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Establishing industrial community energy systems: Simulating the role of institutional designs and societal attributes

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A B S T R A C T

The importance of decreasing industrial CO2 footprints has become evident, as also highlighted in COP26. As such, the transition to renewable energy in the industrial sector is essential to meet the targets. To this aim, establishing industrial community energy systems (InCES) where industries collectively invest in a shared energy system is an economically and environmentally attractive option. Yet, the emergence and continuity of such collective initiatives among industrial companies has neither received considerable attention in the scientific literature nor in practice. This research, as the first of its kind, aims to investigate institutional design options that allow for such collaboration to take place for the establishment and continuity of an InCES. Given the bottom-up and collaborative nature of such initiatives, we take an agent-based modeling and simulation approach, for the first time in this area, that incorporates the institutional and societal attributes that influence the formation and continuation of an InCES. We take data from an industrial cluster in Arak, one of the most prominent industrial cities in Iran. The results of this study confirm the economic feasibility of an InCES as compared to individual renewable energy investment in the cluster. The results also highlight the importance of flexible membership in increasing the number of investors (i.e., industrial companies) in such initiatives. Other important recommendations are: considering the installation of at least 15% extra capacity for the powerplant, restricting electricity consumption and enforcing on-time payment of monthly premium fees.

1. Introduction

According to pathways determined by COP26, the need to drastically reduce carbon footprints in the industrial sector is now evident. This is even more emphasised in the recently published report by Intergovernmental Panel on Climate Change (IPCC) (S.LMasson-Delmotte et al., 2021), highlighting that in the modelled global pathways that limit global warming to 2 °C or lower, most remaining fossil fuel CO_2 emissions until the time of global net-zero CO_2 emissions are projected to occur outside the power sector, mainly in industry and transport.

Decommissioning and reducing utilisation of existing fossil-fuel-based power sector infrastructure, retrofitting existing installations with carbon capture and storage/utilisation (CCS/U) to switch to low carbon fuels, and cancellation of new coal installations without CCS/U are practical options that can contribute to aligning future CO_2 emissions from the industrial sector with emission target. In the assessed pathways, the most appropriate strategies will depend on national and regional circumstances, including enabling conditions, technology availability, and the stability of the current electricity supply system (S.LMasson-Delmotte et al., 2021).

Additionally, the critical role of the industrial sector for the economies to thrive has made it more challenging for industries to choose radical pathways, especially in developing economies where the challenge is not just about decreasing the carbon footprints but also about the unstable electricity provision situation that thwarts the production processes and industrial expansions.

One way to tackle the mentioned challenges is for the industries to gradually shift to renewable electricity (RE) through shared investment and by establishing industrial community energy systems (InCES). This can result in a more diversified, stable, and sustainable electricity supply (Eslamizadeh et al., 2022a).

Collaboration among industries is not new. There is an extensive body of literature on industrial collaborations in the industrial symbiosis (IS) field. Collaborative power generation and demand management in an InCES seem to be highly relevant to the form of collaborations happening among industries in IS. Therefore, many of the principles would similarly be applied to the case of InCES.

In this research, we take a new perspective on industrial

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collaboration by focusing on institutional design principles that have been shown to facilitate collective action (Ostrom, 2005). These principles address the conditions to enter the initiative, conflict resolution, monitoring, and sanctioning among others (Ostrom, 2005). These design principles, developed by the Noble Prize Laureate Elinor Ostrom, have so far been mainly applied to collective initiatives involving individuals (e.g., irrigation systems, forestry, and even community energy of households). Given the large differences between individuals and companies, for example, in terms of energy demand and investment size, this study aims to explore whether the design principles can also guide such forms of collaboration and, if so, what guiding principles can be drawn for designing such systems.

To study how institutional design principles can contribute to the establishment and success of an InCES, we use agent-based modelling and simulation (ABMS) to study the behaviour of such a system over time. ABMS is a bottom-up simulation approach that simulates actors, their decision-making, and interaction in their environment to study emergent patterns stemming from behaviours and interactions (Ghorbani et al., 2013). This simulation approach has proven to have valuable insights when employed to analyse the dynamics of other types of collective actions (Chaigneau and Canessa, 2012; Janssen and OstromEmpirically Based, 2006; Ghorbani and Bravo, 2016). To build the simulation, we bring the well-pronounced differences in the decision-making styles between the industries and households into the spotlight. We take a cost-benefit analysis (CBA) approach (IRENA, 2015), which is widely used by industries to evaluate the financial gains of investment plans. Besides the CBA method, the industrial companies' societal attributes (e.g., how they behave in collective settings) as a crucial dimension in their partnership (Scharpf, 1988a) will be paid attention to. In order to better simulate how industrial companies make decisions in partnerships, Scharpf's game-theoretical (Scharpf, 2018) approach is employed.

The structure of this paper is as follows:

In Section 2, we position this research by reviewing the literature on community energy systems (CES), collaborations among industrial companies, and simulation of community energy systems. In Section 3, the theoretical background of this research in terms of how the investment in an InCES is evaluated and how the industrial companies' societal attributes can influence this process is described. Section 4 states this research's methodological backbone, and the case study is introduced in this section. Section 5 reflects on the agent-based model and its parameters. Section 6 revolves around the extracted results of this research. And finally, in Section 7, the discussion and conclusion are reflected.

2. Related literature

This section revolves around the related literature on the subject of this research. To this aim, we picked and reviewed the fields that seemed to overlap most with this research. Therefore, we ended up reviewing the articles which were positioned in the interception of "collaborations among industries", "industrial symbiosis", "community energy system", "energy cooperatives", "collective investment", and "agent-based modelling". Consequently, the articles with the following keywords by applying the "and" modifier between the keywords were searched on Google Scholar and Scopus. The search for the articles was limited to articles published between 2010 and 2021. Accordingly, the duplicates were deleted from the database, and the abstracts were scanned to exclude the publications with no relevance to the scope of this research.

The following is the description of the current literature and how the novelty of this research is identified.

2.1. Collaborations among industries

Collaboration among industrial companies is not new. There is extensive literature on industrial symbiosis (IS), a type of collaboration in which industrial companies share resources and byproducts (Domenech and Davies, 2011). Industrial collaboration in IS aims to optimize production processes, resource consumption, and the associated economic and environmental benefits for the industrial companies involved (Lombardi and Laybourn, 2012). Collaborative power generation and demand management in an InCES seem to be highly relevant to the form of collaborations happening among industries in IS domain. Accordingly, many aspects seem to be equally applicable to the establishment of an InCES, such as "trust" (Deutz et al., 2007; Chertow and Ehrenfeld, 2012; Walls and Paquin, 2015), "economic benefits" (Deutz et al., 2007; Park et al., 2008; Pakarinen et al., 2010; Yu et al., 2015; Tudor et al., 2007; Heeres et al., 2004; Teh et al., 2014), and "community spirit" (Golev et al., 2015).

Moreover, it is worthwhile mentioning while geographical proximity is a crucial element for an IS project (Jensen et al., 2011), this issue might not be an essential factor in InCES since the generated power in an InCES can be transferred from the collective power plant and among industrial companies through already existing electricity grid. Despite the abovementioned factors, uneven benefits of IS between industrial companies are another critical barrier to IS establishment (Albino et al., 2016). In the case of collaborative power generation, each member of an InCES invests in the project to the extent of their required demand.

Considering the mentioned characteristics of InCES, Eslamizadeh et al. (2020), in a recent study, revealed that initiating an InCES would be possible among industrial companies within an industrial cluster. At the same time, simultaneously, there should be institutions in place to help appropriately govern the InCES. By considering all the above-mentioned commonalities between various types of IS and InCES as a specific form of collaboration, in this research, we looked at the collaborative power generation and demand management in an InCES through the lense of institutional design for collective action, which has not gained proper attention in the existing IS literature, to the best of our knowledge.

2.2. Community energy systems

There is a considerable body of literature on collective renewable electricity production in local communities of households and small businesses. CESs can be found in various organisational, ownership and financial (business model) types across the globe (Bauwens et al., 2022; Walker, 2008; Rae and Bradley, 2012; Hewitt et al., 2019; Koirala et al., 2016). CESs are projects where individual prosumers can generate, store and trade energy within the community, enabling a shift in market power from large utility companies to individual prosumers. Such schemes often involve a group of consumers investing in a community-owned asset such as community-owned wind turbines or shared battery storage. (Magnani and Osti, 2016; Norbu et al., 2021).

Environmental motivations are the primary driving force behind the surge in CES implementation in many developed countries (Pepermans et al., 2005). Apart from the developed economies, CESs have recently become a means of energy provision in many developing countries in rural areas and where the main electricity companies cannot provide stable energy service to the clients (Koirala et al., 2016; Norbu et al., 2021; Mendes et al., 2011; Fthenakis and Kim, 2009; Zebra et al., 2021; Ali et al., 2021; Hailu and Kumsa, 2021).

Economic factors such as inflation rate and expected rate of return play an essential decisive role for the potential members of a CES (Koirala et al., 2016; Wolsink, 2012). Also, the introduction of proper incentive mechanisms from the government proved to be a critical factor in contributing to the larger investment mobilisation towards investing in such projects (Eslamizadeh et al., 2022b; Leonhardt et al., 2022). Along with the economic factors, societal attributes such as the extent of trust and social connectedness among the community members are proven to be highly impacting factors in the formation of CESs (Kalkbrenner and Roosen, 2016; Greenberg, 2014; Tyler and Degoey, 1995; Sovacool, 2014; Raven et al., 2009).

2.3. Agent-based modelling of the community energy systems

Despite the broad literature on CESs, the existing line of research focuses on their organisational structure, business and financial models, types of technology, and the characteristics of members (Martiskainen, 2017; Dóci and Vasileiadou, 2015; Seyfang et al., 2013). Yet, scientific knowledge on how CESs are initiated, the way they evolve through time, and how the government can support them is limited (e.g. (McKenna, 2018; Lepping, 2014; Dóci et al., 2015; Wirth, 2014),).

Moreover, the mainstream line of research on mentioned topic relies on the results derived from existing case studies. Therefore, simulation techniques can be helpful in the generalisation of the results, especially if it is complemented with real-world data. Among different modelling approaches, agent-based modelling (ABM) is the only approach capable of combining the financial aspects of initiating a CES plus the interactions among different actors in such a setting. This approach has already proven to be an effective method in research regarding the initiation and continuation of CESs (e.g., (Fouladvand et al., 2020; Ghorbani et al., 2020; Fouladvand et al., 2022; Verhoog et al., 2016).

Despite the mentioned literature on the agent-based modelling of CESs, the institutional design principles have not yet been explored in such a setting.

This research combines lessons learnt from IS and CES with the institutional design principles in agent-based modelling to explore design strategies that facilitate or hinder the establishment and continuity of InCES.

3. Industrial community energy systems

3.1. Industrial decision-making process

InCESs face many technological, socio-economic, environmental, and institutional challenges different from those of households (Michalena and Hills, 2013). Industrial firms have higher demands for electricity with more stringent requirements on the availability and quality of electricity service provision. There are also more pronounced differences in electricity consumption patterns between industries than between households in a 'conventional' community energy system. Therefore, reaching a consensus between industrial participants of an energy community may be much more challenging than in a household setting where the members have relatively similar demands (Tudor et al., 2007).

Industrial companies can be categorised as composite actors when it comes to decision-making, meaning that the decision-making process might pass through a decision committee with different intentions and interests among each other (Keeney and McDaniels, 2008; Scharpf, 1990). In most cases, investment decisions in industrial companies are taken by a large number of people, either by C-level management, a board of directors, a decision board, employees voting, an owning family, or a combination of these (Scharpf, 1988b; Sheu, 2019). Scharpf presents composite actors as: "*Even though individuals may have considerable difficulty in managing their 'multiple selves', their partners and opponents will generally not hesitate to treat them as unitary actors*" (Scharpf, 1990).

3.1.1. Socio-economic-environmental attributes of industries for participating in an InCES

According to the body of literature on CES, several social, economic and environmental factors affect the willingness of potential participants of CESs to invest in such an initiative. Eslamizadeh et al. (2022a), in a recent study, investigated the role of these factors in the willingness of the industrial companies in Arak industrial city to invest in InCESs. The factors listed below in Table 1 were found to be the most influential ones in the industrial companies' willingness to invest in an InCES.

In this research, we assigned the abovementioned attributes to each industry and assumed that each company should have a minimum level of these attributes to consider joining an InCES. If this minimum is satisfied, companies will go through an economic evaluation of investing in an InCES by performing a cost-benefit analysis (CBA) to assess the economic feasibility of initiating/joining an InCES.

Table 1
List of impacting factors in the willingness of industries to invest in an InCES.

List of impacting socio-economic-environmental factors
1) Concern about the environment
2) Believing in the power of institutions to manage the hurdles of a partnership
3) Awareness regarding the advantages of transitioning to RE
4) Company size
5) Willingness to engage in partnerships
6) The expectation that the price of electricity will increase in the near future

Moreover, it is noteworthy that data shows when no InCES exists in an industrial cluster, industries would be more stringent regarding establishing an InCES. On the other hand, as mentioned in Table 1, these socio-economic prerequisites will be more relaxed after an InCES is established in an industrial cluster (Eslamizadeh et al., 2020).

3.1.2. Financial evaluation of participating in an InCES

The financial rationale for participating in an InCES project is vital for industries. CBA is a technique used by industries as business entities to evaluate the economic feasibility of investments by cataloguing the aggregated benefits (pros) and costs (cons) of a project based on their monetary values. Therefore, companies calculate the total costs associated with (their part in) establishing a renewable power plant and compare it with the total financial benefits they gain throughout the project's lifespan. The total costs and benefits of establishing an InCES are calculated based on Equations (1) and (2), respectively.

$$\text{Total investment costs} = \sum_{1}^{n} I(1+r)^n \tag{1}$$

where I is the present value of the total investments for establishing an RE power plant, and r is the interest rate that applies to the financing of the project, and n is the number of years in which the investment is leased.

$$\text{Total benefits} = \sum_{1}^{n} B(1+r)^n \tag{2}$$

where B is the present value of the monetary gains produced by investing in an InCES. This benefit in this paper is considered the monetary value of the electricity bill, which will not be paid to the utility owner since the electricity is no more being purchased from the electricity company, and r is the interest rate which is associated with this monetary value which is saved throughout the operational lifespan of the power plant, and n is the number of years in which the project is going to continue. An industrial company considers investing in an InCES economically feasible if:

$$CBA = \frac{\textit{Total benefits}}{\textit{Total costs}} > 1 \tag{3}$$

According to Fig. 1 by IRENA (Renewable Power Generation Costs, 2020), we consider that about 30% of the installation costs associated with the "soft costs" (according to Fig. 1) can be divided among shareholders of a solar/wind farm. Therefore, we introduce $CBA_{ind.}$ and $CBA_{col.}$ where the $CBA_{ind.}$ calculates the CBA when a company decides to generate RE individually and is the same as Equation (3) while the $CBA_{col.}$ calculates the CBA when a company chooses to generate RE collectively within a group of $\underline{n}$ members. The $CBA_{col.}$ is calculated using Equation (4).

$$\text{CBA in collective form} = CBA_{col.} = (0.7 \times CBA_{ind.}) + (0.3/n \times CBA_{ind.}) \tag{4}$$

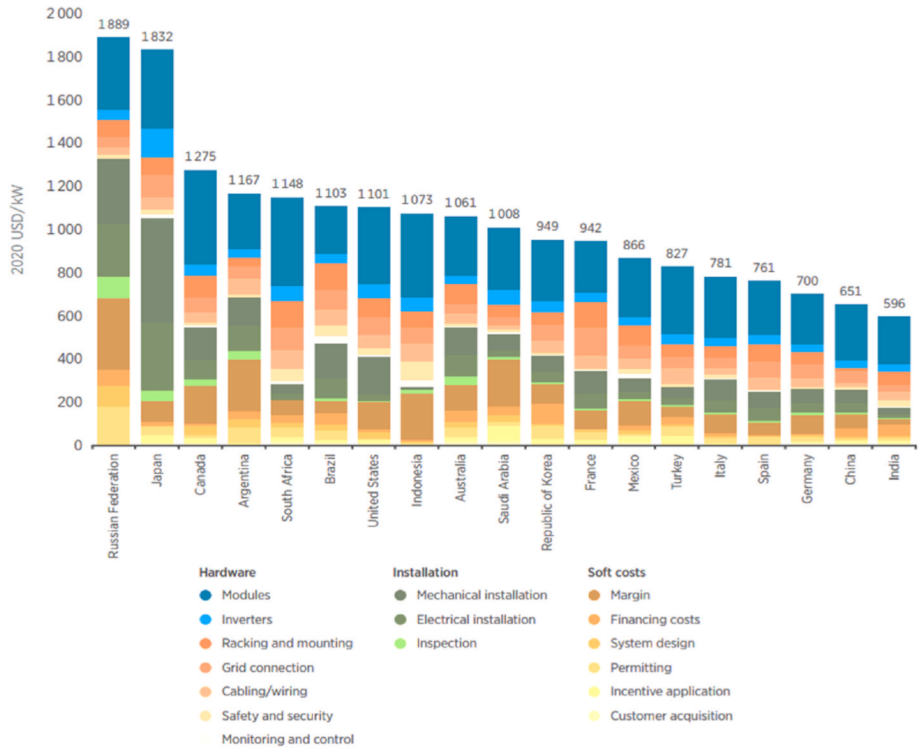

Fig. 1. Renewable farm installation cost breakdown (Renewable Power Generation Costs, 2020).

3.1.3. *Societal attributes of industrial companies in collective settings*

As mentioned earlier, the decision-making process in organisations differs from that of individuals. It follows a more structured procedure due to the decision criterion of the decision-makers in a company. The eventual decision of an industrial company might, in fact, be in contrast with the decision of each of the individuals who participated in the decision-making process. This happens since industries' priorities are different, and stockholders make sure the decision made will not endanger the company's status in various aspects (i.e., the economic well-being of the company). For instance, the CEO of a company might be highly willing to pay more to employ renewable power in his/her household, while this decision seems not to be doable in the company he/she leads since it might put the economic well-being of the company (as the income source of all its employees) in jeopardy. However, this does not ignore the significant impact that each of the decision-makers' attitudes have on the decisions taken at the company level but mainly emphasises the substantial importance of the structured priorities dictating the decision-making process in an industrial company.

Hence, in this research, we consider industrial companies as composite actors and apply Scharpf's decision-making framework for composite actors (Scharpf, 1988a). Based on this framework, we consider three different types of companies regarding their behavioural responses to varying events in partnerships and collaborations. These three attributes are listed in Table 2.

Table 2
Type of composite actors based on their attributes.

Type of composite actors based on their attributes	
Problem-solving	Refers to the attribute where an actor is in pursuit of a collective consensus and a common goal for all parties
Bargaining	Refers to the attribute where an actor is unconcerned about the relative advantage of the other side and exclusively is motivated by its own self-interest
Confronting	Refers to an attribute where, among interactions, winning or the defeat of the other side has become the paramount goal of an actor

According to Table 2, an industry with a problem-solving attribute would not feel unsatisfied if a majority decision is made against its will in a partnership. Every partner participates in the process via a voting session in which we assume that the weight of the votes of all the members is equal. An industry with a bargaining attribute would feel unsatisfied if decisions are made not in line with its interest, and on the other hand, it will feel satisfied if things happen according to its will. An industry with a confronting attribute would feel the same as a bargaining company while the level of satisfaction/unsatisfaction is intensified.

3.2. *The institutional design of an InCES*

As soon as an InCES is formed, it is vital to be cautious regarding potentially problematic events that may arise during interactions within such a cooperative. For instance, it might be agreed that the electricity which is being collectively generated within the InCES is to be consumed to the extent by which each member has invested while they were joining an InCES. Therefore, there should be institutional mechanisms to deal with companies that exceed their consumption limit. Therefore, it is essential to design institutions and put them in place to prevent such occurrences.

In this research, Ostrom's design principle for the self-organisation of collective actions (Ostrom, 2005) is used as the theoretical backbone guiding us through a systematic institutional design for an InCES. Although Ostrom initially developed these design principles to help socio-ecological-related collective actions, it can fit into the case of this research as a socio-technical system (STS) (Kunneke et al., 2018).

Ostrom's eight design principles (Ostrom, 1999) and their description and how they relate to this research are listed in Table 3.[1]

According to the literature on CES and the expert opinions reflected in a previous study by Eslamizadeh et al. (2020), the most

[1] Demand limit is the amount of electricity that each company have invested in when applied for joining an InCES.

Table 3
Ostrom's design principles and their interpretations in this research (Ostrom, 2005).

Ostrom's design principles		
I) Clearly Defined Boundaries	*Definition*	Individuals or households with the right to withdraw resource units from the CPR, and the boundaries of the CPR itself are clearly defined.
	Interpretation	Defining the boundaries of the InCES, such as those authorised to be a member and use its resources, exiting rules etc.
II) Congruence between Appropriation and Provision Rules and Local Conditions	*Definition*	Use rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labour, materials, and/or money.
	Interpretation	Companies should consume electricity in a way not to exceed their demand limit.
III) Collective-Choice Arrangements	*Definition*	Most individuals affected by operational rules can participate in modifying operational rules.
	Interpretation	In the InCES, all the decisions should be made democratically using a voting session in which all the members will attend and vote.
IV) Monitoring	*Definition*	Monitors who actively audit CPR conditions and user behaviour are accountable to the users and/or are the users themselves.
	Interpretation	The processes in which there is a potential for disobedience of the rules should properly be monitored to prevent such issues. Such as monitoring each member's electricity consumption
V) Graduated Sanctions	*Definition*	Users who violate operational rules are likely to receive graduated sanctions (depending on the seriousness and context of the offence) from other users, from officials accountable to these users, or from both
	Interpretation	Definition of punishment rules for those members who are not obeying the guidelines of the InCES. For instance, financial punishments for those members crossing their consumption limit
VI) Conflict-Resolution Mechanisms	*Definition*	Users and their officials have rapid access to low-cost, local arenas to resolve conflict among users or between users and officials
	Interpretation	Definition of institutions by which the occurrence of problematic events will be minimised.
VII) Minimal Recognition of Rights to Organise	*Definition*	External governmental authorities do not challenge users' rights to devise their own institutions.
	Interpretation	Not used in this research.
VIII) Nested Enterprises	*Definition*	Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organised in multiple layers of nested enterprises
	Interpretation	Not used in this research.

socio-economic-related issues which might result in dissatisfaction of the members and eventually lead to their exit from an InCES are related to *a) electricity consumption* and *b) paying the monthly premium fees*. Therefore, we intend to introduce institutions to prevent such actions by setting *"boundary rules," "monitoring the troublesome actions",* and *"sanctioning"* the uncommitted members. Accordingly, three sets of institutions are introduced as follows.

a) Institution 1: Setting membership rules

This institution aims to control the membership of companies with problematic electricity consumption patterns and financial disarray (by performing a background check on their electricity consumption and financial history before they join the InCES). After an InCES is established, the actions of the members are monitored, and those who have not been obeying the rules will be punished (sanctioning process).

b) Institution 2: Monitoring members' electricity consumption by a contract

By this institution, the members' entrance will not be limited by any entrance boundary, and any member who finds joining an InCES an economically feasible plan can/may join the InCES. At the same time, having a contract aims to limit inappropriate actions by the members as such actions entail penalties according to the contract. After an InCES is established, the consumption of the members is monitored, and those who have not been obeying the rules will be punished.

c) Institution No.3: Digital monitoring of members' electricity consumption

This institution intends to have a more holistic view of electricity consumption in an InCES. Accordingly, instead of monitoring the consumption of each of the members, it monitors the cumulative electricity consumption by all the members and tries to prevent it from surpassing the powerplant's capacity. It stems from the idea that while a company consumes more than expected, another company within the InCES might be consuming less than its expected amount. Therefore, the cumulative amount of consumed electricity stays within the capacity range of the powerplant. Similarly, after an InCES is established, the actions of the members are monitored, and those who have not been obeying the rules will be punished.

4. Methodology

In this research, we build an agent-based model based on the theoretical underpinning explained in Section 3 to investigate the impact of proposed institutional designs on the formation and continuation of an InCES, considering the socio-economic-environmental attributes of the industrial companies located in our case study. This model simulates if the industries in our case study can establish an InCES and how this InCES can be managed to ensure its continuity. To this aim, the socio-economic attributes of the industries in our case study and how they might interact under the mentioned institutional designs are simulated. To simulate the socio-economic attributes of the industrial companies in our case study, we made use of the data which was gathered previously and is mentioned to in Section 4.1. Also, the way the dynamics of the interactions between the industrial companies are designed is described in Section 5. The model was built using NetLogo (Wilensky, 1999), and the results were analysed in Minitab 18 (Minitab and Minitab).

4.1. Case study and data collection

In this research, we have selected the industrial city of Arak as one of the leading industrial cities in Iran. The reason behind the selection of Arak as our case study stems from the maturity of this industrial city regarding the variety in types of industries (e.g., part-making, textile, casting, polymer, glass, and food industry) and the large number of active companies. Arak industrial city includes 603 companies geographically distributed over six industrial clusters, as shown in Fig. 2 (each cluster ranging between 5 and 440 companies). Moreover, as a developing economy, the electricity system in Iran is struggling with proper electricity provision in the industrial sector, which is highly required to enable industries to stay in line with their development plans. These factors make our selected case properly representative of the industrial community within a developing economy. We simulated various institutional design settings to compare how different institutional designs perform in sustaining an InCES over time.[2]

To properly assign the socio-economic-environmental attributes of the industrial companies in our ABM, we made use of the data collected via a questionnaire among 212 industries in Arak (Eslamizadeh et al., 2022a). Data on the price of electricity was collected from the publicly available database of Iran's Ministry of Power (Iran' s Ministry of Energy, 2018). Data on the solar power plant installation costs was collected from the active corporations in the field of the sales and installation of renewable power technology (solar) in Iran.

5. An agent-based model of InCES

This section explains the conceptualisation and implementation details of our ABM. The model presents an industrial city with five industrial clusters, each with a variety of industries, with the number of companies per cluster of companies ranging between 5 and 440. In the following, we explain this model's internal mechanisms by first explaining the agents, their attributes, their decision-making processes, and the dynamics of the ABM.

5.1. Agents and interaction

The model consists of one agent type: individual industry. Each industry belongs to one cluster. Each industrial cluster is created with the exact number of active industries in each cluster according to case data. Table 4 shows the attributes associated with each industry agent, some of which are drawn from real-world data (attributes "electricity price" and "solar installation cost").

"Loyalty level" is the extent to which a company respects the rules of an InCES. Once a company disobeys a rule, "loyalty level" will decrease.

data collected from the mentioned survey. In the survey, respondents were asked to answer the question: "When your company participates in a partnership, how do you behave in general meetings in terms of decision making?" and they could choose between options a) We will match our vote with the majority's vote, b) We try to converge others' vote with ours, c) If the majority does not comply with our vote, we will be disappointed by this partnership. These options were representatives of game strategies "problem-solving," "bargaining," and "confronting", respectively. The same extrapolation procedure was done for this attribute in the model.

5.2. Model dynamics

5.2.1. Industries joining an InCES

We assume that only one InCES can be established in each industrial cluster due to the scarcity of space. There is not enough land that is close enough to the cluster and with sufficient space to accommodate the large-scale PV solar installations needed to satisfy industrial-scale power demand.

For joining/establishing an InCES, each industry takes two considerations into account: a) financial feasibility and b) being in line with its societal expectations (which we will be referring to in this research as *"the collective mindset"*). Accordingly, each company, based on its socio-economic-environmental attributes (Table 1), can be categorised as a company with a collective mindset that considers joining a cooperative (InCES) or not. Table 5 describes the qualities of being a company with a collective attitude. Since the collective attitude of each company is drawn from survey data, we assume that it stays constant throughout the simulation. In the model, each tick equals one year.

We considered a difference between ticks one and two because companies normally would be more stringent and pessimistic regarding establishing an InCES when there is no existing one in a cluster. Therefore, it takes stronger qualities for them to consider initiating an InCES, while on the other hand, in the second tick, when an InCES is already established and working, these conditions would be more relaxed .[3]

As described in Section 2, each company performs an economic evaluation by conducting a CBA analysis. The CBA analysis for each company is calculated as follows.

CBA = Total cost/Total benefits

Total costs = investment costs + considering the interest rate (10% yearly) for 10 years[4]

(monthly demand [randomly selected via a range] × 12 / (7 × 300))× installation-cost [chosen randomly via the range (1030 – 931 $)]

On average, Arak has 300 sunny days with an average of 7 hours of sunshine per day

"Desirability level" is the extent to which the InCES is desirable to that member in terms of being in line with its societal expectations. And finally, the "functionality" is the extent to which a company perceives the technical functionality of an InCES. In Section 5.2, we describe in detail how these aspects will be influenced by different actions/interactions in the InCES.

The game strategy was also designated to each member based on the

Total benefits = electricity bill fees which will be saved for 20 years + considering 15% yearly interest

So, each company at the start, firstly, due to the qualities mentioned in Table 5, looks if it has a collective mindset in the first tick or not. In

[2] Google Maps, 2019. *ARU: Arak, Markazi Province, Iran*. Available through: Link to map on Google [Accessed 12 December 2019].

[3] This is the current financial incentive scheme which is being awarded to companies/individuals generating RE. according to this plan, the money needed to be invested in the installation costs is being lent with 10% annual interest.

Fig. 2. Arak's industrial clusters shown on the map.

Table 4
Agent attributes.

Agent	Attributes
Industrial companies	1) Environmental concern 2) Believing in institutions 3) Awareness about the benefits of transitioning to RE 4) Size of the company 5) Trust level 6) Ownership sensitivity level 7) Community engagement level 8) Willingness to invest level 9) Willingness to partnerships 10) Environmental concern level 11) Awareness level 12) Level of being afraid that the price of electricity will increase soon 13) Ownership type 14) Monthly electricity demand 15) Electricity price 16) Solar installation cost 17) Consumption background 18) Financial background 19) Game strategy

Table 5
Qualities for being a company with a collective mindset.

List of impacting socio-economic-environmental factors	Range	Qualities if Tick = 1	Qualities if Tick ≥2
1- Level of being concerned about the environment	[1 5]	≥3	≥2
2- Level of believing in the power of institutions to manage the hurdles of a partnership	[1 5]	≥3	≥2
3- Level of being more aware regarding the advantages of transitioning to RE	[1 5]	≥3	≥2
4- Size of the companies	[1 5]	≥3	≥2
5- Level of being prone to establish partnerships	[1 5]	≥3	≥2
6- Level of feeling that the price of electricity will increase in the near future	[1 5]	≥3	≥2

case it has, it searches over the cluster to see how many other companies have the same quality in that cluster. If ***n*** number of companies in each cluster have this quality in the first tick, they will calculate the $CBA_{col.}$ according to Equation (4) (Section 2). If $CBA_{col.} \geq 1$, then they would consider establishing an InCES in that cluster with those ***n*** members. It is calculated by counting the companies which have the collective mindset

Table 6
Reaction to the voting session based on companies' game strategy.

Game strategy	Company's vote = result of the voting session	Company's vote ! = result of the voting session
Problem-solving	Adds **one** desirability point	Subtracts **0** desirability point
Bargaining	Adds **three** desirability points	Subtracts **one** desirability point
Confronting	Adds **three** desirability points	Subtracts **three** desirability points

as the potentially participating companies and have $CBA_{col.} \geq 1$. Therefore, the minimum amount for ***n*** would be 2 .[4]

After an InCES is formed, from the second tick onwards, companies with a collective mindset (for tick ≥2) calculate the $CBA_{col.}$ according to Equation (4), considering the number of members who have already joined. If the $CBA_{col.} \geq 1$, they will join that InCES.

Companies without a collective mindset would not consider joining/establishing an InCES in the first place, regardless of its economic feasibility, since they do not believe in the functionality of such collective action. Therefore, they would only calculate $CBA_{ind.}$ and if $CBA_{ind} \geq 1$, then they would start generating RE individually.

5.2.2. *InCES members deciding on the business model*

After an InCES is created, members will decide about the next year's business plan at the end of each year. The decision is made among three different options of a) continuing with the current situation, b) expanding the capacity of the power plant and increasing each member's share of electricity produced, and c) increasing the capacity of the power plant and selling the surplus electricity to the grid and paying out dividends.

We assume that this decision will be made via a voting session in which all members will attend and vote. The majority vote will be selected as the plan for the following year. According to its game strategy, each member reacts differently to the outcome of the voting session. The model implements this reaction by adding/subtracting points to/from the "InCES desirability." This process is stated in Table 6.

5.2.3. *InCES members' electricity consumption*

Each member is assigned a random monthly electricity demand

[4] This is the annual interest rate which is being paid if money is deposited in an account. In this research we considered this interest to better calculate the future value of the money throughout the 20 years as the life cycle of a solar farm.

Table 7
Impact of consumption patterns on companies' evaluative criteria.

If the company is "*considerate*"	1 point will be added to member's "loyalty level"
If the company is "moderate"	1 point will be subtracted from member's "loyalty level"
If the company is "*infringer*"	3 points will be subtracted from member's "loyalty level"
If more than 30% of the members are "*moderates*"	a) 1 point will be subtracted from the "considerate" members' "desirability level" b) 1 point will be subtracted from the "considerate" members' "Functionality concept"
If more than 30% of the members are "*infringer*"	a) 3 points will be subtracted from the "considerate" members' "desirability level" b) 3 points will be subtracted from the "considerate" members' "Functionality concept"

Table 8
Procedure for the payment of the monthly premium fee; the ranges are randomly assigned.

Degree of financial background	Payment situation
If financial background ≤3	70% probability not pay the premium fee on time
3 < financial background ≤6	40% probability not pay the premium fee on time
6 < financial background ≤9	10% probability not pay the premium fee on time

ranging between [1.000.000 kWh 200–000.000 kWh] based on. Each member of InCES can consume electricity between half of its monthly demand to 1.5 times more than its demand (i.e., chosen randomly from the range **[0.5 × monthly demand 1.5 × monthly demand])**. The reason why we considered such a range for electricity consumption stems from the variability in the consumption of each company in response to real-life events such as economic recessions/booms.

Although consuming electricity less than each company's assigned monthly demand will not cause any issue for the InCES, crossing the monthly demand limit can result in a) a power shortage for other members b) a system blackout if more than 30% of the members decide to consume 1.5 times their monthly demand.

We capture the reaction of each member to these occurrences by adding/subtracting to/from "loyalty level" and "functionality concept" as proxies reflecting the extent to which a member is loyal to the InCES's rules and the extent to which a member perceives that the InCES is technically functional, respectively.

Accordingly, we defined three labels for companies according to their consumption pattern.

a) If monthly consumption ≤ monthly demand[5] → the company's label is "*considerate.*"
b) If: monthly demand ≤ monthly consumption ≤1.2 × monthly demand → the company's label is "*moderate.*"
c) If: 1.2 × monthly demand ≤ monthly consumption ≤1.5 × monthly demand → the company's label is "*infringer.*"

Table 7 shows how different consumption patterns affect "loyalty level", "desirability level", and "functionality concept".

5.2.4. Companies paying a monthly premium fee

In the model, we considered a monthly premium fee to be paid by each member. These payments are meant to cover the InCES's operational expenses, including maintenance and repairs. In Table 8, each member's willingness to pay is assigned according to that member's financial background.

Accordingly, if a company refuses to pay the premium fee on time, **one** point will be subtracted from its "loyalty level."

[5] In this research we refer to "demand" as the expected amount of electricity which a company is supposed to consume. Therefore, the membership investment has been done according to this amount.

Table 9
Functionality of the institutions in the model.

Institution 1:	Rules involved
Setting entrance rules	Boundary rule + monitoring rule + sanctioning rule
Procedure: Limits the entrance of the members by only accepting companies with a certain level of "financial background" and "consumption background" (Table 12). Then the electricity consumption and the payment of the monthly premium fee are being monitored. According to each member's behaviour, punishment will be executed (Tables 7 and 8). Eventually, if any exit dimensions reach the threshold, the member will exit/be-expelled.	
Institution 2: monitoring members' electricity consumption by a contract	**Rules involved** monitoring rule + sanctioning rule
Procedure: It prevents members from falling into "infringer" or "moderate" groups regarding electricity consumption. Also, it increases the probability of paying the premium fees on time. To do so, different intensity level for this contract is considered (Table 12). According to the intensity level, each member's consumption and premium fee payment are being monitored, and non-obeying members will be punished accordingly (Tables 7 and 8). Eventually, if any exit dimensions reach the threshold, the member will exit/be-expelled.	
Institution 3: monitoring the overall electricity consumption by all the members	**Rules involved** monitoring rule + sanctioning rule
Procedure: Checks if the cumulative consumption by all the members surpasses a certain range of the cumulative demands of all the members. To do so, different levels of cumulative over-consumption with respect to the power plant's capacity will be considered (Table 12). Each member's consumption behaviour and monthly premium fee payment will then be monitored, and non-obeying members will be punished relatively (Tables 7 and 8). Eventually, if any exit dimensions reach the threshold, the member will exit/be-expelled.	

5.2.5. Exit from an InCES

Exit from InCES happens if any of the evaluative criteria of "loyalty level," "desirability level", and "functionality concept" crosses the threshold. Suppose a company decides to leave the InCES because the "functionality concept" has crossed the limit. In that case, it means that the company perceives that the InCES is not a technically functional option to satisfy its electricity requirements. On the other hand, if a company exits the InCES because the "desirability level" has reached the bare minimum, it reflects that the InCES is no longer considered in line with that company's societal goals. And finally, the "loyalty level" crossing the threshold causing a member to exit means that the member was not considered a loyal member to the InCES's rules; therefore, it implies that the member was expelled from the InCES.

5.2.6. The institutional design of the InCES

As described previously in section 3, the three formerly introduced institutions will be implemented in the model as reflected in Table 9.

5.3. Sensitivity analysis

Since the model's outputs change significantly by varying the impacting parameters in the model, we need to perform a sensitivity analysis to determine what parameters the model is sensitive to and what would be the optimum ranges for these variables. Moreover, since

Table 10
Results of the sensitivity analysis.

Scenarios		Loyalty threshold	functionality threshold	desirability threshold	Electricity price	Consumption background	Financial background	Surplus-multiplier-institution-3	Institution-2-consumption-%
No institution	*members_in (high)*	[-50 -13]	[-25 -3.6]	[-30 -1.5]	[80 160]				
	members_out (low)	[-50 -37]	[-25 -13]						
	members_out (high)	[-25 0]			[80 160]				
Institution 1	*members_in (high)*	[-50 -16]			[80 160]	[3 6.7]	[3 7.3]		
	members_out (low)	[-50 -5.1]				[4.3 10]			
	members_out (high)	[-16 0]	[-24 0]		[80 160]	[3 7.3]	[3 6.4]		
Institution 2	*members_in (high)*	[-50 -24]	[-25 -1.2]	[-30 -1.3]	[80 160]				[30% 80%]
	members_out (low)	[-50 -25]	[-25 -3.7]						
	members_out (high)	[-16 0]	[-24 0]		[80 160]	[3 7.3]	[3 6.4]		
Institution 3	*members_in (high)*	[-50 -15]						[1.1 1.3]	
	members_out (low)	[-50 -14]						[1.1 1.3]	
	members_out (high)	[-12 0]	[-22 0]		[80 160]	[3 9]		[1 1.14]	

Table 11
Parameter value setup.

Agent	Attributes		Selection criterion
Industrial companies	1) Environmental concern		Random [1 5]
	2) Believing in institutions		Random [1 5]
	3) Awareness about the benefits of transitioning to RE		Random [1 5]
	4) Size of the company		[1 5]
	5) Trust level		Random [1 5]
	6) Ownership sensitivity level		Random [1 5]
	7) Community engagement level		Random [1 5]
	8) Willingness to invest level		Random [1 5]
	9) Willingness to partnerships		Random [1 5]
	10) Environmental concern level		Random [1 5]
	11) Awareness level		Random [1 5]
	12) Level of being afraid that the price of electricity will increase soon		Random [1 5]
	13) Ownership type		[Private Family-owned State-owned]
	14) Monthly electricity demand		Random [1000000 10000000] kWh/month
	15) Solar installation cost		[931 1030] Euro/kW
	16) Consumption background		Random [1 10]
	17) Financial background		Random [1 10]
	18) Game strategy		[Problem-solving Bargaining Confronting]
	19) Loyalty threshold		−31
	20) Functionality concept threshold		−24
	21) Social desirability threshold		−16
	22) Electricity tariff		[800 3200] IRR/kWh
	23) No. of companies in clusters	Urban cluster	5
		KheirAbad cluster	440
		HajiAbad cluster	140
		Ghotb cluster	136
		No.1 cluster	152

Table 12
Simulation run conditions.

Institutions	Varying conditions	Iteration
No institution	Electricity tariff = 800 IRR	500
	Electricity tariff = 3200 IRR	500
Institution No.1	3 < Consumption background <10, 3 < financial background <10 Electricity tariff = 800 IRR	500
	5 < Consumption background <10, 5 < financial background <10 Electricity tariff = 800 IRR	500
	7 < Consumption background <10, 7 < financial background <10 Electricity tariff = 800 IRR	500
Institution No.2	Contract binding level = 30%, Electricity tariff = 800 IRR	500
	Contract binding level = 55%, Electricity tariff = 800 IRR	500
	Contract binding level = 80%, Electricity tariff = 800 IRR	500
Institution No.3	Cumulative consumptions >1.05 × cumulative demands, Electricity tariff = 800 IRR	500
	Cumulative consumptions >1.1 × cumulative demands, Electricity tariff = 800 IRR	500
	Cumulative consumptions >1.153 × cumulative demands, Electricity tariff = 800 IRR	500

the "loyalty threshold," "functionality threshold," and "desirability threshold" are the values which directly affect the number of exits from the cooperatives, we need to cautiously determine these thresholds, which result in a meaningful outcome for our model. Therefore, we used the Latin Hypercube (ten Broeke et al., 2016) method while carrying out a parameter sweep for each variable's possible values and ran the model 500 times. Since the goal of this model is to determine under what conditions we would end up having InCESs with the highest number of joined companies and with the lowest number of exits, the focus of the sensitivity analysis is to determine the circumstances under which the maximum number of members, minimum and maximum number of exits are witnessed. Table 10 reflects the results of the sensitivity analysis.

5.4. Parameter setup and model run

The parameters of our model are set according to Table 11, following the sensitivity analysis. The model stops after 20 ticks, as the lifespan for most renewable technologies, including PV solar, is estimated to be 20 years (Behrendt, 2015; GE, 2018).

5.5. Model run

The model was run 500 times with the scenarios outlined in Table 12.

6. Results

This section reflects the results of the model run under different institutional scenarios. To address the main research question in this study, the KPIs are defined as (i) the number of companies joining an InCES, (ii) the number of companies which transited to RE individually, and (iii) the number of exits from each InCES during a 20-year period under three aforementioned institutions.

In Table 13, we brought a recap of the definitions we have used in our model concept and referred to in this section to make it easier for the readers to grasp the extracted results.

6.1. Companies joining/exiting InCES

6.1.1. No institutions

As we mentioned previously in Section 3, for industrial companies to join an InCES, they calculate the LCOE and then compare this to the electricity tariff for each kWh they were supposed to buy from the electricity company. Therefore, the higher the electricity tariff of the electricity company is, the more probable it would be for the industrial companies to find investing in an InCES financially beneficial. So, having a lower electricity tariff from the electricity company would increase the number of companies willing to join an InCES and contrarily, a higher electricity tariff makes the individual transition to RE more economically attractive resulting in more companies being willing to transit to RE individually. Therefore, to better grasp the difference in the number of companies which join an InCES in each cluster, we ran the model under two electricity tariffs of 800 IRR (0.0026 €) and 3200 IRR (0.0106 €) and iterated the model 500 times under each condition.

As illustrated in Figs. 3 and 4, the number of companies joining an InCES has a sharp increase in the initial years and then stabilises until the 11th year when experiencing the initial substantial exits. The decreasing trend continues until the end of the 20th year (with no institutions applied). As expected, both graphs reflect an identical trend for joining/exiting of the industrial companies, while the only difference is the substantial difference in the number of members in an InCES, depicting that a higher electricity tariff from the electricity company makes industries more willing to transit to RE individually. That is why we see fewer members in the InCESs in Fig. 4 compared to Fig. 3.

According to the results of the model reflected in Figs. 3 and 4, joining an InCES would be more of an economically feasible option compared to the condition that the electricity tariff is four times as much since joining an InCES would create a lower LCOE compared to an individual transition by each industrial company (see Section 3.1.2). Moreover, according to these figures, InCESs reach their maximum number of members between years two to four, showing that most of the industries that might decide to join an InCES have made their decision during this period. Also, it is illustrated that most of the members in all clusters start reaching their exit thresholds in the 11th year. Figs. 3 and 4 reflect that most of the exits have happened due to members being expelled from the InCESs because of not being loyal to the cooperative's rules (rules which prevent companies from consuming more electricity than what they have invested for and not having paid the monthly premium fees on time). Moreover, less than 20% of the exits in both figures are related to the lack of social desirability. Another important implication of this trend of exits is that "not being loyal to the co-operative's rules" is the first threshold being surpassed by the majority of the members who exit InCESs. Therefore, institutions which tend to limit these actions seem to be more successful in sustaining an InCES, as highlighted in Figs. 3 and 4 while no institutions are applied.

Fig. 5 shows the average number of companies that transited to RE individually while we considered the electricity tariff of 3200 IRR in the model. On the other hand, zero companies chose individual transition if the electricity tariff is 800 IRR. Since changing the electricity tariff only changes the number of joined members to the InCESs and would not make changes in the exit trends, we only reflect the model's results under an electricity tariff of 800 IRR from here onwards.

It should be noted that the reason behind this phenomenon stems from the fact that the price of electricity in Iran is highly subsidised; therefore, the LCOE calculated by an industrial company which is willing to invest in transitioning to RE individually, will always be higher than the tariff being offered to that company from the grid. So, having a higher grid tariff would make the individual transition by each company more economically feasible.

6.1.2. Institution No.1 (setting entrance rule)

As mentioned earlier in Section 3, this institution aims to investigate how setting an entrance rule can establish InCESs with members who are less likely to show problematic actions (Table 13) in the InCES. Therefore, it can lead to a more sustainable InCES with fewer exits during 20 years. To investigate the efficacy of this institution, we ran the model under three different scenarios, as mentioned in Table 14. The results are as follows.

According to the results of this institution, as reflected in Figs. 6–8, the entries to the InCESs have been drastically limited while reducing the number of exits noticeably. Interestingly, under scenarios A and B, this institution has shown a similar performance that reflects only extreme entrance boundaries can result in almost zero exits from the InCESs (scenario C). Although implementing this institution succeeded in limiting the problematic actions by only accepting the membership of selected members, still, most of the exits are related to expulsion from the InCESs due to not obeying the rules. Only under scenario C can we see that there were almost zero exits from all the InCESs by being highly selective regarding the members' electricity consumption and financial backgrounds.

6.1.3. Institution No.2 (monitoring members' electricity consumption by a contract)

The idea of this institution is to ignore entrance rules and welcome members with any attributes while simultaneously, any member should sign a contract with InCES upon membership. This contract is supposed to limit problematic actions such as consuming electricity more than the limit and not paying the monthly premium fee. We considered three

Table 13
Recap of the definitions used in this section.

Title	Definition
Problematic actions	a) Consuming electricity more than what the company have invested for b) Not having paid the monthly premium fee on time
The CBA analysis for transitioning to RE	Individual transition: a) Calculating $LCOE_{ind.}$ and comparing it to the electricity tariff from the electricity tariff Investing in an InCES: b) Calculating the $LCOE_{col.}$ and comparing it to the electricity tariff from the electricity company

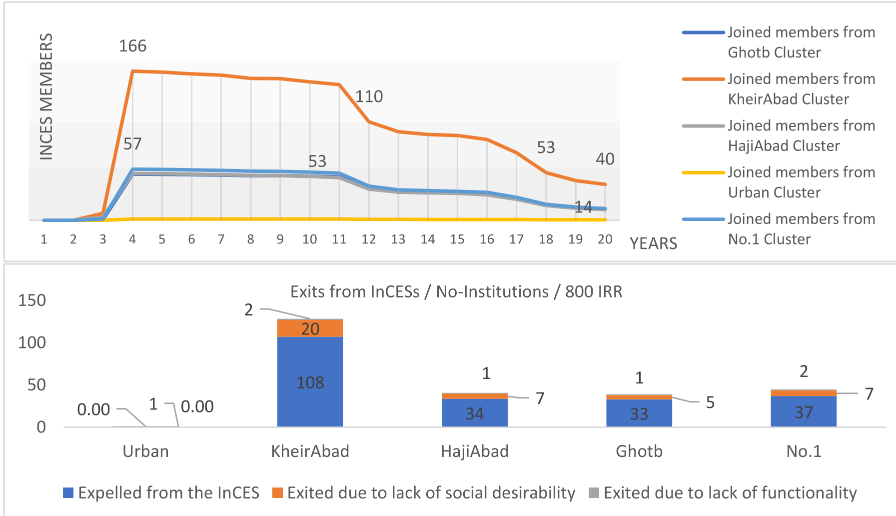

Fig. 3. Number of companies joined/exited InCES in each cluster/electricity tariff = 800 IRR.

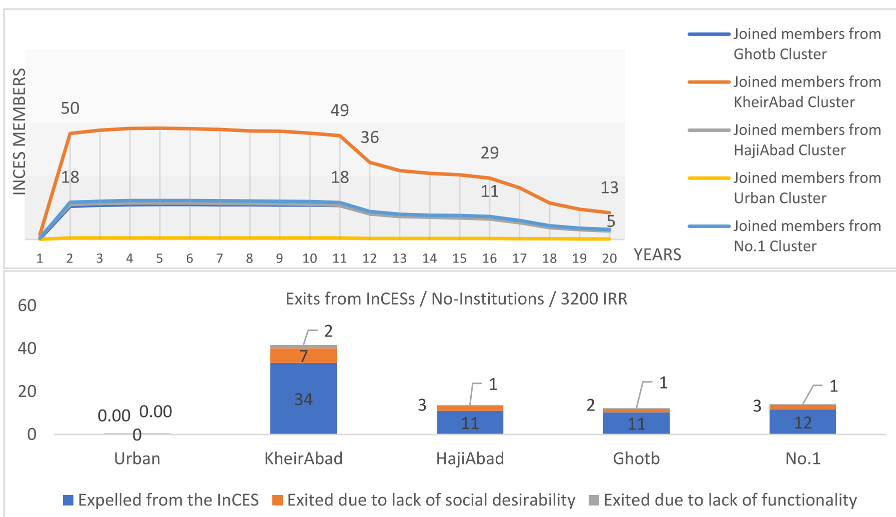

Fig. 4. Number of companies joined/exited InCES in each cluster/electricity tariff = 3200 IRR.

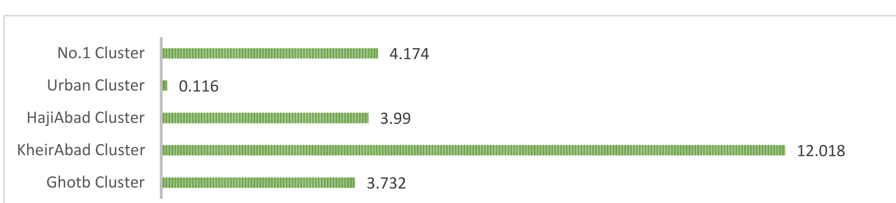

Fig. 5. Average number of companies that transited individually in each cluster/Electricity tariff is 3200 IRR.

Table 14
Scenarios of institution No.1

Adjustments	Scenario
a) Easy entrance rule	Only members with financial and consumption background >3 could join
b) Moderate entrance rule	Only members with financial and consumption background >5 could join
c) Strict entrance rule	Only members with financial and consumption background >7 could join

binding levels for the contract, as mentioned in Table 15 and ran the model under each of these scenarios with 500 iterations. According to Table 15, these percentages are the extent to which the problematic actions would be limited. For instance, in scenario A, we considered that an easy type of contract would force members to obey the InCES's rules by 30%. The results are as follows.

According to the results reflected in Figs. 9–11, this institution generally helps InCESs accept as many members who have assessed joining an InCES as an economically feasible investment. On the other hand, the results under three different scenarios differ drastically.

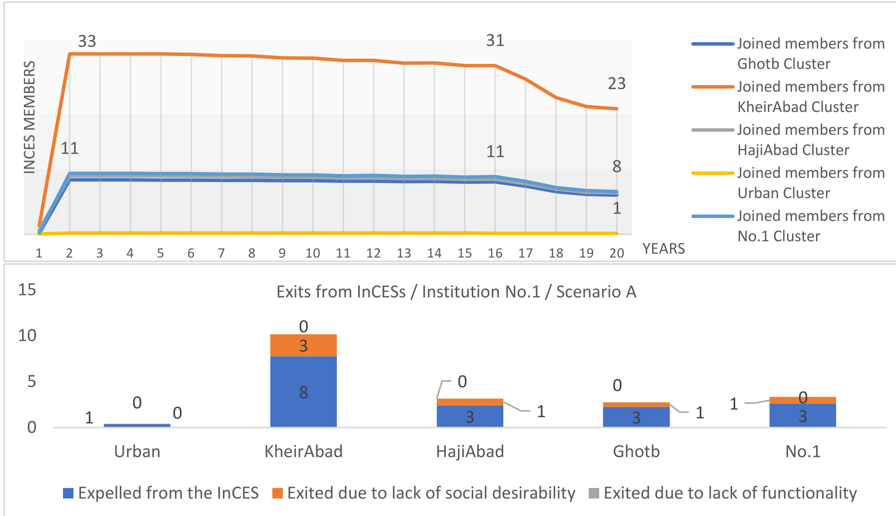

Fig. 6. Number of members joining/exiting from InCESs/Institution No.1/Scenario A.

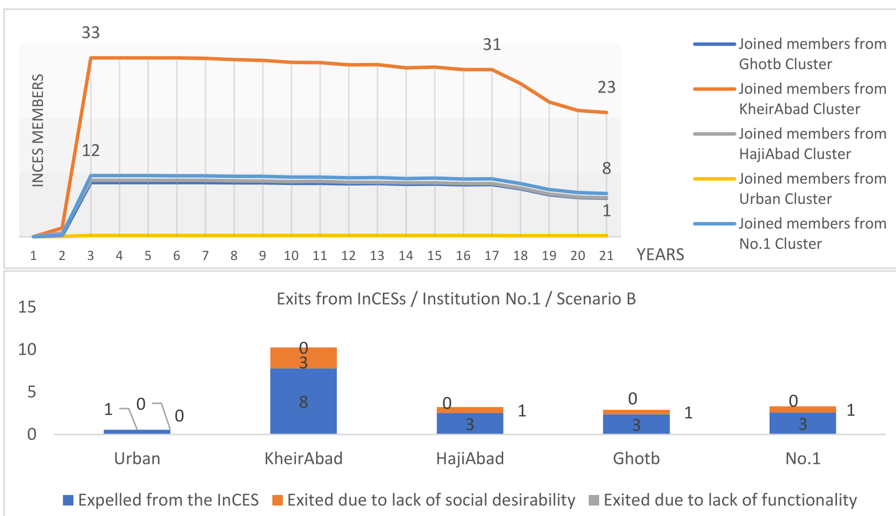

Fig. 7. Number of members joining/exiting from InCESs/Institution No.1/Scenario B.

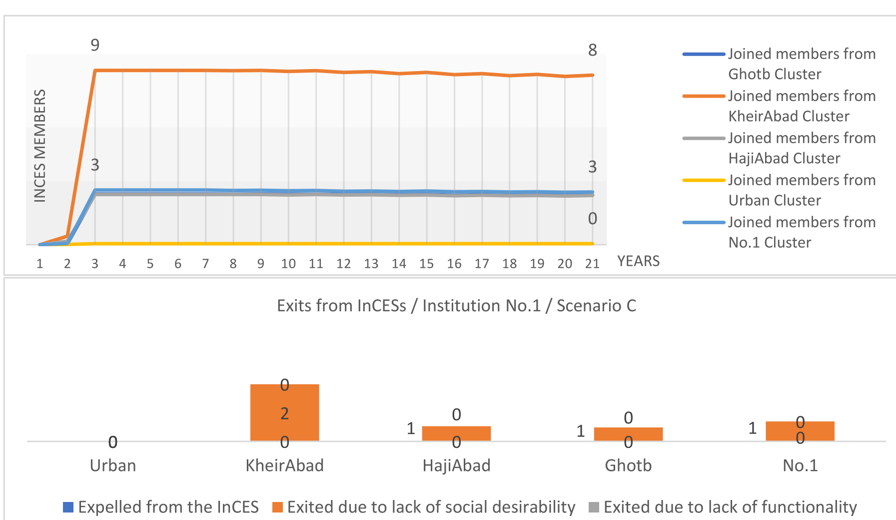

Fig. 8. Number of members joining/exiting from InCESs/Institution No.1/Scenario C.

Table 15
Simulation conditions of Institution No.2

Adjustments	Binding level
a) Easy contract	30%
b) Moderate contract	55%
c) Strict contract	80%

Scenario A seems to be a total failure in keeping the members since almost 95% of the joined members have exited the InCESs over 20 years, while most of these exits are related to "not being loyal to InCES's rules". This reflects that a low-binding contract between an InCES and its members has almost zero effect on preventing members from problematic actions. On the other hand, the results reflected in Figs. 9–11 reflect that the more binding the contract is, the more sustainable an InCES would be during its lifetime. Another outcome reflected in Fig. 11 is that a contract with 80% efficacy can almost entirely limit the non-commitment of the members to InCES's rules, while most of the exits are related to members perceiving the InCES as a socially unattractive option.

6.1.4. Institution No.3 (monitoring the overall electricity consumption by all the members)

By this institution, we tried not to be strict about the consumption of each member but to monitor the total aggregated consumed electricity by all members. We considered if the total consumption of all members surpasses a limit, infringer members would be punished. We expect this institution would help since we believe not all industrial companies will work at their full production capacity at all times. Therefore, while a company is consuming more electricity, another company might consume less than what is expected. In such a situation, the availability of electricity would not be compromised. So, having a holistic view of consumption might help us prevent exits related to members' consumption. Table 16 shows three different consumption thresholds for all the members' aggregated consumptions. For example, in condition A, if the total consumption of the members of an InCES surpasses up to 1.05 times what is expected, the cooperative would not face an electricity shortage and will not punish the infringer. The results are as follows.

According to the results shown in Figs. 12–14, the performance of this institution under scenario A differs drastically compared to scenarios B and C. Scenario A shows that the cumulative electricity consumption of all the members of an InCES usually is more than 1.05 times

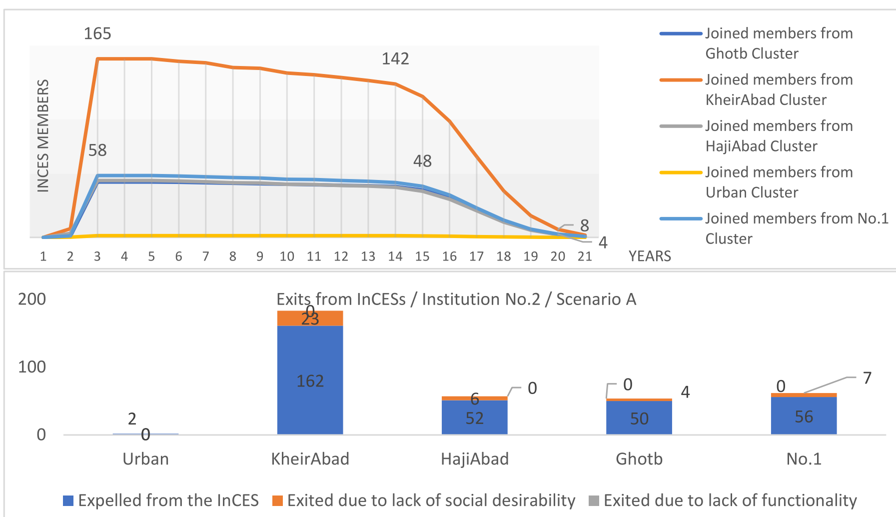

Fig. 9. Number of members joining/exiting from InCESs/Institution No.2/Scenario A.

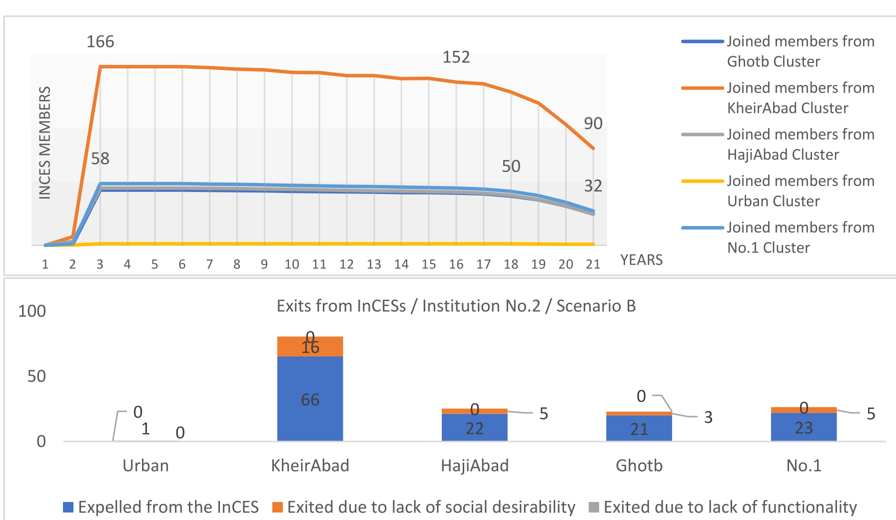

Fig. 10. Number of members joining/exiting from InCESs/Institution No.2/Scenario B.

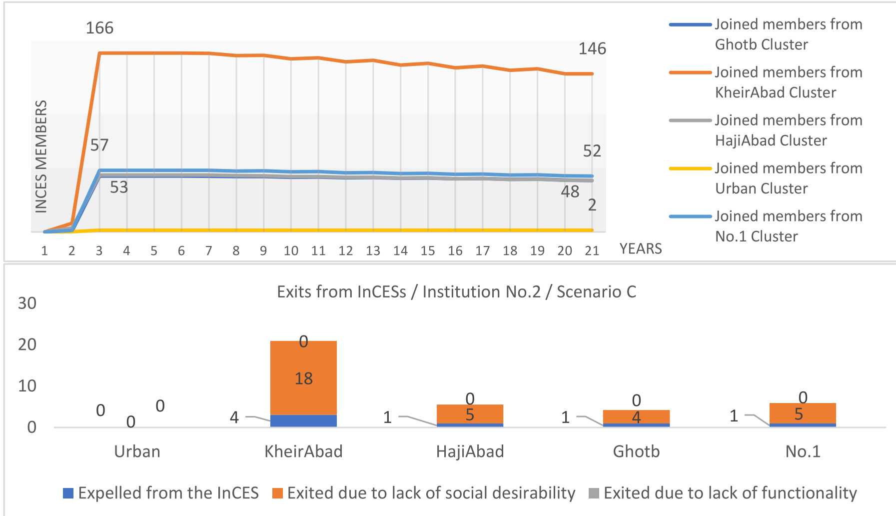

Fig. 11. Number of members joining/exiting from InCESs/Institution No.2/Scenario C.

Table 16
Simulation scenarios of Institution No.3

Adjustments	Surplus multiplier threshold
a) Easy threshold	1.05
b) Moderate threshold	1.1
c) Strict threshold	1.153

their cumulative demands (the expected consumption by each company), which has resulted in a substantial number of exits from InCESs. Also, the exit pattern under scenario A is different from the two other scenarios while we witness two exit peaks in scenario A which have happened in the second and twelfth years. While the exit patterns under scenarios B and C occur with a low-slope decreasing trend. As expected, most of the exits under scenario A happened due to consumption-related behaviours resulting in the expulsion of non-committed members and the exit of the committed members with the perception that the InCES would be incapable of satisfying their electricity requirements.

The better performance of scenario C compared to scenario B reflects that the chance of the cumulative consumption of the members in all InCESs surpassing 1.153 times the cumulative demands of the members is almost rare. This is reflected when we can see scarce exits due to consumption-related behaviours under scenario C. Another critical implication of this institution is that exits due to societal behaviours are an inevitable part of establishing an InCES in the industrial clusters since these introduced incentives could only affect the members' consumption and related financial behaviours and prevent problematic actions.

6.2. Statistical analysis

This section presents the statistical analysis of the collected data to verify if the difference between various institutions applied is significant in terms of members exit. For doing so, we took the average number of exited companies in various years and compared them with different institutions, the result of which highlights the influence of different institutions on exiting companies. The number of exited companies in each year serves as samples, and the effects of institutions are deemed as effects on treatments in the statistical analysis.

Since we have four different conditions, the standard statistical tool for the data would be the repeated measure analysis of variance (ANOVA). However, the repeated measure ANOVA has several assumptions that are not held on our data. For example, the data are assumed to be drawn from normal distributions. This assumption cannot be checked with our data since we have a few numbers of samples (i.e., 20 samples from 20 years). The non-parametric counterpart to the repeated measure ANOVA is the Friedman test. This test also has serious

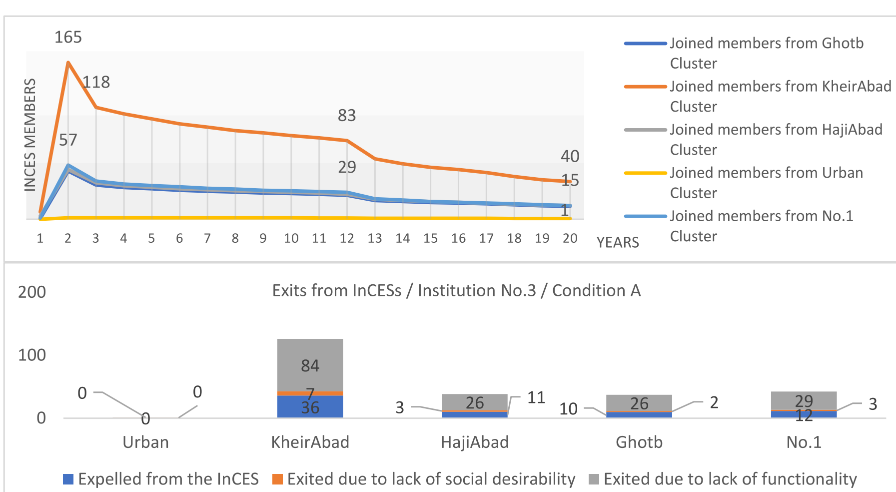

Fig. 12. Number of members joining/exiting from InCESs/Institution No.3/Condition A.

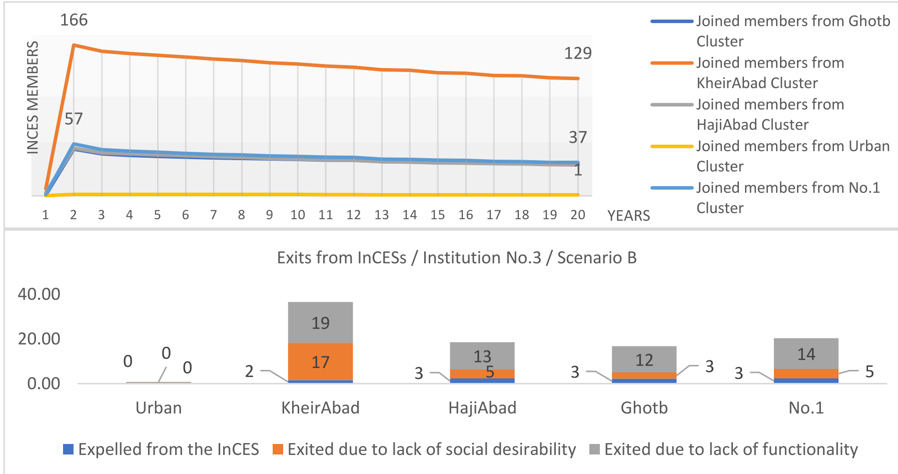

Fig. 13. Number of members joining/exiting from InCESs/Institution No.3/Scenario B.

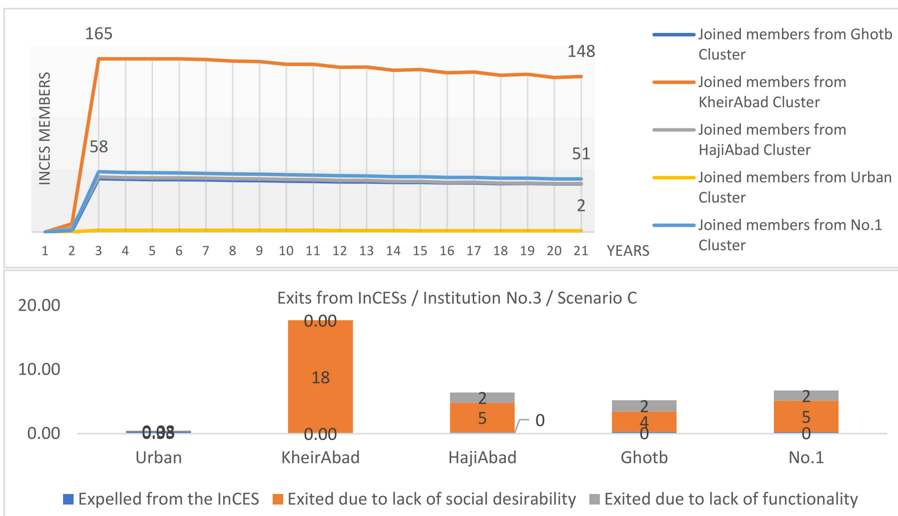

Fig. 14. Number of members joining/exiting from InCESs/Institution No.3/Scenario C.

issues with conducting the post-hoc tests comparing pairwise of treatment.

That being said, we conduct the pairwise comparison of different institutes using the Wilcoxon Signed-rank test. The null hypothesis is if the average number of exited companies in 20 years is the same for an industrial cluster under two different institutions. In the first experiment, we apply the Signed-rank test to the average number of companies for "no institution" and "institution no.3" in the 20-year period. The p-value was 9×10^{-7}, indicating that the null hypothesis is very incompatible with the data. As a result, the null hypothesis is rejected, and the difference between the "no institution" and "institutions no. 3" is significantly different. We apply the same procedure for all the comparisons between different industrial clusters and institutions, all of which resulted in extremely low p-values and the null hypotheses are thus rejected.

7. Discussion and conclusion

In this research, we wanted to investigate the role of institutional settings on the robustness and durability of InCESs within industrial clusters by an agent-based modelling approach. In this model, we acknowledged that the process of establishing/joining an InCES initiates by industries with certain socio-economic attributes while at the same time considering these investments an economically feasible option. The feasibility assessment process occurs by performing a cost-benefit analysis which was elaborately mentioned in Section 3. In the model, we investigated if three different institutional settings can contribute to decreasing the problematic events that emerge in interactions among the members and by actions taken by each member. These institutions were a) setting entrance boundaries, b) signing a contract between InCES and its members, and c) monitoring the consumption of the members by digital tools.

According to the results of this research, setting an entrance boundary (institution No.1) can help stabilise an InCES, but it limits the capacity of an InCES in terms of having a noticeable number of members. In other words, it results in the establishment of a club with a very limited number of members who are loyal to the rules of the club. The stricter the entrance boundary is, the more loyal the members will be to the rules.

The performance of the second institution, signing a contract between InCES and its members, reflects that this institution can help an InCES reach its maximum possible number of members and succeed in keeping these members inside of the InCES if only the contract is highly binding. In this research, an 80% binding contract prevented the exit of almost 88% of the members in all InCESs. Although this was an assumption which was set in our model, it is still questionable how the extent of the bindingness of a contract between parties can be guaranteed in real life.

Monitoring the consumption of the members by digital tools (Institution No.3) and looking at the total consumption made by all members instead of checking the consumption of each individual member presents interesting insights. While the members of an InCES were randomly choosing their consumption between half to 1.5 times their demand (expected consumption), the cumulative consumption of all members merely surpassed 1.153 times the cumulative amount of their demand. This implies that while an InCES is being established, by a relatively small investment and increasing the power plant's capacity by almost 15%, many of the exits related to the consumption of the members can be prevented. The other insight is, planning the working schemes of the members of an InCES can help an InCES not surpass its electricity capacity. The latter issue can be considered when the local authorities are designing an industrial cluster in terms of the type of industries which are better to be located in close proximity.

Moreover, all the institutions introduced in this research have contributed to shifting the member exit peaks to a later year. This was evident when we saw the exit peak without implementing any institutions around the 11th year, while implementing institutions shifted this to the 16th-18th year. This reflects that having institutions, regardless of their type, would help InCES members to reach their exit thresholds much later. Therefore, to design the management institutions of an InCES, more relaxed entrance rules are suggested to increase its attractiveness and mobilise as much investment among potential industrial investors. At the same time, monitoring and sanctioning the infringing members by utilising digitally automated tools (such as what was mentioned above in "Institution No.3") would contribute to limiting the infringing behaviours by the members.

Another important implication of this research is that the differences in the societal attributes of the industries which are affecting their reactions to social events should be acknowledged, as we can see that more than 88% of the exits (when almost all other reasons for the exit of a member from an InCES are prevented) in our best-performing institution (Institution No.3/condition C) is related to lack of social desirability. Therefore, it implies that despite the severe importance of the technical feasibility of establishing such projects, especially in the industrial sector, having a mutual community spirit and social connectedness among the investor industries would increase their social tolerance in such a collective initiative. More transparent information sharing and more frequent formal and informal meetings/workshops/gatherings are suggested to increase the mentioned environment, as was pointed out in the previous publications on household community energy systems.

This also should be noted that this research was limited in the sense that the RE technology costs and electricity tariff was assumed as fixed during a 20-year period due to simplification, which was made to make the research doable in its time constraint.

CRediT authorship contribution statement

Sina Eslamizadeh: Conceptualisation, Methodology, Writing – original draft, Data curation, Visualization. **Amineh Ghorbani:** Conceptualisation, Methodology, Writing- Reviewing and Editing. **Margot Weijnen:** Conceptualisation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this papers.

Data availability

The model code is attached

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