 Feldheim, Germany

Feldheim, a small village 60 km from Berlin with 37 household; this case is used to present ICES in the developed world. This village is a successful example of decentralized self-sufficiency in Germany. Feldheim is organized as a local energy co-operative and is run by the local renewable energy company *Energiequelle* [110]. The installation of a first wind-turbine by a local entrepreneur and co-founder of Energiequelle in Feldheim dates back to 1995. The energy system was gradually increased in size to a final expansion of 81.1 MW wind farm, a 2.25 MW_p solar farm and a 500 kW_e/ 500 kW_t biomass-plant for district heating and storage. Feldheim meets all its local energy demand and sells 99 % of the generated electricity to the central grid [111]. The unsuccessful attempt of Feldheim community to buy or lease the distribution grid owned by E-ON led Feldheim to build its own electricity and heating network, funded by Energiequelle, EU subsidies, capital loans and individual contributions. This alternative form of energy arrangement in the form of ICES, has resulted in lower energy prices which is set independently by the co-operative irrespective of the wholesale market. Feldheim is self-sufficient in terms of energy and is dependent on the national grid only for exporting electricity and providing system services. Recently, Feldheim also started to provide primary frequency control services to a transmission system operator through its 10 MWh battery. Although these results need to be translated carefully due to the subsidies involved, Feldheim nevertheless represent an interesting example of ICES.

6.2.2 Urja Upatayaka, Nepal

The Urja Upatayka Mini-grid Co-operative in Baglung state/region of Nepal is a representative example of how ICES could look like in developing countries. Six nearby micro-hydro units were integrated in 2011. The co-operative functions as grid operator and electricity distributor, while the micro-hydro units work as Individual Power Producers (IPPs). The co-operatives buy electricity from micro-hydro units at 5 € cents/kWh and sell it to the consumers at 8 € cents/kWh, using the difference for operating and maintaining the system. This price is still lower than the price in the Nepalese national grid. With an 8 km long distribution grid, the system provides electricity to more than 1200 households. Due to the integration, the quality, reliability and availability of electricity has been enhanced. The voltage and frequency of the system is stable (390 – 415 V/ 49 – 50.5 Hz). Thanks to the integrated approach, income generating end-use such as a communication tower (15 kW) and a stone crusher (40 hp) has also been made possible. Micro-hydro units were installed through 50 % subsidies from the alternative energy promotion center, 30 % loans and 20 % contribution from the individual members. The integration of six-units of micro-hydro plants was realized through external funding. This project helped to improve inter-community co-ordination, increasing their confidence level to construct, own and manage bigger projects. Demand side management as well as retrofitting of compact florescent lamps with light emitting diodes lamps has also been successfully implemented in the community. The mini-grid has become a social entity for the generation, transmission and distribution of local energy. As a result communities are now convinced that integrated micro-hydro systems can be a permanent source of electricity, while the national grid of Nepal suffers from load shedding of up to 16 hours a day.

7 Conclusion and discussion

This work has reviewed developments in Integrated Community Energy Systems (ICESs), presenting them as an option of comprehensive energy system integration for the transitioning local energy landscape. ICESs are multi-source and multi-product complex socio-technical systems emerging through changes in the local energy landscape. With the motto of ‘think global and act local’, ICESs provide the necessary platform for local energy exchange, through effective integration of different sectors and engagement of local communities. ICESs also provide system-wide services to both neighboring communities as well as larger interconnected energy systems. The above analysis points to ICESs performing exceptionally in terms of self-provision and system support services over other energy system integration options.

As summarized in 4.4, this modern way of organizing local energy systems will impact different actors both directly and indirectly as local and system-wide exchanges and interactions take place. Hence, it is critical that all interests are mapped accordingly in order to avoid issues with coordination in addition to split and perverse incentives (5.2.4). It is important that in ICESs, costs and benefits are shared fairly amongst the stakeholders involved, making sure that those who are not involved in the costs do not rip the resulting benefits. ICESs have the potential to reduce community dependence on national energy systems and provide needed flexibility as well as security of supply, in addition to keeping (smart) grid investment costs at bay (see 5.1.6). Accordingly, ICESs improve the performance of local energy systems while contributing to renewable penetration and energy efficiency targets as well as climate change goals such as EU 2020 objectives and beyond. In section 5.1.5, we discuss the Danish case as a prime example of what ICES can achieve; a stable system and deep RES penetration in addition to emissions abatement.

The attractiveness of ICESs have been internationally demonstrated; as they promote an array of benefits inclusive of sustainability as well as security of supply, self-reliance and energy independence. ICESs result in effective engagement of the local communities by means of collective purchasing, community ownership, co-operative operation and maintenance arrangements as well as from the integration of different sectors such as electricity, heating, cooling, gas and transportation. These arrangements also make citizens more energy conscious, contributing to energy efficiency improvements as well as reduction in CO_2 emissions. In essence, what this work has brought to light is the fact that the engagement of local energy systems can help to defer new investments in power lines, reducing the system peaks and distributing load more evenly throughout the day. With increasing electricity tariffs and grid defection, ICESs will have a progressively important role in the future as they keep the grid intact or enable off-grid options when desired. Widespread availability of flexible generation and energy storage facilities will enable these communities to provide flexibility to the national energy system as needed. In this way, supply and demand will co-operatively optimize system operation while keeping overall costs low, security of supply high and ultimately reaching climate policy objectives. In

Overall, this review has found the main challenges which ICESs need to overcome are a bi-product of dominant culture, structure and practices from the centralized energy system. Institutional design and business models (section 6.1) as well as the regulatory framework still need to be adapted to the emergence of ICESs. Similar to the development of renewable energy, the deployment of ICESs still focus on technical aspects. As indicated above, focusing evenly on technical, socio-economic, environmental and institutional aspects will bring further support in the emergence of ICESs in the smart grid paradigm.

On the basis of the above, ICESs will be shaped by technological, socio-economic, environmental and institutional issues as well as current trends in the energy landscape (section 5). We have identified and further elaborated six technological issues, seven socio-economic issues, three environmental issues and nine institutional issues. ICESs will involve a diverse set of institutions and actors; the operation of such system will lie at the interface of community, policy and institutions. Although ICESs do face tensions, controversies and institutional problems, new technical and socio-economic developments are expected as different actors attempt to align their incentives with those of ICES. These new developments will reshape operational roles and responsibilities, energy markets, behavior of different actors, business models for energy services as well as corresponding institutional arrangements. Moreover, at a local level, various new energy technologies will change the existing energy mix and enhance energy independence. In ICESs, local communities will play a significant role in energy production, consumption as well as distribution. As a result, the power of change is actively given back to consumers.

From this analysis, the authors recommend a quantitative assessment with the empirical data from several demonstration projects to help institute the value of ICESs. Such an assessment is expected to increase the understanding and impact of ICES to different actors as well as to the larger energy system. If these valuations are available in time, the political economy within could be understood more clearly. Accordingly, appropriate governing institutions could be established to overcome barriers and challenges in the design, planning, implementation and operation of ICESs. On this basis, the authors conclude that such an assessment and quantitative outcomes will contribute positively to understanding how ICESs can contribute to the vision of a low-carbon energy future and achieve the trifecta of availability, affordability and acceptability for all.

Overall, increasing environmental concerns and renewed attention on universal energy access are the main drivers for the surge in the progress of local energy communities in both developed and developing countries. Irrespective of where implemented, these systems will be a significant component in future energy systems of developed and developing countries alike. ICESs can transform local energy systems, becoming an inspiring example for sustainable development worldwide.

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