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Exploring industrial community energy systems: a missing link in the industrial energy transition?

Dissertation

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at Delft University of technology

by the authority of the Rector Magnificus, Prof.dr.ir. T.H.J.J. van der Hagen,

chair of the Board for Doctorates

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Friday 31 March 2023 at 12:30 o'clock

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To Afrooz, my shining star

To Farhad Meysami, the eternal teacher

من آن صبحم که ناگاهان چو آتش در شب افتادم
بیا ای چشمِ روشن بین که خورشیدی عجب زادم

ز هر چاکِ گریبانم چراغی تازه می تابد
که در پیراهنِ خود آذرخش آسا درافتادم

چو از هر ذره ی من آفتابی نو به چرخ آمد
چه باک از آتشِ دوران که خواهد داد بر بادم

تنم افتاده خونین زیرِ این آوارِ شب، اما
دری زین دخمه سوی خانه ی خورشید بگشادم

الا ای صبحِ آزادی به یاد آور در آن شادی
کزین شب های ناباور منت آواز می دادم

در آن دوری و بد حالی نبودم از رُخت خالی
به دل می دیدمت وز جان سلامت می فرستادم

سزد کز خونِ من نقشی بر آرد لعلِ پیروزت
که من بر دُرجِ دل مُهری به جز مهرِ تو ننهادم

به جز دامِ سرِ زلفت که آرامِ دل سایه ست
به بندی تن نخواهد داد هرگز جانِ آزادم

هوشنگ ابتهاج

Contents

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It all started with a phone call from one of my closest friends about open positions at the TPM (Technology, Policy, and Management) faculty of TU Delft. Considering Iran's economic instability and uncertainties, this was a recurring discussion if we need to seek a better future outside of Iran. Now I can say, back at the time, as an industrial executive, it was the toughest decision of my life. Even after finishing my PhD, I still cannot be confident if I made the right decision that day. But the inevitable fact is it was a brave decision to stretch my comfort zones way broader than I could ever imagine. The journey became more challenging as of May 2018 when new, and much stricter sanctions were imposed on Iran's economy. Since that time, we Iranians started the gloomiest decade of our history, in my opinion. There were countless moments in which bearing up with the combination of the described situation and the complexities of a PhD was beyond my capacities. Yet, I am writing this acknowledgement when this journey has ended, and it is my pleasure to seize the moment to acknowledge those lovely souls who helped me put a successful end to this adventure.

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I hope you enjoy reading this thesis as much as I enjoyed writing it.

Sina Eslamizadeh

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Executive Summary

The transition to renewable energy sources affects all sectors of society, including the industrial sector. Besides climate policy ambitions and other concerns regarding the social and environmental acceptability of energy provision, the transition to renewables may also improve the availability and affordability of energy services. The latter holds especially in some developing countries, where the development of energy infrastructure often lags behind the needs of industry. For many industries, the energy transition challenge entails the future substitution of high temperature, fossil-fired processes to lower temperature e.g., electrochemical conversion routes, which will make them much more than now depend on the reliable and affordable provision of electricity. However, in many developing economies, even the current provision of electricity is far from reliable. Transitioning to power generation from renewable energy (RE) sources can contribute to a more diversified, resilient, and environmentally-friendly power generation mix.

If the energy sector in developing economies does not sufficiently invest in a robust generation mix for the future, industry itself may consider to take the lead. For individual companies, however, especially small and medium-sized enterprises (SME), the high upfront investment costs of infrastructure for harvesting and transporting renewable energy present a significant hurdle. Inspired by the literature on community energy systems (CES) and industrial symbiosis (IS), this thesis set out to investigate if, and under which conditions, industrial companies may be willing to join forces in industrial community energy systems (InCES) in order to secure their supply of electricity from renewable energy sources.

This thesis aims to answer the following research question:

"How can industries establish and manage InCES in industrial clusters?"

The actual research was structured around four sub-questions:

1) Which characteristics of industrial clusters are relevant for establishing an InCES?

2) What socio-economic-environmental factors affect the willingness of the industrial companies to engage in an industrial community energy system?

3) Which incentive mechanisms can support the establishment/continuation of an industrial community energy system?

4) What internal institutional arrangements are required for successful establishment/continuation of an industrial community energy system?

This research takes a collective action perspective by looking into the feasibility of industrial collaboration and the institutional mechanisms that can facilitate such initiatives. This unique angle has never been applied to cases of collaboration among industries, particularly the rich literature on industrial symbiosis, where various forms of collaboration among industries are covered. The collective action lens can provide insights into institutional mechanisms that would support the successful establishment and continuity of these projects.

This research is designed as a case study in an industrial city called Arak, one of Iran's most prominent industrial cities, with diverse industries scattered in five different industrial clusters. Besides the common challenges industries face in many other countries (e.g., reducing CO2 emissions, meeting increasing demands), Arak suffers from an increasing

investment gap in electricity infrastructure, as the electric utility company's investments do not keep up with the rapid development and increasing electricity demand of the industrial sector in Arak.

The text below summarizes the main findings of this research.

Feasibility of establishing an InCES among industries

The Institutional Analysis and Development (IAD) framework, the main theoretical tool in the collective action literature, provided insights into the feasibility of establishing an InCES in Arak. By capturing endogenous and exogenous characteristics of an InCES (as a collective system), the IAD framework helped to systematically investigate the opportunities and barriers of such a collective endeavour. The data used in this part of the research stemmed from a) policy documents in the context of Iran and b) semi-structured interviews with industrial executives, consultants in the field of RE, and the authorities of the regional power company.

The results of this study showed that in terms of technological and biophysical feasibility, it is possible to have a renewable power plant that can meet the electricity demand of the industries that would like to join an InCES. Given the rules in place for using the national grid, it is economically more attractive for industries in the InCES to stay connected to the national grid than to develop an off-grid project that would require substantial additional investment in energy storage capacity. The grid connection also caters to the widely different consumption patterns of the various industrial companies in Arak, so coordination mechanisms for the distribution of power generated in the collective project are not essential. Yet, many other social and institutional challenges are critical for the success or failure of an InCES in Arak. Starting from the institutional barriers, the uncertainties involved with government incentives make the system extremely vulnerable regarding technological and financial independence. On the one hand, staying connected to the national grid is a safe option financially, technologically and security-of-supply wise. On the other hand, industries cannot count on the feed-in-tariffs and payback arrangements recently introduced by the government, as the regulations may change again.

Regarding the community aspect of the system, the biggest challenge is that industries vary greatly in requirements, interests and investment possibilities. As such, collaboration and reaching an agreement is more complicated than in traditional community energy projects among households. Nonetheless, given the results of our analysis, it seems that even with all the uncertainties in energy policy and regulations, InCES is an attractive option for the industries in Arak as it provides better guarantees for the availability, affordability and environmental acceptability of electricity than any other option.

The willingness of industries to invest in an InCES

To address the second sub-question of the thesis, this part of the research used an empirical approach to identify factors influencing the willingness of the industrial companies to invest in an InCES. A questionnaire was developed based on literature-driven hypotheses and distributed among a sample of 212 industrial companies located in five different industrial clusters within Arak.

The results showed that economic factors are pivotal indicators for the willingness of the industrial companies to invest in an InCES. Also, the industrial companies whose key decision-makers were environmentally aware showed more willingness to invest in an InCES. Furthermore, the role of social identity is an essential factor for industries to consider engaging in an InCES as this helps them to be pictured as social and environmental pioneers in their community. On the one hand, not having trust in other participants negatively correlated with the willingness of companies to invest in an InCES. On the other hand, having trust in the government's promises did not significantly correlate with their willingness to invest in an InCES. This implies that the industries in Arak perceive an InCES as a collaborative bottom-up approach. Contrary to the case of households in CESs, "ownership" is found to be a critical factor for industrial companies. As such, industrial companies are more willing to invest in an InCES if their share is easily and legally tradable.

Interestingly, the results highlighted an important role for the bigger companies in an industrial cluster in initiating such projects. It appears that bigger companies are more willing to tolerate the risks of joining projects with lower ROI and allocating a larger share of their annual revenue if they decide to participate in an InCES. Bigger companies are also more inclined to take the leadership of an InCES.

Contrary to what was hypothesized, we did not find a correlation between the amount of electricity consumption and the willingness of the industrial companies to join an InCES. Importantly though, there is a high motivation to engage in an InCES among those companies that expect electricity prices to increase substantially. This motivation appears strongest in energy-intensive companies directly connected to the high voltage grid, such as companies operating high-capacity induction furnaces. It was also revealed that companies which are more aware of the benefits of joining an InCES and companies whose decision makers believe in the power of proper institutions to govern an InCES are more prone to invest in it.

Role of incentive mechanisms to support InCES establishment

Taking existing financial incentive schemes introduced globally as the basis, this part of the research investigated the role of three particular incentive mechanisms in the initiation and continuation of an InCES. The incentive mechanisms investigated are: a) a feed-in-tariff (FIT), b) a tax incentive, and c) tradable green certificates. We used an agent-based modelling (ABM) and simulation approach to compare the effectiveness of the three incentive mechanisms in fostering InCESs. The simulations were situated in six different cultural environments, derived from Hofstede's cultural dimension theory, and the decision making agents were modelled according to Scharpf's organizational decision theory. In each of the model runs, a period of 20 years is simulated. Each company simulated decides annually whether or not to join and/or stay engaged with the InCES. The combination of Scharpf's organizational decision theory and Hofstede's cultural dimension theory to conceptualize company decision-making in different cultural environments, as embedded in our ABM, is the first of its kind.

The simulations show that the FIT mechanism had the worst performance in incentivizing the establishment of an InCES among industries. In contrast, the TAX incentive showed the best performance in mobilizing investments towards InCES. Similarly, the TAX incentive showed relatively superior performance in electricity generation, the number of established InCESs, and the number of companies joining each InCES. Despite the better performance of the Tax incentive, it was also the most expensive option for the governments as a significant share of the establishment costs of an InCES was put on the shoulders of the governments.

Interestingly, the tradable green certificates, which act similar to Carbon Bonds, showed a relatively identical efficacy while simultaneously being more beneficial for two reasons. First, it was less costly for governments compared to TAX incentives. Second, due to its market mechanism, it incentivizes the use of the best renewable technologies and increases the whole system's efficiency. On top of that, it can create extra revenue streams for the industries, creating more financial flexibility in their business model.

Moreover, this simulation practice showed that despite the pronounced differences in the societal attributes of the different countries, the number of exits from InCESs was not significantly different, indicating that if an InCES is economically beneficial, the societal unattractiveness of an InCES (where there are societal conflicts among InCES members) can be neglected by the members.

The role of internal institutional arrangements in the establishment and continuity of an InCES

To compare different institutional arrangements for the internal governance of an InCES, a second simulation model was developed which focused specifically on the Arak case and made use of its survey data. This model investigated the role of different institutional arrangements in establishing and maintaining an InCES.

Inspired by Ostrom's eight design principles, three institutional arrangements were designed and simulated. The first institution aimed at limiting InCES membership to eligible companies that pass a background check on their electricity consumption and financial history. The second institution entails signing a contract for joining an InCES to enforce an ordered electricity consumption. And finally, the third institution aimed at only considering the cumulative electricity consumption of all members and monitoring that to ensure it is not more than the defined capacity of the power plant. This institution is a replacement for individual monitoring and not limiting the entrance of investors by strict background checks, resulting in more relaxed membership terms while at the same time ensuring that the electricity consumption by InCES participants does not exceed the collective power plant capacity.

The simulation results showed that the electricity tariff offered by the electricity company in Iran makes the individual transition to RE almost impossible since the current tariff is subsidized, so the LCOE calculated cannot be competitive enough under any circumstances. Therefore, collective power generation and demand management within an InCES is the most viable solution for RE transition for industries considering the electricity tariff schemes in Iran.

The application of strict entry rules substantially decreases the number of exits from the InCES, while at the same time it limits the number of entrants. The application of the second institution, which tries to limit the overconsumption of electricity, effectively decreases the number of problematic events (consuming more electricity than expected or not paying the monthly premium fees on time) and eventually exit of the members. But limiting energy consumption based on the amount of investment would be challenging in real life. Finally, the third institution that did not restrict membership and did not limit power consumption based on investment performed the best. This implies that if the power plant is designed with

15% over capacity, the chance of electricity shortage for the whole system would be marginal because it happens most often that while a member is overconsuming, there is a high probability that another company will consume less than expected.

Therefore, among three simulated institutional designs, the third one with a holistic point of view on the electricity consumption by all the members instead of monitoring individual consumption results in more robust InCES governance. At the same time, the membership of an industrial company should not be complicated by strict membership terms (enforcing an strict contractual terms to each participant of the InCES).

Although putting proper institutions in place while designing an InCES showed a substantial effect in decreasing the exit of the members of an InCES, there would always be some exits caused by the differences of industries in terms of their societal attributes in collective settings and the way they tolerate such differences. Therefore, a small but inevitable percentage of members of the InCESs are expected to exit such a project due to the mentioned issue, even if their membership is economically beneficial.

Discussion and Conclusion

Studying the feasibility of InCES in a challenging case like Iran can provide a strong evaluation of the potential of InCES in less challenging scenarios. The case study of Arak is also selected due to accessibility of data, especially given the COVID situation that this research was conducted in.

This research revealed that despite all the technical challenges and vulnerabilities of the policies in place, a gradual transition to renewable power in the Iranian industrial sector is feasible and beneficial in the long run. By joining an InCES, companies can decrease the risks related to insecure electricity supply and the potential increase in the price of electricity. The biophysical characteristics of the Arak industrial city, as the case study in this research, highlight a promising potential both for wind and solar power. At the same time, solar power seems to be the prevailing option considering the photovoltaic power potential between 1680 and 1826 kWh/kWp and an average of about 300 sunny days per year with a daily peak sun hour of 4.5–5.5 kWh/m2. On top of that, access to solar technologies is more practical compared to wind energy in the context of Iran.

Although the financial incentives introduced by Iran’s government showed inconsistency with relatively low efficacy in mobilizing the investments towards InCES, costless transformation and transmission of generated RE throughout the existing electricity grid can be a highly attractive technical incentive by the government, enabling companies to consider more spatially optimum locations to establish the renewable power plant.

Considering the critical role of the larger industrial companies, tailored incentives for these companies are highly recommended to the policymakers since active participation of the big companies would also bring more SMEs on board. Also, using relevant consulting companies as intermediaries to increase the awareness of industries regarding the benefits of joining an InCES would seem to have a discernible influence on making industries interested in investing in InCES.

This research was done in the context of Iran with its unique socio-economic and political characteristics. Yet, many of the findings of this research are generalizable to the industrial sectors in other countries as well. First, most of Iran’s economic and political characteristics (such as the highly subsidized electricity tariff, limitations in having access to RE technologies, and high interest rate) are, in fact, counterproductive for establishing an InCES among industries. However, even with these challenges, the initiation of InCES among Iranian companies is still a feasible and even promising option. As such, this collective solution would be even more practical in countries with more economically and politically stable conditions. On top of this, the factors studied in this research can be considered generic characteristics of industrial companies worldwide (e.g., decision-making process, economic assessment, and technical requirements of establishing an InCES), indicating the generalizability of most results.

Additionally, it might be implied from the results of this thesis that the highly subsidized electricity price in Iran may make the InCES approach an economically attractive option. In contrast, in other countries, with liberalized electricity prices, the individual transition to RE seems more of a convenient option. This should be noted that InCES establishment contributes firstly to decreasing a noticeable share of the investment costs and secondly to saving a substantial amount of time by reducing the time spent for permit acquisition for the collective power plant compared to the individual approach. Therefore, the InCES approach seems to be the optimum solution for the industrial transition to RE.

Besides the specific outcomes summarized so far, this research contributes to the existing literature on collaborations among industries in the field of IS by taking the collective action lens. Emphasizing the pronounced differences of the industries in terms of their decision-making style and the required conditions of industries to invest in InCES is the main scientific contribution of this research, which has not been paid attention to in the existing literature on industrial energy transition.

For future research, comparing the establishment of InCES in the industrial sectors of other developed/developing economies would shed a much brighter light on the role of this approach in the path of an industrial transition towards sustainable power. In addition, in this research, we proposed an on-grid design for the collective power plant to properly deal with the baseload requirement in the industrial clusters. At the same time, an off-grid design with an industrial electricity storage system would be ideal for complete accordance with the climate goals. Therefore, despite the insights highlighted by this research, studying the integration of an industrial cluster with off-grid InCES design and the way it can be functional by innovative business models and policy instruments seems to be a valid area of research for future studies.

Samenvatting

De overgang naar hernieuwbare energiebronnen heeft gevolgen voor alle sectoren van de samenleving, inclusief de industriële sector. Naast de ambities van het klimaatbeleid en andere zorgen over de sociale en ecologische aanvaardbaarheid van de energievoorziening, kan de overgang naar hernieuwbare energiebronnen ook de beschikbaarheid en betaalbaarheid van energiediensten verbeteren. Dit laatste geldt vooral in sommige ontwikkelingslanden, waar de ontwikkeling van de energie-infrastructuur vaak achterblijft bij de behoeften van de industrie. Voor veel industrieën houdt de uitdaging van de energietransitie in dat in de toekomst fossiele processen van hoge temperatuur worden vervangen door processen van lagere temperatuur, bijvoorbeeld elektrochemische omzetting, waardoor zij veel meer dan nu afhankelijk zullen zijn van een betrouwbare en betaalbare elektriciteitsvoorziening. In veel ontwikkelingslanden is echter zelfs de huidige elektriciteitsvoorziening verre van betrouwbaar. Een overgang naar elektriciteitsopwekking uit hernieuwbare energiebronnen kan bijdragen tot een meer gediversifieerde, veerkrachtige en milieuvriendelijke energieopwekkingsmix.

Indien de energiesector in ontwikkelingslanden onvoldoende investeert in een robuuste opwekkingsmix voor de toekomst, kan de industrie zelf overwegen het voortouw te nemen. Voor individuele bedrijven, met name kleine en middelgrote ondernemingen (KMO's), vormen de hoge initiële investeringskosten van de infrastructuur voor het oogsten en transporteren van hernieuwbare energie echter een belangrijke hinderpaal. Geïnspireerd door de literatuur over community energy systems (CES) en industriële symbiose (IS), werd in dit proefschrift onderzocht of, en onder welke voorwaarden, industriële bedrijven bereid zijn hun krachten te bundelen in industriële community energy systems (InCES) om hun elektriciteitsvoorziening uit hernieuwbare energiebronnen veilig te stellen.

Dit proefschrift beoogt de volgende onderzoeksvraag te beantwoorden:

"Hoe kunnen industrieën InCES opzetten en beheren in industriële clusters?".

Het eigenlijke onderzoek werd gestructureerd rond vier deelvragen:

1) Welke kenmerken van industriële clusters zijn relevant voor het opzetten van een InCES?

2) Welke socio-economisch-milieufactoren beïnvloeden de bereidheid van de industriële bedrijven om deel te nemen aan een industrieel gemeenschappelijk energiesysteem?

3) Welke stimuleringsmechanismen kunnen de oprichting/voortzetting van een industrieel communautair energiesysteem ondersteunen?

4) Welke interne institutionele regelingen zijn nodig voor de succesvolle oprichting/voortzetting van een industrieel communautair energiesysteem?

Dit onderzoek gaat uit van een perspectief van collectieve actie door te kijken naar de haalbaarheid van industriële samenwerking en de institutionele mechanismen die dergelijke initiatieven kunnen vergemakkelijken. Deze unieke invalshoek is nog nooit toegepast op gevallen van samenwerking tussen industrieën, met name in de rijke literatuur over industriële symbiose, waarin verschillende vormen van samenwerking tussen industrieën aan bod komen. De collective action lens kan inzichten verschaffen in institutionele mechanismen die de succesvolle totstandkoming en continuïteit van deze projecten kunnen ondersteunen.

Dit onderzoek is opgezet als een case study in een industriestad genaamd Arak, een van Irans meest prominente industriesteden, met diverse industrieën verspreid over vijf verschillende industriële clusters. Naast de gemeenschappelijke uitdagingen waarmee industrieën in veel andere landen worden geconfronteerd (bv. vermindering van de CO2-uitstoot, voldoen aan de toenemende vraag), lijdt Arak onder een toenemende investeringskloof in de elektriciteitsinfrastructuur, aangezien de investeringen van het elektriciteitsbedrijf geen gelijke tred houden met de snelle ontwikkeling en toenemende vraag naar elektriciteit van de industriële sector in Arak.

In de onderstaande tekst worden de belangrijkste bevindingen van dit onderzoek samengevat.

Haalbaarheid van de oprichting van een InCES bij de industrieën

Het kader voor institutionele analyse en ontwikkeling (IAD), het belangrijkste theoretische instrument in de literatuur over collectieve actie, bood inzicht in de haalbaarheid van de oprichting van een InCES in Arak. Door de endogene en exogene kenmerken van een InCES (als collectief systeem) vast te leggen, hielp het IAD-kader om systematisch de kansen en belemmeringen van een dergelijke collectieve inspanning te onderzoeken. De in dit deel van het onderzoek gebruikte gegevens waren afkomstig van a) beleidsdocumenten in de context van Iran en b) semi-gestructureerde interviews met bedrijfsleiders, consultants op het gebied van RE en de autoriteiten van het regionale energiebedrijf.

De resultaten van deze studie toonden aan dat het in termen van technologische en biofysische haalbaarheid mogelijk is een duurzame elektriciteitscentrale te hebben die kan voldoen aan de elektriciteitsvraag van de industrieën die zich bij een InCES willen aansluiten. Gezien de geldende regels voor het gebruik van het nationale net, is het voor industrieën in de InCES economisch aantrekkelijker om aangesloten te blijven op het nationale net dan een off-grid project te ontwikkelen dat aanzienlijke extra investeringen in energieopslagcapaciteit zou vergen. De netaansluiting komt ook tegemoet aan de sterk uiteenlopende verbruikspatronen van de verschillende industriële bedrijven in Arak, zodat coördinatiemechanismen voor de distributie van de in het collectieve project opgewekte stroom niet essentieel zijn. Toch zijn vele andere sociale en institutionele uitdagingen cruciaal voor het slagen of mislukken van een InCES in Arak. Uitgaande van de institutionele barrières maken de onzekerheden in verband met de stimuleringsmaatregelen van de overheid het systeem uiterst kwetsbaar wat betreft technologische en financiële onafhankelijkheid. Enerzijds is het aangesloten blijven op het nationale net een veilige optie op financieel, technologisch en voorzieningszekerheidsgebied. Anderzijds kan de industrie niet rekenen op de onlangs door de regering ingevoerde feed-in-tarieven en terugbetalingsregelingen, aangezien de regelgeving weer kan veranderen.

Wat het gemeenschapsaspect van het systeem betreft, is de grootste uitdaging dat de industrieën sterk verschillen in eisen, belangen en investeringsmogelijkheden. Als zodanig is samenwerking en het bereiken van overeenstemming ingewikkelder dan bij traditionele gemeenschappelijke energieprojecten tussen huishoudens. Gezien de resultaten van onze analyse lijkt het er echter op dat InCES, zelfs met alle onzekerheden in het energiebeleid en de regelgeving, een aantrekkelijke optie is voor de industrieën in Arak, omdat het betere garanties biedt voor de beschikbaarheid, betaalbaarheid en milieu-aanvaardbaarheid van elektriciteit dan enige andere optie.

De bereidheid van industrieën om in een InCES te investeren

Om de tweede deelvraag van het proefschrift te beantwoorden, werd in dit deel van het onderzoek een empirische benadering gebruikt om de factoren te identificeren die de bereidheid van de industriële bedrijven beïnvloeden om te investeren in een InCES. Er werd een vragenlijst ontwikkeld op basis van door de literatuur gestuurde hypothesen en verdeeld onder een steekproef van 212 industriële bedrijven in vijf verschillende industriële clusters in Arak.

Uit de resultaten bleek dat economische factoren een cruciale indicator zijn voor de bereidheid van industriële bedrijven om in een InCES te investeren. De industriële ondernemingen waarvan de belangrijkste besluitvormers milieubewust waren, waren ook meer bereid om in een InCES te investeren. Voorts is de rol van de sociale identiteit een essentiële factor voor bedrijven om te overwegen in een InCES te stappen, aangezien dit hen helpt om in hun gemeenschap als sociale en ecologische pioniers te worden gezien. Enerzijds hield het ontbreken van vertrouwen in andere deelnemers een negatief verband met de bereidheid van bedrijven om in een InCES te investeren. Anderzijds was het hebben van vertrouwen in de beloften van de overheid niet significant gecorreleerd met hun bereidheid om in een InCES te investeren. Dit betekent dat de bedrijven in Arak een InCES zien als een collaboratieve bottom-up benadering. In tegenstelling tot het geval van huishoudens in KMO's blijkt "eigendom" een kritieke factor te zijn voor industriële bedrijven. Industriële bedrijven zijn dan ook eerder bereid in een InCES te investeren als hun aandeel gemakkelijk en wettelijk verhandelbaar is.

Interessant is dat uit de resultaten blijkt dat de grotere ondernemingen in een industriële cluster een belangrijke rol spelen bij het initiëren van dergelijke projecten. Het blijkt dat grotere bedrijven meer bereid zijn om de risico's van deelname aan projecten met een lagere ROI te aanvaarden en een groter deel van hun jaarinkomsten toe te wijzen als zij besluiten deel te nemen aan een InCES. Grotere bedrijven zijn ook meer geneigd het leiderschap van een InCES op zich te nemen.

In tegenstelling tot wat werd verondersteld, vonden wij geen correlatie tussen de omvang van het elektriciteitsverbruik en de bereidheid van de industriële bedrijven om deel te nemen aan een InCES. Belangrijk is echter dat de motivatie om deel te nemen aan een InCES groot is bij bedrijven die verwachten dat de elektriciteitsprijzen aanzienlijk zullen stijgen. Deze motivatie lijkt het grootst bij energie-intensieve bedrijven die rechtstreeks op het hoogspanningsnet zijn aangesloten, zoals bedrijven die inductieovens met een hoge capaciteit exploiteren. Ook is gebleken dat bedrijven die zich meer bewust zijn van de voordelen van toetreding tot een InCES en bedrijven waarvan de besluitvormers geloven in de kracht van goede instellingen om een InCES te besturen, meer geneigd zijn om erin te investeren.

Rol van stimuleringsmechanismen ter ondersteuning van de oprichting van InCES

Op basis van de bestaande financiële stimuleringsregelingen die wereldwijd zijn ingevoerd, is in dit deel van het onderzoek de rol van drie specifieke stimuleringsmechanismen bij de oprichting en voortzetting van een InCES onderzocht. De onderzochte stimuleringsmechanismen zijn: a) een feed-in-tarief (FIT), b) een fiscale stimulans, en c) verhandelbare groene certificaten. We gebruikten een agent-based modelling (ABM) en simulatie aanpak om de effectiviteit van de drie stimuleringsmechanismen in het stimuleren van InCESs te vergelijken. De simulaties vonden plaats in zes verschillende culturele omgevingen, afgeleid van de culturele dimensietheorie van Hofstede, en de besluitvormers werden gemodelleerd volgens de organisatorische beslissingstheorie van Scharpf. In elk van de modelruns wordt een periode van 20 jaar gesimuleerd. Elk gesimuleerd bedrijf beslist jaarlijks of het zich al dan niet aansluit bij het InCES. De combinatie van de organisatorische beslissingstheorie van Scharpf en de culturele dimensietheorie van Hofstede om de besluitvorming van bedrijven in verschillende culturele omgevingen te conceptualiseren, zoals opgenomen in ons ABM, is de eerste in haar soort.

Uit de simulaties blijkt dat het FIT-mechanisme het slechtst presteerde bij het stimuleren van de oprichting van een InCES bij de industrie. De TAX-stimulans presteerde daarentegen het best bij het mobiliseren van investeringen in de InCES. Evenzo presteerde de TAX-stimulans relatief beter op het gebied van elektriciteitsopwekking, het aantal opgerichte InCES en het aantal bedrijven dat zich bij elke InCES aansluit. Ondanks de betere prestaties van de fiscale stimulans was het ook de duurste optie voor de regeringen, aangezien een aanzienlijk deel van de oprichtingskosten van een InCES op de schouders van de regeringen terechtkwam.

Interessant is dat de verhandelbare groenestroomcertificaten, die vergelijkbaar zijn met koolstofobligaties, een relatief identieke doeltreffendheid vertoonden en tegelijkertijd om twee redenen voordeliger waren. Ten eerste waren ze minder duur voor de regeringen in vergelijking met TAX-stimulansen. Ten tweede stimuleert het marktmechanisme het gebruik van de beste hernieuwbare technologieën en verhoogt het de efficiëntie van het hele systeem. Bovendien kan het extra inkomstenstromen creëren voor de industrieën, waardoor meer financiële flexibiliteit in hun bedrijfsmodel ontstaat.

Bovendien bleek uit deze simulatiepraktijk dat ondanks de uitgesproken verschillen in de maatschappelijke kenmerken van de verschillende landen, het aantal uittredingen uit InCES niet significant verschilde, hetgeen erop wijst dat als een InCES economisch voordelig is, de maatschappelijke onaantrekkelijkheid van een InCES (wanneer er maatschappelijke conflicten tussen InCES-leden bestaan) door de leden kan worden verwaarloosd.

De rol van interne institutionele regelingen bij de oprichting en de continuïteit van een InCES

Om verschillende institutionele regelingen voor het interne bestuur van een InCES te vergelijken, werd een tweede simulatiemodel ontwikkeld dat specifiek gericht was op het geval Arak en gebruik maakte van de enquêtegegevens daarvan. Dit model onderzocht de rol van verschillende institutionele regelingen bij de oprichting en instandhouding van een InCES.

Geïnspireerd door de acht ontwerpprincipes van Ostrom werden drie institutionele regelingen ontworpen en gesimuleerd. De eerste instelling had tot doel het lidmaatschap van InCES te beperken tot in aanmerking komende bedrijven die een achtergrondcontrole op hun elektriciteitsverbruik en financiële geschiedenis doorstaan. De tweede instelling houdt in dat een contract wordt ondertekend voor toetreding tot een InCES om een geordend elektriciteitsverbruik af te dwingen. En ten slotte is er de derde instelling die alleen het cumulatieve elektriciteitsverbruik van alle leden in aanmerking neemt en erop toeziet dat dit niet meer bedraagt dan de vastgestelde capaciteit van de elektriciteitscentrale. Deze instelling vervangt het individuele toezicht en beperkt de toegang van investeerders niet door strenge achtergrondcontroles, hetgeen resulteert in soepelere lidmaatschapsvoorwaarden en er tegelijkertijd voor zorgt dat het elektriciteitsverbruik van de InCES-deelnemers de collectieve capaciteit van de centrale niet overschrijdt.

Uit de simulatieresultaten blijkt dat het door de elektriciteitsmaatschappij in Iran aangeboden elektriciteitstarief de individuele overgang naar duurzame energie vrijwel onmogelijk maakt, aangezien het huidige tarief wordt gesubsidieerd, zodat de berekende LCOE in geen geval concurrerend genoeg kan zijn. Daarom is collectieve stroomopwekking en vraagbeheersing binnen een InCES de meest haalbare oplossing voor de overgang naar duurzame energie voor industrieën, gezien de elektriciteitstariefregelingen in Iran.

De toepassing van strikte toetredingsregels vermindert het aantal uittredingen uit de InCES aanzienlijk, terwijl tegelijkertijd het aantal toetreders wordt beperkt. De toepassing van de tweede instelling, die overconsumptie van elektriciteit tracht te beperken, vermindert effectief het aantal problematische gebeurtenissen (meer elektriciteit verbruiken dan verwacht of de maandelijkse premies niet op tijd betalen) en uiteindelijk de uittreding van de leden. Maar het beperken van het energieverbruik op basis van het investeringsbedrag zou in de praktijk een uitdaging zijn. Ten slotte presteerde de derde instelling, die het lidmaatschap niet beperkte en het energieverbruik niet beperkte op basis van de investering, het best. Dit betekent dat indien de elektriciteitscentrale wordt ontworpen met 15% overcapaciteit, de kans op een elektriciteitstekort voor het gehele systeem marginaal zou zijn omdat het meestal voorkomt dat terwijl een lid overconsumeert, de kans groot is dat een ander bedrijf minder verbruikt dan verwacht.

Van de drie gesimuleerde institutionele ontwerpen levert het derde, met een holistische visie op het elektriciteitsverbruik van alle leden in plaats van toezicht op het individuele verbruik, een robuuster InCES-bestuur op. Tegelijkertijd mag het lidmaatschap van een industriële onderneming niet worden bemoeilijkt door strikte lidmaatschapsvoorwaarden (het opleggen van strikte contractuele voorwaarden aan elke deelnemer aan de InCES).

Hoewel de invoering van goede instellingen bij het opzetten van een InCES een aanzienlijk effect heeft gehad op het terugdringen van het aantal leden van een InCES, zullen er altijd enkele uittredingen zijn als gevolg van de verschillen tussen de industrieën wat betreft hun maatschappelijke kenmerken in collectieve instellingen en de manier waarop zij dergelijke verschillen tolereren. Daarom wordt verwacht dat een klein maar onvermijdelijk percentage leden van de InCES een dergelijk project zal verlaten vanwege het genoemde probleem, zelfs als hun lidmaatschap economisch voordelig is.

Discussie en conclusie

Bestudering van de haalbaarheid van InCES in een uitdagend geval als Iran kan een sterke evaluatie opleveren van het potentieel van InCES in minder uitdagende scenario's. De casestudie van Arak is ook gekozen vanwege de toegankelijkheid van de gegevens, vooral gezien de COVID-situatie waarin dit onderzoek is uitgevoerd.

Uit dit onderzoek is gebleken dat ondanks alle technische uitdagingen en kwetsbaarheden van het bestaande beleid, een geleidelijke overgang naar hernieuwbare energie in de Iraanse industriële sector haalbaar en op lange termijn gunstig is. Door toe te treden tot een InCES kunnen bedrijven de risico's in verband met onzekere elektriciteitsvoorziening en de potentiële stijging van de elektriciteitsprijs verminderen. De biofysische kenmerken van de industriestad Arak, zoals de casestudy in dit onderzoek, wijzen op een veelbelovend potentieel voor zowel wind- als zonne-energie. Tegelijkertijd lijkt zonne-energie de belangrijkste optie, gezien het fotovoltaïsche vermogenspotentieel tussen 1680 en 1826 kWh/kWp en een gemiddelde van ongeveer 300 zonnige dagen per jaar met een dagelijkse piekzon van 4,5-5,5 kWh/m2. Bovendien is de toegang tot zonnetechnologieën in de context van Iran praktischer dan die tot windenergie.

Hoewel de door de Iraanse regering ingevoerde financiële stimulansen inconsistent en relatief weinig doeltreffend zijn om de investeringen in de richting van InCES te mobiliseren, kan de kostenloze transformatie en transmissie van opgewekte duurzame energie in het bestaande elektriciteitsnet een zeer aantrekkelijke technische stimulans voor de regering zijn, waardoor bedrijven meer ruimtelijk optimale locaties kunnen overwegen om de duurzame energiecentrale te vestigen.

Gezien de kritieke rol van de grotere industriële bedrijven, worden op maat gesneden stimuleringsmaatregelen voor deze bedrijven ten zeerste aanbevolen aan de beleidsmakers, aangezien actieve deelname van de grote bedrijven ook meer KMO's aan boord zou brengen. Ook het gebruik van relevante adviesbureaus als tussenpersonen om de industrie meer bewust te maken van de voordelen van deelname aan een InCES lijkt een duidelijke invloed te hebben op de belangstelling van de industrie voor investeringen in InCES.

Dit onderzoek werd uitgevoerd in de context van Iran met zijn unieke sociaal-economische en politieke kenmerken. Toch zijn veel van de bevindingen van dit onderzoek ook generaliseerbaar naar de industriële sectoren in andere landen. Ten eerste zijn de meeste economische en politieke kenmerken van Iran (zoals het sterk gesubsidieerde elektriciteitstarief, de beperkte toegang tot duurzame technologieën en de hoge rente) in feite contraproductief voor de totstandbrenging van een InCES in de industrie. Maar zelfs met deze uitdagingen is het initiëren van InCES onder Iraanse bedrijven nog steeds een haalbare en zelfs veelbelovende optie. Als zodanig zou deze collectieve oplossing nog praktischer zijn in landen met stabielere economische en politieke omstandigheden. Bovendien kunnen de in dit onderzoek bestudeerde factoren worden beschouwd als generieke kenmerken van industriële ondernemingen wereldwijd (bv. besluitvormingsproces, economische beoordeling en technische vereisten voor het opzetten van een InCES), wat de generaliseerbaarheid van de meeste resultaten aangeeft.

Bovendien kan uit de resultaten van dit proefschrift worden afgeleid dat de sterk gesubsidieerde elektriciteitsprijs in Iran de InCES-aanpak economisch aantrekkelijk maakt. In andere landen daarentegen, met geliberaliseerde elektriciteitsprijzen, lijkt de individuele overgang naar HE een meer geschikte optie. Er zij op gewezen dat de oprichting van InCES ten eerste bijdraagt tot de vermindering van een aanzienlijk deel van de investeringskosten en ten tweede tot een aanzienlijke tijdsbesparing doordat minder tijd nodig is voor het verkrijgen van vergunningen voor de collectieve elektriciteitscentrale dan bij de individuele aanpak. Daarom lijkt de InCES-aanpak de optimale oplossing voor de industriële overgang naar RE.

Naast de specifieke resultaten die tot nu toe zijn samengevat, draagt dit onderzoek bij aan de bestaande literatuur over samenwerking tussen industrieën op het gebied van IS door de lens van collectieve actie te gebruiken. Het benadrukken van de uitgesproken verschillen tussen de industrieën wat betreft hun besluitvormingsstijl en de vereiste voorwaarden voor industrieën om te investeren in InCES is de belangrijkste wetenschappelijke bijdrage van dit onderzoek, waaraan in de bestaande literatuur over industriële energietransitie geen aandacht is besteed.

Voor toekomstig onderzoek zou een vergelijking van de invoering van InCES in de industriële sectoren van andere ontwikkelde/ontwikkelende economieën een veel helderder licht werpen op de rol van deze aanpak in het traject van een industriële overgang naar duurzame energie. Bovendien hebben wij in dit onderzoek een on-grid ontwerp voor de collectieve energiecentrale voorgesteld om de basislastbehoefte in de industriële clusters naar behoren op te vangen. Tegelijkertijd zou een off-grid ontwerp met een industrieel elektriciteitsopslagsysteem ideaal zijn om volledig te voldoen aan de klimaatdoelstellingen. Daarom lijkt, ondanks de inzichten die dit onderzoek heeft opgeleverd, het onderzoek naar de integratie van een industrieel cluster met een off-grid InCES-ontwerp en de manier waarop dit functioneel kan zijn door innovatieve bedrijfsmodellen en beleidsinstrumenten een valide onderzoeksgebied voor toekomstige studies.

Chapter 1: Introduction

1.1 Research motivation

The industrial sector plays a leading role in supporting economic growth and it is responsible for almost one-third of global energy use [1]. A crucial condition for industry to thrive is the provision of reliable and affordable energy services [1]. As such, energy supply security and price stability are essential concerns for energy policy-making, which is increasingly challenging for two reasons. First, climate policy ambitions necessitate governments to phase out fossil fuels from the energy mix and increase the share of renewable energy sources, according to COP26 [1]. As wind and solar energy replace fossil fuels in the power generation mix, electricity production is becoming more variable (weather dependent) and electricity prices more volatile. Second, as industry itself is also forced to phase out fossil fuels, many high temperature processes which are currently driven by fossil fuel combustion, especially in the chemical and metal industry, will in the future be replaced by lower temperature e.g., electrochemical conversion routes [2,3]. The industrial electricity demand is thus expected to increase substantially in the future [4].

The aforementioned developments prompt industrial corporations to rethink the provision of electricity in the future. In many developing countries, however, the challenge is of a more urgent nature, especially as industrial development there may be thwarted by lagging investment in generation and infrastructure capacity, resulting in more or less frequent interruptions of electricity supply [5].

Industries can structurally improve their energy security and reduce greenhouse gas emissions through investments in improving industrial energy efficiency and through transitioning from fossil fuels to renewable energy sources. Transitioning to a larger share of electricity in the industrial energy mix would facilitate a larger share of renewable energy sources. In this transition effort national governments also have an important role to play, both in their capacity as owners or shareholders of electricity infrastructure and as energy policy makers. The industrial sector itself can adopt an active role in this transition, especially as renewable energy technologies allow for decentralized power generation at a smaller scale than traditional fossil-fueled thermal power plants. Like households, industrial companies may thus choose to deploy their own premises for renewable power generation through wind turbines and photovoltaic arrays.

Considering the energy intensity of many industrial operations, however, industrial companies may find they lack the physical space and/or the investment capital needed for sufficient power generation from renewables to cover their own needs. Inspired by community energy systems (CES) established by households, this thesis investigates if community energy systems may also be established among industries: are Industrial Community Energy Systems feasible and under what conditions can they emerge? In order to find answers to these questions, we start with a literature review on Community Energy Systems and on industrial collaboration in the context of Industrial Symbiosis (e.g., eco-industrial parks).

1.2 Literature review

1.2.1 Industrial symbiosis (IS)

Industrial Symbiosis (IS) focuses on the cooperative management of resource flows through firms' networks. It involves the broader field of industrial ecology, which examines the sustainability of material and energy flows through industrial systems. IS seeks to facilitate the physical exchange of materials, energy, water, and by-products [6] and the exchange of non-material resources, such as knowledge and expertise [7]. Companies can also share utilities, such as energy, water, and wastewater treatments, and services, such as transportation, landscaping, and waste collection services [8]. The main drivers of IS are the economic and environmental benefits realized by the mutual exchange of complementary resources [9,10], as well as the tightening of emission and waste management regulations [11]. In a broader sense, IS aims to support sustainable industrial development strategies and implement modern technologies, eco-innovations, and cultural change in organizations [7,9,12]. Geographical proximity of the firms participating is considered an essential feature of IS given the infrastructure needed for (waste) material exchanges (the cost of which would be prohibitive over long distances), the importance of trust, [2,8], and the sharing of information and norms within social networks [13]. This geographical focus is reflected in the other commonly used term for IS networks: eco-industrial parks [10,14]. Repeated interactions and geographical proximity often lead to the creation of shared norms that influence actors' behaviours and patterns of relationships [13]. There are many examples of successful IS networks globally [15]. Many countries, including European countries and China, have also implemented national-level programmes to promote IS [16–18].

Some researchers have taken an institutional perspective on IS and examined the impacts of regulations, norms, and cultural–cognitive aspects on the emergence and development of IS networks. For instance, supportive regulations [11,19] and informal norms [13] are significant for the emergence of IS networks and their institutional capacity [20]. Institutionalization in mature IS networks is often characterized by a formal organization facilitating the network's activities, such as the regional government or the local authorities [21]. Network-level analyses in IS focus on relationships among industries, as well as governmental and societal organizations involved as knowledge providers or coordinators (e.g., consulting companies) [22]. The geographical proximity of the involved actors leads to embeddedness, such that IS relations are often tied to existing informal relations among actors [11], also known as "close mental distance" [13]. IS networks develop over time through three primary mechanisms: a) self-organization, b) facilitation by organizations or individuals, and c) central planning [18,21,23]. The mentioned mechanisms are seen as the required aspects for a proper IS network development. It should be noted that they either happen all together in parallel in one case or one or two mechanism(s) dominate(s) in a particular instance.

Although many studies on IS development have focused on the self-organization versus central planning dichotomy [24], others have considered the in-between perspective of a coordinator tasked with finding potential partners among participating companies [18,22].

For example, the UK's National Industrial Symbiosis Programme (NISP) facilitates the formation of IS relationships by sharing information and analysing potential exchanges among participating companies [11]. Organizational-level studies have typically examined IS activities by assessing the benefits or barriers for individual firms to engage in IS [21] or how to achieve IS in single facilities [25]. However, there is a considerable lack of research on, for example, how firms decide to engage in IS [15]. In this regard, Mileva-Boshkoska et al. [26] modeled and evaluated the possibilities of forming a regional IS network among industries. In their modeling, they focused on the role of social forces as they consider IS networks to be social networks. They see stakeholders in IS networks (e.g., enterprises, households, policy actors) as social actors operating in the context of bounded rationality: the actors are limited in their rational decision-making not only by their own inherent organizational values but also constrained by the decisions of other organizations. Since the physical exchange of energy and materials occurs between social actors and requires cooperation, communication, and a certain level of trust, its development can be studied by sociological research. In this particular modeling study, the authors considered three types of social forces, namely: a) institutions (formal laws, the formal mechanism for political rule-making and enforcement), b) social networks (social structures made up of a set of social actors such as individuals or organizations, and a set of dyadic ties between these actors) and c) cognitive frames (social interaction, and strategically-selective opportunities for reflection and learning) [26]. It is worthwhile mentioning that in the mentioned studies in the field of IS, the institutions are mainly referred to as the formal laws and regulations in a top-down manner which are determining the ways IS can be facilitated or hindered in its development. These studies highlight the formal rules to which the relationships between the IS stakeholders and the authorities (legislative entity) are subjected.

Mortensen and Kørnøv [27], in a recent study, highlighted the necessity of distinguishing between different phases of an IS network emergence and development. In their research three key stages are identified: 1) awareness and interest in industrial symbiosis, 2) reaching out and exploring connections, and 3) organizing. Furthermore, five groups of critical factors: contextual conditions, actors, actors' roles, actors' characteristics, and actors' activities, are identified which influence the development process in different degrees at different times in the process.

Accordingly, it is discussed that we have little understanding of the decision-making processes at the individual-company level and of the role of individual companies in local/regional IS initiatives. Such processes are vital since the reuse of waste materials in IS, while potentially profitable, generally falls outside a firm's core business strategies. Thus, visionary and far-sighted individual industrial companies, often referred to as "champions", are needed to push forward new types of regional interaction, including complex relational efforts in which individual-level agency plays a key role [27,28]. Champions are individual companies that stand out through their innovativeness, willingness to take risks, and transformational leadership styles [29]. Such individual companies typically possess technical competence, knowledge about the industry, knowledge about the market and political access

[30]. Champions play an important role in how IS networks evolve, especially in the nascent phase of an IS network [31].

1.2.2 Community energy systems (CES)

In traditional power systems, power is generated by central power plants, transmitted over high voltage lines to transformation and distribution stations, and then supplied to the end-users. The activities involved in electricity supply from the producers to the end-users include generation, transmission, distribution, and supply (retail) [32,33]. Generation in large power systems takes place in large-scale power plants, such as nuclear, gas, oil and coal-based generators, which are centralized and controllable. Generation can satisfy load at all times with an appropriate dispatch of these power plants. The costs associated with large power systems include the costs for conducting generation, transmission, distribution and supply (retail) activities [34]. Typically, in the traditional setting of a fully regulated energy market, with a vertically integrated supply chain, the total revenues of power system operators (regional or national monopolists) are covered through regulated tariffs which guarantee cost recovery. In a deregulated or liberalized electricity market, generation and supply become competitive activities, the electricity market determines the energy price, while transmission and distribution remain natural monopolies under regulation [33]. Deregulation of power generation has paved the way for new market entrants introducing new technologies and energy resources, especially renewable energy resources into the established power systems. In recent years, large-scale solar panels and wind turbine power plants are being integrated into large power systems to substitute non-renewable energy sources. In deregulated electricity markets, energy tariffs are partly market-based (generation and supply), partly regulated (transmission and distribution). Tariff design must guarantee cost recovery for producers, suppliers and network operators, and ensure a fair allocation of costs to system users. The application of appropriate and fair tariffs provides short-term and long-term signals to system users, thus contributing to the long-term stability and efficiency of the energy system [35].

With the new technologies for harvesting renewable energy resources, especially wind and solar power, small-scale power generation at the scale of households and small businesses has become economically feasible and widely popular, also thanks to targeted incentives by many governments. These new technologies have enabled the emergence of Community Energy Systems (CESs), local community energy systems consisting of two fundamental components: local distributed energy resources (DER) and a local community [36]. The power is generated from local DERs (such as solar panels and small-scale wind turbines) and directly delivered to local consumers. Customers in CESs have the right to invest in DERs, making them prosumers. CESs also enable local energy exchange and sharing activities. Prosumers can trade their surplus energy in the community, while they are required to purchase energy in CESs. CESs act as an aggregator in the context of this study, dealing with the activity of energy exchange and collective energy purchase from or selling to the grid. CESs can be connected to the central grid or operate in an off-grid fashion. The latter may be the case in remote areas where access to the grid is lacking. In off-grid CESs energy storage units will be required to handle the intermittency of wind and solar power, which adds to the costs of CES. Given sufficient energy storage capacity, a CES can be entirely self-sufficient [35]. In grid-connected CES the grid usually serves as a battery for back-up power.

Community energy systems (CESs) emerged in the transition of local energy systems by integrating local communities and DERs [36]. CESs focus on the local landscape by managing local energy generation, delivery, and exchange to meet local energy demand either with or without grid connection. They aim at improving the performance of local energy systems, for example, by improving energy efficiency, increasing DERs penetration, reducing energy costs, and contributing to CO2 reduction. Different actors are included in CESs, such as investors, local community members (consumers and prosumers), energy service providers, and system operators, which add social attributes to CESs. From an economic perspective, these actors are also considered stakeholders in CESs. Costs and benefits, as well as advantages and disadvantages, must be shared among them fairly. Therefore, CESs are considered comprehensive energy systems, which add technical, economic, environmental, and social merits to the local energy system landscape [37–39]. CESs allow local communities to control the energy systems fully since they can invest, produce, sell, purchase, and consume energy inside the community.

Since CESs are a rather new phenomenon, many challenges exist in their implementation, varying from technical, socio-economic, environmental, and institutional issues [39–41]. For instance, high initial investment costs may hamper the development of CESs. Furthermore, non-similar incentive problems make some members net beneficiaries, whereas others will become net contributors. This problem in CESs is often caused by the fact that the party which made the investment does not automatically reap the associated benefits [16,17]. It is of great importance that costs and benefits are allocated in a fair way in a CES, and therefore, this is an important factor preventing the emergence of conflicts among members of a CES.

The investments made in CESs vary from individual household level to community level. In principle, the costs should be paid by those who consume energy and use energy-related services in the system, and the benefits should be assigned to those who made the investments [39]. Accordingly, Li et al. [35], in a recent study, reveal the crucial role of a fair cost allocation among the members of a CES. They revealed that a fair cost and benefit allocation in CESs helps to enhance the cooperation of local community members and thus the engagement of the local community in its entirety. Local communities are the fundamental actors that CESs do not exist without. Therefore, it is important that local community members remain engaged with the CES. This also contributes to avoiding free-rider behaviour with certain members being able to use the service for free or at too low a cost, while others are paying too much. Moreover, a fair sharing of costs and benefits and acknowledgement of the preferences and opinions of the local community members is crucial for the social acceptance of CES [35]. As a CES cannot exist without the engagement of the local community members, the importance of social acceptance for a CES' robustness cannot be underestimated.

Apart from the cost allocation aspect of CESs, the socio-economic aspects associated with a CES establishment play a critical role. In a recent publication, Joshi and Yenneti [42] investigated cases of CES in India and concluded that the expansion and scalability of community energy projects in India, as a developing economy, needs combined policy support of both “participatory approach” and “top-down approach”. In developed economies, CESs are often established by bottom-up consumers initiative, as many consumers are willing to pay more for energy from renewable resources. For instance, 92% of Germans advocate the growth of renewable energy supply and are willing to pay more for electricity from renewable resources [43]. Germany is one of the countries where many communities of households and small businesses successfully established collaborative energy systems. Targeted financial incentives, such as attractive feed-in-tariffs, play an important role in the willingness of households to invest in decentralized electricity production from renewable resources [44]. Economic stability, inflation, and interest rates are important in deciding whether to invest in projects with long payback periods. Environmental motivations are the major driving force behind the surge in CES implementation in many developed countries [45]. Together with the improvement in efficiency and reliability, CESs are seen as an environmentally friendlier alternative to the centralized power supply system [46].

The extent of social connectedness among community members is another crucial factor influencing their willingness to engage in community initiatives rather than individual actions [47]. The stronger the community identity, the stronger the collaboration among households/citizens [48]. Furthermore, the literature shows that trust is essential for establishing a community energy project [49–51]. These perceptions are typically embedded in a society’s social norms. In a fragmented society, the chance of establishing a cooperative would therefore be marginal [52,53].

1.3 Research gap, study objectives and research questions

Reviewing the literature on IS and CESs, we see great similarity between the two bodies of knowledge, especially in the common principle of collaboration occurring in a social platform within which the social attributes of the actors are key influential factors. We hypothesize that this conceptual model is equally applicable to the emergence and development of Industrial Community Emergy Systems (InCESs).

It should be noted that the current literature on IS only briefly touches on the role of institutions (as the formal and informal rules and legislations between the IS network members and the legislative entity) in initiating and developing IS networks. However, institutional mechanisms are essential for collective action situations such as the ones in IS. Moreover, the decision-making process of the stakeholders involved in the emergence of such collective action also plays a considerable role that requires further investigation.

Although the current literature on CES gives more focus and attention to institutions and coordination mechanisms, this literature only addresses community energy systems where the members are households and small businesses. These entities, however, practice a considerably different style of decision making in comparison with industrial firms, and business entities requirements regarding coordination differ from households. For instance, a decision made by a household seems to be highly influenced by the personal preferences of the decision-makers, whereas the decision making in an industrial company follows a well-structured process in which the corporate benefits are the highest priority factors. An industrial company is unlikely to invest in RE unless it is economically beneficial and supportive of the company's continuity. Loyalty to the local industrial community or the establishment of an environmentally friendly corporate image may play a role, but as such are deemed insufficient justification for substantial investment. Furthermore, industrial companies, as business entities, should take into account that investing in an InCES as a shared investment project, comes with risks and uncertainties associated with the shared investment, ownership, operations, and facilities which could potentially be troublesome for an industrial company.

To summarize, collective electricity production from renewable energy sources in an InCES is not only a potentially viable solution for the energy transition in the industrial sector but also a new area of research that has not received much attention in the literature. Yet, the literature on IS and CES both miss the critical aspects of the social process within which such collective action can be established. That is: the institutional mechanisms that enable and facilitate such collective action and the decision-making process that leads to the emergence of those institutions. Thus, this research aims to study how industries in an industrial cluster can coordinate to establish and manage an InCES in order to produce electricity from renewable energy sources to meet their electricity demands.

Accordingly, the main question of this study is:

"How can industries establish and manage InCES in industrial clusters?"

To answer the main question, it is necessary to answer the below sub-questions:

1) Which characteristics of industrial clusters are relevant for establishing an InCES?
2) What socio-economic-environmental factors affect the willingness of the industrial companies to engage in an industrial community energy system?
3) Which incentive mechanisms can support the establishment and durability of an industrial community energy system?
4) What internal institutional arrangements can industries use for the successful establishment/management of an industrial community energy system?

1.4 Research approach

Given the definition of collective action as: " the action taken by a group (either directly or on its behalf through an organization) in pursuit of members' perceived shared interests'" [57–60], it appears that a collective action approach is a promising theoretical lens to study the formation of InCESs.

Collective actions naturally deal with shared resources and services [61,62]. In managing a common pool resource (CPR) (like fishes in a fishery) or a shared infrastructure (like an irrigation system) communities face so-called collective action problems. For example, in collective actions, a number of individuals may act in their own self-interest and pursue a course of actions that will not result in the ideal collective outcome. This may happen because of different trust [63] and autonomy levels among individuals or to circumvent the imposed risks and expenses by the collective action. This phenomenon is known as the "prisoner's dilemma" in game theory literature [64] which can be a severe barrier in collective action projects [65–67]. Also, the so-called free-rider[1] problem [68], which can result in the tragedy of the commons[2] [69–71] has always been a part of collective action problems.

Besides the collective action problems, different trust and autonomy levels among involved industrial actors can be crucial factors impacting the dynamics of such collaboration.

Elinor Ostrom [59] highlighted that in order to have a stable collective action, eight design principles should be taken into consideration as below:

1. Clearly defined boundaries
2. Congruence between appropriation and provision rules and local conditions
3. Collective-choice arrangements allowing for the participation of most of the appropriators in the decision-making process
4. Effective monitoring by monitors who are part of or accountable to the appropriators
5. Graduated sanctions for appropriators who do not respect community rules
6. Conflict-resolution mechanisms which are cheap and easy of access
7. Minimal recognition of rights to organize (e.g., by the government)
8. In case of larger CPRs: Organization in the form of multiple layers of nested enterprises, with small, local CPRs at their bases.

This research takes a collective action perspective in studying the feasibility of industrial collaboration and the institutional mechanisms that can facilitate such initiatives. This unique angle has never been applied to cases of collaboration among industries, including the rich literature on industrial symbiosis, where various forms of collaboration among industries are covered. The collective action lens can provide novel insights into institutional mechanisms that would support the successful establishment and continuity of industrial energy communities.

1.5 Research methodology

To answer the research questions, different forms of research were conducted: theoretical, empirical, and modeling studies. To perform the theoretical and empirical steps of this research, Arak industrial city, one of the most prominent industrial cities in Iran, was selected as a case study. The reason behind the selection of this case study stems from the maturity of Arak industrial city regarding the variety in types of industries and the large number of active companies distributed in six different industrial clusters.

The diversity of industries in Arak industrial city is vast. The six different industrial clusters (grouped by area) contain industries with vastly different electricity consumption patterns:

- Part-making industries (steel parts)
- Textile industry

[1] In economics the free-rider problem happens when those who benefit from resources, goods, or services do not pay for them [89]

[2] The tragedy of the commons is an economic theory of a situation within a shared-resource system where individual users acting independently according to their own self-interest and behave contrary to the common good of all users by spoiling that resource through their collective action.

- Chemical and petrochemical industry
- Polymer industry
- Food industry
- Mineral industry
- Aluminum industry (aluminum parts)
- Aluminum industry (making aluminum bar from Alumina)

According to Iran's Ministry of Industry, the size of industrial companies is classified based on the below characteristics:

- Small size industries: companies with below 50 workers
- Medium-size industries: companies with between 50 to 150 workers
- Big size companies: companies with more than 150 workers

About 80% of the industries in Arak are small and medium sized companies. More than 90% of the companies in Arak are private companies. Due to the long-term vision of Iran's government to privatize all state-owned companies, the rest 10% of companies are currently in a hybrid situation where most of the stocks are owned by the private sector, and state-owned organizations are controlling some shares.

The methodological steps used in this research are divided into three categories as a) theoretical studies, b) empirical studies, and c) modelling and simulation.

1.5.1 Theoretical study

As previously discussed, based on the goal of this research and the approach we have defined, the Institutional Analysis and Development (IAD) Framework was selected as the theoretical frame for this research. Large differences in the development of RE cooperatives have been observed among different countries. Various factors have been explored to explain such disparity. Formal institutions, like incentive mechanisms for renewables, along with societal norms such as attitudes toward the cooperative model and cultures of local energy activism, have been identified as major influences on the occurrence of locally owned community energy systems [72–76]. Other explanations include biophysical and physical conditions and the actors' ability to act strategically to changes in their environment. In this work we strive to investigate how these factors interact in a systemic fashion rather than studying them in isolation [77–79]. The IAD Framework developed by the Noble Prize laureate Elinor Ostrom and her colleagues is a relevant analytical tool that is helpful in this task.

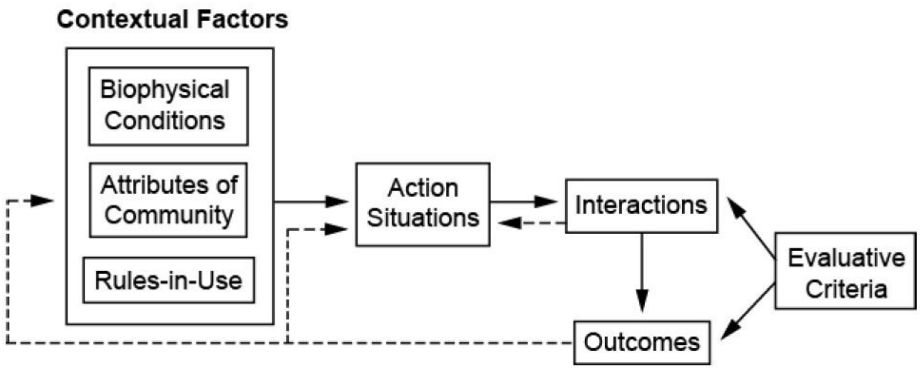

Figure 1: IAD Framework [80]

So far, the IAD framework has mainly been applied to socio-ecological systems, for which it was developed. Yet, in this research, we will be looking at an InCES as a socio-technical system, which begs the question if application of the IAD framework is justified. To address this issue, firstly, it is worth mentioning that McGinnis and Ostrom believed that although the IAD framework was introduced to analyse the sustainability of social-ecological systems (SES), it can also be applied to socio-technical systems [81]. After all, nowadays, it is almost impossible to find any ecological system that is entirely free from human interference. In this sense, by modifying the current framework, it would be applicable to socio-technical systems (STS) as well [82,83]. Secondly, regarding the applicability of the IAD framework to socio-technical systems, it is worth pointing out the similarities between SES and STS. Each social-ecological system consists of the below characteristics [84–86]:

a) A coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner
b) A system that is defined at several spatial, temporal, and organizational scales, which may be hierarchically linked
c) A set of critical resources (natural, socio-economic, and cultural) whose flow and use is regulated by a combination of ecological and social systems
d) A perpetually dynamic, complex system with continuous adaptation

As these characteristics equally apply to socio-technical systems, we conclude that the IAD framework is as applicable to socio-technical systems as it is to social-ecological systems.

Thirdly, Hodbod and Adger also discussed the framing of energy systems as social-ecological systems [78]. From this perspective, we also can build the conceptual framework of this research using insights from the IAD Framework. Also, Ghorbani [87] has explored this framework's applicability to STS and concluded that it could be applied without any modifications.

Therefore, to summarize, the IAD Framework seems fit to be applied in the context of STS.

1.5.2 Empirical study

To perform the theoretical and empirical analyses, and considering that we have chosen Arak industrial city as our case study, it is necessary to collect information on the existing situation of Iran's electricity system and the country's progress regarding the transition to renewables (visions, plans, incentives, etc.). In addition to an understanding of Iran's electricity sector, information about industrial clusters in Iran is required. The industrial diversity and large number of industries operating in Arak offer a representation of Iran's industrial sector in general.

Since the required data in this research consist of a wide range of information in both qualitative and quantitative types, below data gathering methods are carried out:

a) carrying out an extensive analysis of different types of databases like regulatory reports, legislation regarding RE generation and introduced incentives, and documents from relevant actors to collect quantitative data such as electricity tariff, electricity demand, etc.

b) Conducting surveys to gain insights into the general appreciation/willingness of the individual industries to engage in InCES

c) Conducting interviews with key actors (industry managers and executive board members, intermediary actors (consultancies), policymakers). The interviews were performed in both "semi-structured" and "open" fashion.

The collected data were used to perform theoretical analysis using the IAD Framework and the empirical analysis to identify the most impacting factors influencing the willingness of the industrial companies to invest in an InCES. This data will also be used in our modeling practice which is described in the next section.

1.5.3 The modeling study

Despite the broad literature on community energy systems (CES), the existing line of research focuses on their organizational structure, business and financial models, technology types, and members' characteristics [28–30]. Yet, scientific knowledge on how CESs are initiated, how they evolve through time, and how the government can support them is limited (e.g., [31–34]).

Moreover, the mainstream line of research on the mentioned topic relies on the results from existing case studies. Therefore, simulation techniques can be helpful in the generalization of the results, especially if it is complemented with real-world data. Among different modeling approaches, agent-based modeling (ABM), as mentioned previously, is the only approach capable of combining the economic and societal aspects of the formation of an InCES 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., [35–38]).

Employment of the IAD Framework in this research helps us to analyse the system as is, in the present time. Simulating the dynamics of interactions in an InCES over time is needed to provide further insights into the conditions that may lead to the initiation of an InCES and its durability. Modeling enables us to add the "time" dimension to our research while simulating different scenarios in different time frames, exploring significant correlations between inputs, variables, and outputs.

Amongst different modeling methods, agent-based modeling was selected as the preferred modelling approach, since we are interested in how the dynamics of interactions between the individual companies engaging in an InCES determine the evolution of the InCES over time. Agent-based models are frequently applied in policy-making contexts to explore and study various policy options. As Deadman [88] points out, "… *ABM is a bottom-up approach, and instead of defining the overall behavior, the overall system behavior emerges as a result of the actions and interactions of the individual agents"*. Using ABM allows us to define "actors", their decision-making strategies and social attributes, and simulate how these actors are interacting with each other in an InCES.

By implementing the IAD Frameworks' insights in an agent-based model, we were able to broaden the capacity of this framework by allowing for analysis of institutional dynamics in what-if scenarios in which we varied the decision-making style of the industrial companies and the cultural/social attributes of industries impacting their decision making and tolerance of collective investment. Therefore, we built our Agent-Based simulation model based on the insights from the IAD analysis, the empirical data collected from our case study, and the potential scenarios regarding financial incentive schemes and different institutional arrangements within an InCES.

Consequently, in this research, we used ABM to:

a) simulate the role of different financial incentives introduced by governments, which influence the cost-benefit analysis (CBA) performed by individual industrial companies when considering investing in an InCES.
b) Simulate how the societal attributes of InCES members impact the internal interactions among members, which is a crucial aspect for the durability of an InCES.
c) simulate the role of different institutional arrangements in the establishment/management of an InCES.

1.6 Scientific contribution

This research aims to contribute to the existing body of knowledge on collaboration among industries in Industrial Community Energy Systems as a means to accelerate the energy transition in the industrial sector. This research addresses a particular knowledge gap in the established bodies of knowledge on IS and CES, pertaining to critical aspects of the social process within which an InCES can be established. In this research, an InCES is considered a prime example of collective action, which is studied through the IAD framework. This research aspires to shed light on the institutional mechanisms that enable and facilitate such collective action and the decision-making process that leads to the emergence of those institutions.

1.7 Social relevance

The outcomes of this research can help in a better understanding of how successful collaboration can be staged between industries, especially with regard to the institutional requirements for the emergence and durability of Industrial Community Energy Systems. This would assist the industrial sector, policymakers, and society at large in accomplishing the energy transition.

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Chapter 2: Can Industries be parties in collective action? Community energy in an Iranian Industrial Zone

The industrial sector plays a huge role in creating economic growth. While energy is vital for industries to thrive, various factors are undermining the availability of energy including phasing out of fossil fuels, CO2 emission caps and, the large gap between the fast developments of industrial clusters and the energy supply, especially in developing countries.

Recently, enabled by renewable energy technologies, a transition process is taking place towards decentralized settings for energy provision where households in neighbourhoods initiate renewable electricity cooperatives. The question addressed in this research is if or to what extent the model of collective action deployed by citizen cooperatives is applicable to collaborations between industries in an industrial cluster.

We identified the conditions for the establishment of Industrial Community Energy Systems (InCES) from a collective action perspective by using Ostrom's Institutional Analysis and Development Framework. The case study selected is the industrial city of Arak, one of the largest and most diversified industrial clusters in Iran. Besides desk research, data was also collected by conducting semi-structured interviews and by holding stakeholder workshops.

The results of this study highlight the importance of community spirit and trust for the establishment of InCES, unlike citizen cooperatives where finance and environmental attitude are essential. A transparent legal framework to resolve conflicts that might emerge in industrial partnerships is another crucial element given the many differences among industries such as differences in energy demand and in usage patterns.[3]

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Abbreviation:

RES: Renewable energy sources

IAD: Institutional analysis and development

InCES: Industrial community energy system

CES: Community energy system

MOE: Ministry of energy

REC: Regional electricity company

PGMC: Power generation management company

DISCO: Distribution company

GENCO: Generation company

IGMC: Iran grid management company

IEMRB: Iran electricity market regulatory board

FIT: Feed-in-tariff

CPR: Common pool resource

CEO: Chief executive officer

kWh: Kilowatt hour

kWp: Kilowatt peak

MWh: Megawatt hour

PV: Photovoltaic

MW: Megawatt

CSP: Concentrated solar power

ISIPO: Iran's small industries and industrial parks organization

IRR: Iranian Rial

1. Introduction

The industrial sector plays a leading role in driving economic growth. A crucial condition for industry to thrive is the provision of reliable and affordable energy services [1]. As such, security of electricity supply and price stability are important concerns for energy policy making, which is increasingly challenging for two reasons. First, climate policy ambitions necessitate governments to phase out fossil fuels from the power generation mix and increase the share of renewable energy sources (RES)[1]. As wind and solar energy are replacing fossil fuels in the generation mix, electricity production is becoming more variable (weather dependent) and electricity prices more volatile. Second, as industry itself is also forced to phase out fossil fuels, many high temperature processes which are currently driven by fossil fuel combustion, especially in the chemical and metal industry, will in the future be replaced by electrochemical conversion routes [2,3]. The industrial electricity demand is thus expected to increase substantially in the future [4].

Aforementioned developments are important reasons for many industrial corporations to rethink the provision of electricity. In many developing countries, however, the challenge is of a more urgent nature, as industrial development there may be thwarted by lagging investment in generation and infrastructure capacity, resulting in more or less frequent brown-outs of electricity supply [5]. To tackle these challenges, one possible solution for industries is to self-generate the electricity required. For this strategy to be sustainable, only renewable energy resources apply. Besides the high initial investment, it is most often the limited availability of space that poses an unsurmountable hurdle for industrial plants to become self-sufficient [6].

Another approach, given the fact that industries are often located in industrial clusters, is to collectively produce electricity from renewable energy sources and collectively manage electricity demand. Instances of collective power generation and consumption are commonly referred to as "community energy systems" (CES) [7]. CESs are becoming increasingly popular among households in various neighbourhoods around the world. CESs are valuable in terms of self-sufficiency and sustainability [8]. Moreover, they contribute to decreasing the amount of power loss through the transmission and distribution grid. Therefore, a great deal of research is being directed towards their development [7,9–20] and one line of research in particular focuses on their bottom-up, self-organizing nature by viewing their management as a collective action problem [19,21–27].

Although CESs may also hold great potential for communities of industrial partners, to-date, energy management in industries has never been studied as a collective action problem. Given the great potential of community-driven energy management, and the challenges industries currently face, our goal in this research is to study whether industrial clusters can be considered as communities to collectively produce electricity and manage their demand.

In order to identify the conditions that lead to collective action for establishing an industrial community energy system, we use the Institutional Analysis and Development (IAD) framework [28] of the Noble Laureate, Elinor Ostrom. This framework has been proven effective in studying collective action problems [28] and has been successfully used to study CESs [21–27].

In this research, the IAD framework is applied to analyse the industrial cluster of Arak in Iran as a case study. This industrial cluster consists of seven distinct industrial zones with diverse types of industries and a large number of active industrial companies which are working with different working shift schemes and with different demands for electricity. Our goal is to study whether collective action is possible among industries in this case study, and to identify opportunities, challenges and barriers for such collective action. More specifically and given the factors raised by the IAD framework, we will be looking into the physical (both bio and technological), the social (i.e., community) and the institutional opportunities and barriers of establishing an industrial community energy system, which we will refer to as InCES in this paper.

The structure of this paper is as follows. In Section 2, the challenges for collective management of electricity in an industrial cluster are explained. In Section 3, we will discuss how a collective action lens can benefit this research. Section 4 presents the case study, electricity management in Arak, the role of the government in promoting renewable energy in the industrial sector and the data collection process. Section 5, delineates the systematic analysis of our case study using the IAD framework. In Section 6, we reflect on our findings. Finally, Section 7 provides the conclusion.

2. Challenges for Collective Management of Electricity in an Industrial Cluster

2.1. Existing collaborations among industries

Collective action is defined as: " the action taken by a group (either directly or on its behalf through an organization) in pursuit of members' perceived shared interests'" [29]. Collective action or collaboration between industrial companies is not new. There is an extensive body of literature on industrial symbiosis (IS) which is a well-known model of cooperation in which industrial companies exchange resources and by-products [30]. This sharing of resources results in the improvement in eco-efficiency of industrial clusters by reducing the use of virgin raw materials and industrial waste. Although the final goal of IS is to have a more sustainable and efficient industrial process in terms of both energy and raw materials, it principally has tight strings with "cyclical industrial activities" and the focus of this approach is on optimization of resource consumption as a result of collaboration between various industries [31]. Collaborative electricity generation in an industrial cluster as proposed here, is different from IS, in the sense that the main focus is entirely on electricity generation from shared RE sources and the challenges are primarily related to social collaboration among the industrial community members rather than optimization of production processes as in IS.

2.2. Key collective management challenges for industries

There is a comprehensive body of literature on the formation of CES for the case of private households [9,16,17,32–34] which is however not directly applicable to industrial communities. One of the main differences is related to the decision-making process. Decision making within and between private households is typically not structured by strategic and rational procedures [35,36] comparable to those of large industrial companies [37,38]. However, in the latter case, these are required for reaching consensus between different decision makers with different interests and viewpoints (referred to as political decision making) [39–44].

In addition to the decision-making process, InCESs face many technological, socio-economic, environmental and institutional challenges different from those of communities of households [45]. Industrial firms have higher demands for electricity with more stringent requirements on the availability and quality of electricity service provision. There are also much more pronounced differences in electricity consumption patterns between firms compared to households in a 'conventional' community energy system. Therefore, reaching consensus between industrial participants of an energy community may be much more challenging than in a household setting where the members have similar demands [46].

The diversity of energy demand in industry largely stems from the different needs of industrial production processes. For example, while in process industries, production processes are often continuous or semi-continuous, manufacturing industries (producing specific product parts or assembling products) are intermittent and therefore, differ in energy needs and flexibility [47]. Such differences create challenges for a community of industries who aim to generate electricity collectively to satisfy the collective and yet diversified demand. Further complications arise from the variable (weather dependent) nature of both solar and wind power, which may require additional investment in energy storage capacity so as to satisfy the large baseload of the industrial community at all times [48]. Another hurdle for industrial community energy systems aiming for renewables is the land requirement. Most industrial zones are characterized by a high density of industrial buildings and installations, and hence do not have sufficient space for renewable power generation facilities. The industrial community is, therefore, likely to rely on generation capacity to be built outside the industrial zone [49].

Our goal in this paper is to look at these challenges through a collective action lens, and to use existing theories to explore the feasibility of this type of collective action.

3. Energy Management in Industries from a Collective Action Perspective

3.1. The collective action problem of InCES

Collective action problems traditionally deal with shared resources and services [50–52]. These resources and services can be common pool resources (CPR) such as forests, or common infrastructures such as irrigation systems. In collective action problems, individuals may act in their own self-interest and pursue a course of action that will not result in the ideal collective outcome. This may happen because of different levels of trust [18,53] or autonomy among individuals [54], or in order to circumvent the imposed risks and expenses by the collective action. This phenomenon is known as the "prisoner's dilemma" in game theory literature [55] which can be a serious barrier for collective action projects [56–58]. Furthermore, the so-called free-riders[4] problem [59], which can result in the tragedy of the commons[5] [60–62] has always been a part of collective action problems.

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4 In economics the free-rider problem happens if those who benefit from resources, goods, or services do not pay for them [79].

5 The tragedy of the commons is an economic theory of a situation within a shared-resource system where individual users act independently according to their own self-interest, eventually resulting in the depletion or destruction of the resource.

For illustrative purposes and to explain how building an InCES can be seen as a collective action problem, we postulate that we are dealing with shared infrastructures, investments and power generated which can all be seen as CPRs [63]. Electricity generation and consumption, as well as investments in infrastructure and generation capacity, may be allocated unevenly among participants in an InCES given the differences among the participating industries as discussed in Section 2. Furthermore, if we consider the produced electricity and also the shared infrastructure as CPRs, free-riding can happen if members of the community do not pay their monthly or yearly fees which may lead to inadequacy of the power plant and eventually lead the whole system to supply shortages. Furthermore, different trust and autonomy levels among industrial participants can be crucial factors impacting the dynamics of collective action. To prevent problematic situations, institutional arrangements are required to help industries coordinate their collective investment decisions and the management of the shared resources (i.e., electricity and infrastructure).

The IAD framework addresses collective action problems such as the ones described above. The IAD framework provides a systematic approach to analyse a social system through an institutional lens. It helps analysts to understand complex social situations and to break these situations down into manageable sets of practical activities [64]. The framework can also help in organizing knowledge from empirical studies [65].

The core of the IAD framework is the 'action situation'; a conceptual unit that can be utilized to describe, analyse, predict and explain behaviour within institutional arrangements (see Figure 2) [28]. Contextual factors (left in Figure 2) affect action situations which are the social spaces where individuals interact and exchange goods. The actions taking place in the action arena lead to patterns of interaction that explain the outcomes of the system. Using a set of evaluative criteria, the patterns of interaction and outcomes can be analysed. This analysis may lead to changes in the contextual factors including the institutions, and even the technological components of the system which in our case is the energy infrastructure.

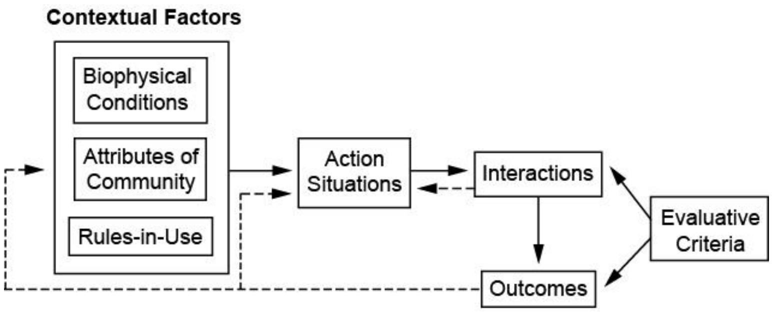

Figure 2: IAD Framework [28]

Figure 2. shows three categories of contextual factors affecting an action situation at a particular time [66]. Biophysical conditions include the physical and material conditions that influence action situations. Attributes of community describe the cultural context and the norms of behaviour. Rules-in-use are the institutions in the system that influence the actions, interactions and outcomes.

3.2. Using the IAD framework to analyse InCES

We divide the IAD framework into three main sections as illustrated in Figure 3. In this paper, we use the components in Box A which are the contextual factors for having a community energy system, to analyse the industrial cluster from a collective action perspective in order to find out whether an InCES is feasible in the context of our industrial cluster case. The challenges that were raised in Section 2 can be categorized into the IAD components in Box A. We use the "attributes of the community" component to look into the industrial cluster as a community, and to identify the social and economic challenges. We use the "rule-in-use" component to look into the formal rules (i.e., government regulations and incentives) that provide constraints or support for establishing an InCES project. We also look into the informal rules within the community that also play a great role in shaping an InCES. Finally, we use the "bio-physical conditions" to identify the environmental conditions for different energy sources. Technological aspects, however, do not entirely fit into the bio-physical conditions of the IAD framework, which is why we have included a fourth component in Figure 3 called "technical aspects of the power plant". This is because applications of the IAD framework so far mainly focus on socio-ecological systems, and the technological aspects such as the power plant and the grid have a different nature in terms of financial feasibility and availability. Therefore, we propose to analyse these aspects separately, as will be shown in the coming section.

Using the aforementioned components of the IAD framework, we will analyse our industrial cluster to explore the full potential of having an InCES. We will explore the feasibility of such collective action by highlighting the barriers and opportunities.

Given our extensive analysis, our main focus will be on box A. The action arena (Box B) will be used to propose action situations in a potential InCES which is the next step in our research. Box C will be used to project the potential outcomes of such a collective action scenario which we partly address in our concluding section.

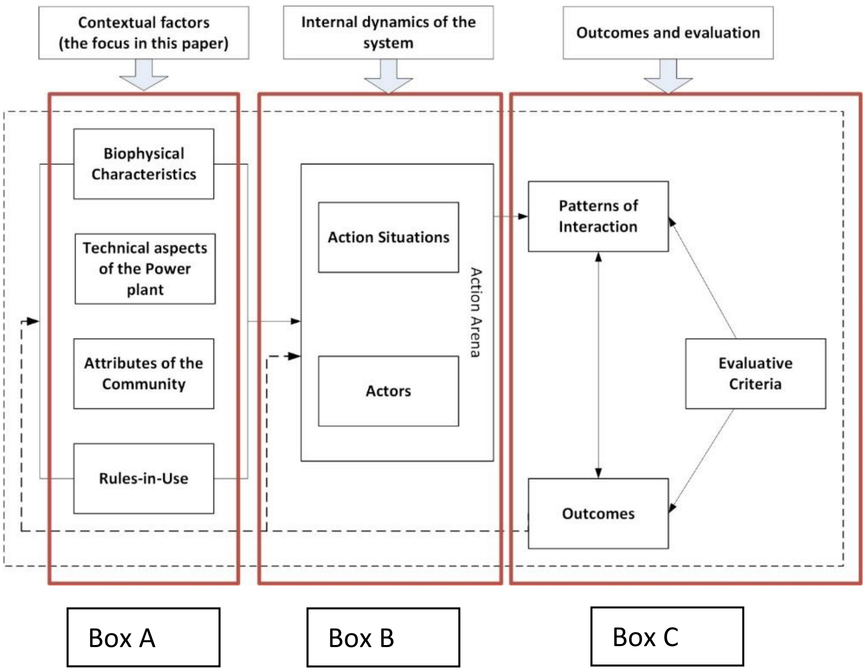

Figure 3: conceptualization of the IAD framework in this paper

4. Material and Method

In order to study the feasibility of collective energy management in InCES, we take a case study approach which will be thoroughly analysed from a collective action perspective using the IAD framework.

4.1. Case study: Arak industrial cluster

For the feasibility study of InCES formation we selected Arak industrial cluster in Iran. Industry in Arak, and wider Iran, struggles with power shortages on a regular basis, mainly as a result of infrastructure investments lagging behind the increase of electricity demand in Iran's industrial sector. Moreover, recent long drought periods necessitate several weekly brown-outs due to lack of cooling water resources for the conventional fossil-fired power plants. Considering the urgent need for expansion of power generation capacity, renewable energy resources come into play. However, due to heavy subsidies on electricity price, power generation from renewable sources is currently financially infeasible. Given the mission of Iran's power ministry to gradually privatize the electricity sector and liberalize the electricity market, the business case for investment in renewables is bound to improve in the near future. In addition, this liberalized electricity price in the future can increase the production costs and be considered as a threat for the industrial companies. Moreover, the Iranian government has recently introduced financial incentives to stimulate the utilization of renewable energy resources. Hence, renewable power generation is promising for industries in Iran. We selected Arak as a case study, as it is a mature industrial city with a large number of active companies and a large variety in types of industries. Arak is spatially distributed over seven industrial zones/clusters, with the smallest and largest cluster consisting of 30 and 400 companies, respectively.

4.1.1. Electricity management in Arak

Ministry of Energy (MOE) is the chief player in Iranian electricity sector in general and in Arak in particular. Iran Power Transmission, Generation and Distribution Company (Tavanir), a state-owned company working under the supervision of MOE is responsible for generation and transmission capacity and electricity wholesale all over the country [67].

Accordingly, in Arak, the regional electricity company as a regional subordinate of Iran's MOE is the only player in charge of electricity provision. Similar to other regions in Iran, the price of electricity in Arak is determined by the MOE, based on the consumption patterns of the consumers in different sectors. So, the key element in the price of the electricity bill for industrial companies in Arak is the amount of electricity that they use during different hours of a day.

4.1.2. Role of government in promoting Renewable Energy in the Industrial sector

From 2010, Iran's government issued a series of incentives to promote renewable energy in Iran. Following this goal, the Iranian government announced plans to build 2,000 MW of renewable energy capacity between 2010-2015. Iran is also working to make renewable energy commercially viable and the MOE is required to buy privately produced renewable energy at world market prices. Also, the MOE introduced feed-in-tariff (FIT) mechanisms in payment terms of contracts between renewable energy producers and the government as an incentive.

In 2012, Iran allocated €500 million from the National Development Fund to renewable energy projects, partly in support of the renewable (solar) industry in Iran. The state-sponsored Renewable Energy Organization of Iran (SUNA), with an annual budget of around €55 million, is associated with the MOE.

4.2. Data collection

According to the IAD framework, to study the feasibility of InCESs in Arak, we need information regarding the technical feasibility of various renewable energy sources, the existing government incentives and regulations regarding local power generation from renewable sources, the attributes of various industries such as their size and electricity consumption patterns, the perception of industries about community electricity production and their willingness to contribute to such initiatives. To collect this data, we used various means:

- Workshops

  We held two 3-hour workshops in Arak's industrial cluster. In the first workshop, the participants were the CEOs of 36 industrial companies in the region. We discussed existing challenges which industrial companies are facing with regard to their electricity demand and also discussed possible solutions for that. The second workshop included the CEOs of 22 industrial companies in the region and some authorities from the regional power company in Arak in order to discuss the feasibility of establishing an InCES in this industrial cluster and the effectiveness of existing government incentives for encouraging renewable power generation.

- Semi-structured interviews

  We used the IAD framework to design semi-structured interviews. We conducted 9 interviews with CEOs of industrial companies in Arak and asked questions regarding their difficulties in meeting the electricity demand in their companies, their mindset about joining partnerships in general and collective power generation specifically. Also, we solicited their opinion about the establishment of an InCES and the required institutional arrangements that need to be in place. For selecting these interviewees, we considered the size of the industrial companies (small, medium and big) as an indicator of their electricity consumption.

  Additionally, we conducted a semi-structured interview with the Director General of the Power Generation and Supervision Bureau of Iran's Ministry of Energy (MOE) as one of the key authorities in order to gain insight regarding the current rules, incentives, payback periods and existing challenges of renewable power generation in Iran. Moreover, we conducted three more semi-structured interviews with consultants in the field of renewable energy regarding their analysis of the cost and benefits of a renewable power plant in Arak.

- Study of legal documents

  We conducted an extensive desk research on the existing rules and regulations regarding the power sector in Iran, including the limitations, incentives, and the goals towards meeting their environmental targets which might affect the feasibility of establishing an industrial renewable cooperative. Moreover, we studied the different versions of contracts signed between the MOE and renewable power generation companies to assess their effectiveness in encouraging clean electricity production.

5. Systematic analysis of Arak Industrial Cluster

5.1. Biophysical characteristics of Arak industrial city

The biophysical conditions of Arak determine which renewable energy resources are feasible in the region. A thorough exploration of the potential for various renewable energy resources in the region of Arak, show that both solar and wind energy can be utilized. The photovoltaic power potential factor of Iran is shown on the map in Figure 4. The border of Markazi province in which Arak is located has been highlighted in red on the map. According to *globalsolaratlas.info*, the photovoltaic power potential in this region is between 1680 to 1826 kWh/kWp. Moreover, on average, Arak has about 300 sunny days per year with a peak sun hour of 4.5 – 5.5 kWh/m^2 per day [68] which makes this region an attractive area for solar power generation.

In addition, according to *globalwindatlas.info*, The wind blow intensity in Arak which is about 250 W/m2 is shown in Figure 5. The average wind speed in this region is about 4.2 m/s. Within this region and based on these data, a recent model of a 2.5 MW wind mill would be able to produce about 3 MWh electricity per year[6].

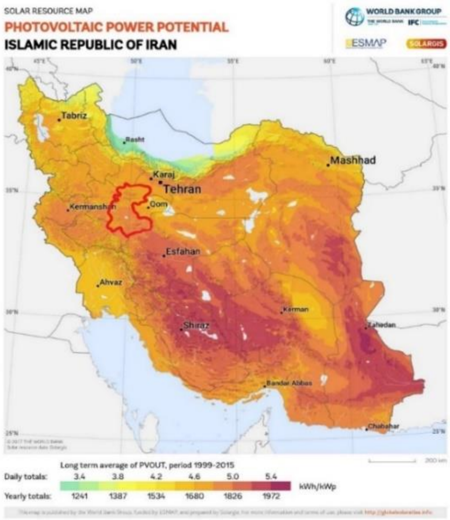

Figure 4: Solar radiation intensity of Iran [7]

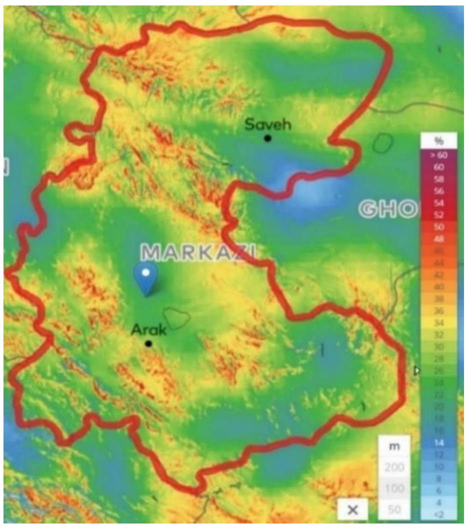

Figure 5: Wind blow intensity in Arak [8]

[6] The calculation of the power output is done based on:
Hub height of the wind mill: 85 m, rotor diameter: 104 m, wind speed: 4 m/s, Weibull parameter (β): 2.7,
air density (ϱ): 1.035 kg/m^3

[7] Map obtained from obtained from the "Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group.

[8] Map obtained from "Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group.

5.1.1. Biophysical challenges for Arak

This information illustrates that both wind and solar technologies can be utilized in this region for power generation. Nevertheless, selection of a specific technology would not affect the results of this research considerably since the focus is on the socio-economic challenges of forming an InCES, regardless of the type of the technology involved.

Another issue worth discussing in this section is the *location* of the power plant in relation to the industrial cluster. In solar power generation, land usage differs substantially based on the production method. For instance, for small and large photovoltaic (PV) power plants, the area needed ranges from 2.2 to 12.2 acres per megawatt (MW), with a capacity-weighted average of 6.9 acres per MW, while concentrated solar power plants (CSP) require land between 2.0 to 13.9 acres per MW with a capacity-weighted average of 7.7 acres per MW [49][69]. Unlike solar energy, the projection of wind energy land-usage is more complex due to the type of selected wind mill and its wake effect accordingly [70]. However, it is noteworthy that both wind and solar technologies have seen substantial developments during recent years which consequently decreases the land usage of these technologies [70].

Considering the industrial demand for electricity in our case study and regardless of the type of solar and wind technology which might be utilized, it can be concluded that *land-usage* is a crucial aspect which should be taken into account. Given the geographical dispersion of Arak industrial city, which is in fact composed of seven industrial clusters, the distance between the power plant and the industrial community members which are making the investment is a significant factor. In fact, acquiring a suitable piece of land which is large enough in terms of solar power generating capacity and close enough to the industrial community might be a hurdle for an Arak InCES to be brought into being.

5.2. Technical aspects of Arak industrial city

The technical aspects for this case are mainly concerned with the choice of generation technology, the existing electricity infrastructure and whether or not investment in transmission and distribution infrastructure is needed. Independence from the national grid makes a substantial difference in terms of capital and technological requirements, as compared to being connected to the grid. Off-grid design of the power plant necessitates the InCES to implement energy storage capacity, such as high capacity batteries (or other energy storage technologies), so that the collective electricity demand can be satisfied at all times. Without storage capacity, for instance if we use solar energy, night shifts cannot be operated and even during daylight hours, electricity shortages can occur due to the variability of solar irradiation intensity. Energy storage capacity, however, requires a substantial additional investment. Being connected to the national electricity grid prevents the need for investment in energy storage capacity. This option also creates the opportunity for the InCES to sell its electricity surplus to the utility owner which in the case of Arak is the government of Iran.

Furthermore, all industries in Arak industrial cluster are connected to the national grid. Most of the companies represented by the interviewees had never experienced power blackouts or had only experienced it once a week. So, until recently, the current electricity system has been providing adequate reliability of service. This relatively stable electricity supply situation has changed, however, due to the more frequent occurrence of prolonged drought periods in Iran, resulting in cooling water shortages for the thermal power plants which dominate the national power generation mix. As a consequence of the droughts, the electricity system has been facing series of brown-outs during the hot seasons. For the future, many companies in Arak industrial city indicate serious concerns about the inability of the regional power company to satisfy their increasing electricity demand. The lack of investment in both new generation capacity and expansion of transmission capacity implies that the industries in Arak cannot fully utilize their production capacity. This is a strong motivation for industrial companies to consider collective power generation in order to satisfy their electricity demand.

5.3. Attributes of the community

The industrial cluster of Arak which can be considered as our "community" in Ostrom's terms is very diverse in terms of the type of industry. The type of industry influences the electricity demand and consumption pattern. According to Iran's Small Industries and Industrial Parks Organization (ISIPO), Arak industrial city has 646 active industrial companies in different sectors as shown in Figure 6. [71]:

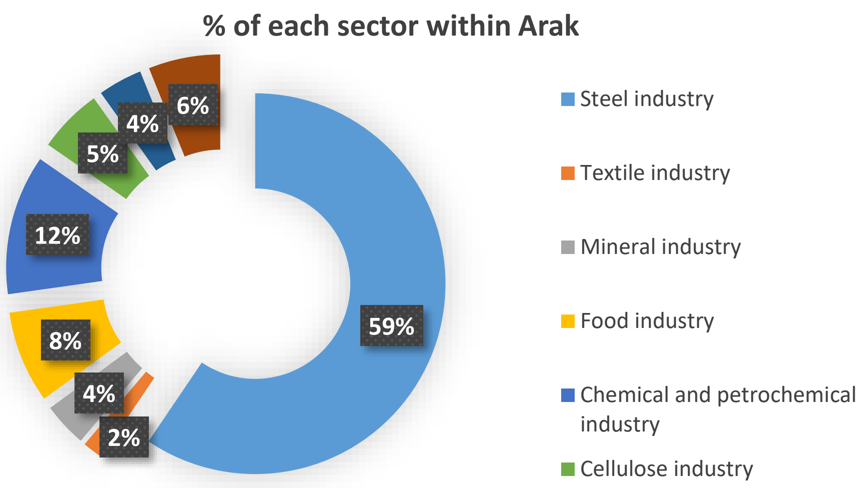

Figure 6: Percent of each sector within Arak industrial city [71]

Currently 98% of the companies in this area are privately owned and the rest are public companies, with their stocks being traded in the public stock market.

The diversity in type and size of industries in Arak indicates large differences between individual companies in how dependent they are on electricity provision and especially how flexible they are in dealing with service interruptions of short and longer duration. Depending on their sensitivity to service interruptions and on their plans for production capacity expansion in the future, different companies are not equally motivated to join an InCES. Evidently, not every company will be willing to invest, and not every company which does invest will be prepared to make the same investment contribution. To some extent, such differences in willingness to invest are also at play in the formation of household CES. In a community of households, however, the differences in electricity demand and consumption patterns are far less pronounced than in the case of an InCES as we are exploring for Arak industrial city.

A promising aspect about Arak, however, is that companies are already engaged in other forms of collective action and already see themselves as a community. The clearest example of collective action in Arak is a community banking system that has been successfully running for almost four years. The initiative of establishing a community bank stemmed from the inadequacy of the Iranian banking system to meet industry needs. In order to become independent from the Iranian banks in financially disconsolate periods, a collective of industries in Arak industrial city decided to form a community bank, providing loans with no interest rate. In this collective fund system, rules were collectively defined in order to ensure its reliability for all members. The initiators first created a list of prominent industrial company owners eligible to join the 'club' as core members. The main mission of the founders of this collective fund system was to ensure the reliability of the members and to guarantee that the money will circulate safely among the members. The institutional arrangements included both "entrance rules" and "sanctioning rules" (as a tool for punishing the members who abused trust within this community).

Since shared practical understandings can influence humans' daily routines and can influence their attitude towards changes to new situations [72,73], the existing collective fund system with about 36 industrials members has already made the industries in Arak familiar with the collective action approach. In our interviews, we were eager to find out if the positive experience with the collective fund system may contribute to the industries' willingness to also pursue collective action in solving their energy problems. Yet, our interviews revealed that many industries which had not participated in the collective fund system are not also particularly eager to partner with other industries for collective power generation. Many of mentioned CEOs interviewed preferred not to share electricity infrastructure with other industrial companies since they considered electricity as a highly strategic issue. They did not want to be bothered with partnership challenges such as not having enough trust in partners, and not having full autonomy over their electricity supply and consumption. This is mostly because these CEOs see the lack of a clear and agile legal structure in Iran as a critical factor that may put the whole partnership on hold in case of a serious conflict which can only be resolved in court. However, some of the CEOs did indicate interest in collective power generation as a potentially reliable solution to meet their companies' electricity demand. These CEOs believe that the partnership challenges can be overcome with effective institutional arrangements to manage conflicts that might arise due to different levels of trust, autonomy, etc. Last but not least, almost all of the interviewees mentioned that due to the poor condition of Iran's economy (worsened by the current boycott and global trade conflicts) they are unwilling to invest in a long-term strategic plan.

During our interviews, it became apparent that most industries in Arak had no or very limited information about renewable energy. Almost none of these companies were aware of the requirements of renewable power generation, its costs and the incentives introduced by the government to encourage such projects. As a result, they were inclined to see industrial scale renewable power generation as a mission impossible. Given the lack of knowledge, it seems that collective action towards an InCES cannot evolve spontaneously from the Arak industrial community itself. This issue was also experienced by cooperatives in Europe, like the case of formation of the REScoops[9] [74]. It seems that a third party may be needed to inform the

[9] REScoop.eu is the European federation of renewable energy cooperatives. It's a growing network of 1,500 European energy cooperatives and their 1,000,000 citizens who are active in the energy transition[74].

industrial companies on the potential of renewable energy and to define a feasible project, which specifies the costs and benefits for all industrial partners involved.

5.4. Rules in-use

In this section, we explain the institutional setting that can affect the emergence of an InCES in Arak Industrial Cluster. We extracted formal rules (in-use and in-form) through legal documents and interviews and identified the informal rules in our interviews and workshops.

5.4.1. Current institutional setting for Electricity management in Arak

As it was mentioned in Section 4, the only electricity provider in Arak is the regional power company as a subset of Ministry of Energy. This company provides a centralized system in which most of the electricity comes from a thermal power plant with a capacity of 1300 MW. In this system, each of the customers are billed for their electricity consumption at the beginning of the month and have a three weeks deadline for paying the electricity bill. Legally speaking, those customers who refuse to pay their bills after two official notices, will be detached from the electricity grid and in addition to paying the electricity bill with a surcharge, they will also be charged for getting re-connected to the grid.

Although Arak industrial cluster has been benefiting from relatively stable electricity provision over past decades, due to recent drastic drought periods in Iran, the industrial sector faces frequent black-outs during hot seasons. To deal with this issue, the regional power company organizes scheduled black-outs (brown-out) during hot seasons to prevent sudden power outages. Although, this seems to be an acceptable solution, it would eventually result in insufficient production capacity for industrial companies.

In addition to the power outages during hot seasons, electricity posts located in Arak work with their full capacity indicating that there has not been sufficient investment for increasing the capacity to meet industrial developments in the region. Correspondingly, companies with expansion plans will be incapable of satisfying their additional electricity requirement. Asking for additional capacity is possible but is a long and bureaucratic process.

5.4.2. Institutions influencing establishment of InCES

The formal rules can be categorized into the following types:

- Rules regarding the establishment of a local private electricity market
- Incentives introduced by the government for producing renewable electricity
- Rules regarding transformation and transmission of electricity through the national grid
- Rules regarding the ownership of a grid that is developed by a private company in Iran

In this section, we will describe the rules and the institutional arrangements which have an impact on the establishment of an InCES.

Rules regarding the establishment of a local private electricity market

Currently, the price of each kilowatt hour electricity in Iran's industrial sector, based on the latest directive by the Ministry of Energy, is calculated as table 1:

Consumption time	Price (IRR per kWh)
Peak time	1,270 (0.01 €)[10]
Mid-peak	639 (0.005 €)
Off-peak	320 (0.0025 €)

Table 1: Price of Electricity for Industries in Iran [75]

It is allowed by law to generate and sell renewable electricity privately. As the price of electricity which is being offered by the government is highly subsidized, the chance of establishing a local private market with a higher price than offered by the government is low therefore currently there is no private electricity market for renewable electricity. However, at times of insufficient electricity supply from the government, the industrial consumer might be interested to buy electricity from a private supplier, if there is one. It could also be the case that at the location of the consumer there is no electricity grid and therefore, the private electricity market may be the only option. In this case, they only need to develop a grid between their company and the local power plant which, in some cases, would be relatively more financially feasible than establishing a grid between their company and the national grid.

Incentives introduced by Iran's government for producing electricity from renewable sources

- **Land allocation:** In some places, based on the availability, the government has committed itself to allocate land for power generation from renewable energy sources. The land would be rented to the producer almost free of charge for long periods.
- **Feed-in-tariff (FIT) incentives:** the government will buy the generated renewable electricity based on a FIT system. The FIT system's budget is financed by allocating 8% of each electricity bill which the government collects from all the electricity consumers per year. The price of generated electricity varies based on the scale of production and is calculated as depicted in Table 2:

Amount of RE production	Price (IRR per kWh)
Capacity Less than 20 kW	8,000 (0.063 €)
Capacity between 20 to 100 kW	7,000 (0.055 €)
Capacity between 100 kW to 10 MW	4,900 (0.038 €)
Capacity between 10 MW to 30 MW	4,000 (0.031 €)
Capacity more than 30 MW	3,200 (0.025 €)

Table 2: Price of renewable electricity to be purchased by the government [76]

  Based on the FIT contracts and according to the production scale, the above prices would be fixed and guaranteed for a 15 years period. In addition, the average inflation rate would be added to the annual payments by the government.
- **Financial aids:** The government supports renewable electricity producers to invest in renewable energy technologies in the form of bank loans to cover up to 80% of the

At the time of conducting this research, the exchange ratio between Iranian Rial and Euro was: 1 € = 126,000 IRR required investment with a 5 years grace period. It must be noted though that the interest rate for these loans is relatively high (currently 18%).

Rules regarding transformation and transmission of electricity through the national grid

In case the power plant is connected to the national grid, it is allowed by the government to export the power to the grid and import it somewhere else almost free of charge. This can be an effective incentive for those producers who are harvesting renewable electricity in the central parts of Iran (where solar irradiation intensity is highest). They may choose to export the power generated to neighbouring regions or countries. An InCES in Arak could also decide to harvest solar power in central Iran and use the national grid for free storage and transmission to the location where the power is consumed.

Rules regarding the ownership of the grid that is developed by a private company in Iran

Development and ownership of a private electricity grid is possible but must be done under the supervision of the regional power company. If the private grid is to be connected to the national grid, the design of the private grid should be approved by the regional power company. Also, if the private grid is connected to the national grid, the access of the regional power company to this grid cannot be excluded.

5.4.3. Informal institutional setting

By interviewing various industrial CEOs and holding workshops, we aimed to identify the informal rules and norms that apply within the current community of industries. Generally speaking, the CEOs of the industrial companies in Arak are confident that they are able to gain support from the local government, as the government is dependent on the local industrial sector to curb the unemployment rate in the region. The CEOs tend to trust the local government, as they see the interests of the local government to a large extent aligned with the interests of their own companies. Regarding the mutual trust among the industrial companies, we see large differences. From the responses of the interviewees, we already concluded that many industrial companies in Arak are not eager to partner with other companies, for lack of trust in the reliability of a partnership. The mutual fund system, however, illustrates that there is a community of industries in Arak which trust each other enough to help one another in financially or technically difficult times by lending money or giving free technical consultancy. Overall, this implies that we are dealing with a fragmented community regarding mutual trust in Arak industrial zone.

Furthermore, the interviewees response to the questions regarding the electricity price and availability reflected that most of the CEOs see their companies as entitled to abundant supplies of cheap electricity. This attitude is the traditional norm for oil-rich countries which however, is rapidly changing [77]. It creates a negative atmosphere towards generating electricity from renewable resources which would require a large upfront investment.

Another social norm in the industrial community of our case study which was mentioned by the managers of two industrial clusters in Arak during the interviews and is worth highlighting here is that the companies of an industrial cluster normally look up to the bigger and more powerful companies in that cluster. This means that the level of persuasiveness among the companies are not the same. Therefore, leadership for such collective projects may be largely dominated by bigger companies.

In our interviews with the CEOs, we specifically probed the members of the "community bank system" to get a better understanding of the agreements and rules that they collectively defined to manage the system and to ensure its robustness.
We categorized the existing in-use community rules which may also be functional in the case of InCES, using Ostrom's eight design principles [29].

i) **Clearly defined boundaries**
In this regard, the founders of the community bank system defined a set of strict entrance rules in order to build a trustworthy environment for the potential members. Any candidate requesting to join the community, will be subjected to a background check on the basis of which he can be accepted or rejected.

ii) **Congruence between appropriation and provision rules and local conditions**
The amount which the system can provide in loans to the members is equal to the cumulative amount which was invested by the members when they joined this system. There is a minimum investment contribution for each member joining the community.

iii) **Collective-choice arrangements allowing for the participation of most of the appropriators in the decision-making process**
In this system, institutional arrangements (rules by which the community bank is supposed to run) were being defined through a democratic process in which all the members had the right to vote.

iv) **Effective monitoring by monitors who are part of or accountable to the appropriators**
For monitoring the status quo of the system, an accountant was hired. The role of this inspector position is to monitor if the loans to members are being paid back on time or not. The accountant provides a monthly report on the financial situation of the bank.

v) **Graduated sanctions for appropriators who do not respect community rules**
Founders of this system deeply believe that trust-killing actions by the members should be strictly sanctioned. Accordingly, there is a consensus among members that if any member's action is damaging trust, that member will be sanctioned, which implies that he will not be allowed to join any other collective initiative in the industrial cluster (which is counted as an intense punishment). Trust eliminating actions are normally related to delays in payback.

vi) **Conflict-resolution mechanisms which are cheap and easy to access**
Although the founders of this system tried rigorously to avoid any type of conflict by setting strict entrance rules, they defined a mechanism as the guarantee for the loaned money in case there is a conflict between the system and a member. In this sense, if a member is borrowing money from the bank, he/she should deliver a check with the same amount to the inspector as the guarantee.

vii) **Minimal recognition of rights to organize (e.g., by the government)**
There is a board of directors who are elected by the members and these directors have discretionary rights to decide about some issues such as extending the period of a loan, prioritizing requests when there is a high number of requests for borrowing money, etc.

6. Result: Can community energy be a solution for Arak?

In this research, our goal was to see whether a community energy system, like the ones established between households in a neighbourhood, can emerge in a cluster of industries. In other words, we aimed to study whether industrial actors can also perform collective action to pursue shared goals. We used the IAD framework to analyse an industrial cluster in Arak, Iran and conducted multiple interviews and organized workshops to grasp the technological, institutional and community attributes of the system.

Our analysis shows that collective action can be a possibility for energy management among industries in Arak and potentially other places as we explain below.

In terms of technological and biophysical feasibility, it is possible to have a renewable power plant that can meet the electricity demand of the industries that would like to join the collective action project. Yet, other requirements need to be addressed in this regard including grid connection and storage. Given the rules in place for the use of the national grid, it is economically more attractive for industries in the collective project to stay connected to the national grid than to develop an off-grid project which would require substantial additional investment in energy storage capacity. The grid connection also caters for the widely different consumption patterns of the various industrial companies in Arak, so that coordination mechanisms for the use of power generated in the collective project are not needed.

Yet, there are many other social and institutional challenges, that are critical for the success or failure of an InCES in Arak. Starting from the institutional barriers, the uncertainties involved with government incentives make the system extremely vulnerable in terms of technological and financial independence. On the one hand, staying connected to the national grid is financially, technologically and security-wise the safe option. On the other hand, industries may not be wise to count on the feed-in-tariffs and payback arrangements recently introduced by the government, as the regulations may change again.

Regarding the community aspect of the system, the biggest challenge is that unlike households, industries do not have similar or comparable electricity consumption in terms of volume and pattern. While some industries are large and have high demand with limited working shifts, others may be small but with 24-hour working shifts. Therefore, their requirements and their investment possibilities and interests vary to a great extent. As such, collaboration, and reaching an agreement is more difficult than in traditional community energy projects among households.

Nonetheless, given the results of our analysis, it seems that even with all the vulnerabilities coming from the government side, a collective investment in electricity production from renewables is still an attractive solution for the industries in Arak as it actually makes them more energy independent than any other solution. Connecting the renewable power plant to the national grid is a crucial condition for the feasibility of the project, as a grid connection obviates the need for investment in energy storage capacity. In fact, it appears that even if the project cannot rely on government payback with regard to electricity feed-in, it is still economically feasible.

6.1. Proposed institutional design principles for collective action in InCES

In addition to the existing principles that hold for typical collective action problems including community energy systems among households, to establish an InCES the following principles for institutional arrangements hold:

1- Management of diversity: given the immense heterogeneity among members in multiple aspects, it is important to come up with rules that specifically address how members with such different profiles can 1) invest in a shared resource system and 2) use it. Computer aided support may in fact be helpful in this respect (see for example GENIUS [78] for electronic negotiation).
2- Trust building: as mentioned previously, electricity is one of the most crucial requirements for any industrial company. This is why many industrial companies are deciding about joining the inCES rigorously and seriously. Any successful experience which can enhance the industrial companies' mutual trust is greatly helpful in encouraging industrial companies to invest in an inCES.
3- Long-term vision: satisfying industrial electricity demand requires large and long-term financial investments. Therefore, the economic stability of the country in which the investment is taking place is a crucial factor.

Our final and key finding is the importance of community spirit among industries which we had not foreseen before this analysis. Regarding the social aspects of collaboration, although differences in the size and type of industries make collaboration very challenging, reaching consensus may still be feasible, at least in our case study. The community banking system established in Arak has demonstrated that the heterogeneity challenges in a community of industries can be tackled. It is very promising to see that a *community culture*, which is a main attribute of a community according to the IAD framework, already exists within the Arak industrial cluster and that there are strong social ties between the CEOs of the industrial companies. These existing ties are a strong cultural basis for further collaboration, in particular for a community energy system where the shared interest is strongly acknowledged by all members.

6.2. Lessons for InCES from a global perspective

This research focused on a specific case. Although the challenges for an InCES in Arak may seem very different from other industrial zones in the world, the challenges and opportunities of such a project are in many ways also similar. For example, although government related uncertainties may not exist or be as strong in other countries as in Iran, the fact that the world is moving toward a carbon-neutral footprint puts pressure on industries around the world to reduce their CO2 emissions, hence providing similar incentives for industrial companies in other countries to join in collective action.

The three design principles: diversity management, trust building and long-term vision hold for every industrial zone. It is important to stress that the most important finding of our research that leads to successful design of these three principles is community spirit. In an industrial zone, community spirit plays a huge role in the success of such projects by reducing points of conflict. This aspect is especially important given the differences in size and type of industries which complicates negotiations and collaboration in general. The Arak industrial zone has the advantage of existing community collaboration. For other industrial zones in the world, if similar community spirit exists, the chances of successfully establishing an InCES are equally promising.

7. Conclusion

The goal of this research was to use a collective action perspective to study whether community energy projects which commonly take place among households are possible in industrial zones where the members of such projects are industrial companies. We used the IAD framework to analyse the system and to identify the opportunities and challenges for such form of a collaboration.

Focusing on Arak as our case study, we found that even with the many uncertainties industries face with regard to the incentive mechanisms provided by the government at different levels, an InCES is a promising approach to reach an acceptable level of independence for meeting electricity demand.

By looking into the key factors highlighted by the IAD framework, we were able to touch upon issues that would have otherwise not been in the spotlight to explore in this study. Most importantly, the "attributes of the community" part of the IAD framework was particularly insightful. The key factor that plays the most significant role in successfully establishing collaborative projects is the community spirit and the social bonding between the industrial partners in the cluster. This does not only hold for Arak, but any other zone in the world and the reason for that is the diversity of industries and the importance of trust. Since industries are different in terms of type and size, reaching consensus to initiate such projects and to resolve potential conflicts are extra challenging. The social bonding among industries can be a catalyser and a lubricant to smoothen such processes.

Although our key findings seem to hold for other industrial zones around the world, from a formal institutional perspective, given that there are no strict enforcement mechanisms to reduce CO_2 emissions, industries in Arak are only driven by financial incentives rather than environmental factors. This could be a point of difference between this cluster and other industrial clusters around the world.

Although the interviews provide many insights, the number of interviewees was limited to gain a full understanding of the opinions of the industries. Therefore, our next step is to conduct a survey among industries to better identify their characteristics and to propose pathways that can facilitate the formation of InCES in industrial areas. As a continuation of this research, we will continue to use the IAD framework and we will focus on the Action Situations to formulate the aforementioned pathways.

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Chapter 3: Collaborative Renewable Energy Generation among Industries: The Role of Social Identity, Awareness and Institutional Design

Like many other sectors, climate change strategies have put various restrictions on industry, the most prominent one being caps on CO_2 and other energy-related emissions. At the same time, and especially in many developing economies, the industry struggles with an increasing gap between the fast development of the sector and lagging energy supply capacity. Collective generation of renewable energy is seen as a promising means of transition, next to other forms of renewable energy generation (centralised, individual). The aim of this research is to investigate factors influencing willingness to participate in Industrial Community Energy Systems (InCES). Using existing literature on Industrial Symbiosis and Community Energy Systems, we formulate plausible hypotheses on the most relevant factors for the willingness of industries to join such initiatives. As one of the largest and most diversified industrial clusters in Iran, Arak industrial park is selected as the case study. Data were collected from the CEOs of 96 companies through survey research. Our results highlight the crucial role of awareness about the benefits of renewable power generation in an InCES. Social identity among industries and trust between them are also determining factors for their willingness to join InCES. Finally, proper institutional design for overcoming the partnership complexities (e.g., conflict resolution) was highlighted as a crucial factor for industries. It can be concluded from the results of this study that policymakers should avoid one-size-fits-all incentive design approaches and reach out to larger companies with targeted incentives, introduce specially designed bank loans for different target groups, and make use of consulting companies as intermediaries to increase the awareness of the industries regarding the benefits of investing in an InCES.[11]

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1. Introduction

Electricity is an essential commodity for any economy, and its importance for the industrial sector is expected to increase significantly as the industry strives to reduce greenhouse gas emissions [1]. At the same time, in many developing countries, the increase in industrial electricity demand is not matched by adequate investment in generation and transmission capacity, resulting in more or less frequent brownouts of electricity supply. Consequently, industrial companies are forced to rethink the future provision of electricity.

A possible solution for industry is to engage in power generation itself, employing renewable energy resources in the process, in line with climate policy targets. For an individual company, however, the high upfront investment in electricity production capacity and in the storage facilities needed to deal with the variability of renewable energy supply is a sheer, insurmountable hurdle, especially in energy-intensive industries.

Given that industrial companies are usually located in physical proximity to each other in industrial clusters, another approach is to engage in collective electricity production from renewable resources and collective demand management. The practice of collective power generation and consumption is already being demonstrated in various communities of households worldwide and is commonly referred to as "community energy systems" [2]. Community energy systems (CES) have widely been studied and are concluded to be especially valuable in terms of self-sufficiency and sustainability, e.g., as they contribute to decreasing the amount of power loss through the grid [3]. Despite the extensive body of literature on CESs, the establishment and performance of such energy initiatives among industrial companies within an industrial cluster have not been adequately studied [4]. Considering the intrinsic differences between the decision-making style/process of industrial companies and households, the conditions under which an InCES can be established in an industrial cluster are worth studying.

In this paper, we study the conditions under which industrial companies located in a geographically defined industrial cluster may be willing to engage in an industrial community energy system (InCES). Although other forms of collaboration between industries exist (e.g., Industrial Symbiosis), community energy systems in a community of industrial companies have, to date, neither been established nor studied to the best of our knowledge. We use empirical research to investigate the social, economic, environmental and institutional factors affecting the willingness of industrial companies to participate in an InCES. Empirical data are collected via a survey among the CEOs of a sample of the industrial companies in Arak industrial city, Iran.

This paper is organised as follows: Section 2 positions this research by reviewing the literature on collaborative industrial action and renewable community energy systems. In Section 3, the methods and measures used in this study are reported. Section 4 presents the statistical analysis of our empirical research. Section 5 provides our discussions, and finally, Section 6 reflects our conclusion.

2. Related Literature on Industrial Community Energy Systems

In this research, rather than focusing on the technical (e.g., Micro-grid) or business requirements (e.g., Finance), we focus on the social, economic and environmental factors that may influence the willingness of industrial companies to join an InCES. In the remainder of this section, we reflect on the literature related to (collaborative) renewable energy generation among industrial companies.

2.1. Industrial Communiy Energy System: Motivation and Challenges

As mentioned previously, establishing an InCES would be a feasible approach for industrial companies to deal with the instabilities related to their electricity provision. These instabilities can be witnessed in developing countries more vividly, mainly for two reasons. First, there is a lag between the increase in the capacity of the electricity system by utility companies and the developments in industrial clusters [5]. Therefore, there would be a lack of capacity for the new industrial companies and for the expansion phases of the existing industries. Second, due to long drought periods in many developing countries, access to water resources needed for cooling down the power plants is limited [6]. Therefore, the whole system faces brownouts, especially during the hot seasons of the year.

Consequently, investing in an InCES would be a bottom-up approach for the industrial companies to tackle the aforementioned challenges. Establishment of an InCES would, however, face industrial companies with a number of serious barriers. First, due to the intermittent nature of renewable resources, the process of power generation would be stochastic throughout a day [2]. Therefore, dealing with the baseload required by the industries is a critical challenge, requiring industrial companies to invest in high-storage capacity batteries [7]. This would confront enterprises with high upfront investments, which might not be economically feasible considering the limited access to cost-efficient batteries, particularly in developing countries. Second, investing in an InCES would bring the participating industries into a form of partnership within which ownership dilemmas, demand management and conflicts may be pressing issues [8].

To tackle the mentioned challenges, (a) an on-grid design may be preferred to help companies deal with baseload challenges; (b) partial investments in InCES that would fulfil the excess demand (instead of the whole demand) can be promising solutions that InCES may provide.

2.2. Industrial Collaborations and Industrial Microgrids

Collaboration among industrial companies is not new. There is an extensive body of literature on industrial symbiosis (IS), a type of collaboration in which industrial companies share resources and by-products [9]. Among various kinds of industrial ecosystems, industrial symbiosis is defined as a structured system for exchanging water, energy, or material flows, so that flows discarded by some companies as waste flows can be used as valuable inputs by other companies. This sharing of resources leads to an overall improvement in the eco-efficiency of the local industrial cluster through reduced consumption of virgin materials and reduced production of industrial waste. A successful example is Kalundborg industrial park in Denmark [9]. The focus of industrial collaboration in IS is on optimising resource consumption and the associated economic and environmental benefits for the industrial companies involved [9]. Whereas collaborative power generation and demand management are not known to be part of established IS communities, there are some publications that have briefly hinted at “trust” [10–12] and “community spirit” [13] as the potentially influential factors for a successful IS establishment, while “economic benefit” [10,14–19] has been strongly emphasised in the IS domain as a crucial factor.

A key difference between IS and InCES, however, is that while geographical proximity is a crucial element for IS projects [20], this issue might not be an essential factor for an InCES since power can be transferred from a collective power plant to and among industrial companies through the (established) electricity grid. Furthermore, while in IS, an uneven distribution of costs and benefits between the industrial companies is known as an important barrier [21], the case of collaborative power generation in an InCES would allow each member company to invest in the project to the extent of their electricity demand.

Besides IS, it is worthwhile mentioning that there is a noticeable body of literature on industrial microgrids in which the employment of renewable resources has been discussed. Meanwhile, this cited literature mainly investigates methods to better optimise the energy/electricity management in the industrial microgrids while considering the stochastic nature of energy generation from renewable resources [22–27]. Despite the relevance of this body of literature to industrial electricity management, it misses the social and institutional aspects related to the establishment of InCES as an industrial microgrid and the way in which such initiatives can emerge in an industrial cluster.

2.3. Community Energy Systems

There is a vast body of literature on collective renewable electricity production in local communities of households and small businesses. Koirala et al. [2] have provided a comprehensive review of the existing literature on CES, which are also referred to as "energy cooperatives" [28–33]. From this literature, many factors can be identified relevant to the successful establishment of CES, such as a lack of grid access in rural areas, especially in developing countries, where electricity cannot be obtained unless households invest in individual or community facilities [32,34–36]. Within the same context, in a recent publication, Joshi and Yenneti [37] investigated cases of CES in India and concluded that the expansion and scalability of community energy projects in India, as a developing economy, need a combined policy support of both a "participatory approach" and a "top-down approach". On the other hand, in developed economies, consumers are often willing to pay more for energy from renewable resources. For instance, 92% of Germans advocate the growth of renewable energy supply and are willing to pay more for electricity from renewable resources [38]. Germany is one of the countries where many communities of households and small businesses have successfully established collaborative energy systems. Targeted financial incentives, such as attractive feed-in-tariffs, play an important role in the willingness of households to invest in decentralised electricity production from renewable resources [38]. Economic stability, inflation, and interest rates are important aspects in decisions on whether or not to invest in projects with long payback periods. Environmental motivations are the major driving force behind the surge in CES implementation in many developed countries [39]. Together with the improvements in efficiency and reliability, CESs are seen as an environmentally friendlier alternative to the centralised power supply system [40].

The extent of social connectedness among community members is another crucial factor influencing their willingness to engage in community initiatives rather than individual actions [28]. The stronger the community identity, the stronger the collaboration among households/citizens [41]. The literature furthermore shows that trust is an essential condition for establishing a community energy project [29,42,43]. These perceptions are typically embedded in a society's social norms. Therefore, the chance of establishing a cooperative in a fragmented society would be marginal [44,45].

Speaking of the abovementioned qualities emphasises that establishing an InCES is not just a business collaboration among industries with close proximity. There are other motives, such as "trust" and "community spirit" among community members, which can act as the enabling factor for the industries to consider joining/establishing such initiatives [5].

2.4. Identification of Potential Success Factors for InCES

All of the factors so far identified from the CES literature seem to be equally relevant for establishing community energy systems between industrial companies. Several of these factors (i.e., economic benefits, trust, and community spirit) are also highlighted as essential factors for collaboration between industrial actors in the IS literature.

In addition to these factors, we expect industrial companies to be quite sensitive about the ownership arrangement of an InCES because the capital investment will vary widely among the industrial participants, depending on, e.g., company size and energy intensity. Companies with a large electricity demand will have a stronger bearing on the necessary investments for an InCES than companies with low electricity consumption [5]. This is unlike CES practice between households where the ownership arrangements are not considered a decisive factor influencing households' willingness to join a CES [2]. Nonetheless, in household CES, various ownership arrangements occur, ranging from full ownership by the community to co-ownership agreements with private or public actors [46]. However, shared ownership can complicate cooperation in InCES as it complicates the potential exit of companies if, for some reason in the future, the partnership in this collective action is no longer beneficial for a member.

Furthermore, we assume that the company's size can affect its willingness to join an InCES for various reasons. First, a large company has more budget to allocate for new investment projects. Second, due to the capital invested, a large company is more likely to make long-term investment decisions [47]. Moreover, awareness regarding the availability of incentive mechanisms and knowing the benefits of RE generation is assumed to positively correlate with the industrial companies' willingness to invest in an InCES [2,42,48]. Last, energy demand is expected to be an important factor related to company size. Large companies running energy-intensive processes have to think strategically about opportunities to lower the cost of electricity use and reduce their vulnerability to service interruptions. The cost issue is critical to the risk of electricity price changes. This risk is certainly relevant in the case of Iran, where the government decides on the electricity tariff system and where consumer tariffs are heavily subsidised by surcharges on the electricity service tariffs for industry [49].

Accordingly, from the literature on both IS and CES, we hypothesised (a) social, (b) economic, and (c) environmental factors as the impacting ones on the willingness of the industries to participate in an InCES. The above-mentioned factors are listed in Table 1.

Table 1. Hypothesised impacting factors on the willingness of the industrial companies to invest in an InCES.

Factor	Hypothesis	Citation
Willingness to pay	**H1.** *Willingness to pay more for renewable electricity has a positive correlation with willingness to join an InCES*	[10–12,14,15,38]
Upfront investment and financial incentives	**H2.** *Willingness to invest in long-term projects has a positive correlation with the willingness of industries to join an InCES*	[10,16–19,50]
Environmental motivation	**H3**. *Pro-environmental industries have a stronger motivation to join an InCES or initiate one.*	[39,40,51–53]
Community identity	**H4.** *Strong social connectedness and being a part of the community have a positive correlation with the willingness of industrial companies to join an InCES*	[13,28,41]
Trust	**H5.** *Trust among community members positively correlates with the willingness of industrial companies to join an InCES*	[10–12,29,43–45]
Ownership	**H6.** *Sensitivity on ownership negatively correlates with the willingness of industrial companies to join an InCES.*	[2,46,54,55]
Awareness	**H7.** *Being aware of the financial benefits and incentives related to RE generation positively correlates with the willingness of industrial companies to join an InCES*	[2,43,48]
Industry-specific factors:		
Size of the company	**H8.** *The size of the industrial companies positively correlates with their willingness to join an InCES*	

Electricity demand	**H9.** *Industrial companies with large electricity consumption are more willing to join an InCES*

3. Materials and Methods

In this research, we employ survey research to investigate factors impacting the willingness of the industrial companies to invest in an InCES. Figure 1 shows the research design.

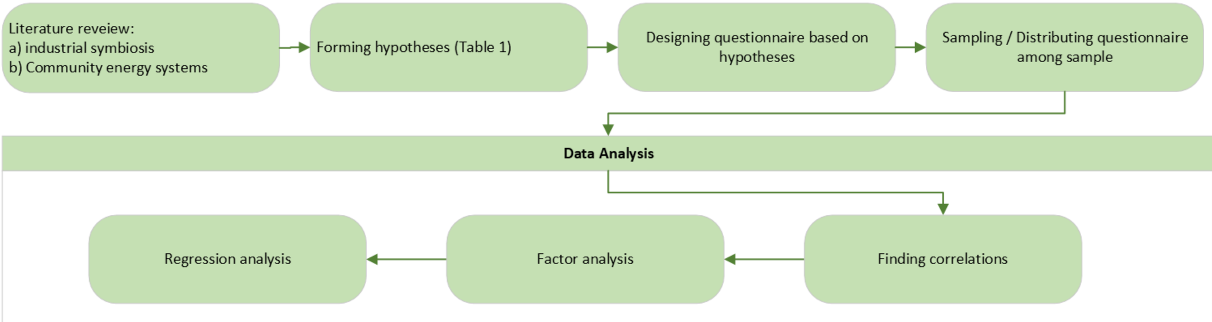

Figure 1. Flow of the research design.

This research conducts a survey (Appendix A) distributed among the CEOs of a sample of industries in Arak Industrial city. 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 numbers 603 companies, geographically distributed over six industrial clusters, as shown in Figure 2 (each cluster ranging between 5 to 278 companies).

Figure 2. Industrial clusters located in Arak [12]

The questionnaire was designed to test the hypotheses formulated in Table 1. The questionnaire addresses the extent to which the industrial companies' executives meet with each other, how willing they are to partner with the industrial companies of their zone, and how important it is for them to become independent from the government for electricity supply. Moreover, the survey contains inquiries into the factor(s) which may hinder collaboration between the companies in an InCES, such as "trust." Besides the companies' opinions and behaviours, data were also collected on their attributes, including their location,

[12] (Google Maps, 2019. ARU: Arak, Markazi Province, Iran. Available online.

number of employees, production field, electricity demand, electricity consumption pattern, and monthly electricity bill (Appendix A). In addition to testing the hypotheses in Table 1, the research also took an inductive approach by exploring other possible factors that could potentially affect industrial companies' willingness to join an InCES. These factors will be further explained in the results section.

The collected data were statistically analysed using IBM SPSS STATISTICS 25, IBM, New York, NY, United States.

4. Results

4.1. Data Sample and Descriptive Statistics

In order to carry out this research, we selected a sample from each of the industrial clusters located in Arak industrial city following the systematic expert sampling method [56]. The companies were selected from the list of provided by each cluster's management office with the aim to cover the full range in terms of size, electricity demand, and number of employees.

The sample in which we conducted the survey covers 35% of the total number of industrial companies located in Arak (212 out of 603). The distribution of respondents, the sample, and the population among the five industrial clusters (Kheir Abad industrial cluster consists of two parts. The newer cluster is known as the "expansion phase". Here for the sake of simplicity we showed these two clusters under the category of "Kheir Abad" industrial cluster) are shown in Figure 3.

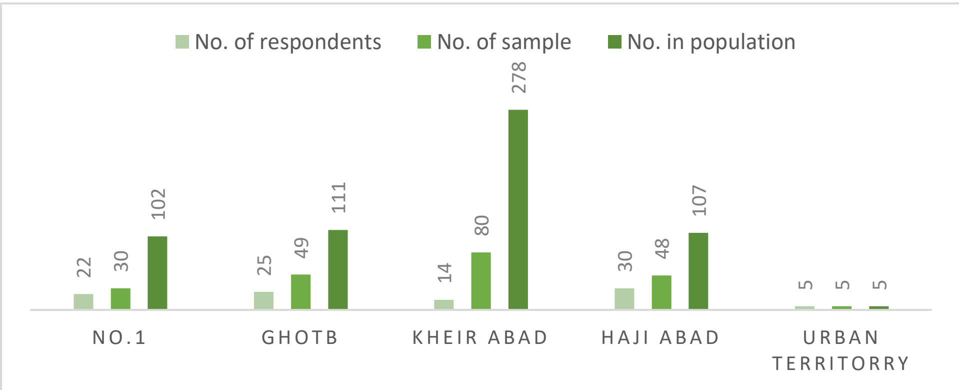

Figure 3. Survey population mix.

As reflected in Figure 3, the survey was distributed among (the CEOs of) 212 companies, and we succeeded in collecting 96 completed responses (~46%) which can be considered as a relatively high response rate for surveys distributed among industrial executives [57].

Table 2 gives an overview of the attributes of industries that participated in the survey.

Table 2. Demographic data on responsive companies.

Demographic Results	*n*	% Among Total Respondents
	Size	
1–50 Workers	64	66.6
50–100 Workers	14	14.5
100–150 Workers	9	9.3
150–200 Workers	2	2

>200 Workers	7	7.2
Ownership type		
Private	70	72.9
Private (Family company)	24	25.1
Public	2	2
Electricity consumption per month		
0–10 MWh	55	57.2
10–50 MWh	23	23.2
50–100 MWh	8	8.3
100–400 MWh	3	3.1
>400 MWh	2	2
CEO didn't know	6	6.2
Working shifts		
1 shift per day	56	58.5
2 shifts per day	20	20.8
1 day and 1 night shift	14	14.5
3 shifts per day	6	6.2

As illustrated in Table 2, 98% of the responsive companies are private companies. Furthermore, 66.6% of them have less than 50 workers, reflecting that most of our respondents are small-scale enterprises. The monthly electricity consumption data indicate that 57.2% of the responsive companies consume less than 10 MWh per month and 23.2% consume between 10 MWh to 50 MWh. This also confirms that around 60% of respondents can be considered as small and 23% as medium-sized enterprises, which is compatible with the number of respondent industries in terms of size (Table 2).

Regarding the working shifts, we can see that the majority of the industrial companies (60%) that took part in this survey had only one shift per day schedule (at the time of the survey, Iran's economy was experiencing a deep recession due to US sanctions against Iran). Therefore, many companies were forced to operate no more than one shift per day).

4.2. Factors Affecting the Willingness to Join an InCES

4.2.1. Dependent Variable

Since the objective of this research is to characterise the willingness of the industrial companies in Arak to engage in an InCES, the dependent variable in our survey is: "*Eventually, in case there is an InCES in your zone (or is going to be initiated), would you be willing to invest in it?"*. Respondents could score this question between 1 to 10, reflecting whether they completely disagree or completely agree with this phrase, respectively. For the sake of better visibility, in our tables and figures, we labelled this question as "INCES-INVESTMENT".

4.2.2. Independent Variables

To investigate the impact of the factors hypothesised previously in Table 1, we designed the survey in such a way as to reflect the opinion of the respondents regarding a range of variables which can be clustered into three categories: *(a) social factors*, *(b) economic factors,* and *(c) environmental factors*. Within the mentioned categories, besides the hypothesised factors (Table 1), we also collected data on some other aspects that we found to be informative/impacting regarding the willingness of the industrial companies to invest in an InCES. These factors are marked as "exploratory" in Table 3.

These variables and their designated labels are listed in Table 3.

Table 3. List of independent variables and their labels.

List of Independent Variables and Their Labels	Label	*n*	Mean	MIN	MAX	SD
Demographic factors						
1. Education	EDU	96	3.25	1	5	0.785
2. Size of the company (**H8**)	SIZE	96	1.68	1	5	1.96
Social factors						
3. Degree of social bonding within the industrial zone (**H4**)	SOCI-BOND	96	3.46	1	10	1.04
4. Willingness to make partnerships with other companies (exploratory hypothesis)	PARTNER-WILL	96	5.73	1	9	2.161
5. Degree of willingness to take the leadership of InCES (exploratory hypothesis)	LEAD-WILL	96	4.25	1	9	2.501
6. Degree of not being interested in making partnerships with other companies due to not having trust in them (**H5**)	NO-TRUST-OTHER	96	6.71	2	9	1.383
7. Degree of not being able to trust governments' promises (incentives) over time (**H5**)	NO-TRUST-GOV	96	7.87	3	10	1.274
8. Degree of not being interested in sharing the information on your company's electricity consumption with others (exploratory hypothesis)	NO-INFO-SHARE	96	6.23	1	10	1.954
9. Degree of your tendency to value transparency in partnerships (exploratory hypothesis)	PRO-TRANSPARENCY	96	8.44	5	10	1.099
10. Degree by which you align your decisions with prominent companies' decisions if they decide to join InCES (exploratory hypothesis)	ALIGN-PROM-COMP	96	7.03	4	10	1.333
11. Degree by which you value democratic decision making in partnerships (exploratory hypothesis)	PRO-DEMOCRACY	96	8.13	1	10	1.606

12. Degree by which you believe that the complexities of partnerships can be overcome by establishing proper institutions (exploratory hypothesis)	INSTITUTION-BELIEVER	96	7.47	4	9	1.05
13. Degree by which you are not aware of the incentives and benefits of RE in Iran (**H7**)	NOT-AWARE	96	6.17	3	10	1.843
Environmental factors						
14. Degree by which you believe that RE should replace fossil-based energies because of environmental concerns (**H3**)	FOSSTORE-PERSONAL	96	7.54	4	10	1.236
15. Willingness to pay more for RE in your household due to environmental concerns (**H1**)	WTP-RE-PERSONAL	96	7.09	3	10	1.452
16. Willingness to use RE in your company due to environmental concerns if it is economically feasible (**H3**)	WTP-RE-CORPORATE	96	7.39	4	10	1.223
17. Degree of your willingness to participate in socially and environmentally friendly plans regardless of their economic benefits (**H3**)	SOCI-ENV-PIONEER	96	6.19	2	10	1.6
Economic factors						
18. Desired amount of allocation of annual revenue for InCES (**H1**)	ANN-REV	96	5.21	1	10	0.704
19. Desired ROI in investment projects (**H2**)	ROI	96	6.42	1	10	0.515
20. Degree of not being interested in making partnerships in strategic issues such as electricity (exploratory hypothesis)	NO-PARTNER-STRATEGIC	96	6.78	1	10	1.776
21. Degree by which you are interested in having a share in a partnership which is easily tradable (**H6**)	PRO-TRADABLE-SHARE	96	8.87	6	10	1.064
22. degree by which you are interested in joining InCES only for economic benefits by selling generated RE (**H2**)	SELL-RE	96	7.17	4	10	1.173
23. Degree by which you assume that an increase in the price of electricity is probable, and you are willing to become gradually independent in terms of your electricity (exploratory hypothesis)	PROBABLE-ELEC-INCREASE	96	6.8	3	10	1.326
24. Degree by which you entitle your company to cheap electricity in an oil-rich country (**H9**)	ENTITLE-CHEAP-ELEC	96	6.78	2	10	1.708

25. Degree by which you are interested in investments with fast cash out conditions (**H6**)	PRO-FAST-CASHOUT	96	7.71	5	10	0.836
		Dependent variable				
Willingness to invest in InCES	INCES-INVESTMENT	96	6.79	2	9	1.398

4.2.3. Correlation Tables

The results of the Spearman correlation test for each of the three categories are shown in Tables 4, 5, and 7 respectively.

(a) Social and demographic factors:

Table 4 shows the correlation matrix related to social and demographic factors.

Table 4. Correlations between the Social and demographic factors and the dependent variable

Correlation table – Social and demographic factors														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1-EDU	1													
2-SIZE	.131	1												
3-SOCI-BOND	.116	.341**	1											
4-PARTNER-WILL	.066	.382**	.403**	1										
5-LEAD-WILL	.168	.454**	.482**	.621**	1									
6-SOCI-ENV-PIONEER	.419**	.354**	.234*	.194	.365**	1								
7-NO-TRUST-OTHER	-.107	-.076	-.119	-.195	-.154	-.335**	1							
8-NO-TRUST-GOV	.000	.113	.053	.204*	.150	.148	.244*	1						
9-NO-INFO-SHARE	-.191	.095	.088	-.096	.112	-.048	.128	-.005	1					
10-PRO-TRANSPARENCY	.239*	.188	.126	.096	.156	.376**	-.011	.223*	.160	1				
11-ALIGN-PROM-COMP	.358**	.320**	.304**	.132	.339**	.581**	-.353**	.065	.112	.397**	1			
12-PRO-DEMOCRACY	.219*	.027	.098	.130	.278**	.293**	.060	.206*	.272**	.197	.291**	1		
13-INSTITUTION-BELIVER	.408**	.247*	.070	.001	.185	.472**	-.284**	.005	-.023	.250*	.483**	.286**	1	
14-INCES-INVESTMENT	.320**	.259*	.207*	.298**	.307**	.655**	-.374**	.092	.069	.248*	.569**	.391**	.547**	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

According to the results presented in Table 4, there are significant positive correlations between "education" (0.32), "the degree by which industrial companies are willing to join partnerships in their industrial zone" (0.298), "the degree by which it is important for industrial companies to be a part of socially and environmentally friendly projects (regardless of the economic feasibility of these projects)" (0.655), "the degree of positive motivation induced by prominent companies of their zone investing in an InCES" (0.569), "the degree by which the decision making in the InCES will be organised democratically" (0.391), "the degree by which companies believe that proper institutions can overcome the complexities in partnerships" (0.547) and "the willingness of the industrial companies to invest in InCES".

Besides these positive correlations, the factor "not trusting other members in terms of them being erratic in financial issues, etc." negatively correlates with our dependent variable (−0.374).

Based on these correlation coefficients, it appears that the factor "being interested in being a part of a socially and environmentally friendly project" has a substantial impact on companies' willingness to invest in an InCES. This factor is also positively correlated with education and company size, implying that bigger companies with more educated decision makers are more likely to invest in socially and environmentally friendly plans. Furthermore, we can see that bigger companies tend to be more socially connected to their peers in their industrial cluster and are more prone to join partnerships and to take a leadership role. This reflects the hypothesised role of bigger, more prominent companies in encouraging other companies in their industrial cluster to join an InCES.

Besides, as expected, a lack of trust in other companies as potential members of an InCES has a negative impact on joining one. Interestingly though, a lack of trust in the government's plans to promote renewable energy does not significantly correlate with almost any of the factors above. Apparently, the respondents are indifferent about government and government policies, which may be interpreted as looking at a potential InCES as a completely bottom-up initiative without any role for the government.

The preference of respondents for a partnership in which the decision-making processes are being carried out democratically is an important parameter to be taken into account for the institutional setting of an InCES. This preference may be related to previous experiences of industrial companies in partnerships with uneven dominance levels between members [5].

Besides analysing the social and demographic factors and their correlation with our dependent variable, we evaluated the willingness of the industrial companies to invest in InCES for each of the different industrial clusters. The results are shown in Figure 4.

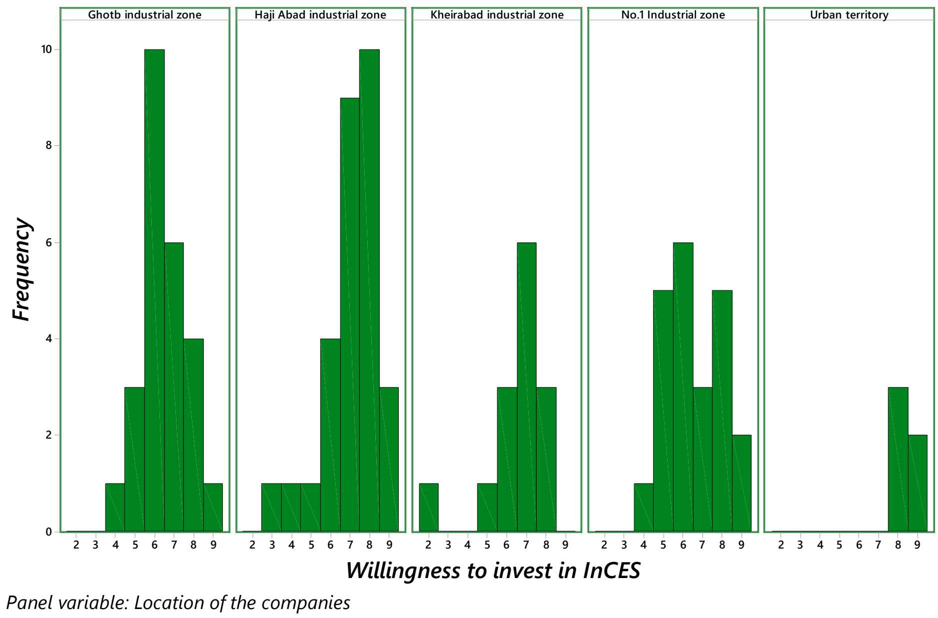

Figure 4. Willingness of industrial companies to invest in InCES vs. Location.

Figure 4 shows that the industrial companies located in Haji Abad and Urban Territory have significantly scored higher on willingness to invest in an InCES. This may be explained by the fact that these two industrial zones have the longest history, as they were the first industrial clusters to be established in Arak. Moreover, companies located in Urban Territory are significantly bigger than those in other industrial clusters. While historically, the location of these companies was outside the urban territory of Arak, it is through the development of the city over time that they have now become part of Arak's urban territory. It is worth mentioning that the companies located in Haji Abad also turned out to be the most socially bonded companies (SOCI-BOND factor, Table 3), according to their responses to the questionnaire.

(b) Economic factors:

Table 5 illustrates the correlation matrix related to economic factors:

Table 5. Correlations between the Economic factors and the dependent variable

Correlations matrix – Economic factors	1	2	3	4	5	6	7	8	9	10	11
1-EDU	1										
2-SIZE	.131	1									
3-ROI	.038	.172	1								
4-ANN-REV	.124	.322**	.383**	1							
5-PRO-TRADABLE-SHARE	.421**	.202*	.073	.011	1						
6-SELL-RE	.127	.038	-.048	-.207*	.026	1					
7-PROBABLE-ELEC-INCREASE	.366**	.295**	.365**	.422**	.299**	-.040	1				
8-ENTITLE-CHEAP-ELEC	-.172	-.201	-.244*	-.216*	-.045	-.002	-.419**	1			
9-PRO-FAST-CASHOUT	.050	-.020	.037	-.003	.101	.127	-.073	.013	1		
10-NOT-AWARE	-.147	-.067	-.221*	-.288**	-.016	.420**	-.334**	.127	.053	1	
11-INCES-INVESTMENT	.320**	.259*	.320**	.360**	.304**	-.218*	.752**	-.176	-.081	-.374**	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

coefficients in Table 5 show a positive correlation of "education" (0.32), "willingness to invest in projects with lower ROI" (0.320), "willingness to allocate a larger part of annual revenue to an InCES" (0.360), and "being interested in easily tradable shares in an InCES" (0.752) with the "willingness of industrial companies to invest in an InCES". There is a negative correlation (−0.374) between the degree of the companies' awareness of the benefits and incentives related to RE generation and their willingness to invest in an InCES.

Moreover, we see a significant positive correlation between the size of industrial companies and their willingness to allocate a larger share of their annual revenue to an InCES (if they choose to invest), reflecting the role of bigger companies in bearing the upfront investment costs related to RE generation projects. This is also consistent with the behaviour of bigger companies with respect to the social variables previously discussed.

A strong, significant positive correlation (0.752) is found between the degree to which the industrial companies expect the price of electricity to increase and their willingness to evade this threat by pursuing independence in power supply through an InCES. This expectation fits with the trend of de-subsidising electricity prices in many oil-rich countries. Interestingly, Table 5 also shows that this notion negatively correlates (−0.419) with a feeling of entitlement to cheap and abundant electricity, which still persists in oil-rich countries.

The significant positive correlation between the willingness of industrial companies to join in partnerships where their share is legally credible and easily tradable highlights the importance of a clear exit policy to be accounted for in the institutional setting of an InCES. Companies are more willing to join an InCES if they can be reassured about possible complications which might arise in case they decide to end their participation.

Besides the results shown in Table 5, we explored the behaviour of the industrial companies in financing their participation in an InCES. For this purpose, we asked them, "*In case you are interested in investing in an InCES by getting loans from banks, which of the following would be more interesting to you?*"

Figure 5 shows the histogram chart of the companies' responses to this question. This chart indicates that 65.3% of the industrial companies which have participated in our survey are more willing to seek loans with longer payback periods (we have interpreted a duration of 5 to 7 years as a long payback period by taking Iran's economic characteristics into consideration. This might not be interpreted as a long payback period in other countries with different economic attributes. In the same context, a loan with a payback period of up to 3 years is considered a short-term loan) and use other types of credits (such as the financial value of the installed solar technology) as the guarantee of the loans rather than a real-estate guarantee. These results reveal a crucial hint for policymakers to promote transitioning to RE in the industrial sector by introducing loans that accept RE technology assets as (a part of) the loan guarantee.

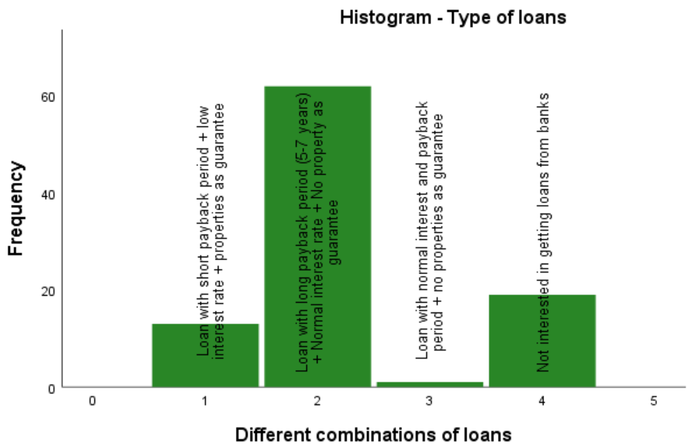

Figure 5. Histogram—types of loans.

Electricity consumption scheme:

To dig into more detail, we explored the relationship between the electricity consumption schemes of the industrial companies and the degree to which they are willing to become independent from the grid due to the high probability of an increase in the price of electricity.

Figure 6 shows the difference in the mean value of the scores which industrial companies with different electricity consumption schemes assigned to the phrase *"Similar to other energy carriers, we assume that an increase in the price of electricity is probable and we are willing to invest in InCES to become gradually independent"*. According to Table 6, this difference is statistically significant.

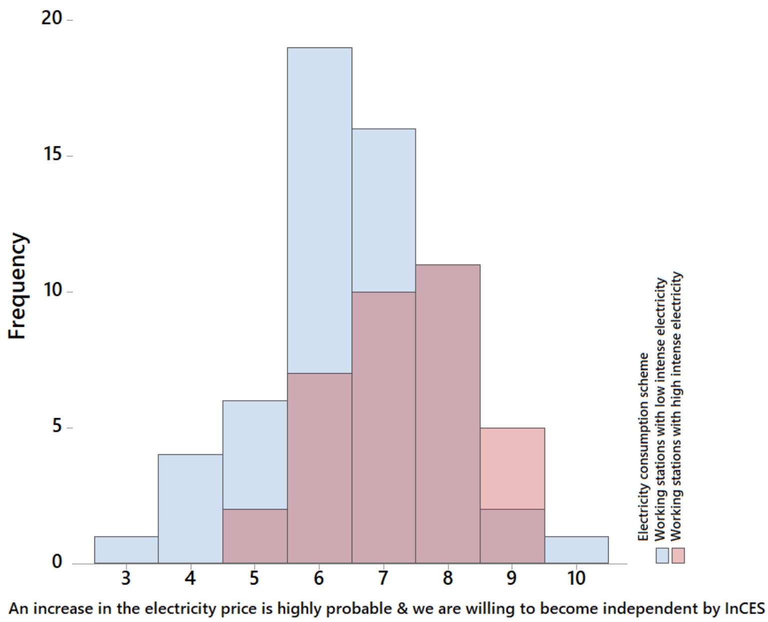

Figure 6. Electricity consumption scheme vs. willingness to become independent from the grid due to high probable increase in the price of electricity

Table 6. Electricity consumption vs. willingness to become independent from the grid due to high probable increase in the price of electricity.

	Electricity consumption scheme	N	Mean	Std. Deviation
PROBABLE-ELEC-INCREASE	Working stations with low intense electricity	60	6.52	1.359
	Working stations with high intense electricity	35	7.29	1.126

Levene's Test for Equality of Variances

		F	Sig.	t	df	Sig. (2-tailed)
PROBABLE-ELEC-INCREASE	Equal variances assumed	.845	.360	-2.827	93	.006
	Equal variances not assumed			-2.970	82.131	.004

This difference appears to be related to a significant difference in the share of electricity in the production costs. Companies where the production costs strongly depend on the electricity price have a strong incentive to neutralise the threat of an increase in the price of electricity.

(c) Environmental factors:

As illustrated in Table 7, there are significant positive correlations (0.697) between the willingness of CEOs to pay more for RE in their households for environmental concerns and their willingness to invest in an InCES. This positive correlation can also be seen between the degree by which the CEOs of the companies believe that fossil fuel-based energies should be replaced by RE due to environmental concerns and their willingness to invest in an InCES

(0.552). It is also noteworthy that education shows a significant positive correlation with both of the aforementioned factors. In other words, we can expect companies with CEOs who are more educated and more inclined to transition to RE in their personal lives to be more willing to invest in an InCES.

Table 7. Correlations between the Environmental factors and the dependent variable

Correlations matrix – Environmental factors							
	1	2	3	4	5	6	7
1-EDU	1						
2-SIZE	.131	1					
3-WTP-RE-PERSONAL	.408**	.213*	1				
4-WTP-RE-CORPORATE	.185	.041	-.039	1			
5-FOSSTORE-PERSONAL	.462**	.310**	.647**	.268**	1		
6-SOCI-ENV-PIONEER	.419**	.354**	.588**	-.060	.551**	1	
7-INCES-INVESTMENT	.320**	.259*	.696**	-.064	.552**	.655**	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

4.3. Factor Analysis

Besides the obtained results from the correlation tables discussed earlier, we ran a factor analysis test to explore how our responsive population can be divided into different clusters based on their responses to the independent variables. The Kaiser–Meyer–Olkin (KMO) test, which indicates that the sampling adequacy was 0.786, shows that the correlation patterns are compact and that the factor analysis should generate reliable and distinct factors. Moreover, Bartlett's Test of Sphericity was significant ($\chi2(190) = 787$, $p = 0.00$). Both the KMO test and Bartlett's test confirmed that the factor analysis (principal component analysis) could be appropriately applied for this sample dataset to reduce dimensions and provide some segmentation based on the respondents' responses.

Initially, five factors were chosen due to having eigenvalues over one and covering 63% of the variance. The extraction method used is the principal component analysis [58].

As expected, the factors had intercorrelations, so the direct oblimin rotation method was used [58], generating five rotated factors reflected in Table 8.

The first group includes companies whose managers are more environmentally concerned and more socially aware. The second group are those companies with bigger size, whose managers are more likely to tolerate economic risks and are confident to initiate an InCES and lead it. The third group are those companies who, as the residents of an oil-rich country, entitle themselves to cheap electricity and are not interested in investing in renewable energy or energy autonomy. The fourth group consists of companies currently unaware of the incentives and benefits of RE-based power generation in Iran. Finally, the fifth group includes companies that are reluctant to share information related to their electricity consumption.

Table 8. Factor analysis results.

	Groups				
	Socially aware and environmentally concern (20%)	Economically confident (15%)	Oil-rich-resident mindset (11%)	Not aware (10%)	Information sensitive (6%)
1-EDU					
2-SIZE		.608			
3-SOCI-BOND		.683			
4-ROI					
5-ANN-REV		.687			
6-LEAD-WILL		.846			
7-PARTNER-WILL		.804			
8-FOSSTORE-PERSONAL	.620				
9-WTP-RE-PERSONAL					
10-SOCI-ENV-PIONEER	.651				
11-NO-TRUST-OTHER					
12-NO-INFO-SHARE					.799
13-PRO-TRANSPARENCY	.695				
14-ALLIGN-PROM-COMP	.704				
15-PRO-DEMOCRACY					
16-PRO-TRADABLE-SHARE	.792				
17-INSTITUTION-BELIVER	.646				
18-PROBABLE-ELEC-INCREASE					
19-ENTITLE-CHEAP-ELEC			.813		
20-NOT-AWARE				-.770	

4.4. Regression Analysis

Finally, to predict willingness to invest in InCES, we performed a regression analysis. To determine those variables with the highest predictability power (for the willingness of the industrial companies to invest in an InCES), we entered variables from the factor analysis with noticeable eigenvalue into the regression model.

In order to nullify the multi-collinearity effect between the variables, we selected a *stepwise linear regression* model to specify which of these variables really contributes to predicting the willingness of the industrial companies to invest in an InCES. This model arrived at six variables with the highest predictability power, which are shown in Table 9. The adjusted r-square after including these six variables is 0.596, indicating that our six predictors (variables) account for about 60% of the variance in the overall willingness of the companies to invest in an InCES.

As we used the factors derived from the factor analysis method, the multicollinearity effect is already nullified. In Appendix B, the linearity and homoscedasticity as the preconditions of a proper linear regression model are discussed.

Table 9. Regression Analysis.

Stepwise regression model - coefficients					
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.798	.891		.895	.373
(a) SOCI-ENV-PIONEER	.238	.079	.272	3.000	.004
(b) INSTITUTION-BELIVER	.286	.107	.215	2.670	.009
(c) NOT-AWARE	-.163	.052	-.215	-3.122	.002
(d) ALLIGN-PROM-COMP	.196	.091	.187	2.164	.033
(e) PARTNER-WILL	.100	.044	.154	2.257	.026
(f) FOSSTORE-PERSONAL	.230	.083	.239	2.755	.007
Dependent Variable: Willingness to invest in InCES					

Since our variables have identical scales, we prefer interpreting the coefficients rather than the beta coefficients. Accordingly, our final model reflects that:

$$Y = 0.798 + (0.238)(X_1) + (0.286)(X_2) - (0.163)(X_3) + (0.196)(X_4) + (0.1)(X_5) + (0.230)(X_6)$$

where Y accounts for the dependent variable and (X_n)s are the independent variables according to Table 9. This equation implies that among our affecting variables, "*Degree of your willingness to participate in socially and environmentally friendly plans regardless of their economic benefits*", "*Degree by which you believe that the complexities of partnerships can be overcome by establishing proper institutions*", "*Degree by which you are not aware of the incentives and benefits of RE in Iran*", "*being aligned to prominent companies of the industrial sector in terms of joining an InCES*", "*Willingness to make partnership with other companies*" and, "*Degree by which you believe that RE should replace fossil-based energies because of environmental concerns*" have the highest impacts in predicting the willingness of the industrial companies to invest in an InCES.

5. Discussions

The quantitative analysis of the responses of the CEOs of our sample revealed several important insights that can play important roles in the direction of a company regarding its decision to join/not join InCES in the future. We will discuss these insights here.

In line with the first and second hypotheses (Table 1), companies which are more willing to allocate bigger shares of their annual revenue to an InCES and the ones which are inclined to invest in projects with lower ROI were shown to be more willing to invest in an InCES.

According to the results, as also formulated in the second hypothesis, high upfront investment costs proved to be a pivotal barrier for RE to become mainstream. Of course, our case only proves this for developing countries with relatively unstable economies, but this may potentially hold for developed nations as well because of the relatively larger investment requirement, considering industrial electricity demands. Bank loans are therefore crucial parts of RE incentives globally. Our case study shows that bank loans can be effective as RE stimuli if they allow for extended payback periods and accept the RE technology assets as part of the loan guarantee rather than real estate. The latter practice undermines financing opportunities for companies conducting their business in a rented workshop (not owning the place in which you live or work and still wanting to participate in RE transition is one of the basic motivations for joining community energy services, when it would be unreasonable for you to invest in installing RE technology in a place in which your stay is not guaranteed for a long time) and causes them to shy away from participating in an InCES.

Similarly to the willingness of households to engage in a CES and in line with the third hypothesis, industrial companies are more willing to join an InCES if the strategic decision maker is environmentally concerned. CEOs who believe in the necessity of shifting from fossil fuel-based to RE resources and who are willing to pay more for RE in their own household are more likely to invest in an InCES.

Moreover, in line with the fourth hypothesis, willingness to be known as a social and environmental pioneer on both collective and personal levels seems to be a crucial impacting factor with a high level of predictability (as mentioned in the regression analysis) on the willingness of the industrial companies to invest in an InCES.

Furthermore, in accordance with the fifth hypothesis, not having trust in other industrial companies was shown to negatively impact the willingness of the industrial companies to invest in an InCES. Interestingly, the degree of trust to the government's supporting plans did not prove to be a crucial decisive factor for the industries, if they want to consider investing in an InCES. This can be interpreted as looking at a potential InCES as a completely bottom-up initiative, without any role for the government.

In line with our sixth hypothesis, in contrast to communities of households, the role of "ownership" is found to be a crucial factor in the willingness of industrial companies to join an InCES. As such, industrial companies are more willing to invest in an InCES in which their share is legally credible and easily tradable. This implies that companies are more inclined to join an InCES if the exit rules are more relaxed and there is room for strategic manoeuvre for possible profits if trading is also allowed.

In accordance with the seventh hypothesis, the results also emphasise the need for awareness-raising policies. Companies which are not aware of renewable energy technologies and their financial benefits have no interest in joining an InCES. This finding signals that consulting companies may have an important role in catalysing the industrial energy transition by informing companies about RE policy incentives and technologies.

Impressively, in line with our eighth hypothesis, we find an important role for the bigger companies in an industrial cluster in initiating such projects. It appears that bigger companies are more open to tolerating the risks of joining projects with lower ROI and allocating a larger share of their annual revenue if they decide to participate in an InCES. Bigger companies are also more inclined to take the leadership of an InCES. The bigger companies appear to be more socially bonded and more willing to establish partnerships with their peer industries. This provides a significant lead for policymakers wishing to stimulate the use of renewable energy resources in the industrial sector. They can encourage the establishment of an InCES by targeted incentives and support large industries to initiate and lead an InCES in their industrial zone. This would create a seed for forming a potential InCES in an industrial cluster and would raise the interest and offer knowledge on the InCES to the follower companies in the cluster. Availability of knowledge plays a vital role in the uptake or start of InCES, as we will discuss later in this section.

Contrary to the ninth hypothesis, the amount of electricity demand did not prove to impact the willingness of the industrial companies to join an InCES. Importantly though, we find a high motivation to engage in an InCES among those companies that expect electricity prices to increase substantially. This motivation is strongest in energy-intensive companies which are directly connected to the high voltage grid, such as companies operating high-capacity induction furnaces.

As mentioned previously, apart from the hypothesised factors, a number of other factors were also explored inductively and were shown to have a crucial impact on the willingness of the industrial companies to invest in an InCES. Consequently, it was shown by regression analysis that industrial companies in an industrial cluster pay attention to other companies' behaviour in their cluster or proximity. Therefore, bringing prominent companies on board is found to be a crucial factor in encouraging other companies to join such environmentally sustainable projects as it is positively correlated with companies' willingness to engage in an InCES.

Besides this, it has also become evident that transparency and democratic decision making are important prerequisites for industrial companies to join an InCES. This complies with Elinor Ostrom's design principles for robust collective action and strengthens the case to consider an InCES as a collective action endeavour [5]. In the same context, it is interesting that CEOs who believe that proper institutions can overcome the complexities of a partnership have scored significantly higher on the willingness to invest in an InCES.

The education level of the strategic decision makers, as a factor which was not hypothesised in the beginning of this research, positively and significantly correlates with the willingness of industries to join an InCES. The analysis also reveals that high education levels not only correlate with the awareness of the complexities of such a partnership, but also with the notion that these complexities can be overcome by proper institutional arrangements.

The results of the factor analysis gave us a different dimension of the data, showing five different latent mentalities of the industrial companies in approaching InCES projects. These mindsets or attitudes of the company leaders can help policymakers to provide alternative incentive schemes or to adopt a range of policy measures to encourage/incentivise the companies to join RE, since a one-size-fits-all approach has proven to be less effective in jumpstarting such initiatives.

Finally, regression analysis additionally showed that among all aforementioned factors, "believing in proper institutional design to overcome the partnership complexities", "willingness to be known as a social and environmental pioneer in both collective and personal levels", "willingness to follow the role model of prominent companies if they engage in an InCES", "being aware of the benefits and incentives of transitioning to RE in Iran" and "willingness to partner with other industrial peers in their cluster", had the strongest predicting power in determining the willingness of an industrial company to invest in an InCES.

6. Conclusions

This research aimed to identify factors that influence industrial companies' willingness to invest in an InCES. We performed elaborate statistical analysis on the empirical data collected from the CEOs of a large sample of industrial companies located in Arak industrial city.

We looked into the existing literature on industrial collaboration in the domain of industrial symbiosis and the literature on community energy systems to formulate hypotheses regarding the most influential factors for the formation of an InCES. By considering the mentioned hypotheses, a questionnaire was designed to collect data on the opinions of the industrial executives regarding their willingness to invest in an InCES. Besides these hypotheses, additional data were collected to gain more potential insights into this problem in an inductive fashion.

As expected, a combination of social, economic, environmental, and demographic factors (size and education) impact the willingness of industrial companies in Arak to invest in an InCES.

All hypothesised factors, except the electricity demand, are shown to be statistically significant impacting factors on the willingness of the industrial companies to invest in an InCES. Besides these hypothesised factors, "being aligned with prominent companies of the cluster", "transparency" and "democratic decision-making process" in an established InCES, "believing in overcoming the complexities of a partnership by designing proper institutions", and "having a CEO (as a strategic decision-maker) with higher levels of education" have shown to be crucial impacting factors on the willingness of an industrial company to invest in an InCES which were extracted by exploring the data inductively.

According to the findings of this research, besides those that should be taken care of by industrial companies, some aspects can be aided with the help of policymakers. Consequently, to adequately stimulate the willingness of the industrial companies to invest in an InCES, it is suggested to policymakers to (a) prevent one-size-fits-all incentive design approaches, (b) reach out to larger companies with targeted incentive schemes since these companies are entities which are more prone to tolerate investing in initiatives with lower ROIs and are more likely to initiate such collective actions and take their leadership, (c) introduce specially designed bank loans with extended payback periods and with the ability to accept the RE technology as the loan guarantee, (d) make use of consulting companies in the field of renewable energies to increase the awareness of industrial companies regarding the technical and economic benefits of transitioning to RE, and (e) introducing environment-related promotion plans such as tax incentives to increase the willingness of the industries to take part in environmentally-friendly projects.

While this research was performed in the context of Iran as an oil-rich developing country, we believe that the results can, to a large extent, be generalised to other developing economies. First, although Iran has substantial oil and gas resources, the country has a strategic plan to increase the share of renewables in its energy supplement mix [59]. Second, there are quite noticeable similarities between Iran's economic and political situation and many of other developing countries which are struggling in a similar fashion with unstable economic conditions and consequently with high uncertainty about future electricity prices, and where the accomplishment of environmental and climate policy goals may be driven more by the personal motivation of industrial decision-makers than by strict enforcement.

Although this research sheds light on the factors stimulating the willingness of the industrial companies in Iran to invest in such projects, it is limited in the sense that the opinions of the industrial executives may be influenced by the economic sanctions against Iran, positioning the transition to RE as a lesser-priority plan. Yet, according to the findings of this research and the abovementioned reasons, transitioning to RE in Iran's industrial sectors seems to be a valid area of research which can be continued by performing cost–benefit analyses while bringing different introduced incentive mechanisms [60] and the best renewable technologies [61] to be used in the spotlight.

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Abbreviations

IEA	International energy agency
CES	Community energy system
InCES	Industrial community energy system
CEO	Chief executive officer
IS	Industrial symbiosis
kWh	Kilowatt hour
MWh	Megawatt hour
MW	Megawatt
ANOVA	Analysis of variance
WTP	Willingness to participate

Appendix 2A

The content of the distributed survey is shown below:
Questions regarding the identity of the respondent and the company he/she is affiliated with:
(i) Name of the company:
(ii) First and last name of the respondent:
(iii) Address:
(iv) Phone number:
(v) Email address:

(1) What is your company's field of activity?
(2) Please choose your latest educational degree
- High-school
- Associate degree
- Bachelor
- Master
- PhD

(3) In which industrial cluster in Arak is your company locate?
- Ghotb industrial zone
- Kheir Abad industrial zone
- Haji Abad industrial zone
- No.1 industrial zone
- Urban territory

(4) Which of below options best describe your company's electricity consumption scheme?
- Working stations with Intensive electricity needed
- Multiple working stations with low-intense electricity needed (no need to high-capacity electricity post)
- Too many working stations with low-intense electricity needed (High-capacity electricity post needed)

(5) What type of ownership does your company have?
- State-owned
- Private
- Private (family business)
- Public
- Hybrid

(6) How many people are working in your company?

- 1–50 people
- 50–100 people
- 100–150 people
- 150–200 people
- More than 200 people

(7) How much is the average monthly electricity consumption of your company?
- 0–10 MWh
- 10–50 MWh
- 50–100 MWh
- 100–400 MWh
- >400 MWh

(8) How much is your monthly electricity bill? (1 USD = 120,000 IRR)
- 0–500,000 Toman
- 500,000–2,000,000 Toman
- 2,000,000–10,000,000 Toman
- 10,000,000–20,000,000 Toman
- >20,000,000 Toman

(9) How many working shifts do you have?
- 1 daily shift
- 2 daily shifts
- 1 daily and 1 night shift
- Three shifts

Questions regarding the "environmental attitudes": (Please rate below phrases between 1 to 10)

(10) Personally, I am concerned about the environment and I believe fossil-based energies should be replaced by renewables

(11) Personally, due to environmental concerns, I am willing to pay more for RE in my household

(12) Due to environmental concerns, we are willing to use RE in our company but only if it is economically feasible (the economic feasibility is more prior)

(13) It is important for us to participate in societal and environmentally friendly projects even if they are not economically feasible

Questions regarding the "societal attitudes": (please rate below phrases between 1 to 10)

(14) We are not interested in partnering with other companies since we cannot trust them in issues such as their on-time payments

(15) We don't like other companies to have access to our electricity consumption information

(16) We would participate in partnerships projects if only all the financial and operational performances are transparent to all the members

(17) We cannot trust introduced incentives from the government since we doubt if these promises can be kept by different governments over time

(18) We would be interested in investing in a project if prominent companies join that project

(19) We believe that in partnerships all the members should have the right to vote and decisions should be made in general meetings in a democratic way

(20) We are not interested to partner with other companies in strategic issues such as electricity and water

(21) In partnerships, we want our shares to be legally credible and tradable

(22) We are aware of the partnerships' complexity but we believe that we can overcome them by setting strict institutions
(23) How interested are you to partner with other industrial companies in your area? (financial investments or project partnership)
(24) How connected are you with the companies of your industrial zone?"

Questions regarding the "economic attitudes": (please rate below phrases between 1 to 10)

(25) We have no problem in our electricity provision and if we participate in an InCES it would only be for economic profitability by selling RE
(26) Similar to other energy carriers, we assume that the increase in the price of electricity is probable and we are willing to invest in InCES to become gradually independent
(27) We entitle the industrial sector to cheap electricity and we are not willing to invest in InCESs to prevent the probable expensive electricity threat
(28) To invest in a project, the ability of fast cash out is very crucial
(29) We are not aware of the incentives dedicated to RE generation at all
(30) In case you are interested to invest in an InCES by getting loans from banks, which of the following would be more interesting to you?

- Loan with short payback period + low interest rate + properties as guarantee
- Loan with long payback period (5–7 years) + Normal interest rate + No property as guarantee
- Loan with normal interest and payback period + no properties as guarantee
- Not interested in getting loans from banks

(31) How much (of your annual revenue) are you willing to invest in a collective renewable electricity production project?

- less than 5% of annual revenue
- 5% to 10% of annual revenue
- more than 10% of annual revenue
- Not willing to invest revenue

(32) In case your company invests in collective renewable electricity production, how long would be your preferred investment's payback period?

- Less than 3 years
- Between 3–5 years
- Between 5–10 years
- Between 10–15 years
- >15 years

(33) Eventually, in case there is an InCES in your zone (or is going to be initiated), would you be willing to invest in it? (dependent question) (please score between 1 to 10)

Appendix 2B

The below figures are generated to reflect the linearity of the regression model, which was discussed in the manuscript.

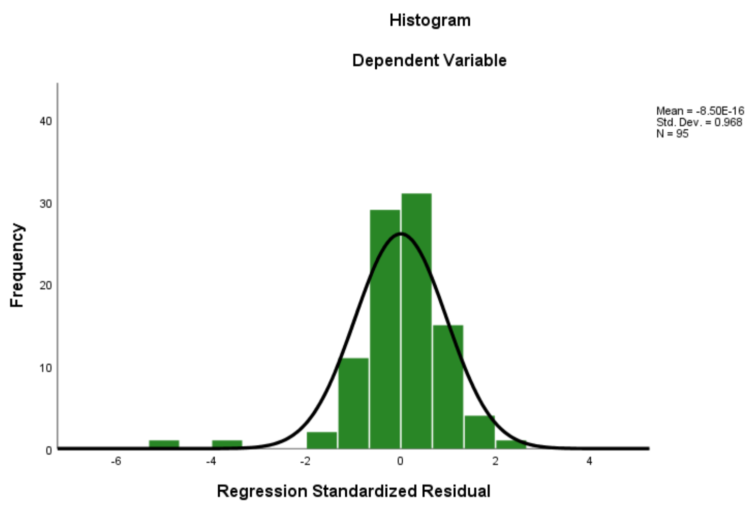

Figure A1. Homoscedasticity conditions of the regression analysis.

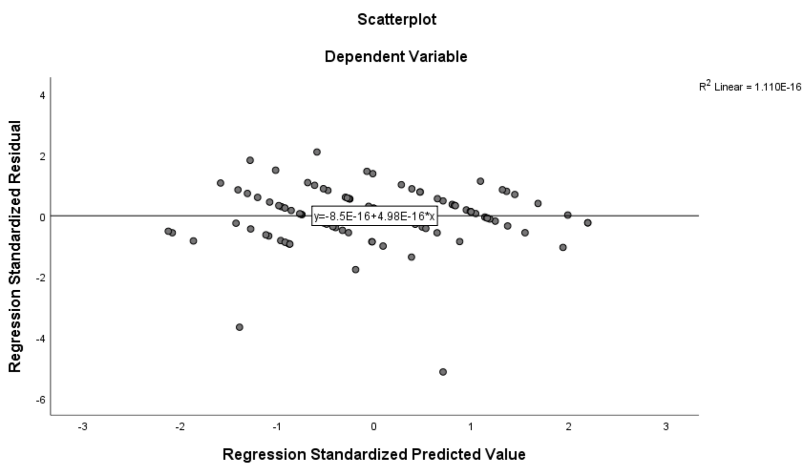

Figure A2. Linearity of the regression analysis.

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Chapter 4: Industrial Community Energy Systems: Simulating the role of financial incentives and societal attributes

Considering that the industrial sector consumes almost one-third of the energy demand globally, it is an urgent call to reduce the carbon footprints in this sector. Among different approaches to meet this goal, such as the employment of carbon capture technologies and increasing energy efficiency within industries, transitioning to renewable electricity (RE) would be another outlook to reduce the carbon footprints and increase the energy security of the industries.

Collective power generation within communities has shown to be feasible and promising in the Industrial sector, where groups of industries collaborate to generate energy and meet their energy demand. Given that the literature has so far paid marginal attention to the challenges of establishing the industrial community energy systems (InCES), in this research, we investigated how the initiation and continuation of such systems among industrial companies can take place and what financial incentives can act as the proper supporting systems to be introduced by governments.

We used agent-based modelling and simulation, in combination with cost-benefit analysis to assess the feasibility of initiating/joining an InCES by industries. Also, we considered cultural factors in the decision-making process of industrial companies. For the cultural context six countries, namely, Japan, Iran, the Netherlands, Australia, Brazil, and the United States, were studied to better generalise this research's findings.

The results show that the type of financial incentive schemes does not substantially impact the number of established InCESs, and the number of companies joining/exiting InCES. At the same time, the amount of generated RE is significantly influenced by the type of incentive mechanisms. The Feed-in-Tariff incentive showed the worst performance and the TAX incentive was the best stimuli for the RE generation. Interestingly, the Tradable Green Certificate (TGC) incentive showed almost similar performance to TAX incentive, while its market-dependent nature results in the employment of the most efficient RE technologies by industries. [13]

[13] chapter has been published as Eslamizadeh, S., Ghorbani, A., Costa, R. C. B. F., Künneke, R., & Weijnen, M. (2022). Industrial community energy systems: Simulating the role of financial incentives and societal attributes. Frontiers in Environmental Science, 1-18. The first author has conceptualised and performed the research. The other authors have performed an advisory role.

1. Introduction

The industrial sector consumes almost one-third of the energy demand globally [1]. The urgent need to reduce emissions and the commitments countries have made due to Cop 26 makes it more crucial for the industrial sector to take faster and more concrete steps towards this goal. Improving industrial energy efficiency by implementing best practices and new technologies is necessary for achieving such targets. Although deploying carbon capture and storage (CCS) technologies can reduce the manufacturing industry's carbon dioxide (CO2) emissions, CCS technology is an expensive option compared to other low-carbon technologies. Even so, these technologies do not reduce the reliance on fossil fuels. Therefore, transitioning to a more electrified energy system in the industrial sector that dominantly uses renewable resources would be the only way to achieve higher and long-term reductions in the industrial sector's fossil fuel demand and related emissions.

Shifting from fossil-based energy to renewable electricity requires massive upfront investments given the substantially higher demands and baseload in the industrial sector than in other sectors (e.g., built environment). This would hinder the development of such projects by industrial companies. One way to tackle this investment hurdle is to collectively invest in renewable energy systems and establish "community energy" among industrial companies of an industrial cluster. The shared investment would reduce the costs by almost 30% [2]. Also, this decentralised electricity system will decrease the amount of power loss throughout the grid.

Globally, different incentive mechanisms have been introduced by governments to promote the generation of electricity from renewable resources for CESs, wherein almost all shareholders are households and small businesses [3]. However, given the significant differences in energy demand and energy consumption patterns of industrial companies, these incentive mechanisms can be substantially different. To this date, schemes that can best incentivise industrial companies' willingness to form an industrial community energy system have not yet been studied to the best of our knowledge.

This research aims to investigate the role of different mechanisms in incentivising the formation of an industrial community energy system (InCES). We use agent-based modelling and simulation to identify the conditions that lead to the formation and continuation of an InCES. The simulation model can help explore how industrial companies can be incentivised to invest in energy cooperatives and how this partnership can sustain over time. We bring the well-pronounced differences in the decision-making styles between the industrial companies and households in the spotlight. The model takes a cost-benefit analysis (CBA) approach, which industrial companies often use to evaluate the financial gains of investment plans [cite]. Besides the CBA method, the model also considers the societal attributes of the industrial companies when they decide about the continuation of their partnership [cite]. This conceptualisation builds on Hofstede's cultural dimensions theory [4] combined with Scharpf's organisational decision-making theory. Using these theories, we create a heterogeneous population of industrial companies with distinguished social reactions in the partnership that influences their sustained membership in the cooperative.

In this research, data from six different countries (Japan, Brazil, Australia, the United States, Iran, and the Netherlands) are used to inform our model. This choice of country data helps us better generalise this research's findings due to noticeable differences in economic structures, societal attributes, and biophysical characteristics of these countries. We experiment with the settings for each of these countries to compare how different incentive mechanisms would act in mobilising the investments of the industrial companies in the formation and continuation of InCESs.

The structure of this paper is as follows:

In Section 2, we position this research by reviewing the literature on the collaborations among industrial companies, simulation of community energy systems and the way they are being supported by incentive mechanisms. In Section 3, the theoretical background of this research in terms of the way the investments in an InCES is evaluated and implemented, is described. In Section 4, the methodological backbone of this research is stated and the case studies are introduced. Section 5, reflects on the agent-based model and its paramters. Section 6, revolves around the extracted results of this research. And finally, in Section 7, the discussion and conclusion are reflected.

2 Literature review

2.1 Collaborations among industrial companies

Collaboration among industrial companies is not new. There is an extensive body of literature on industrial symbiosis (IS), a type of collaboration in which industrial companies share resources and byproducts [5]. Industrial collaboration in IS aims to optimize resource consumption and the associated economic and environmental benefits for the industrial companies involved [6]. Although collaborative power generation and demand management in an InCES seem to be intrinsically different from the industrial collaboration happening in the energy exchange among industries in IS domain, many aspects seem to be equally relevant for the establishment of an InCES, such as "trust" [7–9], "economic benefits" [7,10–15] and "community spirit" [16]. Moreover, while geographical proximity is a crucial element for an IS project [17], 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 the industrial companies is another critical barrier to IS establishment [18]. At the same time, 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. [19], in a recent study, revealed that initiation of an InCES would be possible among industrial companies within an industrial cluster while at the same time there should be institutions in place to help appropriately govern the InCES. Also, proper policies should be introduced to help industrial companies overcome the financial barriers of initiating such plans.

2.2 Financial incentives to support CESs

High upfront investment costs is known as one of the most critical barriers to establish a CES, especially in developing economies where the availability and financial feasibility of renewable technologies is not yet prepared [12–14]. Therefore, financial incentives are globally introduced by governments to help investors overcome the mentioned critical barrier while establishing a CES.

There is a body of literature on the incentive mechanisms to promote CESs. These incentives are introduced to help citizens as local investors establish CESs in order to generate local development opportunities, and to build social support for transitioning to a low-carbon sustainable power supply system. Curtin et al. [20] in a recent study reflect that in the starting phase of a CES, incentives such as "targeted loans" and "grants" can be most effective in the establishment of CESs while in the later project stages, "grants", "feed-in-tariffs (FIT)" and, "tax" incentives can act as market-independent supports for investors [20]. Alongside with mentioned incentives, "tradable green certificates" which are bond-like certificates and are issued for every certain level of RE production, have been introduced as a market-type incentive both for CESs and RE generation projects in general [3].

2.3 Agent-based modeling of the community energy systems

There is a considerable body of literature on collective renewable electricity production in local communities of households and small businesses. Energy communities are formed by members who share the values associated with a specific location, such as societal attributes, a particular spatial territory, and common ethics. They engage in a collective investment and consequently benefit from its advantages [21]. In this regard, energy cooperatives (REscoops) are one of the most known types of energy communities in which renewable energy would be generated and/or supplied to provide power or revenue (or both) to its members [22–27].

Despite the broad literature on CESs, the existing line of research focuses on their organizational structure, business and financial models, types of technology, and the characteristics of members [28–30]. 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., [31–34]).

Moreover, the mainstream line of research on mentioned topic relies on the results derived from existing case studies [cite]. Therefore, simulation techniques can be helpful in the generalization of the results, especially if it is complemented with real-world data. Among different modeling approaches, agent-based modeling (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., [35–38].

Despite the mentioned literature on the agent-based modeling of CESs, the way such an initiative can be established and be supported by financial incentives among industrial companies in an industrial cluster has not been paid attention to, to the best of our knowledge.

3 Theoretical background

3.1 Initiation of an industrial community energy system (InCES)

As it was mentioned earlier, crucial socio-economic factors have been identified in previous studies for the initiation of a CES for the case of household membership which are not necessarily applicable to the case of an InCES due to the differences between industrial companies and private households. One of the main differences is related to the decision-making process. Decision making between private households is typically not structured by strategic and rational procedures [39,40] unlike those of large industrial companies [41,42].In the latter case, these are required for reaching a consensus between different decision-makers with different interests and viewpoints (referred to as political decision-making) [43–48].

In addition to the decision-making process, InCESs face many technological, socio-economic, environmental, and institutional challenges different from those of communities of households [49]. Industrial firms have higher demands for electricity with more stringent requirements on the availability and quality of electricity service provision. There are also much more pronounced differences in electricity consumption patterns between industrial companies 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 similar demands [13].

3.2 Industrial decision-making process

Industrial companies can be categorised as composite actors when it comes to decision-making. 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*" [50]. In most cases, decisions in the 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 [51,52].

3.2.1 Social attributes of industrial companies for participating in an InCES

In this research, we use Scharpf's game-theoretical decision-making framework for composite actors to simplify the complex decision processes of big organisations [53]. The framework, presented in Figure 1, captures the possible decision-styles of composite actors on one axis (Unanimous decision, Majority decision, or Hierarchical decision) and the type of its decision rule (Problem-solving, Bargaining or Confrontation) on the other axis. Every actor has a preferred way to make a decision, which is a combination of its predominant decision-style and decision rule [51]. In this research, we use the different <u>*decision rules*</u> to characterise the companies in terms of the way they make decisions and what their reactions would be to the decisions made by other companies in a collective setting.

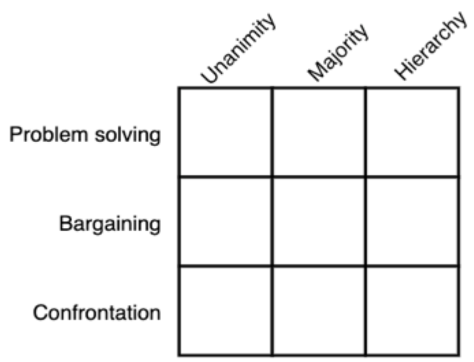

Figure 1: Decision-style framework [51]

In addition to the decision-making framework, industrial companies are also influenced by the act of their peers within their network, especially when they are deciding on joining a partnership [50]. In the realm of network theory, every individual entity follows a network of peers with some random social ties known as the "small-world network" [51] which influences the decision-making process of the members. Practically, the connections within this small-world network can be classified into a) weak ties and b) strong ties [54].

A weak tie implies a relationship between two companies with substantially limited interactions. In contrast, a strong tie reflects a relationship where the two connected companies consider each other similar (the homophily principle). This principle creates several interaction triangles, which, for industrial companies, translates to having a network of partners. The members of the strong network provide a more affluent influence on each other's decisions [54].

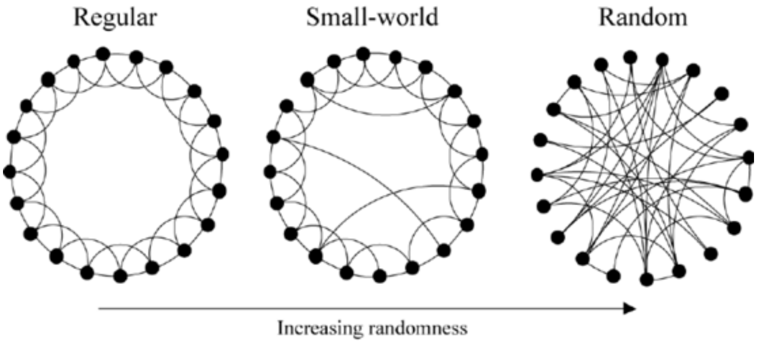

Figure 2: Small-world network and randomness [62]

The small-world network proposed by Watts-Strogatz [55] is a circular graph where each node connects to its neighbour nodes. Each node can rewire and connect nodes across the graph based on a probability; shortening the paths between nodes (Figure 2.) [54]. This depicts a relatively close representation of reality as companies connect with their neighbours but may also be strongly connected to companies much further away.

Besides considering a network structure, we use Hofstede's culture dimensions theory [4] to define the cultural attributes of a single industry within a cluster, thus making a heterogeneous population. The six dimensions are *Power Distance, Individualism vs. Collectivism, Assertiveness vs. Caring, Uncertainty avoidance, Long-Term Orientation, and Indulgence vs. Restraint*. For the detailed definition of each dimension, please visit Appendix 2. The cultural dimensions are also used to customise the model for particular countries by using real-world values on each dimension [4].

In this research, to reflect the differences in decision-making styles of companies in different cultures, we used the values from Hofstede's social dimension theory in Scharpf's decision matrix for each company to reflect the way each company would react (decides) in a collective setting. We use the "decision rule" axis of the matrix and place the companies in terms of their social behaviour into three categories of a) problem-solving, b) bargaining and c) confronting. To allocate different values to each company according to the country it is located in, we use Hofstede's values of "Power Distance", "Indulgence vs. restrain" and, "Long-term orientation". The three mentioned dimensions (the average of these three values) can be interpreted as the higher Hofstede's values, the more a company's social characteristics shift from problem-solving to confronting according to Scharpf's decision rule. In other words, the higher Hofstede's values, the more companies tend to act selfishly in collective settings.

3.2.2 Financial evaluation of participating in an InCES

The financial soundness of participating in an InCES project is a vital matter for companies. Cost-benefit analysis (CBA) is a technique to model industrial companies as business entities that evaluate the economic feasibility of investments by cataloguing the aggregated benefits (pros) and costs (cons) of a project based on their monetary values. For evaluating projects with a duration of more than one year, companies compare financial benefits based on the net present value (NPV) of the years in which the project has been running. A reliable method for implementing CBA in an RE investment project is calculating the Levelized Cost of Electricity (LCOE) [56].

Using LCOE (Equation 1), each company calculates how much renewable electricity unit (kWh) is generated against the project's total cost. This technique can help compare different renewable technologies with different lifespans for generating a desirable amount of electricity [57].

$$LCOE = \frac{\sum_{i=0}^{n} \frac{I + OM}{(1+i)^t}}{\sum_{i=0}^{n} \frac{G}{(1+i)^t}}$$

Equation 1: LCOE calculation equation

Where '"I' is the total investment in present value, '"OM' is the current value of the periodic operations and maintenance costs, '"G' is the total generation of energy during the 'project's life span, 'i' is the project discount rate, and 't' is the project life span.

Following Figure 3 by IRENA [58], we assume that about 30% of the installation cost associated with the "soft costs" can be divided among stockholders of a solar/wind farm. Therefore, we introduce $LCOE_{ind.}$ and $LCOE_{col.}$; where $LCOE_{ind.}$ measures LCOE when a company decides to generate RE individually (same as Equation 1), and $LCOE_{col.}$ calculates LCOE when a company chooses to generate RE collectively within a group of <u>*n*</u> members (Equation 2).

$LCOE_{col.} = (0.7 * LCOE_{ind.}) + (0.3/n * LCOE_{ind.})$, $LCOE_{ind.} = LCOE$

Equation 2: LCOE in collective form

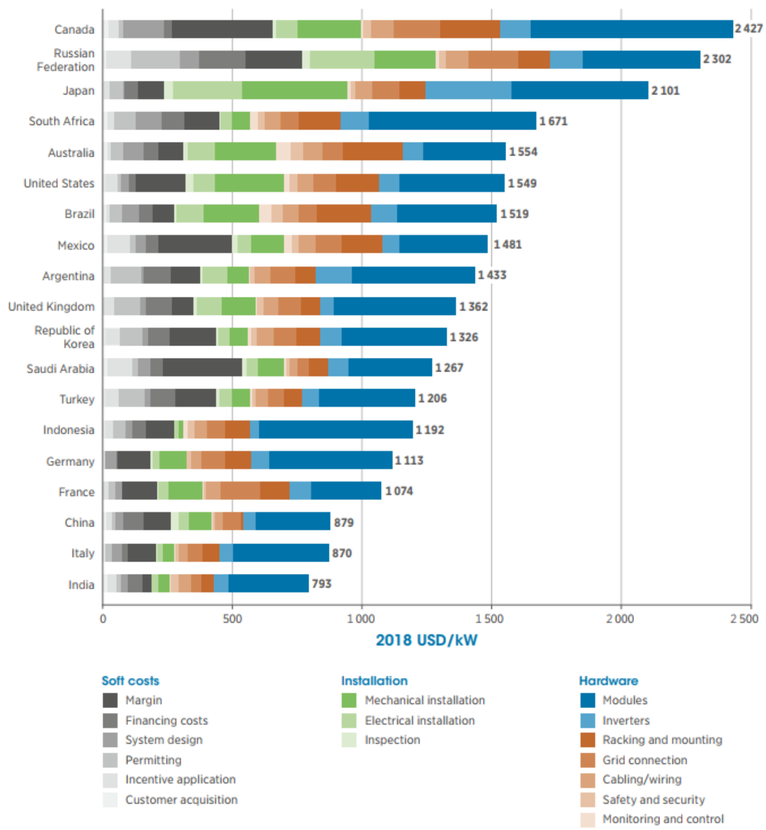

Figure 3: Renewable farm installation cost breakdown [58]

With this method, the financial impact of incentive mechanisms introduced to promote renewable electricity generation can be assessed. This research applies the most common financial incentives in the literature [3,59,60] as listed below:

i) Feed-in-tariff (FIT)

FIT is the most commonly used incentive to promote RE generation globally [61]. Under this incentive, the government guarantees the purchase of generated RE for a fixed price higher than the grid price for a certain period to make investments in RE generation financially more attractive [3].

ii) Tax incentives

Tax incentives create an exemption of some (or all) taxes related to renewable energy generation. This type of incentive mechanism aims at encouraging renewable energy consumption through applying tax credits or tax deductions on the purchase, installation, generation, and/or consumption of RE, facilitating the penetration of renewable energy deployment into the market. This type of incentive can be a direct discount when purchasing and installing the equipment or a lowered future tax [3].

iii) Tradable green certificates

Tradable green certificates (TGC) are financial incentives that reward energy producers based on the amount of RE they generate. By doing so, they receive tradable certificates with a fixed face value for every unit (for example, one certificate = fixed dollars = 1MWh). Such a certificate is treated like stocks bonds and can be traded in the market. TGC is a quantity-based incentive, while the FIT mechanism is price-based. Therefore, to increase the number of certificates, a company only needs to increase RE generation [3,62].

In this research, we will use the general idea behind these three mentioned incentives to study the role of incentive mechanisms for the formation and continuation of InCES. However, note that these incentives are only loosely used as the exact definition depends on the country and the situation it is being applied to. Other incentive mechanisms or adjustments of these three can be incorporated into the model for further exploration, making the model a tool to study incentives.

Figure 4 illustrates our theoretical approach regarding how an industrial company's decision is shaped for InCES initiation/participation and continuation.

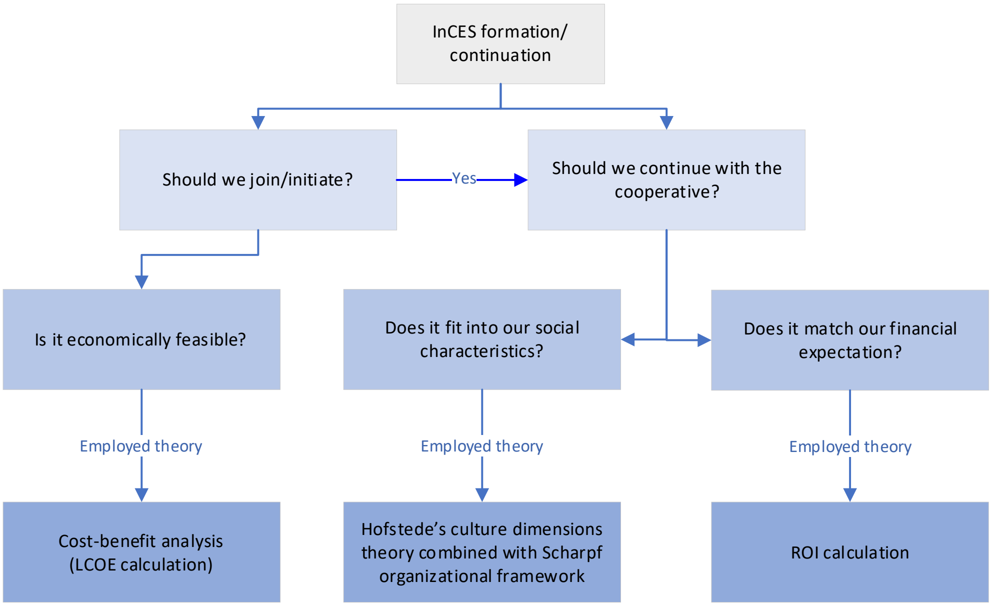

Figure 4: Theories used for simulating an InCES establishment

4 Methodology

In this research, we built an agent-based model based on the theoretical underpinning explained in Section 3.2 to investigate the impact of financial incentives on the formation and continuation of an InCES in a context with given socio-economic characteristics. This simulation approach has already proven to have valuable insights when employed to analyse the dynamics of other types of collective actions [63–65]. The model was built using the MESA package for Python, and the results were analysed in Python data analytics packages [66].

4.1 Case studies

As mentioned before, we aim to explore the effectiveness of the financial incentive mechanisms for the formation and continuation of InCESs by considering industrial companies' societal attributes and economic preferences in an industrial cluster. Given the factors we are considering in our model (i.e. cultural dimension for decision-making style, biophysical characteristics of the location, the electricity price, the interest rate and the installation costs), the results heavily depend on the country where an InCES is being implemented. Therefore, to gain context-specific insights, this paper customises the model to represent six different countries . These countries are Iran, the U.S., the Netherlands, Australia, Japan, and Brazil, covering a wide range of societal and economic conditions. Since the calculation of the price of electricity generated from renewable resources depends on the biophysical characteristics of the exact location, we select a city within each country (Table 1), to better use the available datasets (e.g. wind speed or sun irradiation intensity, Appendix 1).

Table 1: List of reference cities within our case studies

Country	*Reference city*
Australia	Sydney
Brazil	São Paulo
Iran	Arak
Japan	Kyoto
Netherlands	Rotterdam
United States	Los Angeles

5 An agent-based model of InCES

This section explains the conceptualisation and implementation details of the ABM. The model presents an industrial park with a heterogeneous population of companies (0 – 50 companies). In the following, we explain this model's internal mechanisms by first explaining the agents, their attributes, their decision-making processes to initiate/join an InCES, and the dynamics of the model.

5.1 Agents and interaction

The model consists of two different types of agents: a) *individual companies* and b*) InCES*. Table 2 shows the description of each of these agents.

Table 2: Agents attributes in the model

Agents	*Attributes*	*Attribute Value*	*Decisions*
Company	Electricity demand*	Randomly selected from a range	- Initiate/join an InCES - Vote on whether they accept InCES's yearly plan (if they join one) - Leaving an InCES
	Strong and weak connections to the peers	Randomly selected based on Watts-Strogats model	
	Decision rule	Randomly selected based on the cultural distributions (Section 4.2.3) resulting to be either “collaborative”, “bargaining”, or “confronting”	
	Expected rate of return (EROI)	Randomly selected between (0 – 0.05]	
	Loyalty level	Calculated during the interactions in an InCES (if they join one)	
	Interest rate	Fixed for each country and retrieved from existing databases (World Bank)	

InCES	Electricity demand	Calculated based on sum of members' demand	- decision on which strategy to choose based on members' vote

*This demand is the extra amount of electricity that each company will require for the next year compared to the previous year, calculated at the end of each fiscal year by each company.

5.2 Model Dynamics

5.2.1 Companies joining/establishing an InCES

At the end of each fiscal year, each industry calculates how much more electricity they would require in the next year compared to the current year. Consequently, the companies decide whether it is economically viable to satisfy this extra demand[14] from renewable resources or not by conducting a cost-benefit analysis using the LCOE calculation (details in Section 3). In this analysis, companies compare $LCOE_{ind.}$ with the grid tariff. If it is less than the grid tariff, the company looks for an existing InCES in the cluster. If an InCES is present, the industry will join that InCES since the $LCOE_{col.}$ is assumed to be always less than $LCOE_{ind.}$ (Equation 2). If there is more than one InCES present, the company will join the one with more members leading to less $LCOE_{col.}$. If there are no existing InCES, the industry will check peers in its strong network with $LCOE_{ind.}$ less than grid tariff and join them to initiate an InCES. In that case, an $LCOE_{col.}$ is calculated and if it is less than the grid tariff, these companies will initiate an InCES collectively. If there are no InCES in the cluster and there are no companies with $LCOE_{ind.}$ less than grid tariff in the strong network, the company will decide to generate renewable power individually.

While calculating $LCOE_{ind.}$ in the initial phase, if the value is higher than the grid tariff, the company will search the cluster for any existing InCES. In case there is one, the company will calculate the $LCOE_{col.}$ for that InCES and if it is less than grid tariff, it will join that InCES. If there are more than one InCESs in the cluster, the company will join the one with more members (resulting in less $LCOE_{col.}$). If the $LCOE_{ind.}$ is higher than the grid tariff, and there are no InCESs existing in the cluster, the company will no longer consider generating renewable power and will continue using the national grid. Figure 5 recaps the decision process that each company follows.

[14] In this research, we only considered the extra electricity demand of each industrial company per year, since we believe that transitioning to RE in the industrial sector should happen gradually due to large industrial electricity demands. Therefore, this assumption makes the research more in line with what is practically being experienced in the industrial sector.

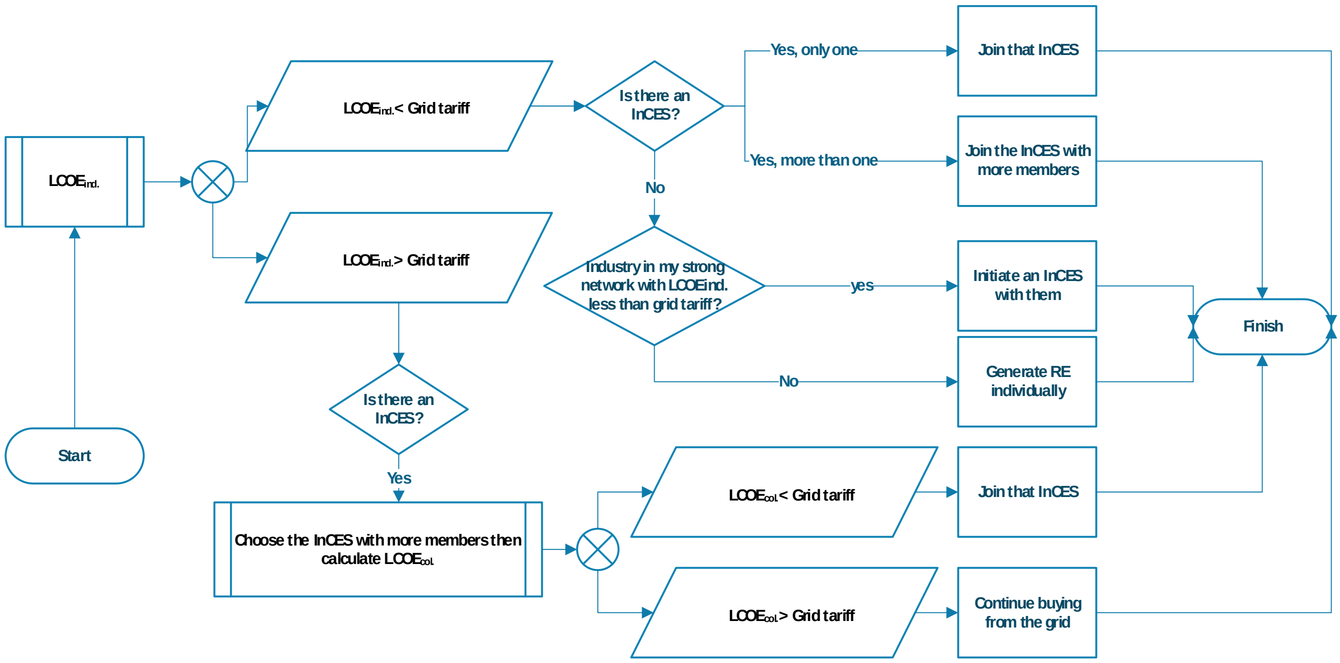

Figure 5: Flowchart of an industry joining/establishing an InCES or Exiting one

The costs in the decision-making process are calculated based on the incentive mechanism under study in the model and the technological availability in that geographical location (this process happens by each individual company before they decide to join/initiate and InCES).

5.2.2 Dynamics of interactions in an established InCES

Once established, an InCES decides whether *a) to generate RE to meet members' demands* or *b) to generate RE to meet members' demands* and *sell the excess generated electricity to the grid and pay out dividends*. Also, the technology they should choose for these two alternatives is selected.

Technology selection:

To do so, the InCES agent calculates the LCOE based on three alternative technologies of a) only solar, b) only wind, or c) a combination of both. To select the technology, InCES agent calculates the LCOE under each of the mentioned alternatives and the one with the lowest LCOE will be selected.

Yearly strategy selection:

To decide whether the InCES wants to a) *generate RE and provide it to the members* or b) *sell the generated electricity to the grid and payout dividends*, the InCES considers the return on investment (ROI) ratio. The InCES selects the plan with higher ROI and will put it to vote for the members.

Voting on the proposed plan by the InCES:

In the voting session, members of the InCES evaluate whether the plan chosen by the InCES is acceptable to them or not using two criteria: a) feasibility and b) financial desirability.

To assess the feasibility of the plan, each industrial company calculates the LCOE and compares it to what they pay to the grid. If the LCOE is less than that amount, they consider this plan feasible.

To assess the financial desirability, each company compares the ROI of the proposed plan to its expected ROI. The expected ROI is randomly assigned to each company from the range (0 – 0.05] (Table 2). If the ROI of the offered plan by the InCES is higher than the company's expected rate of return, they would consider the plan a financially desirable plan.

Companies that evaluated the plan as both "feasible" and "financially desirable" will vote "yes"; otherwise, their vote would be "no". Eventually, if the majority of the members vote "yes" for the plan that the InCES agent offered, it will be selected as the pathway of the InCES for that particular year (tick).

5.2.3 Leaving InCES

The decision for each company to stay or leave the InCES happens based on two dimensions, a) the loyalty point and b) the financial desirability (ROI).

By combining Scharpf decision-making framework and Hofstede's social dimensions theory, we assigned each company a "decision rule" related to Scharpf's decision matrix. Based on these characteristics, each company reacts differently (adding/subtracting loyalty points) to satisfactory/unsatisfactory events during the course of interactions in an InCES (the voting session in the case of our ABM).

"Decision rule" is the attribute by which companies react to the outcome of the voting sessions in an InCES. To put it in simple word, based on "decision rule", companies evaluate how their vote was compared to the outcome of the voting session.

To determine a company's decision rule (i.e., problem-solving, bargaining, or confronting), we generate a normal distribution between 0 and 100 for each country. This distribution is derived by considering its mean as the average of the three cultural dimension ("Power Distance," "Indulgence vs. restrain" and, "Long-term orientation) for that country. To calculate the standard deviation for this distribution, we utilised the average standard deviation of the Hofstede's values of the mentioned three dimensions per country. Consequently, a random value from this country-specific distribution is assigned to each company for that country (Figure 6). Therefore, companies in different countries can have any of the three different decision rules, but the number of companies belonging to each decision rule category differs depending on the countries' cultural distribution. As explained in Section 3, the higher Hofstede's values for the three cultural dimensions are (we use the average of these three mentioned dimensions), the more companies shift from being problem-solving-oriented towards confronting. Therefore, in the calculated normal distributions per country, values between 0 – 33 represent problem-solving companies, values in 34 – 66 are bargaining companies, and values in 67 – 100 represent confronting companies.

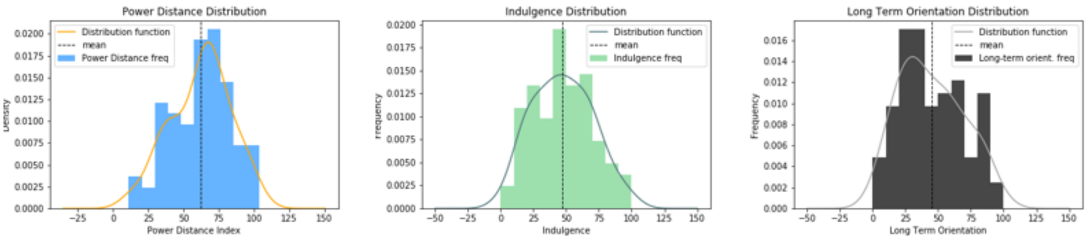

Figure 6: Determination of decision rule for one country as an example

Table 3 shows how each company adds/subtracts loyalty points based on their decision rule and the different outcome alternatives in a voting session.

Table 3: Assessing the loyalty points

		Alternative occurrences in a voting session	
		Company's vote = outcome of the voting session	**Company's vote != outcome of the voting session**
Decision rule	Problem solving	Adds **1** loyalty point	Subtracts **0** loyalty point
	Bargaining	Adds **3** loyalty point	Subtracts **1** loyalty point
	Confronting	Adds **3** loyalty point	Subtracts **3** loyalty point

Based on the dynamics of interactions introduced above, each member would add/subtract loyalty points until it reaches its bear minimum. At this point, the company checks if staying in the InCES is financially desirable (according to its expected ROI). If positive, they will remain with the community. If not, the company will exit.

5.3 Parameter setup and model settings

This section describes the parameter setup of the simulation. Three incentive scenarios are defined for each country: Feed-in-tariff, Tax Incentive, and Tradable Green Certificates, as shown in Table 4.

The maximum number of industrial companies in an industrial cluster is 50, following a definition by World Bank [67] on industrial clusters. We limited the number of InCESs in each cluster to 25 since each InCES needs at least two members to exist. The model stops after 20 ticks representing 20, which is currently considered the lifespan of renewable technologies [68,69]. Furthermore, each industrial company's electricity demand is selected randomly from a uniform distribution between 200 kWh and 30,000 kWh. The runs were repeated 500 times. Table 4 outlines the parameters and their values.

Table 4: ABM parameters description

Parameter	Type	Country	Value	Reference
Grid tariff	Random distribution	Australia	[5,19 - 6,35]	[70]
		Brazil	[9,61 - 11,74]	[71]
		Iran	[4,68 - 5,72]	[72]
		Japan	[10,84 - 13,25]	[73]

		Netherlands	[6,78 - 8,29]	[74]
		United States	[7,17 - 8,76]	[75]
Solar Installation Costs	Random distribution	Australia	[800 - 2000]	[76]
		Brazil	[800 - 2000]	[76]
		Iran	[800 - 1300]	[76]
		Japan	[1400 - 2100]	[76]
		Netherlands	[900 - 3490]	[77]
		United States	[800 - 2000]	[76]
Wind Installation Costs	Random distribution	Australia	[1300 - 2000]	[76]
		Brazil	[1200 - 2500]	[76]
		Iran	[1100 - 2100]	[76]
		Japan	[1600 - 2600]	[76]
		Netherlands	[1000 - 3100]	[76]
		United States	[1200 - 2500]	[76]
Solar energy potential	Numeric	Australia	[2270,2]	[78]
		Brazil	[1732,7]	[78]
		Iran	[2951,8]	[78]
		Japan	[1773,29]	[78]
		Netherlands	[1542,3]	[78]
		United States	[3254,20]	[78]
Wind energy potential	Numeric	Australia	[2525,80]	[79]
		Brazil	[1673,16]	[79]
		Iran	[2760,86]	[79]
		Japan	[979,66]	[79]
		Netherlands	[3749,28]	[79]
		United States	[2562,38]	[79]
Discount rate	Numeric	Australia	[7]	[80]
		Brazil	[10]	[80]
		Iran	[5,8]	[81]
		Japan	[4]	[82]
		Netherlands	[3]	[80]
		United States	[3]	[80]
Decision Rule	Numeric	Australia	[67,33]	[83]
		Brazil	[54,33]	[83]
		Iran	[47,66]	[83]
		Japan	[77,66]	[83]
		Netherlands	[49]	[83]
		United States	[66,33]	[83]
Industry Energy	Random choice	-	[200 – 30000]	*From grid tariffs*
Scenario 1 – FIT	Numeric	-	[2,1 ; 2,5 ; 3]	*calculated*
Scenario 2 – TAX	Numeric	-	[0,2 ; 0,4 ; 0,6]	[68]
Scenario 3 – TGC	Numeric	-	[0,015; 0,02; 0,025]	[84]
Number of companies	Numeric		50	
Number of communities	Numeric		=< 25	
Renewable energy generation lifespan	Numeric		20	
Energy demand by industry	Numeric		200 – 30000 kWh	
Wind Energy threshold	Numeric		5000 kW	
Loyalty Threshold	Numeric		12 /24	

6 Results

To address the main research question of this study, which was to explore the role of different incentive mechanisms on the formation and continuation of InCES, KPIs of (i*)* *electricity production per scenario*, (ii) *number of established InCESs*, (iii) *number of members in each*

InCES and, (iv) *number of exited members from each InCES after 20 years*, are measured. Additionally, the costs of such incentives for the government are also calculated.

It is important to emphasise that the countries we are presenting here are parameterised using a limited set of values from various data sources. This inevitable simplification implies that there might be other factors (e.g., political) that shape the outcomes of a country differently than the results of this simulation. The same holds for incentive mechanisms: their implementation may be different across countries, and our representation of them may not be accurate in the simulation. Our goal in this research is to do a *comparative* study; focusing on the relative differences rather than actual output values.

6.1 Number of established InCESs

The total number of established InCESs is measured by the sum of all active InCESs for each year per scenario and per country. The outcome shows that the effects of the TAX and TGC incentives were almost the same in establishing InCESs (Figure 7). On the other hand, the FIT incentive shows better performance in initiating InCESs, especially in Australia and the Netherlands (See Table 5). The number of communities is relatively constant, with its numbers increasing rapidly in the initial years and stabilising through the lifetime of the InCES. Peak values start in the second year, showing that almost all companies who might join/establish an InCES have already decided by the end of the second year. After that, no drastic change in the number of formed InCESs is made.

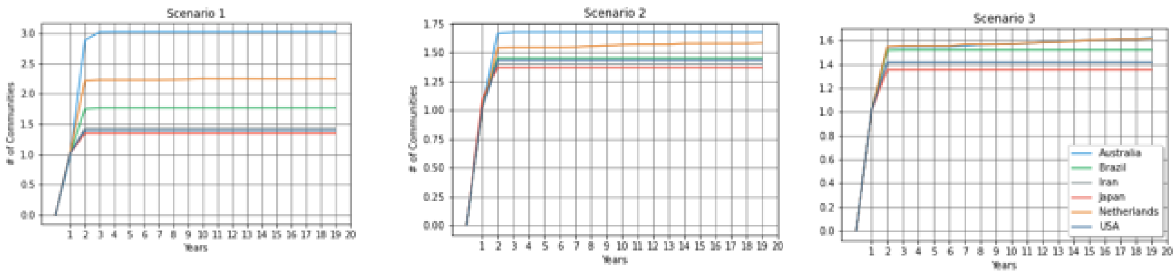

Figure 7: Number of established InCESs

Table 5:Number of established InCESs

Country	The average number of communities for all simulation runs			Standard deviation (σ^2)
	Scenario 1 (FIT)	**Scenario 2** (TAX)	**Scenario 3** (TGC)	
Australia	3.02	1.67	1.62	1.46
Brazil	1.77	1.45	1.52	0.95
Iran	1.43	1.4	1.41	0.76
Japan	1.34	1.37	1.35	0.70
Netherlands	2.25	1.58	1.61	1.16
United tates	1.39	1.43	1.41	0.77

Although the number of established InCESs gives a general insight into the effectiveness of the incentive mechanisms, it is not necessarily sufficient to assess the performance of incentive mechanisms. Therefore, we also measured how many companies joined these InCESs and continued with the initiative.

6.2 Number of members in established InCESs

Table 6 shows the average maximum number of companies that joined the communities under each incentive scenario.

Table 6:No. of members in InCESs

Country	The average highest number of members			Standard deviation (σ^2)
	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)	
Australia	4.84	9.99	9.79	2.92
Brazil	8.51	9.97	9.83	0.80
Iran	10.004	9.81	9.81	0.11
Japan	10.1	9.98	9.88	0.10
Netherlands	6.77	10.01	9.85	1.82
United States	10.18	9.97	9.83	0.17

The results of Table 6 illustrate that different types of financial incentives in the United States, Japan, Brazil and Iran do not significantly influence the number of companies that join an InCES . On the other hand, for Australia and the Netherlands, different incentive schemes performed differently where the FIT scenario performs worst.

6.3 Number of exited members from InCESs

Exiting an InCES is another crucial metric that should be carefully analysed since leaving an InCES is not straightforward given the high industrial electricity demands [19]. Also, the exit of a member from the community can be a heavy economic burden on the shoulder of an InCES [19]. Therefore, it is vital to measure how many members left the InCES in 20 years and what caused this phenomenon. As mentioned previously in Section 4, the exit of a member happens when both aspects of "loyalty level" and "economic desirability" are not reasonable for that member. Loyalty is determined during the voting process, and reflects how a company perceives its belonging to the community through its interactions with other members of the InCES. Table 7 shows the number of members who left an InCES under different incentive scenarios.

Table 7: No. of exited members from InCESs

Country	The average maximum number of members who exit a community			Standard deviation (σ^2)
	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)	
Australia	0.03	0.01	0.34	0.18
Brazil	0.24	0.25	0.25	0.005
Iran	1.06	0	0	0.61
Japan	0.81	1.82	0.21	0.80
Netherlands	0.38	0.61	0.36	0.14

United States	1.07	0.002	0.03	0.60

Table 7 reflects that the number of members who left an InCES in all countries is far less than the number of companies who joined an InCES. According to Table 7, almost no member exited the InCESs under different scenarios considering the very distinct social preferences (according to Hofstede's social dimensions theory). The reason behind this lies in the fact that for each member to exit, both thresholds for economic desirability and loyalty level should exceed. Therefore, even if a member is not happy with the social dynamics of an InCES, it stays since the InCES satisfies its economic desirability. Note that there is a noticeable overlap between the CBA analysis when a member decides to establish/join an InCES and economic desirability analysis when a member wants to leave an InCES. Although the methods to conduct these mentioned analyses are different, if an InCES seems economically beneficial for a member to join, it stays economically desirable during the membership period preventing that member from leaving the InCES.

6.4 Electricity generation

The amount of generated RE in InCESs is one of the most critical metrics, particularly in the eyes of policymakers. This amount is presented for each country and under different financial incentives in Table 8.

Table 8: Amount of generated RE in each country

Country	FIT		TAX		TGC		Max energy	% to max energy	
	Solar	*Wind*	*Solar*	*Wind*	*Solar*	*Wind*	*(MWh)*	*Solar*	*Wind*
Australia	12255	79	56915	44	53326	950	56958	99.92	0.08
Brazil	5379	7	61224	139	40941	71	61363	99.77	0.23
Iran	278	0	62109	0	62058	0	62109	100	0
Japan	4627	0	63897	0	23711	0	63897	100	0
Netherlands	7267	11087	31392	15079	11282	17098	46472	67.55	32.45
United States	87	0	62405	0	62254	0	62405	100	0

Based on the findings reflected in Table 8, wind energy is the least common renewable resource. The Netherlands is almost the only country that heavily utilises this resource for electricity generation. The reason behind this outcome is the minimum installation capacity for windmills set to 5 MW, which is reasonable due to higher installation costs of wind parks compared to solar farms. Therefore, the Netherlands is the only country with more than 5 MW of demand which is economically feasible to be supplied from windmills due to having more wind resulting in more wind electricity production potential.

In terms of incentives, the FIT incentive appears to have the worst performance, while the TAX incentive seems to be the most effective one for generating RE.

Nonetheless, although the RE generation potential of our case studies varies significantly (refer to Appendix 1), the total generated RE in each of the case countries is not substantially different. The better performance of a country such as Japan in RE generation within its established InCESs can be justified by the much higher grid tariff than other countries making

RE production more economically attractive. However, contrary to Japan, the lower solar potential and the minimum demand requirement for wind energy installation (as mentioned above) made RE generation less financially desirable in the Netherlands.

In addition to the impact of grid tariff, the discount rate in Japan is notably low (refer to Appendix 1), making the LCOE lower and more economically viable.

6.5 The total amount of investments

This section investigates the total investment to establish an InCES. By introducing incentive mechanisms, the government contributes to the total amount of investment required to establish an InCES. Tables 9 and 10 show the cost composition related to establishing an InCES in each of our cases under different incentive scenarios.

Table 9: Investment by InCES members

Country	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)
Australia	1,531,020	4,215,627	7,018,936
Brazil	2,286,061	6,016,729	9,565,892
Iran	1,310,571	2,818,090	4,705,052
Japan	3,672,871	8,043,490	13,254,686
Netherlands	7,104,634	9,016,960	9,780,848
United States	1,122,019	3,550,789	5,882,753

Table 10: Investment by the governments

Country	Scenario 1 (FIT)	Scenario 2 (TAX)	Scenario 3 (TGC)
Australia	1,377,934	8,736,423	13,723,368
Brazil	6,308,655	12,386,981	11,448,527
Iran	11,888,364	13,543,884	15,377,164
Japan	13,227,114	15,478,174	17,556,538
Netherlands	2,075,180	13,143,118	18,810,163
United States	12,755,845	6,712,148	19,070,796

According to Tables 9 and 10, communities made the least investment in the FIT scenario, while the TGC scenario appeared to be the costliest scenario for the governments. But combining the insights from these tables with the total RE generated sheds a brighter light on the performance of the incentive scenarios. Table 11 captures the cost composition related to the most effective incentive for each country in terms of power generation, which happens to be the tax incentive. For some countries, we considered both TAX and TGC scenarios due to small differences in the electricity productivity results.

Table 11: Cost composition of the incentive mechanism

Country	Productive scenario(s)	Produced energy (MWh)	Investment by the communities (USD) (1)	Investment by the government (USD) (2)	(1)/(2)
Australia	TAX	TAX: 56,958	4,215,627	8,736,423	0.48
Brazil	TAX	TAX: 61,363	6,016,729	12,386,981	0.49
Iran	TAX/TGC	TAX: 62,109	2,818,090	13,543,884	0.20
		TGC: 62,058	4,705,052	15,377,164	0.30
Japan	TAX	TAX: 63,897	8,043,490	15,478,174	0.52
Netherlands	TAX	TAX: 46,472	9,016,960	13,143,118	0.69
United States	TAX/TGC	TAX: 62,405	3,550,789	6,712,148	0.53
		TGC: 62,254	5,882,753	19,070,796	0.30

The reason which makes the TAX scenario more attractive for industrial companies is that in all of the countries except the Netherlands, communities invest about half and even less of the investment made by the government. Interestingly, for Iran and the United States, the TGC scenario had almost the same impact on electricity generation while a much bigger portion of the expenses to generate the electricity was paid by the government.

7 Discussion and Conclusion

In this research, we aimed to explore the role of financial incentive mechanisms in the formation and continuation of InCESs. To address this goal, we took an agent-based modelling approach. We combined Scharpf's organisational decision-making theory with Hofstede's social dimensions theory to determine the decision-making styles of industrial companies based on their culture. Consequently, we simulated the economic impact of the three incentive mechanisms of feed-in-tariff, tax-cut, and tradable green certificates, which were our suggestions of plausible financial mechanisms from governments to promote RE production.

To better generalise the findings of this research, we selected six different countries of Australia, Brazil, Iran, Japan, the Netherlands, and the United States to cover a wide variety of economic and societal characteristics.

This study shows that the FIT incentive scenario was the least effective in encouraging industrial companies to establish/join an InCES. Also, communities generated the least amount of RE under this incentive scenario. On the other hand, the TAX incentive scheme, which operates as a discount in RE technology, turned out to be the most effective scenario in terms of RE generation.

The study also showed no substantial differences between incentive scenarios regarding community establishment, the number of members, and the number of member exits from InCESs in 20 years. Yet, the TAX scenario showed superior outcomes in all mentioned aspects especially in terms of RE generation, while putting most of the installation expenditures on the shoulders of the governments. Interestingly, the TGC incentive scheme acted almost the same as the TAX incentive in terms of RE generation but with more investments from both government and communities. Although this reflects the cost efficiency of the TAX incentive, it should be noted that this incentive, even if cheaper than TGC, cannot promote the most efficient RE technologies due to lack of market mechanism[15]. Besides, TGC has the potential to create a new bond market, similar to carbon bonds, adding significant value to this option in the near future. These bonds can be traded like any other government bonds producing additional revenue for their holders. Part of the mentioned revenues from TGC could also be used to fund subsidies for reducing carbon emissions. Despite the high potential of the TGC scenario, the TAX incentive makes more liquidity, helping industrial companies' revenue streams access to cash in shorter periods which is a crucial aspect for industrial companies.

In summary, the model shows that the answer to "which financial incentive is the most effective between TAX and TGC?" depends on the economic preference of the government and policy analysts. For example, should the government bear more costs or reduce its investments, making communities invest more? This question cannot be simply answered as each government and administration has a different political-economic view on such a problem.

Besides the economic insights, the way industrial companies in different cultures would behave in a partnership (InCES) did not have a noticeable difference in the exit of members from an InCES. This highlights that even though there is a substantial cultural difference between industrial companies in our case countries, companies will not choose to leave an InCES if staying as a member satisfies their economic preferences. If the model had not considered the exit of a member to be dependent on both economic desirability and societal attractiveness (loyalty points), there would have been more exits from the InCESs. This was however observed while the loyalty points of many members crossed the exit threshold through the 20 years period but members did not exit because the economic desirability threshold had not reached the bear minimum for the same members to exit the cooperative. This seems to be an important finding while we are dealing with industrial companies as the members of a cooperative while in CESs with households as members, societal challenges would lead to higher percentages of member exits. This did not happen in InCES since the economic desirability accounts for a lion share of the decisions industrial companies make and also their exit from an InCES would not happen easily due to much higher upfront investments in an InCES considering the very large electricity demands of the industrial companies compared to households. This finding was also validated in another study by Eslamizadeh et al. (citing the paper of my own ABM) which shows the irresistible exit of some members due to societal challenges if we don't involve the economic desirability of an InCES into the decision-making process for exit from an InCES.

Finally, it is worth mentioning that this research used various assumptions and simplifications for modelling purposes. Using one incentive mechanism at a time and not investigating the role of a combined scenario is one example of the mentioned simplifications in this study. It is worth reemphasising here that our model made a simple representation of the incentive mechanisms that may influence the outcomes. The goal here was to focus on the

[15] TGC and FIT are behaving based on a market mechanism. Meaning that the more electricity you generate, the more your financial reward will be. This results in promoting the most efficient technologies to generate the maximum amount of RE. While in TAX incentive, a fixed percentage of the expenses will be paid by the government.

fundamental idea behind these incentives and build the model in such a way to allow for other incentives to be implemented in the future in the same model. The same goes for country specifications. The differences were only related to the cultural dimension values, price of electricity, and biophysical differences, resulting in the different potential for RE production and the economic structure of the countries (interest rate, installation costs, etc.). As such, we are not aiming to determine which country is successful and which one not, but rather studying them in relation to each other given the differences. Additionally, a deeper dive into why incentive schemes similar to what we considered in this research as the FIT is such a desirable incentive mechanism worldwide, considering its remarkable inferior results shown in this research, seems to be a legit research topic for further investigations. Moreover, this study can be extended by future inquiries on how a TGC incentive mechanism can be a more popular mechanism for promoting RE generation and what lessons can be learned from the "carbon credit market" to avoid its downsides.

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Appendix 4A.

Social-related data

As described in Section 2, to shape the agents' societal attributes in our ABM, we used Hofstede’s social dimensions theory, and World Value Survey [85] was used to extract the data related to the calculation of Hofstede’s dimensions for our case studies. This data is shown in figure 4.

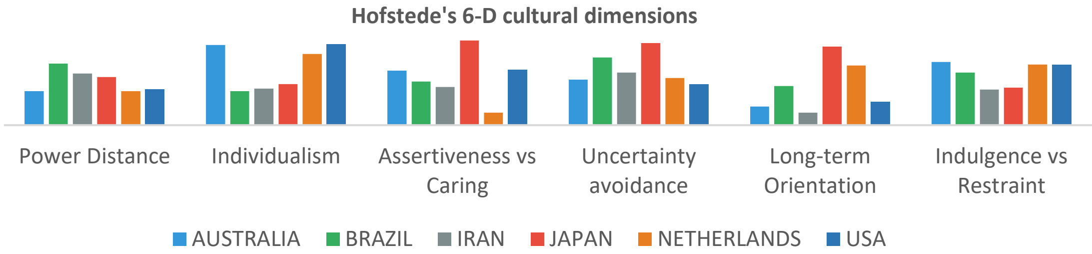

Figure 8: Hofstede’s values related to our case studies

Economy-related data

According to our model concept, economic data such as *mean grid tariff, RE installation costs, RE maintenance costs,* and *discount rates* were needed to be collected. We used data from the Power Generation Costs by the International Renewable Energy Agency (IRENA) 2018 [76] to determine the RE installation and maintenance costs. Figures 5 and 6 show the installation costs of RE parks among our cases.

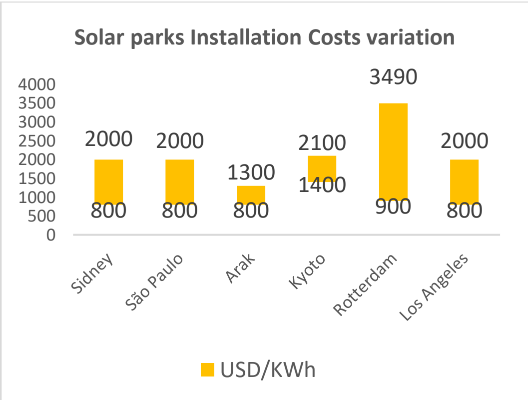

Figure 9: Solar park installation costs

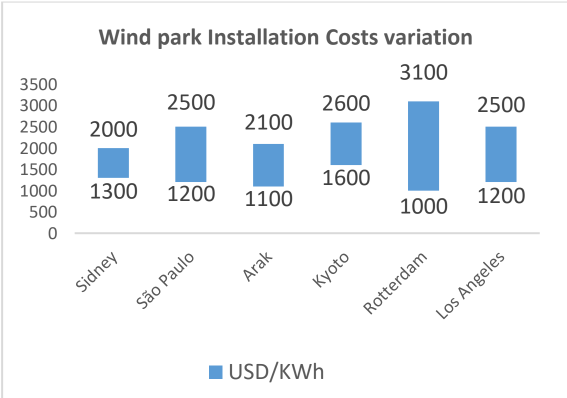

Figure 10: Wind park installation costs

For grid energy tariffs, they were collected from several different sources. Australia [70], Brazil [71], and the United States [75] were collected directly from the energy regulator or its statistics branch. The Netherlands’ grid tariff came from the European Union Statistics agency [74]. Iran’s grid tariff came from a World Bank report [72], and finally, Japan’s grid tariff came from a UK Ministerial report on Asian tariffs [73]. Finally, those values in currencies different than US dollars were converted to USD using the currency rate of 31-Dec-2018. The grid tariff variation is shown in figure 7.

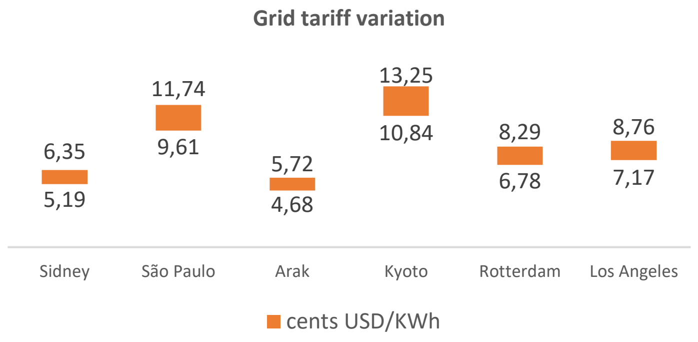

Figure 11: Grid tariff variation among our cases

Weather-related data

To determine how much electricity can be generated per year in our case studies, we needed to access weather-related data such as the distribution of wind speed throughout the year and total yearly sunshine hours. We used the open data website *windfinder.com* [86], which collects and presents statistics over wind collected in several weather stations worldwide to collect the data related to wind energy. Another data source that could provide data for several locations was the United Nations Database [87]. From this website, it was possible to collect the total yearly sunshine hours regarding our selected cases. These data are shown in figure 8.

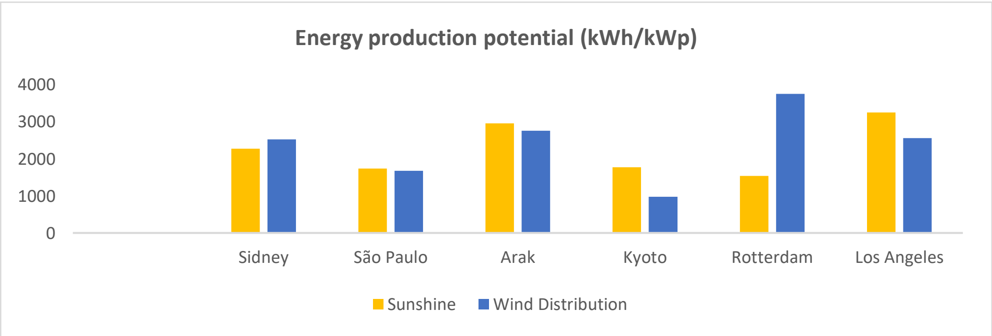

Figure 12: RE generation potential

Appendix 4B.

Below is the exact definition of each of the social dimensions introduced in Hofstede's Culture Dimension theory [88].

Power Distance

Power Distance is defined as the extent to which the less powerful members of institutions and organisations accept that power is distributed unequally. People in societies exhibiting a large degree of Power Distance accept a hierarchical order in which everybody has a place, with no further justification. In societies with low Power Distance, people strive to equalise the distribution of power and demand justification for inequalities of power.

Individualism vs. Collectivism

Individualism stands for a society in which the ties between individuals are loose: a person is expected to look after himself or herself and his or her immediate family only. Collectivism stands for a society in which people from birth onwards are integrated into strong, cohesive in-groups, which continue to protect them throughout their lifetime in exchange for unquestioning loyalty. The higher the score, the more individualist the country is.

Assertiveness vs. Caring

Assertiveness (or masculinity in the original publication) stands for a society in which social gender roles are distinct: men are supposed to be assertive, tough, and focused on material success; women are supposed to be more caring, tender, and concerned with the quality of life. The Assertiveness side (higher score) of this dimension represents a preference in society for achievement, heroism, assertiveness, and material rewards for success. Its opposite, Caring, stands for a preference for cooperation, modesty, caring for the weak, and quality of life.

Uncertainty avoidance

The fundamental issue here is how a society deals with the fact that the future can never be known: should we try to control the future or just let it happen? Countries exhibiting strong UAI maintain rigid codes of belief and behavior and are intolerant of unorthodox behavior and ideas. Weak UAI societies maintain a more relaxed attitude in which practice counts more than principles.

Long-term orientation

Every society has to maintain some links with its past while dealing with the challenges of the present and the future. Societies prioritise these two existential goals differently. Long Term Orientation stands for a society that fosters virtues oriented towards future rewards, in particular adaptation and perseverance. Short-term orientation stands for a society that fosters virtues related to the past and present, in particular, respect for tradition and fulfilling social obligations.

Indulgence vs. restraint

Indulgence stands for a society that allows relatively free gratification of some desires and feelings, especially those that have to do with leisure and consumption. Its opposite Restraint stands for a society which controls such gratification, and where people feel less able to enjoy their lives.

Chapter 5: Establishing Industrial Community Energy Systems: Simulating the Role of Institutional Designs and Societal Attributes

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 attractive option. Yet, the emergence and continuity of such communities among industrial companies have not been profoundly studied.

This research 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 by incorporating 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. Considering the dynamics of interactions in an InCES and its members' societal attributes, the institution by which the membership of an investor is not limited by strict entrance rules and the imposition of inflexible membership terms, increases the number of investors. Simultaneously, considering the installation of 15% extra capacity for the powerplant while monitoring and punishing members in terms of their electricity consumption and on-time payment of monthly premium fees, is recommended.[16]

[16] This chapter has been submitted as an original research article by Eslamizadeh, S., Ghorbani, & Weijnen, M. to the journal of Cleaner Production on 30 – 06 – 2022, and is under review. The first author has conceptualised and performed the research. The other authors have performed an advisory role.

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 emphasized in the recently published report by Intergovernmental Panel on Climate Change (IPCC) [1], 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 reduced utilisation of existing fossil-fuel-based power sector infrastructure, retrofitting existing installations with carbon capture and storage/utilization (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 [1].

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 the 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 [2].

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 collaboration by focusing on institutional design principles that have been shown to facilitate collective action [3]. These principles address the conditions to enter the initiative, conflict resolution, monitoring, and sanctioning among others [3]. 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 the institutional design principles can contribute to the establishment and success of an InCES, we use agent-based modeling and simulation (ABMS) to study the behavior 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 behaviors and interactions [4]. This simulation approach has proven to have valuable insights when employed to analyze the dynamics of other types of collective actions [5–7]. 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 [8], 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 [9] will be paid attention to. In order to better simulate how industrial companies make decisions in partnerships, Scharpf's game-theoretical [10] 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. In Section 4, the methodological backbone of this research is stated, and the case study is introduced. 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

2.1. Collaborations among industries

Collaboration among industrial companies is not new. There is an extensive body of literature on industrial symbiosis (IS), a type of collaboration in which industrial companies share resources and byproducts [11]. Industrial collaboration in IS aims to optimize resource consumption and the associated economic and environmental benefits for the industrial companies involved [12]. 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" [13–15], "economic benefits" [13,16–21], and "community spirit" [22].

Moreover, it is worthwhile mentioning while geographical proximity is a crucial element for an IS project [23], 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 the industrial companies is another critical barrier to IS establishment [24]. 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. [25], in a recent study, revealed that initiation of an InCES would be possible among industrial companies within an industrial cluster while simultaneously, there should be institutions in place to help appropriately govern the InCES. By considering all the abovementioned 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 organizational, ownership and financial (business model) types across the globe [26–29]. 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. [30,31].

Environmental motivations are the primary driving force behind the surge in CES implementation in many developed countries [32]. 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 are unable to provide stable energy service to the clients [29,31,33–37].

Economic factors such as inflation rate and expected rate of return play as an important decisive element for the potential members of a CES [29,38]. 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 [39–43].

2.3. Agent-based modelling of the community energy systems

Despite the broad literature on CESs, the existing line of research focuses on their organizational structure, business and financial models, types of technology, and the characteristics of members [44–46]. 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., [47–50]).

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 generalization 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., [51–54].

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

This research combines lessons learnt from IS and CES with the institutional design principles in an 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 [55]. 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 [19].

Industrial companies can be categorized 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 [56,57]. 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 [58,59]. 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*" [57].

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. [2], 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.

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

Table 1: List of impacting factors in the willingness of industries 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.

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 [25].

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.

$$\text{Total costs} = \sum_1^n I(1+r)^n$$

Equation 1: Total investment costs

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.

$$\text{Total benefits} = \sum_1^n B(1+r)^n$$

Equation 2: Total benefits

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:

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

Equation 3: CBA formula

According to Figure 1 by IRENA [60], we consider that about 30% of the installation costs associated with the "soft costs" (according to Figure 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 <u>n</u> members. The $CBA_{col.}$ is calculated using Equation 4.

$$CBA_{col.} = (0.7 * CBA_{ind.}) + (0.3/n * CBA_{ind.})$$

Equation 4: CBA in collective form

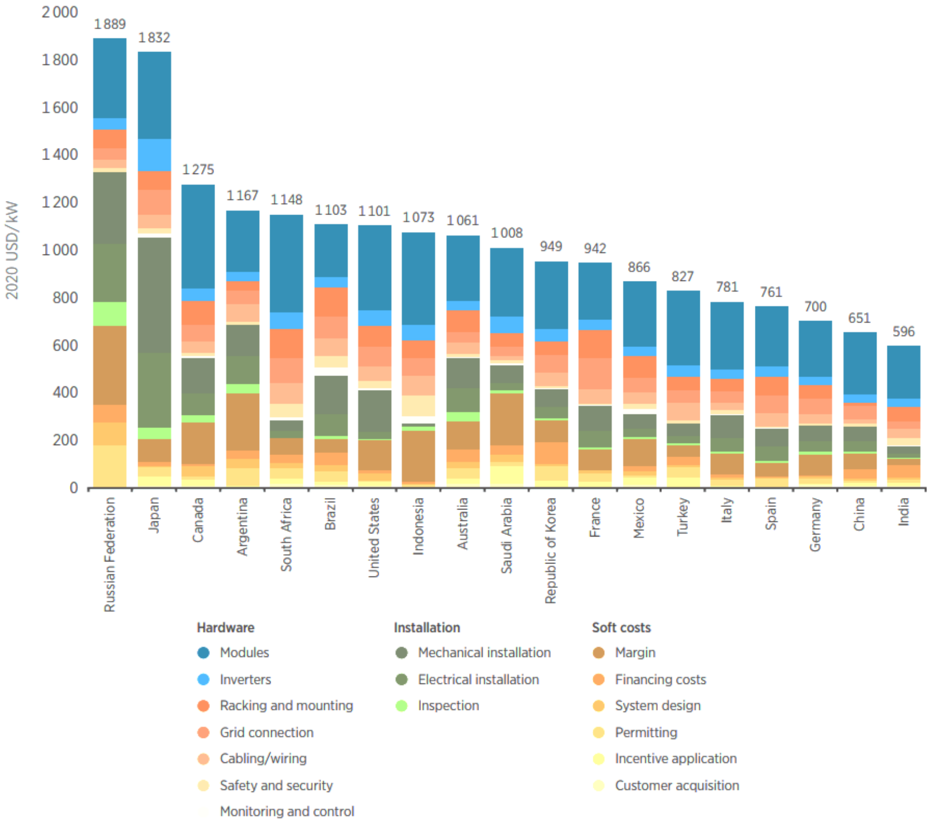

Figure 1: Renewable farm installation cost breakdown [60]

3.1.3. Societal attributes of the industrial companies in collective settings

As mentioned earlier, the decision-making process in organizations is different from that of individuals. It follows a more structured procedure due to the decision criterion of the decision-makers in a company [cite]. 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., 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 emphasizes 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 [9]. 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.

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

Table 2: Type of composite actors based on their attributes

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 who 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-organization of collective actions [3] 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) [61].

Ostrom's eight design principles [62] and their description and how they relate to this research are listed in Table 3.

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 authorized 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[17].
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 minimized.
VII) Minimal Recognition of Rights to Organize	*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 organized in multiple layers of nested enterprises
	Interpretation	Not used in this research.

Table 3: Ostrom's design principles and their interpretations in this research [3]

According to the literature on CES and the expert opinions reflected in a previous study by Eslamizadeh et al. [25], the most 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).

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

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. The model was built using NetLogo [63], and the results were analyzed in Minitab 18 [64].

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 Figure 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 a proper 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.

Figure 2: Arak's industrial clusters shown on the map

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 [2]. Data on the price of electricity was collected from the publicly available database of Iran's Ministry of Power [65]. 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 conceptualization 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")

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 4: Agent attributes

"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. "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 4.2, 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 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 categorized 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.

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

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

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.

As described in Section 2, each company then performs an economic evaluation by carrying out 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[18]

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

in average, Arak has 300 sunny days with and average of 7 hrs of sunshine per day

Total benefits = electricity bill fees which will be saved for 20 years + considering 15% yearly interest[19]

So, each company in tick one firstly, due to the qualities mentioned in Table 5, looks if it has a collective mindset in the first tick or not. In 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 (section2). 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 as the potentially participating companies and have $CBA_{col.} \geq 1$. Therefore, the minimum amount for n would be 2.

[18] 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 lend with 10% annual interest.

[19] 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.

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 that InCES. 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.

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 point	Subtracts **one** desirability point
Confronting	Adds **three** desirability point	Subtracts **three** desirability point

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

5.2.3. InCES members' electricity consumption

Each member is assigned a random monthly electricity demand ranging between [1000000 kWh 200000000 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 the 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) power shortage for other members b) 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[20] → 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".

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 7: Impact of consumption patterns on companies' evaluative criteria

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.

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

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

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

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

[20] 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.

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.

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 7,8). Eventually, if any exit dimensions reach the threshold, the member will exit/be-expelled.	
Institution 2:	**Rules involved**
monitoring members' electricity consumption by a contract	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 7,8). Eventually, if any exit dimensions reach the threshold, the member will exit/be-expelled.	
Institution 3:	**Rules involved**
monitoring the overall electricity consumption by all the members	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 7,8). Eventually, if any exit dimensions reach the threshold, the member will exit/be-expelled.	

Table 9: Functionality of the institutions in the model

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 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 [66] 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.

Scenarios		Loyalty threshold	functionality threshold	desirability threshold	Electricity price	Consumption background	Financial background	Surplus-multiplier-institution-3	Institution-2-consumptuin-%
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 10: 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 [67,68].

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
	Urban cluster	5

23)	No. of companies in clusters	KheirAbad cluster	440
		HajiAbad cluster	140
		Ghotb cluster	136
		No.1 cluster	152

Table 11: Parameter value setup

5.5. Model run

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

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

Table 12: Simulation run conditions

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.

Title	Definition
Problematic actions	a) Consuming electricity more than what 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

Table 13: Recap of the definitions used in this section

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.

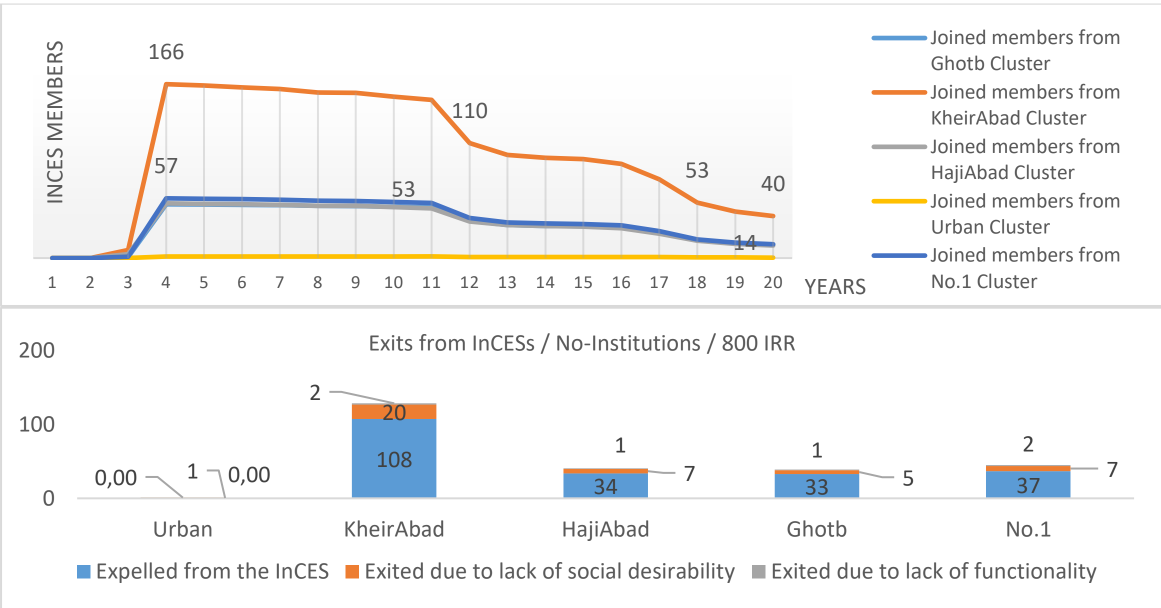

Figure 3: # of companies joined/exited InCES in each cluster / electricity tariff = 800 IRR

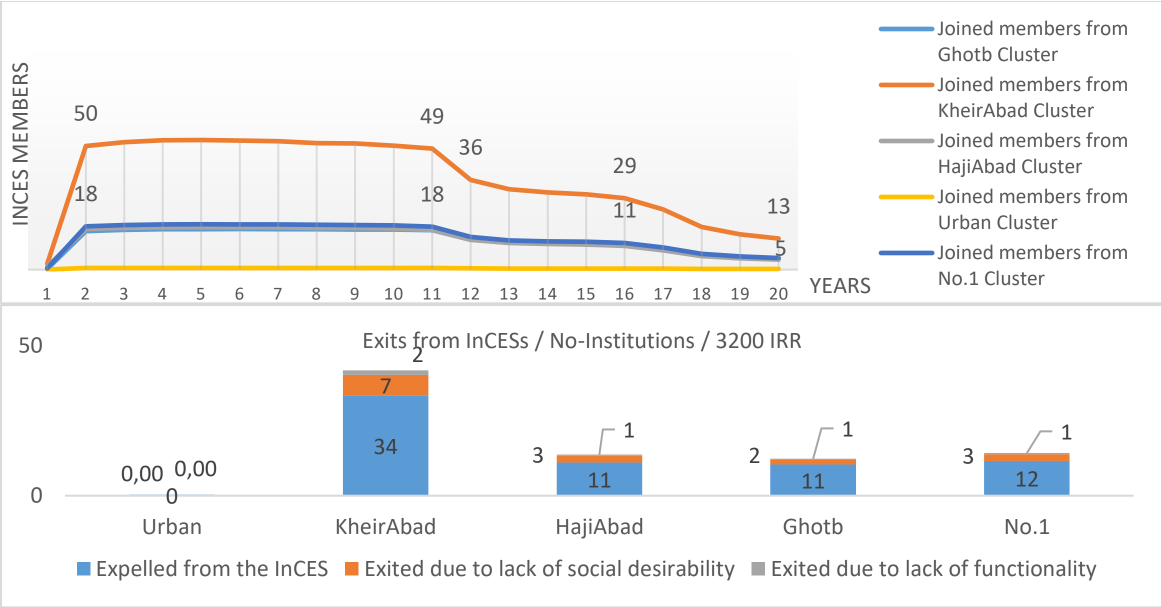

Figure 4: # of companies joined/exited InCES in each cluster / electricity tariff = 3200 IRR

As illustrated in Figures 3 and 4, the number of companies joining an InCES has a sharp increase in the initial years and then stabilizes 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 Figure 4 compared to Figure 3.

According to the results of the model reflected in Figures 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. Figures 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 cooperative'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 Figures 3 and 4 while no institutions are applied.

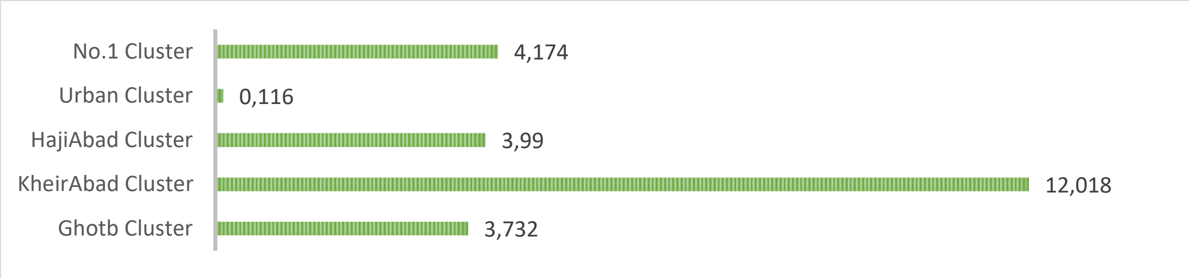

Figure 5: Average number of companies that transited individually in each cluster / Electricity tariff 3200 IRR

Figure 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 subsidized, therefore the LCOE calculated by an industrial company which is willing to invest on 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.

	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

Table 14: Scenarios of Institution No.1

Scenario A:

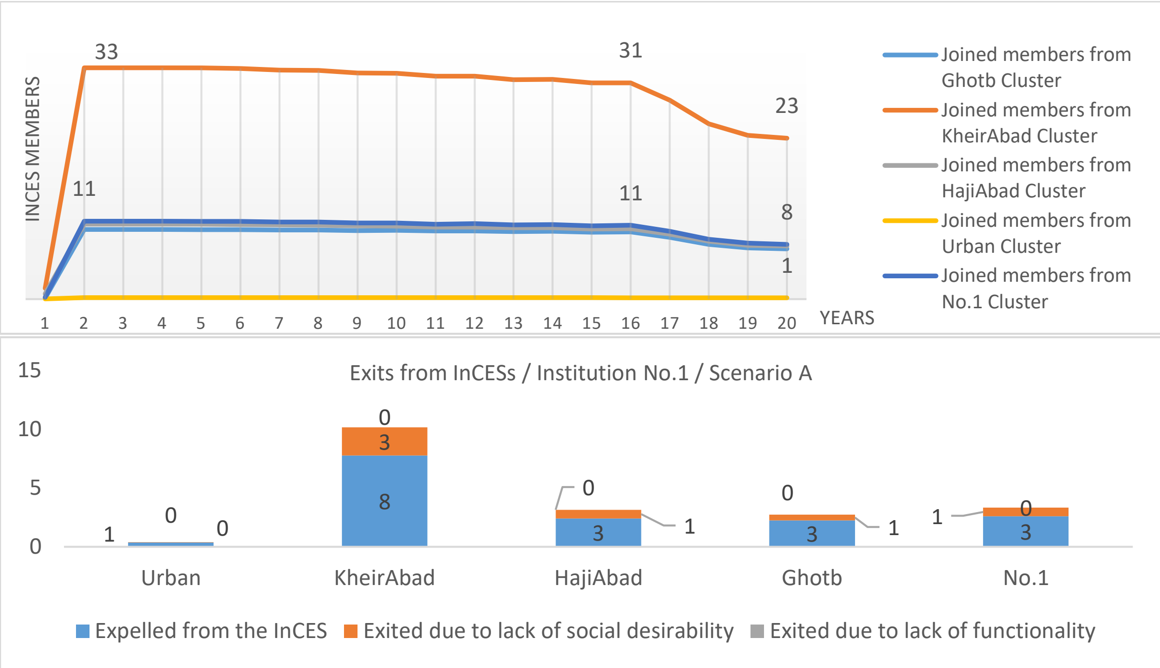

Figure 6: # members joining/exiting from InCESs / Institution No.1 / Scenario A

Scenario B:

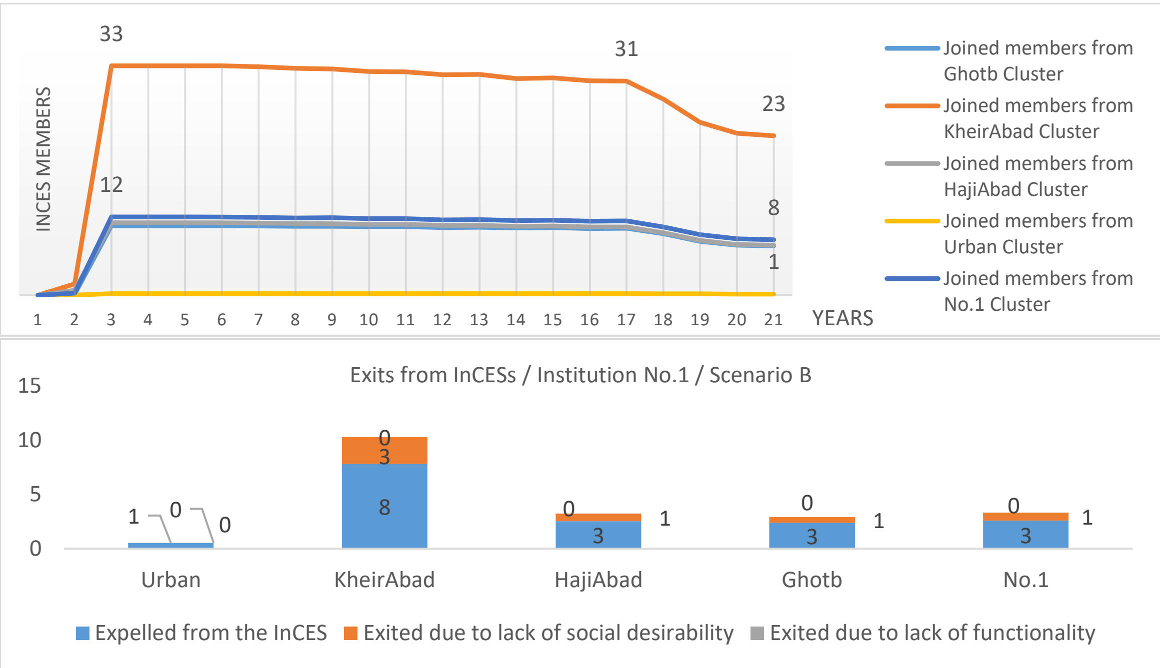

Figure 7: # members joining/exiting from InCESs / Institution No.1 / Scenario B

Scenario C:

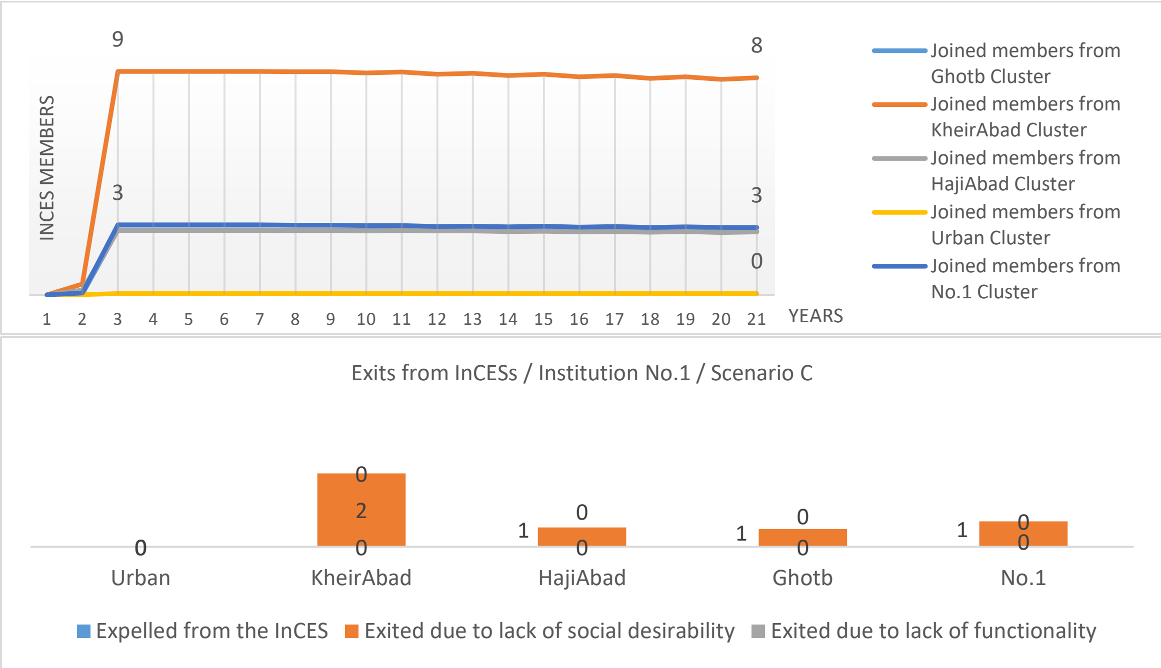

Figure 8: # members joining/exiting from InCESs / Institution No.1 / Scenario C

According to the results of this institution, as reflected in Figures 6, 7, and 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 the problematic actions such as consuming electricity more than the limit and not paying the monthly premium fee. We considered three 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.

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

Table 15: Simulation conditions of Institution No.2

Scenario A:

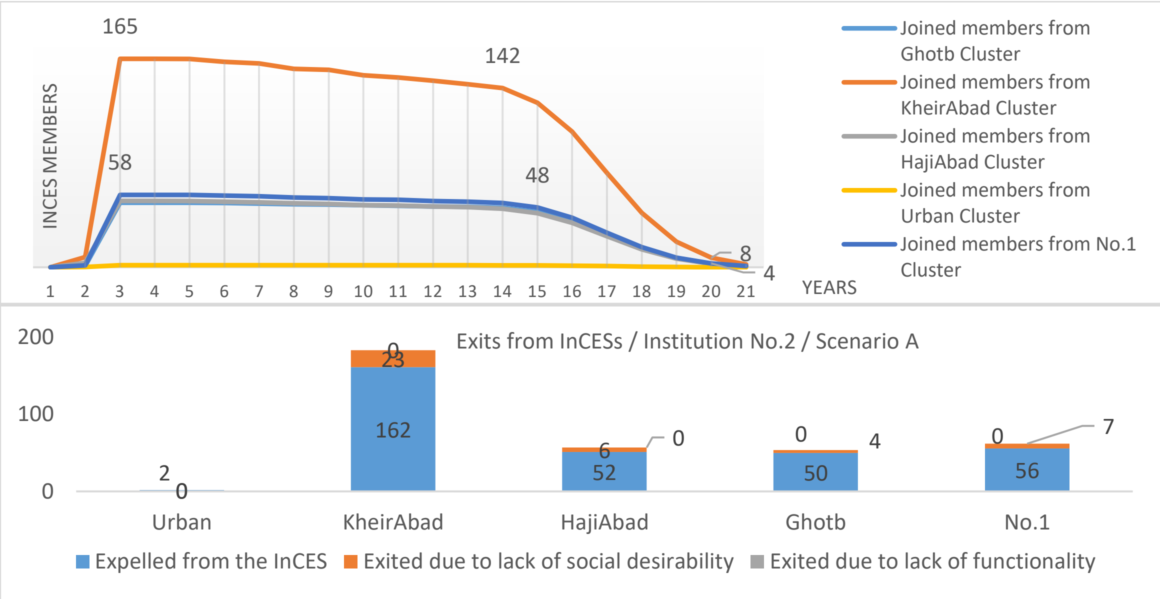

Figure 9:# members joining/exiting from InCESs / Institution No.2 / Scenario A

Scenario B:

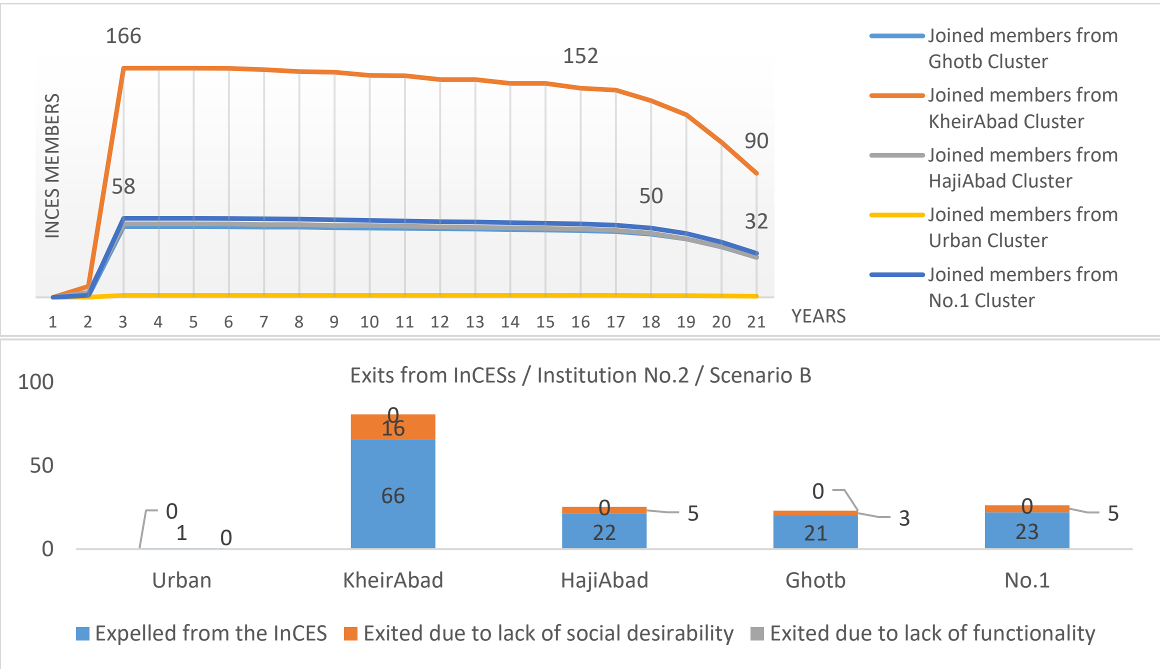

Figure 10:# members joining/exiting from InCESs / Institution No.2 / Scenario B

Scenario C:

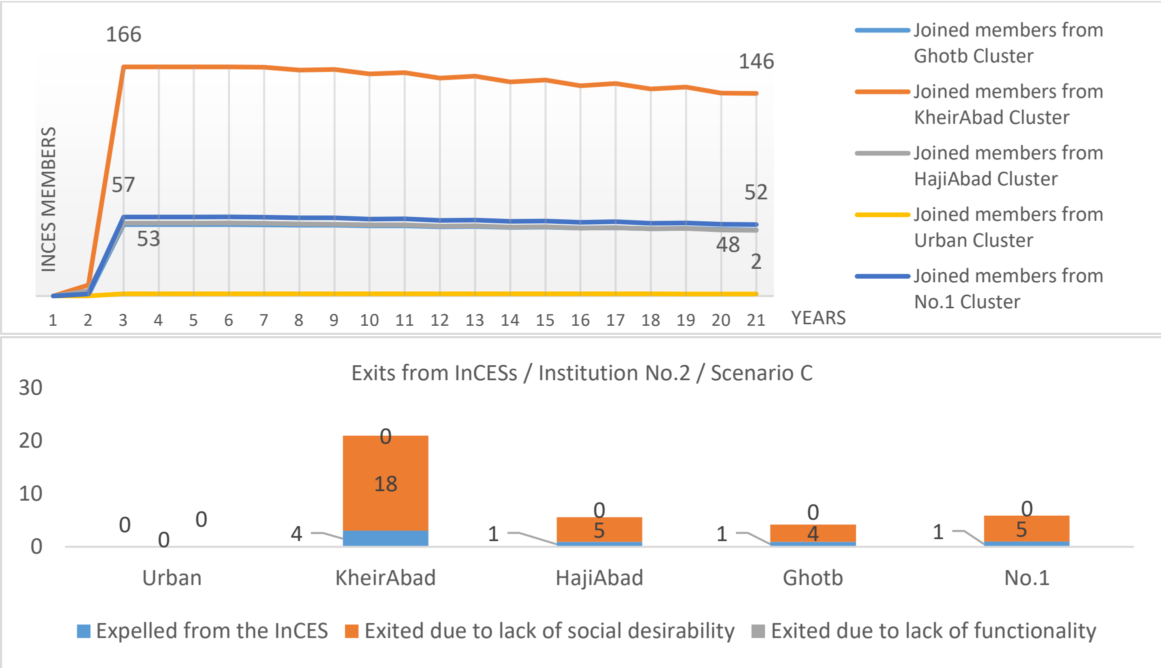

Figure 11: # members joining/exiting from InCESs / Institution No.2 / Scenario C

According to the results reflected in Figures 9, 10, and 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. Scenario A seems to be a total failure in keeping the members since almost 95% of the joined members have exited the InCESs during 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 Figures 9, 10, and 11 reflect that the more binding the contract is, the more sustainable an InCES would be during its lifetime. Another outcome reflected in Figure 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 infringer. The results are as follows.

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

Table 16: Simulation scenarios of Institution No.3

Scenario A:

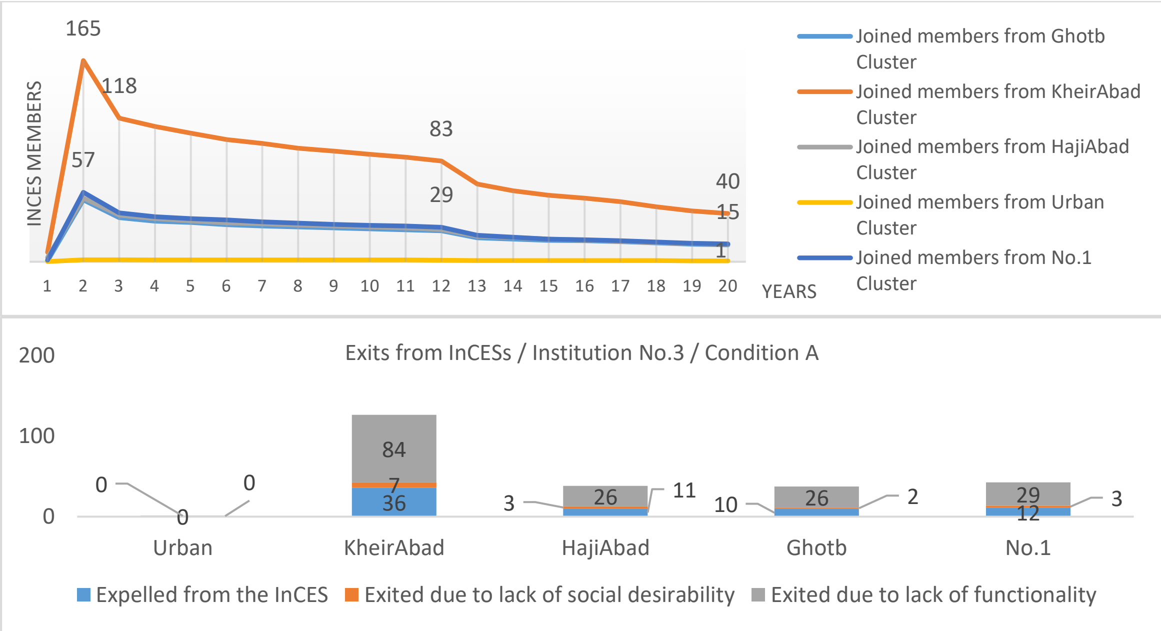

Figure 12: # members joining/exiting from InCESs / Institution No.3 / Condition A

Scenario B:

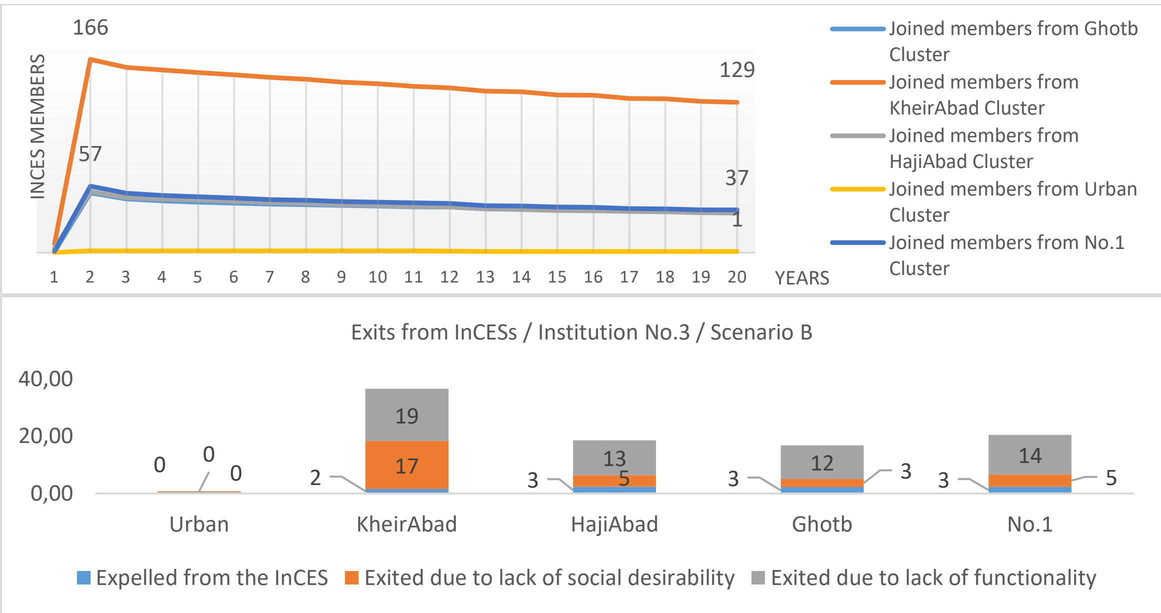

Figure 13: # members joining/exiting from InCESs / Institution No.3 / Scenario B

Scenario C:

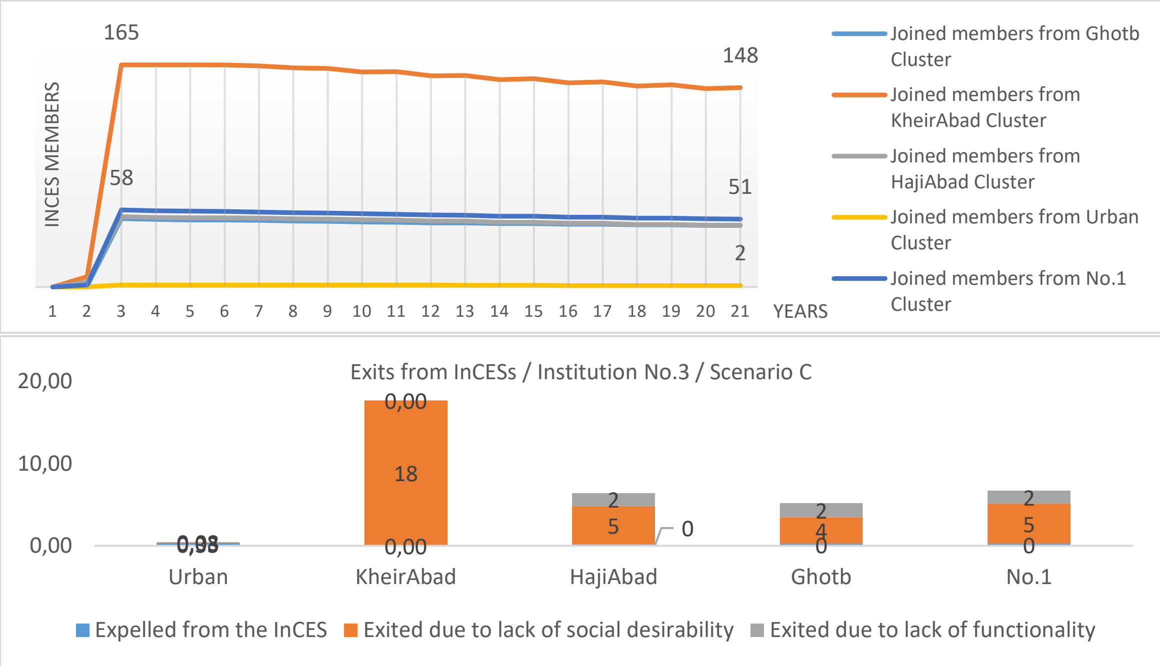

Figure 14: # members joining/exiting from InCESs / Institution No.3 / Scenario C

According to the results shown in Figures 12, 13, and 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 of 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 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 while 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.

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 modeling 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 consider these investments an economically feasible option. The process of feasibility assessment 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 in decreasing the problematic events which emerge in the course of 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 stabilizing 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 which are loyal to the rules of the club. The stricter the entrance boundary is, the more loyal the members would 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 succeeded in prevention of 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 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 members 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 the 1.153 times the cumulative amount of their demand. This means, while an InCES is being established, by a relatively small investment and increasing the capacity of the power plant 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.

Moreover, all the institutions introduced in this research have contributed to shifting the member exit peaks to a further year. This was evident while we saw that the exit peak without implementing any institutions in around the 11th year while implementing institutions shifted this to 16-18th year. This reflects that having institutions, regardless of their type, would help InCES members to reach their exit thresholds much later.

Another important implication in this research is, 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 exit are prevented) in our best-performing institution (Institution No.3/condition C) is related to lack of social desirability.

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-years period due to simplification which was made to make the research doable in its time constraint.

Conflict of Interest

Hereby, it is declared that there is no conflict of interest, relationship, financial or otherwise, that might be perceived as influencing an author's objectivity in this research.

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Chapter 6: Conclusion

Transitioning to electricity from renewable sources and transitioning to a larger share of electricity in the industrial energy mix would help the industrial sector to both increase the security of electricity supply and decrease its carbon footprint. However, this transition does not come without challenges. First, the upfront investment required to satisfy industrial demand is a major hurdle. Second, satisfying the industrial baseload at all times is a formidable challenge considering the variability of power generation from renewable resources. Third, the land requirements for establishing renewable power plants at industrial capacity are substantial and might not be available in every industrial cluster.

While these challenges are not to be underestimated, this thesis concludes that Industrial Community Energy Systems hold great promise for supporting the industrial transition to electricity produced from renewable resources, provided the institutional requirements for the establishment of successful InCESs are met.

This research took a "collective action" lens to study how successful collaboration between industrial firms in an InCES may be established. This is a novel perspective, with a focus on institutional requirements, that has not been applied in the rich literature on IS and CES.

This research was designed as a case study in Iran, more specifically in Arak industrial city. Arak is one of Iran's most prominent industrial cities in terms of the number and diversity of industrial companies present and throughout its five decades history. The industries in Arak are spatially clustered in five locations. Besides the common challenges industries face in many other countries (e.g., reducing $CO2$, meeting increasing demands), industries in Arak also face a shortage of power generation capacity due to lagged investment by the electric utility company. The investment gap has detrimental consequences for the security of the electricity supply and thwarts industrial expansion plans.

The findings of this thesis are the outcome of answering the following research question:

"How can industrial community energy systems be established and sustained in industrial clusters?"

To adequately address the main research question as mentioned above, the following four sub-questions were addressed:

1) *Which characteristics of industrial clusters are relevant for establishing an InCES?*

To address the first research sub-question and investigate whether establishing an InCES among industries of an industrial cluster is feasible, the Institutional Analysis and Development (IAD) Framework was applied to Arak industrial city. The IAD framework, the main theoretical tool in the collective action literature, provided insights into the feasibility of establishing an InCES in Arak. By capturing endogenous and exogenous characteristics of an InCES (as a collective system), the IAD framework helped to systematically investigate the opportunities and barriers of such a collective endeavour. The data used in this part of the research stemmed from a) policy documents in the context of Iran and b) semi-structured interviews with industry executives, consultants in the field of RE, and the authorities of the regional power company.

Focusing on Arak as our case study, it was highlighted that even with the many uncertainties industries face with regard to the incentive mechanisms provided by the government at different levels, engaging in an InCES is a promising approach to decrease the vulnerability of industries regarding the unreliability of electricity service provision.

By looking into the key factors highlighted by the IAD framework, issues that would have otherwise not been in the spotlight to explore in this study were touched upon. Most importantly, the "attributes of the community" part of the IAD framework was particularly insightful. The key factor that plays the most significant role in successfully establishing collaborative projects is the community spirit and the social bonding between the industrial partners in the cluster. The social bonding among industries can be a catalyst and a lubricant to smoothen such processes. Moreover, it was found that the level of "trust" among industrial companies is a factor that highly impacts the social acceptance of such collaborative projects. Only if the industrial companies trust each other will they consider joining the InCES rigorously and thoughtfully. Any successful experience which enhances the industrial companies' mutual trust is beneficial in encouraging industrial companies to invest in an InCES.

2) What socio-economic-environmental factors affect the willingness of industrial companies to invest in an industrial community energy system?

As the second step of this research, an empirical approach to identify the most influential factors in the willingness of the industrial companies to invest in an InCES, was taken.

This research aimed to identify factors influencing industrial companies' willingness to invest in an InCES. Elaborate statistical analysis was performed on the empirical data collected from questionnaires among and interviews with the CEOs of a large sample of industrial companies in Arak industrial city.

The existing literature on industrial collaboration in the domain of industrial symbiosis (IS) and the literature on community energy systems (CES) were used to formulate hypotheses regarding the most influential factors for forming an InCES. On the basis of these hypotheses, a questionnaire was designed to collect data on the willingness of the industrial executives to invest in an InCES and the conditions required for collective investment. Besides these hypotheses, additional data (such as the willingness of the company to lead an InCES, the degree that the company believes in the power of proper institutional designs in overcoming the conflicts of a shared investment, etc.) were collected to gain more potential insights into this problem in an inductive fashion.

The results showed that a combination of social, economic, environmental, and demographic factors (company size and education level of the CEO) impact the willingness of industrial companies in Arak to invest in an InCES.

As the analysis reflected, economic aspects are pivotal indicators for the willingness of the industrial companies to invest in an InCES, similar to the case of households in CES. Also, the industrial companies whose key decision-maker was environmentally concerned showed more willingness to invest in an InCES. As expected, the role of social identity is highlighted as an essential enabling factor for industries to consider InCES in order to reflect a socially and environmentally pioneer image in their community. On the one hand, not having trust in other industrial participants negatively correlated with the willingness of companies to invest in an InCES. On the other hand, having trust in the government's policies did not significantly correlate with their willingness to invest in InCES. This, implies that the industries in our case study perceived InCESs as a completely bottom-up approach. Contrary to the case of households in CESs, "ownership" is found to be a critical factor for industrial companies. As such, industrial companies are more willing to invest in an InCES if their share is easily and legally tradable.

Interestingly, an important role for the bigger companies in an industrial cluster in initiating such projects was found. It appears that bigger companies are more open to tolerating the risks of joining projects with lower ROI and allocating a larger share of their annual revenue if they decide to participate in an InCES. Bigger companies are also more inclined to take the leadership of an InCES. Contrary to what was hypothesized, the level of electricity demand did not correlate with the willingness of the industrial companies to join an InCES. Importantly though, a high motivation to engage in an InCES was found among those companies that expect electricity prices to increase substantially. This motivation is strongest in energy-intensive companies directly connected to the high voltage grid, such as companies operating high-capacity induction furnaces. It was also revealed that companies who are more aware of the benefits of joining an InCES and companies whose decision maker believes in the power of proper institutions to govern an InCES are more prone to invest in it.

3) Which incentive mechanisms can support the establishment/continuation of an industrial community energy system?

To address this research sub-question, the role of financial incentive mechanisms in the formation and continuation of InCESs was explored. We took an agent-based modeling approach in which we introduced the decision-making style of companies as a variable. In defining decision-making styles, we combined Scharpf's organisational decision-making theory with Hofstede's social dimensions theory. With agents representing different archetypes of decision-making styles according to Scharpf we simulated the effectiveness of three types of incentive mechanism: a feed-in-tariff (FIT), a tax-cut (TAX), and tradable green certificates (TGC). Different cultural environments for the industrial decision makers were introduced as an additional variable. Hofstede's cultural dimensions theory was used to model this cultural environment. The six cultural environments were based on Hofstede's characterization of Australia, Brazil, Iran, Japan, the Netherlands, and the United States, thus ensuring that a wide variety of economic and societal characteristics were covered.

Our simulations showed that the FIT incentive scenario was the least effective in encouraging industrial companies to establish/join an InCES. Also, communities generated the least amount of RE under this incentive scenario. On the other hand, the TAX incentive scheme, which operates as a discount in RE technology, turned out to be the most effective scenario regarding RE generation.

The study also showed no substantial differences between incentive scenarios regarding community establishment, the number of members, and the number of member exits from InCESs in 20 years. Yet, the TAX scenario showed superior outcomes in all mentioned aspects, especially regarding RE generation, while putting most of the installation expenditures on the shoulders of the governments. Interestingly, the TGC incentive scheme acted almost the same as the TAX incentive in RE generation but with more investments from both government and communities. Although this reflects the cost efficiency of the TAX incentive, it should be noted that this incentive, even if cheaper than TGC, cannot promote the most efficient RE technologies due to a lack of market mechanism. Besides, TGC has the potential to create a new bond market, similar to carbon bonds, adding significant value to this option in the near future. These bonds can be traded like any other government bonds producing additional revenue for their holders. Part of the mentioned revenues from TGC could also be used to fund subsidies for reducing carbon emissions. Despite the high potential of the TGC scenario, the TAX incentive creates more liquidity, helping industrial companies' revenue streams access to cash in shorter periods which is a crucial aspect for industrial companies.

In summary, the model shows that the answer to "which financial incentive is the most effective between TAX and TGC?" depends on the economic preference of the government and policy analysts. For example, should the government bear more costs or reduce its investments, making communities invest more? This question cannot be simply answered as each government and administration has a different political-economic view on such a problem.

Besides the economic insights, the simulations also revealed that the way industrial companies in different cultures would behave in an InCES partnership did not result in significant differences in the stability of an InCES, with respect to the exit of members from an InCES. This highlights that even though there is a substantial cultural difference between industrial companies in different countries, companies will not choose to leave an InCES if staying as a member satisfies their economic preferences. This seems to be an essential finding while we are dealing with industrial companies as the members of a cooperative. Contrarily, in CESs with households as members, societal challenges are less tolerated and would lead to more member exits from the cooperative. This did not happen in InCES since economic desirability accounts for the lion's share of the decisions industrial companies make. Also, their exit from an InCES would not occur easily due to much higher upfront investments in an InCES, considering the large electricity demand of industrial companies compared to households.

4) What internal institutional arrangements are required for the successful establishment/continuation of an industrial community energy system?

To address the fourth sub-question of this thesis, the role of institutional settings on the robustness and durability of InCESs within industrial clusters by an agent-based modeling approach was investigated. In this model, it was acknowledged that industries with specific socio-economic attributes initiate the process of establishing/joining an InCES if they consider this investment an economically feasible option. The process of feasibility assessment occurs by performing a cost-benefit analysis. In the model, it is investigated which institutional settings can effectively support the stability of the InCES, in terms of decreasing the occurrence of problematic events (consuming electricity more than expected and not paying the InCES premium fees on time) that emerge in the interactions among the members and by actions taken by each member. The institutions examined were: a) setting strict entrance boundaries, b) signing a contract between InCES and its members, and c) monitoring the overall consumption of the members by digital tools.

According to the results of this research, setting an entrance boundary can help stabilize an InCES, but also limits an InCES in terms of expanding its members. In other words, it is likely to result 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, the more dedicated members are to the rules.

The performance of the second institution, signing a contract between InCES and its members, reflected that this institution could help 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.

The last institutional arrangement incorporated in the model aimed at monitoring the overall electricity consumption of the InCES members by digital tools and looking at the total consumption made by all members instead of checking each member's consumption. While the members of an InCES were randomly choosing their consumption between 0.5 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 means that while an InCES is being established by a relatively small extra investment and increasing the power plant's capacity by almost 15%, many of the exits related to the overconsumption of individual members can be prevented. The other insight is that planning the working schemes of the members of an InCES can help an InCES to not surpass its electricity capacity.

Moreover, all the institutions introduced in this research contributed to shifting member exit peaks to a further year. Without implementing institutions, the exit peak occurred around the 11th year after InCES establishment, while implementing institutions shifted this exit peak to the 16-18th year. This reflects that all of the incorporated institutions in the model helped InCES to create a more tolerable environment for its members for a more extended period.

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 highly relevant. As it turns out, our simulations showed that more than 88% of the InCES membership exits in the most stable situation (under institution no.3) are related to a loss of social desirability.

Addressing the main research question of this thesis:

"How can industrial community energy systems be established and continued in industrial clusters?"

This research revealed that despite technical, social, and economic challenges, InCESs present a feasible option to accomplish a gradual transition to renewable power in the industrial sector. By this approach, companies can reduce the risks related to insecure electricity supply and a potential increase in the price of electricity offered by the utility company. In the specific case of Arak industrial city, the case study of our empirical research, the biophysical characteristics ensure a high potential both for wind and solar power. At the same time, solar power seems to be the prevailing option considering photovoltaic power potential between 1680 and 1826 kWh/kWp and an average of about 300 sunny days per year with a daily peak sun hour of 4.5–5.5 kWh/m2. On top of that, access to solar technologies would be more practical compared to wind energy in the context of Iran.

Although the financial incentives introduced by Iran's government showed inconsistency and relatively low efficacy in mobilizing industrial investments in an InCES, free-of-charge power transmission of generated RE through the existing electricity grid is a highly attractive economic incentive provided by the government. It enables companies to consider more spatially optimum locations to establish the renewable power plant without bothering about the transformation and transmission costs. It should be noted though that this incentive will delay necessary investments in the transformation and transmission infrastructure in the long run, making this incentive unreliable and unsustainable.

Moreover, it was illustrated by this research that economic feasibility plays a critical role among the many factors impacting the willingness of industrial companies to invest in an InCES. Industrial companies highlighted the crucial role of trust among the participants of an InCES as a vital prerequisite for engaging in such an initiative. While most of the CEOs of the industrial companies were aware of the complexities of an InCES partnership, those who believed in the power of proper institutional design to overcome these complexities showed an apparent willingness to invest in an InCES.

Besides these two aforementioned factors, the role of larger and more prominent companies in initiating InCES projects in an industrial cluster was highlighted in this research. Therefore, tailored incentives, particularly for these companies, are highly recommended to policymakers since attracting these companies is likely to bring more SMEs on board. Moreover, consulting companies may play a conducive role as intermediaries, especially to increase the awareness of industries regarding the benefits of joining an InCES. Without this awareness, industries will obviously not be interested in investing in an InCES.

Besides the willingness of industries themselves to invest in an InCES, the role of governments in promoting such initiatives is critical, e.g., through financial support. The positive role of tradable certificates as a financial incentive, similar to how Carbon Bonds work, was highlighted. This incentive can financially support industries to invest in an InCES and create revenue streams by generating more RE. Additionally, according to the market mechanism nature of this incentive, it can nurture the most efficient technologies to generate more RE.

Moreover, introducing institutions turned out to be crucial in ensuring the robustness of an InCES. Proper institutions help an InCES reduce problematic events (i.e., InCES members consuming more electricity than agreed and not paying the InCES premium fees on time), which would lead to technically or socially undesirable situations. It was concluded that among three simulated institutional designs, monitoring the overall electricity consumption by all the members instead of checking the consumption of each member could result in a more robust InCES government. At the same time, the membership of an industrial company would not be complicated by strict membership entrance rules or membership terms.

Although putting proper institutions in place while designing an InCES showed a substantial effect in decreasing exits of InCES members, there would always be some exits caused by the differences between industries in terms of their societal attributes in collective settings and the way they tolerate such distinctions. Therefore, a small but inevitable percentage of members of the InCESs are expected to exit, even if their membership is economically beneficial.

Generalizability of findings

Although this research was done in the context of Iran with its unique socio-economic and political characteristics, many of the findings of this research can be generalized to other economies, in both developed and developing countries. Arak industrial city was selected as the case study for this research due to easy access to the top-level industry executives and the absence of cultural and linguistic barriers, which ensured the feasibility of the data collection process, despite the COVID-19 pandemic situation that this research was conducted in.

With regard to the generalizability of this research, while this research was performed in the context of Iran as an oil-rich developing country, the results can, to a large extent, be generalised to other developing economies due to several reasons. First, although Iran has substantial oil and gas resources, it has a strategic plan to increase the share of renewables in its energy supplement mix. Second, there are noticeable similarities between Iran's economic and political situation and many other developing countries, which are struggling similarly with unstable economic conditions and consequently with high uncertainty about future electricity prices, and where the accomplishment of environmental and climate policy goals may be driven more by the personal motivation of industrial decision-makers than by strict enforcement. Third, the results shown in addressing the third research question in this thesis reflect that despite the substantial cultural differences between different countries (shown by Hofstede's social dimension theory), if an InCES guarantees economic benefit for its members (e.g., by proper financial incentive support), the social/cultural mismatches will be tolerated by the members. This latter shows a strong signal for the generalizability of the idea of InCES establishment.

Moreover, from the results of this research, we conclude that, despite the highly subsidized electricity price, the InCES approach is an economically attractive option for industries in Iran. In other countries, with deregulated electricity markets, the individual transition to RE may seem more convenient. However, it should be noted that InCES establishment contributes firstly to decreasing a noticeable share of the investment costs and secondly to saving a substantial amount of time by reducing the time spent for permit acquisition for the collective power plant compared to the individual approach. Therefore, the InCES approach holds much wider relevance as the preferred solution for the industrial transition to RE than only in the case of Iran.

It is worthwhile mentioning that Iran's unique economic and political characteristics present detrimental disincentives to establishing InCES's among industries. Yet, despite these characteristics (such as the highly subsidized electricity tariff, limitations in having access to RE technologies, and high interest rate), the InCES approach seemed a feasible option for an industrial transition to RE in Iran. In countries with more economically and politically stable conditions, InCES formation is much more favorable. On top of this, other findings of this research are considered generic characteristics of industrial companies worldwide (such as the way they make decisions, the way they make the economic assessment, and the technical requirements of establishing an InCES), which should be taken into account if this approach is going to be considered for the industrial transition to RE. Moreover, although this research sheds light on the way an InCES can be established and sustained among Iranian industries, it is limited in the sense that the opinions of the industry executives may be influenced by the economic sanctions against Iran, positioning the transition to RE as a lesser-priority plan. Yet, according to the findings of this research and the aforementioned reasons, transitioning to RE in Iran's industrial sectors seems to be a feasible solution to reduce the risks associated with the insecure electricity provision in Iran's industrial sector.

Discussions and recommendations:

Although establishing an InCES among industries of an industrial cluster can indeed decrease the vulnerabilities associated with unreliable electricity provision, there seems to be a long way for such projects to make industries fully independent in terms of satisfying their own electricity demand due to several reasons. First, the current technological advancements do not enable such a complete transition to RE in the industrial sector, especially for those companies that rely on the high voltage electricity grid for their production processes. Second, considering the intermittent nature of RE generation from renewable resources, coping with the industrial baseload requirements would be a critical drawback, necessitating the industries to make use of electricity-storage facilities at an industrial scale. Accordingly, there has been substantial recent attention and mobilization of investments in green hydrogen toward the industrial transition to RE.

Therefore, an on-grid design for an InCES was recommended in this thesis to deal with the intermittency of power generation from renewables. Although being connected to the electricity grid helps deal with the mentioned drawbacks, industrial companies that have invested in an InCES can still fall victim to system disruptions in an unstable electricity system. Therefore, the more critical issue here is highlighted as having a guarantee from the utility company to ensure the security of supply as a high priority plan at an attractive tariff. Establishing such a binding condition when the system struggles with a lack of generation capacity seems not plausible. Accordingly, besides the complexities associated with the investment costs and technological challenges of an InCES initiation, coordinating these priorities with the utility company/grid operator is a pivotal issue that should be paid attention to.

On top of the aforementioned issues, a grid-connected InCES does not seem to need a sophisticated consumption-related coordination mechanism as proposed in this thesis since it would not face a technical breakdown in case of overconsumption by its members, thanks to the connection to the grid. Regardless of the availability of electricity in such a design, proper institutions should be in place in case there is an incentivized tariff from the grid for the investors of an InCES in the agreement between the InCES and the electricity company. Therefore, mechanisms are needed to monitor over-consumption by individual InCES members and prevent infringing companies from free-riding these incentives.

Policy recommendations

Based on the findings of this research, several measures to reduce the barriers to establishing InCESs can be suggested to public policy makers. It is recommended they encourage large industrial companies to champion InCES initiatives. Large companies, especially those with capital intensive operations, tend to have a longer strategic planning horizon and tolerate investments with lower ROIs than smaller companies and SMEs. Policy makers are thus recommended to reach out to these large companies e.g., with targeted incentive schemes, as they are more likely to initiate collective action and take leadership than smaller companies. Moreover, the commitment of large companies is likely to bring (more) SMEs on board. For both large and small companies to engage in an InCES, the financial barrier must be lowered by proper incentives, like specially designed bank loans with extended payback periods and featuring acceptance of the RE technology as the loan guarantee. First of all, however, it is important to increase the awareness of industrial companies regarding the technical and economic benefits of transitioning to RE. Consulting companies may be incentivized to play this role. Policy makers can also help to create an environment-friendly business climate e.g., through tax incentives, to increase the willingness of industries to take part in environmentally-friendly projects.

Limitations and recommendations for future research

The modelling work in this thesis focused on the institutions required for the formation of a stable InCES in different cultural contexts and given differences between industrial companies in decision-making style. Due to time constraints, simplifications were made in the representation of certain investment and operational cost components and financial incentive mechanisms. RE technology costs and electricity tariff were assumed to be fixed during each 20-years simulation run. For future research, it is recommended to introduce technology learning curves and associated cost reductions, and to introduce a more sophisticated (dynamic) electricity tariff scheme. With regard to the role of financial incentive mechanisms, our simulation models used fairly simple representations of 'archetype' mechanisms and investigated only one mechanism at a time. For future research, the model was built in such a way as to allow for more advanced representations of incentive mechanisms and alternative incentives to be implemented.

For future research on collaborative action by industries for the sake of security and sustainability of energy supply, highly relevant case study material is provided by currently ongoing projects with joint investments from industries in green hydrogen [1,2]. As in InCES, these projects confront the participating industries with the complexities of collective investments and associated coordination issues. It is certainly recommended to study if the institutions that we found to be conducive for the establishment and continuity of InCESs also hold for green hydrogen projects.

Scientific contribution

This research contributes to the existing literature on collaboration among industries in the field of IS and among households in CES by taking the collective action lens. The mentioned lens helps examine the feasibility of industrial collaboration in an InCES and the institutional mechanisms that can facilitate such initiatives. This angle has never been applied to situations of collaboration among industries, as we established in our literature review on industrial symbiosis, where various forms of collaboration among industries are covered. The collective action lens is of interest as it can provide unique insights into the institutional mechanisms that would support the successful establishment and continuity of InCES initiatives. Choosing this lens helped with providing theories and frameworks such as the IAD framework and the institutional design principles to look into the institutional machanims that are need to govern such systems (e.g. setting boundary rules to control the entrance and exit of the members and setting monitoring and sanctioning rules to monitor and prevent the problematic events in an InCES) and the embedding of those institutions in their socio-technical systems and how these institutions influence other components of the system and are they influenced by them. Furthermore, the fact that the "community spirit" plays a critical role in establishing and managing an InCES was an outcome of taking such a perspective and application of the IAD Framework (the attributes of the community) in this research.

Consideration and incorporation of the pronounced differences between industries in terms of their decision-making style and the required conditions of industries to invest in InCES is the main scientific contribution of this research, which has not been paid attention to in the existing literature on industrial energy transition. Additionally, simulating the industrial companies' behaviours in collective settings by assigning a "decision rule" to them as a result of combining Hofstede's social dimensions and Scharpf's organizational theories was the first of its kind in this research. Incorporation of these theories into the dynamics of interactions in an InCES helped with a more realistic simulation of the behaviours of industrial companies in a collective setting where they need to coordinate their personal attitutes with the collective choices being made in a democratic approach (voting sessions). Designation of a "decision rule" to each company shed light on how the societal attributes of industrial organizations influence their tolerance while the collective choice does not match their individual decisions and preferences. Conclusively, as a result of using these theories, it was reflected that even by designing proper institutions there would be some inevitable exits from InCESs only due to the mismatch of the societal attributes of some industrial companies with collective settings.

Societal relevance

This thesis presents recommendations to industrial companies to experience a smoother path towards transitioning to RE by investing in InCESs while simultaneously signaling to them how this collective investment should be governed by proper institutional design to reach an optimum level of continuity. Also, a set of policy implications were recommended in order to make InCES establishment an attractive investment plan for the industries, resulting in the mobilization of the investments towards InCES establishments. The research provided relevant insights for governments as to how they can financially support an InCES by introducing industry-tailored incentive mechanisms.

List of publications

Peer reviewed publications

- **S. Eslamizadeh**, A. Ghorbani, R. Künneke, M. Weijnen, "**Can industries be parties in collective action? Community energy in an Iranian industrial zone**," Energy Research and Social Science 70 (2020) 101763
- **S. Eslamizadeh**, A. Ghorbani, Y. Araghi, M. Weijnen, "**Collaborative Renewable Energy Generation among Industries: The Role of Social Identity, Awareness and Institutional Design,**", Sustainability 2022, 14(12), 7007
- **S. Eslamizadeh**, A. Ghorbani, R.C. Costa, R. Künneke, M. Weijnen, "**Industrial Community Energy Systems: Simulating the role of financial incentives and societal attributes**," Frontiers in Environmental Science (2022): 1-18

Submitted Articles:

- **S. Eslamizadeh**, A. Ghorbani, M. Weijnen, "**Establishing Industrial Community Energy Systems: Simulating the Role of Institutional Designs and Societal Attributes**," Under review at "Cleaner Production"

Conference Contributions:

- **S. Eslamizadeh**, A. Ghorbani, T. Comes, "**Conceptualizing the sustainability of urban commons - lessons learned from "community resilience**," The International Association for the Study of the Commons (IACS) 2021
- **S. Eslamizadeh**, A. Ghorbani, T. Comes, "**Would urban commoning contribute to better urban resilience?**," Joint International Resilience Conference (JIRC) 2020
- R.C. Costa, **S. Eslamizadeh**, A. Ghorbani, R. Künneke, "**The role of financial incentive mechanisms in the formation and robustness of an industrial community energy system (InCES)**," Joint International Resilience Conference (JIRC) 2020
- **S. Eslamizadeh**, A. Ghorbani, M. Weijnen, "**Industrial collective action: Renewable electricity production in a cluster of industries**," The International Association for the Study of the Commons (IASC) 2019
- **S. Eslamizadeh**, A. Ghorbani, M. Weijnen, "**Community energy systems among industries**, " Sustainable Urban Energy Systems (SUES) 2018