Goal Oriented Prosumer Community Groups for Smart Grid

-Issues, Challenges and Proposals –

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Introduction

The demand for energy in the world is continually rising. Most of the current demand is met by non-renewable energy sources, like coal, petroleum and natural gas. However, currently, the society is faced with the problem of dwindling scarce non-renewable energy resources, resulting in the shortage of energy. Moreover, the process of energy production from non-renewable sources is increasing greenhouse gas emissions, leading to unpleasant and potentially dangerous climatic changes. Therefore, in today's world, the focus is on inducing users to reduce their household energy consumption, and shift to using energy produced from renewable sources, such as solar, water, and wind. Not only this, they are being encouraged to generate the green energy, and either to store the surplus for future usage or to feed it to the utility grid. In order to evolve such bidirectional energy and information flow, the concept of smart-grid (SG) has been proposed in the society[1].

The smart-grid has opened up a new role of economically motivated 'prosumer' in energy value network, who not only consumes energy, but also generates the green energy and shares the surplus with the main utility grid or other energy consumers. In current society, a massive number of energy consumers have initiated domestic green energy production and energy sharing due to many reasons such as the strong societal attitude regarding alleviating the negative climatic impacts, desire to decrease the electricity costs, and various government regulations, including generous feed-in tariff schemes. Under such circumstances, managing the prosumers connected to the utility grid has become pivotal within the energy sharing network, and the vision of goal oriented prosumer community groups is an innovative thought to fulfil that requisite[2-4]. However, the concept of prosumer community groups is still in its infancy, and therefore, the existing literature has very little to offer, either by way of investigating the related concepts or resolving the associated challenges. Therefore in this article, we investigate the key issues and challenges associated with developing prosumer-community-groups and present innovative proposals to address the identified challenges.

Prosumer participation in smart-grid energy sharing process

In this section, we briefly discuss about the existing literature on prosumer participation schemes. In most of the previous commercial and research projects, the individual prosumers are directly connected to the smart grid. This facilitates direct energy sharing between the prosumers and the utility grid, and the energy-sharing decisions are

made based on the individual perceptions. One of the apparent disadvantages of this is that, the individual prosumers are often excluded from the wholesale energy market due to their perceived inefficiency and unreliability. For example, in most cases, the individual renewable generators such as solar systems and wind turbines are too small to compete effectively in the market with conservative power generators. Not only are they too small, but more importantly, their supply is unpredictable in the sense that it depends on uncertain climate conditions.

Another common method is to join a set of prosumers to the energy sharing process through dedicated electrical infrastructure in the form of VPPs (Virtual Power Plant) or micro-grid[5]. Here, a VPP is identified in literature as a large group of distributed energy resources (DERs) with an aggregated capacity, analogous to a usual power plant. VPPs can communicate with the energy market and also negotiate with other distributed energy sources. Two VPP management architectures can be identified, namely centralized architecture and decentralized architecture. In the more common centralized architecture, grid-connected prosumers are controlled through a centralized controller. The centralized controller is responsible for capturing the power flow information, analysing it, and taking decisions accordingly to control the prosumers in the VPP. On the contrary, in decentralized architecture, the agents can act independently without the involvement of a central controller. The decentralized VPP enables the participating prosumers to autonomously perform certain communications and decision making tasks.

On contrary, the concept of micro-grid has emerged in recent years as a localized connection of DERs through dedicated infrastructure. This concept appears to be somewhat similar to that of a VPP, but has following key differences: the micro-grids are smaller in size and concerned with a locality in operation, while VPPs can vary from small to large sizes and follow traditional energy sharing on a large scale. One significant benefit of micro-grid over VPPs is the reduced transaction cost as a result of a lesser number of intermediary parties. Similar to a utility-grid, this small-scale version, the micro-grid, locally generates, distributes and regulates the flow of electricity to consumers. The sources in the micro-grid have an ability to power the users in the micro-grid, discontinuing the connection with the main utility grid and leading to the concept of islanded micro-grid.

However, one of the main shortcomings of grouping prosumer through dedicated technical infrastructure (VPPs and Micro-grid) is that this type of fixed architecture may result inflexibility which makes it complex to add or remove

new members to the VPP/ Micro-grid. For instance some prosumers may offer whatever amount of energy they can contribute, or prefer to contribute, resulting in an unreliable energy supply to the energy buyers in the long-term, ultimately resulting negative morale towards the entire VPP or Micro-grid enabled prosumer-group. Moreover, the prosumer groups (exist in literature) are not goal oriented, as well as the prosumers have been merely interconnected via a technical infrastructure without considering their diverse energy sharing preferences and behaviors. Consequently, the lack of goal-oriented behavior reduces the reliability in energy supply to energy buyers in the long-term. Moreover, chances of possible disagreements among members are high in existing prosumer-groups because of their differing energy sharing interests and preferences.

Goal-oriented prosumer community groups

In order to address the aforementioned deficiencies of existing prosumer groups, as well as to promote sustainable social aspects with regard to the prosumer management in long-term, the concept of goal-oriented prosumer community groups has been emerged in the society. Following the concepts of the generic 'virtual community', the prosumer community groups are also emerged by virtually aggregating the prosumers from different locations, but with similar energy behaviors. The concept of prosumer-community-group upgrades the existing paradigms of VPPs and micro-grid and strengthens the vision of the socio-economic aspects of SG. The major difference between the prosumer-community-group and VPP or micro-grid is that the prosumer community group members may not necessarily be technically interconnected; they are virtually joined together based on their energy sharing behaviors and stimulated to achieve a common goal, while VPP/micro-grid often presents ad-hoc prosumer groups, which are connected through an electricity grid.

The key motivation behind the emergence of prosumer-community-groups is illustrated as follows: firstly, if an individual prosumer finds a group of prosumers with the similar energy behaviors, then an opt-in sort of prosumer-community-groups can be established, which they increase the quantity of energy to be sold, enhancing the bargaining power in the energy market. This would enable the small players, i.e. the prosumers, to have a negotiating power at par with that of the big players, i.e. the providers, and eliminate the gap dividing them. Secondly, the goal-oriented nature of the community groups attains reliable supply of energy to the energy buyers. Overall, the prosumer community groups lead sustainable energy-sharing process, and creates dynamic ecosystem of

cooperating prosumers. We will further discuss about the benefits that the society can gain though this concept in the "Discussion" section.

Now we look at the technological overview of the prosumer community groups, which is illustrated in Fig.1. As illustrated in it, the distributed domestic energy generation sources, and energy consuming household appliances of multiple residential prosumers are connected to each other via a Home Area Network (HAN), which is further linked to the local power distribution network through smart metering infrastructures (SMI), forming a local area network, where the prosumers and utility grid communicate. For instance, such prosumers who generate energy using solar sources and produce surplus energy between 10kW to 50 kW have been aggregated into community group1. The prosumers who generate energy using solar and wind sources and produce surplus energy between 51kW to 100kW have been joined together to make community group2. The community groups interact with each other and with the utility grid, through the community gateway which is a smart, intermediate node that bridges the utility grid with smart devices of each distributed energy resource belonging to a community group. The smart storage represents a storage facility that can temporarily store excess or unused electricity, which can be utilized to offload the energy consumption of the members of prosumer community group as required. Furthermore, such a community based energy sharing network is managed by central operation platform, called community management platform.

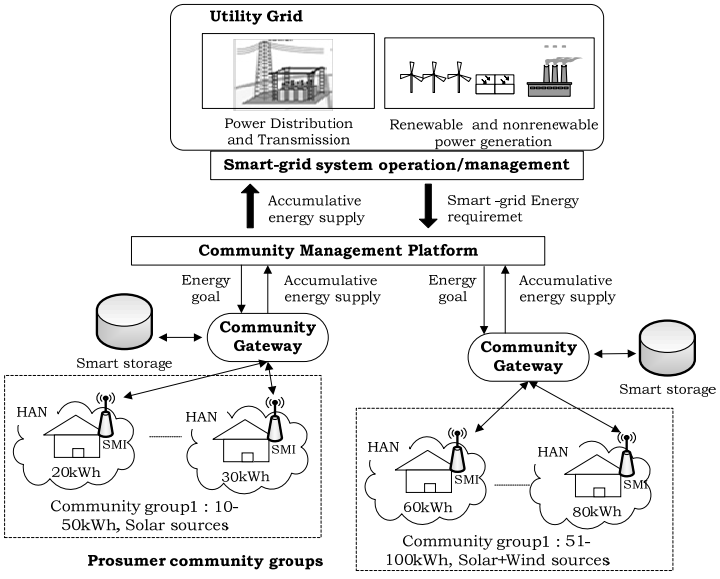

Figure 1. Prosumer community groups [2]

Moreover, if we talk about the internal guidelines of this model, it is to be noted that each prosumer community-group is associated with a prequalification criteria defined by the group. The prosumers should agree with the defined prequalification criteria in order to obtain its membership. Further, the members of a community group are inspired to achieve the mutually decided goal, which can be different from other community groups. For instance, one community group may want to gain high profits by selling the energy to the utility grid, another group may attempt to reduce emission or energy costs, etc. The community groups of prosumers can collectively utilize their unused energy to either (i) offload their energy demand or (ii) auction off their unused energy to the other energy buyers (such as individual consumers, retailers, or the main utility grid).

For the prosumer community groups to emerge and be able to meaningfully interact with the smart grid infrastructure, several challenges have to be addressed. Some of them are anyway considered to be deployed as core part of the smart grid, some exist in other context (e.g. online communities), while others will need to be developed. Additionally, integration among all of them will have to be realized with the energy as target focus area. In this article, we address four key challenges involved with managing prosumer community groups.

Four key challenges in managing prosumer community groups

Managing prosumer community groups is challenging. Hereby, we investigate the following four socio-technical challenges of managing prosumers in prosumer community groups:

1. **How to define the prosumer community group membership categories and the pre-qualification criteria**

This issue becomes apparent in the very first stage of the prosumer community group formation. This involves defining the prosumer community groups and associated prequalification criteria, which the prosumers should comply with in order to obtain the membership. The proposals that address this challenge should consider the variable nature of the prosumers' energy sharing behaviours throughout the year, in order to define the optimal community groups and associated prequalification criteria.

2. **How to recruit dynamic prosumers to the prosumer community groups**

This issue emerges while recruiting new prosumers to the appropriate prosumer community groups. Due to the huge diversity in prosumer profiles over time, differentiating active prosumers from the passive prosumers may be complicated. Thus, it would be a short-sighted to decide a prosumer's stability in the energy sharing process by observing a single energy transaction. For instance, a prosumer who exceeds the energy expectation in one energy transaction may fail to do that in subsequent energy transactions. Therefore, before recruiting the new prosumers to the prosumer community groups, it is necessary to monitor the prosumers' behaviours over a period of time to see whether the desired energy goals are being achieved.

3. **How to define an optimal set of mutual goals**

The community based energy sharing process comprises multiple incommensurable objectives such as achieving the energy demand of customers, cost constraints, incentive maximization, etc. In many cases, one objective may be achievable only at the expense of other objectives. Furthermore, establishing a hierarchy of importance among incompatible objectives is necessary, such that the achievement of the lower order goals are considered only after the higher order goals have been satisfied or have reached a point beyond which no further improvements are desirable. Overall, an effective negotiation among the different objectives is essential in order to define practically achievable mutual energy goals for prosumer community groups.

4. **How to rank the prosumers based on an assessment criteria for fair incentive distribution**

Even in a single prosumer-community-group, the members may exhibit dissimilar behaviors over the membership duration. Therefore, treating all the members of a community group in the same fashion may be inequitable in certain scenarios, like when allocating incentives. Therefore, ranking the individual members based on relevant assessment criteria (that includes meeting the conditions of the agreement, historical performance, etc.) is necessary to achieve fair incentive distribution.

An examination of the existing literature clearly shows that the managing prosumer community groups is still in the preliminary phases, and there has been very little attention paid for addressing the challenges associated with it. Therefore, we hereby present an aggregated set of proposals to overcome the abovementioned four challenges.

Proposals to resolve the challenges

In this section, we suggest innovative proposals in order to address the challenges mentioned in the previous section. As illustrated in Fig.2, the first proposal is to define different prosumer community groups by segmenting the energy sharing profiles of the prosumers, thereby identifying the associated prequalification criteria of each community group. Relying on the different community groups formed on the basis of the first proposal, the second proposal involves recruiting the new prosumers to the appropriate community groups. It requires a proactive evaluation of the prosumers' stability as well as reliability in energy sharing, before finalizing their membership status. This is an important process during the growth of the existing groups. The third proposal defines practically achievable optimal energy goals for the prosumer community groups, by negotiating the different conflicting objectives. This is important to create a goal-oriented nature within the prosumer community group. The fourth proposal identifies the influential prosumers within the community group by ranking the prosumer behaviours based on the assessment criteria. This proposal is crucial for fair allocation of incentives to diverse members.

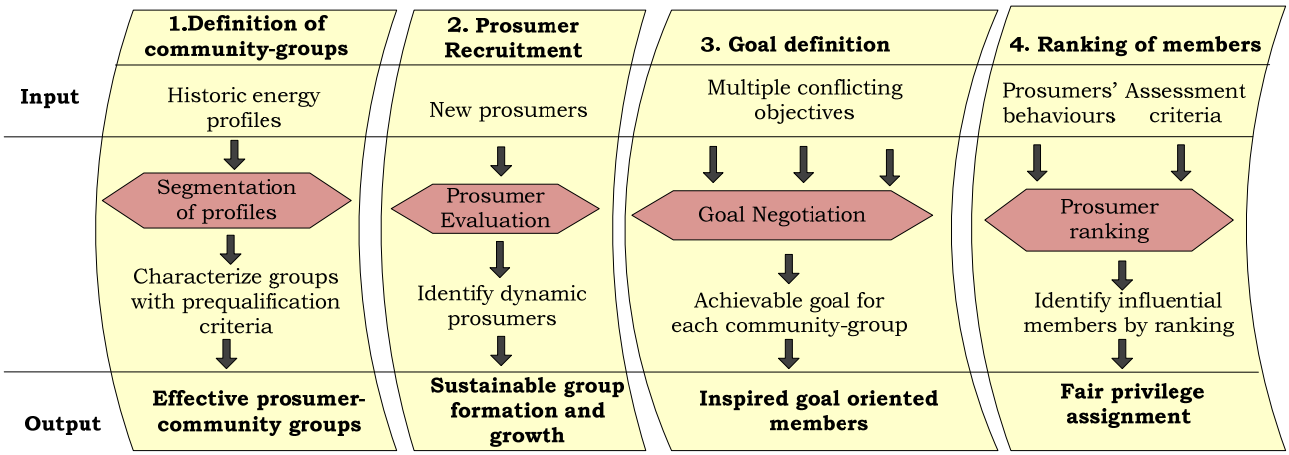

Fig.2. Proposals to address the challenges

Each process, which we have proposed above, requires aggregation of different effective methodologies. Fig.3 demonstrates the proposed overall framework that represents relevant methodologies for each proposal.

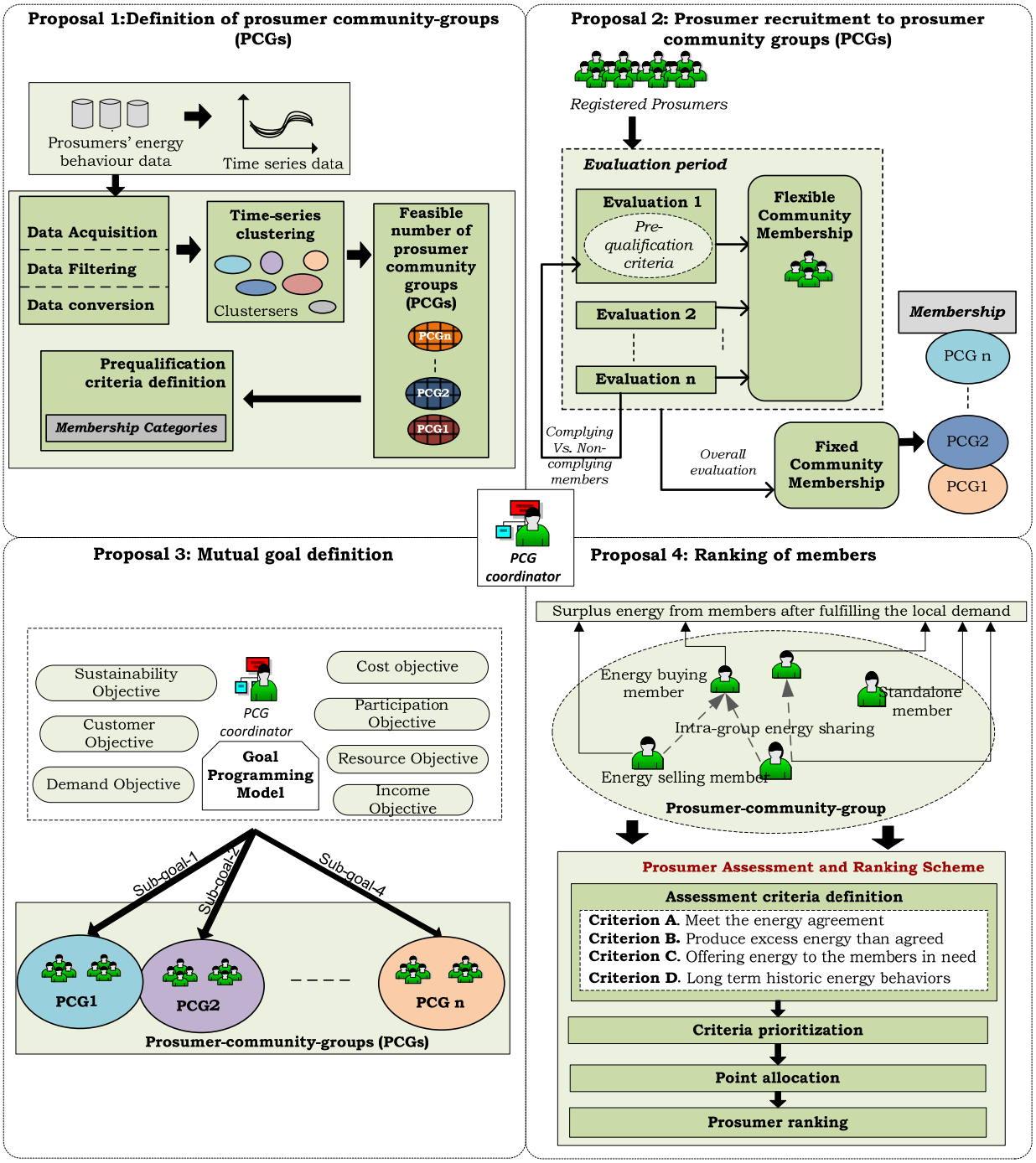

Fig.3. Concise overview of proposed methodologies

As shown in the Fig.3, the key actor involved in the overall framework is the prosumer community group coordinator (PCG coordinator), who can be broadly defined as an entity or group of entities involved in forming, evolving and managing the prosumer community groups (PCGs).

The first proposal we discuss is the definition of community groups. In this proposal, the community-coordinator acquires the multi-dimensional energy sharing profiles of all the prosumers who show interest in joining any of the community groups. The energy time-series data are clustered into the partitions. The two common criteria to be focused for finding the cluster models are the cluster's compactness, in which the objects of each cluster should be as close to the other objects on the same cluster as possible, and the cluster's separation, in which the different clusters should be clearly spaced from each other. The number of prosumer clusters obtained via the clustering system is optimized into feasible number of prosumer community groups to ensure each prosumer community group supplies sufficient quantity of energy and includes viable number of prosumers. The prosumer community group coordinator considers the output from the overall system in order to define and characterize the prosumer community groups. The identified characteristics of prosumer community groups can be represented as prequalification criteria for each prosumer community group. For instance, a registered prosumer should exhibit characteristics specified in the prequalification criteria of the specific membership category, to become a member of the corresponding community group.

The second proposal relates to the recruitment of new prosumers to the different prosumer community groups, which have been identified in the previous proposal. Here, a scheme for proactive, continuous evaluation of the prosumer's early energy behaviours is proposed, before finalizing their membership. In order to achieve that, the prosumers are requested to supply energy for consecutive number of energy transactions, which we call this an 'evaluation period'. During each energy transaction of the evaluation period, the prosumer's real-time energy sharing quantity is assessed, and if the corresponding energy sharing quantity satisfies the prequalification criteria, such complying prosumer is eligible to move forward in the evaluation period, and is assigned to a flexible community group membership category. Here the term 'flexible' is used, because this membership status is not the prosumer's actual final membership status within the framework, and it can fluctuate throughout the evaluation period. The fixed final membership category is decided only at the end of the evaluation period, after evaluating the overall

performance of the prosumer. Ultimately, this proposal achieves a long-term prosumer evaluation followed by effective recruitment of prosumers to the appropriate prosumer-community groups.

The third proposal is about defining optimal set of mutual goals for community groups. Here, a goal programming model is used to find a compromised solution among the following key objectives of the energy sharing process: the resource objective that aims to maintain sufficient resources (storage and handling) to hold the information and energy produced by the prosumer community groups, demand objective that fulfils at least the energy shortage of its own members, the customer objective that aims to satisfy the energy requests of energy buyers (such as main utility grid, other community groups, and other individual consumers), incentive objective that targets to achieve higher incentives, and the cost objective that aims to reduce the combined cost of bringing the energy resource to the end-use point, and finally the sustainability objective that aspires to increase the overall number of members from all the community groups who actively share the energy in energy sharing framework. A goal programming model is developed to find an optimal solution that negotiates among the conflicting objectives in the order of specified priorities. The final outcome of this phase is a coordinated set of goals for prosumer community groups that guarantees the satisfactory level of goal attainment.

The fourth proposal has been made to assess and rank the diverse prosumers in any prosumer community group. This includes four ongoing steps, as shown in Fig.3: (i) assessment criteria definition, (ii) criteria prioritization, (iii) point allocation, and (iv) prosumer ranking. The assessment criteria definition step involves defining the four assessment criteria that respectively measure the prosumer's ability to meet the energy agreement, produce surplus energy above the agreed amount, to share the surplus energy with the fellow members who are in need of energy, and the prosumer's quality of the long term historic energy behaviors. In the second step of criteria prioritization, the aforesaid criteria are prioritized based on their relative importance for the community-group's overall sustainability. In the third step of point allocation, the points are allocated to the members based on their capacity in satisfying the identified criteria. Finally, in the prosumer ranking step, the prosumer community group coordinator ranks the individual prosumers based on the allocated points. These ranks can be used as a benchmark for fair incentive allocation for members.

The proposed frameworks have been verified in simulation environment using prosumers' energy sharing profiles (generated on the basis of Australian conditions). First, the simulation results of the proposal 1 (definition of prosumer community groups) illustrates that the proposed framework clusters the prosumers' energy sharing behaviours into different prosumer community groups, while detecting the outliers (the prosumers showing unreasonable energy behaviours) , and characterizes prosumer community groups with suitable pre-qualification criteria. Second, the simulation results of the proposal 2 (prosumer recruitment) illustrate that non-complying prosumers are identified in each evaluation in the proactive evaluation process (evaluation period). Further, the simulation results of the proposal 3 (mutual goal definition) demonstrates that one goal is achievable only at the expense of other goals, thus require to alter their target values in order to ensure the satisfactory level of attainment of all the goals. Moreover, the simulation results of the proposal 4 (ranking of members of prosumer community groups) demonstrates that the proposed ranking framework, which assesses the prosumers' performance in multiple criteria shows fairer ranking than the conventional ranking method that mostly considers a single criteria.

Discussion

Now we discuss the significance of promoting the goal-oriented prosumer community groups in the current society. One of the key benefits would be that the consumers can directly buy the energy from geographically closer prosumer community groups, which will often deliver the power it commits, rather interrupting the main utility grid. In fact, the prosumer community groups can fulfill the consumers' energy demand in long-term in more consistent manner than the individual prosumers. This local approach to power distribution minimizes energy losses as the energy travels a shorter distance to reach the consumers while providing higher selling price for the prosumers. Furthermore, a prosumer community groups can be driven to fulfil the energy demand of its own members, while disconnecting from the main grid. This encourages the local members to limit their electricity needs go above the anticipated on demand energy production by the overall community group, thus eliminates electricity wastage. This is particularly advantageous in remote areas that do not have abundant energy resources and also involves huge costs and difficulties in transporting energy to satisfy the energy needs of the users. In such situations, a strong interaction among the prosumers, consumers and the utility grid will induce each individual to work together to more efficiently manage their electricity usage. Such strategies are essential to act as incentives for the users to conserve energy, and later utilise it for their own benefit.

Furthermore, the prosumer community groups are formed by clustering the prosumers based on the homogeneity of energy sharing behaviours. In case, if the number of clusters are higher than the desired number of prosumer community groups, the closer clusters can be joined together to reach the preferred number of community groups. Then the grid and distribution companies can make contracts with these optimal number of prosumer community groups, making the process of managing prosumers much more efficient. This is because the grid or the distribution company doesn't have to worry about interacting with many small individual producers. In addition, since each prosumer community group comprises members having similar energy sharing behaviours, it minimizes the disagreements among the members, leading to more firm groups in the long-term. Ultimately, this results more sustainable energy sharing process in long term.

Moreover, the social impact of this concept leads to a more symmetrical interaction between a community group of prosumers and the utility companies, since the community group has a stronger bargaining power than a single consumer. Further, compared to an individual, being part of a bigger community group can be seen as a big motivator for behavioural changes with regard to energy usage, because the impact of a community group's behaviour can be more relevant and stronger than the impact of individual behaviour. As a result, the prosumer community groups can create dynamic ecosystem of cooperating prosumers in the society.

Conclusion

In this article, we provide an overview on the emerging concept of goal oriented prosumer community groups, which is an ideal choice to achieve a sustainable energy sharing process. However, the development of the prosumer community groups is still in its introductory phases, and there are hardly any effective proposals to develop this concept further. In this article, we investigate the key challenges of managing prosumer community groups, and made some innovative proposals to overcome them. We have evaluated the functionality of those proposed frameworks using prosumers' historic energy sharing profiles (generated on the basis of Australian conditions), and in future, we plan to implement an ICT platform using JADE (Java Agent DEvelopment Framework) for prosumer community groups, which allows prosumers to virtually connect to the suitable prosumer community group and

trade the energy in the energy market. Ultimately, we hope to experiment this framework in regional Western Australia.

For Further Readings

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