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A socially intelligent approach to consumers' collective capabilities in smart grids

1st Faezeh Bagheri-Moghaddam
Department of Architecture
University of Strathclyde
Glasgow, UK
ORCID: 0000-0002-1809-0855

2nd Sonja Oliveira
Department of Architecture
University of Strathclyde
Glasgow, UK
Sonja.dragojlovic-oliveira@strath.ac.uk
ORCID: 0000-0003-4303-6612

3th Ed Atkins
School of Geographical Sciences
University of Bristol
Bristol, UK
ORCID: 0000-0001-8694-8465

4th Anna Chatzimichali
Department of Engineering
University of Bath
Bath, UK
ORCID: 0000-0002-3040-3594

***Abstract*— There is a pressing need to investigate consumers' social relations within energy systems particularly in the context of socially smart grids at the domestic level. However, no studies to date have categorised or explained how such social relations manifest and what role different consumers play in managing home energy demand. This work provides for the first time, a categorisation of household archetypes through the social relations that govern them. This study draws on mixed data including a large-scale ethno-visual survey and interviews conducted with energy consumers in Glasgow and Bristol, UK. The analysis forms part of a wider study which integrates social identity theory (SIT), practice theory and rhythm-analysis. We primarily focus on insights derived from SIT as an approach to identifying consumers' capabilities in smart energy systems and Home Energy Management (HEM) through a study of social relations. The findings reveal novel perspectives on how social identities shape HEM patterns and how the consequent socio-spatial and technical implications play a role in future demand reduction and the development of socially smart grids. The contribution of this study is two-fold; firstly, to demonstrate how prioritising social practices, identities, and rhythm-analysis can lead to novel interventions in smart grids and redefine the roles of the community, and neighbourhoods, and secondly to discuss the policy implications for planning future automated demand management via the acquisition of new socio-spatial insights into how diverse social identities and practices can foster just transitions and equitable energy futures in the UK and beyond.**

Keywords*— *Collective Capabilities; Socially Intelligent; Social Relation; Home Energy management; Rhythms-analysis; Smart Energy Systems; Socially Smart Grids.

I. INTRODUCTION

In recent years, there has been a growing interest in exploring the operational mechanisms of future smart grids [1]. While many studies have focused on technological advancements to improve grid functionality [2-6], there is increasing recognition of the crucial social role played by consumers and communities, particularly during energy crisis events like peak load reduction scenarios [7-15]. Savelli et al., [16] highlight the significance of social relations and cooperation in optimising smart grid design and operation. Hargreaves et al., [17] identify three types of social relations that can influence smart grid deployment including those established within a person's social network including relatives, friends, partners, and co-workers [18], those between the local community and commercial actors such as energy suppliers, and those related to identities such as gender, age, ethnicity, and disabilities. It is evident that social relations can influence consumer actions through their daily routines and practices, which can be further influenced by feedback mechanisms from smart home appliances or peer-to-peer feedback [17]. Katzef and Wangel [19] highlight key social characteristics that could impact smart grid functionalities, such as consumer engagement, peer influence and norms, collective decision-making, collaborative usage and energy sharing, community resilience, communication and trust, and social equity and inclusion. However, what is missing from this body of work is a characterisation of social relations that shape home energy demand and may in the future govern the operation of smart grids.

Social relations play a vital role in shaping consumer behaviour, facilitating collaboration among stakeholders, and enhancing community engagement in the smart grids [20-22]. Recognising and harnessing collective characterisations of social relations could lead to more effective, socially smart grids. However, there has been a lack of attention on understanding the factors that shape and influence the collective aspects of social relations in smart grids. A better understanding of social relations requires a greater analysis of collective behaviour and social coordination [23-25]. The capacity of consumers and collectives to engage in collaborative endeavours, share resources, and make collective decisions is critical to the effective operation of smart grids [24, 26]. Notably, consumer coordination plays a pivotal role, comprising activities such as optimising energy usage patterns, actively participating in demand response programmes, and peer-to-peer energy-sharing initiatives [20]. These collective endeavours have the potential to reduce energy use, improve grid stability, and encourage reliance on renewable energy sources [12, 27]. Foreseeing these collective activities is critical for developing and operating socially smart grids [11, 28]. Whilst computational studies have built-in assumptions of some potential collective behaviour in energy demand scenarios for instance in [29], there has been a lack of empirical or theoretical advances in this direction to date.

Social Identity Theory (SIT) provides a useful framework for analysing collective behaviour in the context of crisis or disaster events, including those related to the energy [30-35]. By applying an SIT framework, new insights can be gained into social identity processes and group dynamics that influence consumers' behaviour and responses during crisis events. This understanding can be used to develop strategies that leverage collective behaviour and activities to enhance community resilience, mitigate risks, and promote effective energy management in smart grid operations during crises. By acknowledging energy disruptions as critical events that impact communities and trigger collective responses, SIT could help us consider the social identities and collective behaviours of different groups.

The purpose of this paper is to discuss potential collective capabilities that can be considered within socially smart energy systems, with a specific emphasis on smart grids. The research draws on a large project carried out in the cities of Glasgow and Bristol, employing a combination of ethno-visual surveys, interviews, and visual analysis as data collection methods. The following section discusses the literature on consumers' social relations and collective capabilities relevant in the context of smart grids. This helps outline the need and applicability of social identity theory (SIT) which is discussed in section III. Section IV Provides an outline of the empirical setting and methodology. The final sections highlight the findings and conclude with contributions and areas for future research.

II. Socially smart grids – characterising consumers' social relations

A. Social Science Insights

Research across disciplinary domains from social sciences to computation has been examining collective characterisations of social relations in the smart energy systems [36]. In social science studies, these collective characterisations are seen through a) different modes of collaborative governance b) shared objectives and experiences c) dynamics of social interactions and habits, as well as d) diversity of consumer engagement and empowerment. Collaborative governance is seen to depend on procedures and organisational arrangements such as effective communication, coordination and participation [37]. Geelen et al. [38] argue that collective collaboration can play a crucial role in effectively governing smart grid initiatives.

In addition to governance arrangements, socially shared objectives such as economic and social goals were found by Savelli et al., [16] to have collective characteristics manifested in social cohesion, resilience, and overall well-being in the community. Masera et al. [10] examine collective dimensions of social relations through collaborative interactions, highlighting the complexity and interconnectedness of the smart grid ecosystem. Skjølsvold et al. [26] emphasise the transformative nature of consumer interactions and routines in shaping the collective connecting infrastructure. Bell et al. [39], highlight that social relations impact consumers' behaviours collectively through daily habits and practices. Camarinha-Matos [20] suggests that collective activities involve engaging and empowering community members.

Collective characterisations of social relations embody collective abilities, capacities, and resources that emerge from interactions, shared experiences, goals and practices within a group or community [40]. Collective actions are influenced by various social factors, including group identity, norms, communication patterns, leadership dynamics, and trust among group members [30, 41, 42]. Whilst social science research has delved into the social dynamics, acceptance, and implications of smart grids within communities, computational studies have explored the technical and algorithmic aspects of socially smart grids, aiming to optimise their performance and functionality.

B. Computational studies – key perspectives

Computational research has approached the collective characterisation of social relations by modelling energy systems drawing on a range of social consumer profiling data, however with little or no consideration of their collective relational character. These approaches include modelling consumer behaviours in demand response scenarios [43], simulating consumer behaviour change related to energy consumption data [44], as well as anticipating consumers' network functionalities in resource allocation and scheduling in smart grids [45, 46]. Zeng et al. [43] propose a cooperative demand response method, incorporating multi-agent deep reinforcement learning to improve the profitability of Load Serving Entities by considering consumer social profiling and load differences in valuing electricity. Simoiu et al. [44] demonstrate the impact of personalised recommendations on consumer behaviour and the potential for non-enthusiastic members to become enthusiastic through community engagement. Nair et al. [45] suggest the utilisation of multi-agent systems in optimising resource allocation and scheduling in smart grids. They emphasise the potential importance of social relations among the agents within the smart grid ecosystem, however, with no empirical data sets to draw upon. Stai et al. [46] highlight that social relations can be theoretically modelled through game theory approaches in the development of an energy source allocation mechanism. From a computational lens, foreseeing collective actions involves theoretical computational models, algorithms, and data analysis techniques to predict and anticipate the collective abilities and capacities of a group or community [47].

However, there has been a lack of empirical advances in the characterisation of collective capabilities, manifestations of social relations or indeed how collectives' capabilities may shift in crisis scenarios such as peak load reductions or power cuts. The following section discusses research on how collective capabilities emerge during crisis scenarios drawing on social identity theory studies.

III. Social identity perspectives in collective capabilities during crisis scenarios

Social identity theory (SIT) explains how people's group affiliations impact their attitudes, activities, and interactions [32]. In crisis scenarios, SIT suggests that people's group identification can influence their responses, including increased in-group cooperation and potential intergroup conflicts [48]. Understanding social identities allows for the identification and addressing of specific needs, challenges, and disparities faced by different social groups, ensuring more targeted and equitable crisis response efforts [34, 35].

The application of social identity perspectives to identify collective actions during crisis scenarios offers valuable insights into the intricate dynamics of social relations and their consequential influence on collective actions and behaviours [34]. From a social science lens, collective collaborations in crisis scenarios refer to the collective actions, behaviours, and capacities of consumers and groups to effectively respond, adapt, and recover during challenging circumstances [49]. Within the context of socially smart grids, collective actions during crisis scenarios encompass the collaborative efforts and resources mobilised by stakeholders to address disruptions, mitigate risks, and ensure the resilience of the grid [23].

Though not examined in the energy context, collective actions in crisis scenarios have been investigated in a) small-scale crisis scenarios, which pertain to local or regional events [35, 48], and b) large-scale environmental crises [50]. In small-scale crisis scenarios, Davidson et al. [48] explore the concept of shared social identity among local-level responders during the COVID-19 pandemic in the UK. He highlights the role of pre-existing relations and a sense of shared common fate in facilitating collective activities. Drury [35] highlights the behavioural and cognitive outcomes associated with shared social identity, such as increased expected support, coordinated behaviour, and collective efficacy, which contribute to collective self-organisation.

The significance of collective actions in addressing large-scale environmental crises from a social identity lens has also been studied by Fritsche et al. [50]. They suggest that collective actions in response to global environmental crises have the potential to create inclusive communities and tap into humanity's cooperative abilities for managing complex environmental challenges. They highlight that social identity processes as drivers of environmental appraisals and responses open novel avenues for understanding and supporting pro-environmental action, potentially leading to inclusive communities and harnessing humanity's cooperative potential in managing global environmental crises.

Overall, the application of SIT offers valuable insights into the dynamics of social relations and their influence on collective actions and behaviours during crisis scenarios. Taking an SIT lens can enhance understanding of how social identities shape the collective capabilities necessary for effective response, adaptation, and recovery within smart energy systems.

IV. Empirical Setting and Methods

Our research employed a mixed methods experimental approach [51], drawing on diverse data including surveys, photos, smart meter data and interviews with residents in Glasgow and Bristol. The cities were selected as the research settings due to their different climatic as well as neighbourhood, social and spatial characteristics while sharing similarities in local energy policy. The employed mixed-method experimental design, along with the iterative thematic inquiry (ITI) approach [52], allows for the gathering of diverse socio-technical identity and social relations data. This paper reports on the data sets and analysis concerned with social relations and identities rather than the overall project, namely survey and interview data.

The data collection and analysis were conducted in stages. The first stage involved a survey shared via Qualtrics. A total of 1427 participants took part in the survey. After filtering incomplete and duplicate responses, a total of 617 responses were included in the final sample. Among them, 231 participants were from Bristol and 386 participants were from Glasgow. The survey was designed to explore four key categories based on the project's overall conceptual approach [14] including i) participants' home spatial and social characteristics, ii) HEM approaches, iii) neighbourhood approaches to energy and social dynamics, and iv) home daily and weekly energy consumption and management routines. An initial analysis of the categories' responses revealed that there is no significant variation in demographic parameters, such as age group (58% aged 25 to 34 and 20% aged 35 to 44) and gender (44% female and 56% male), etc. Additionally, there is no substantial variation in the types of energy systems as the majority of participants reported having electricity (80%) and gas (43%) in their homes.

Participants were also asked to submit photos of their typical evening routine and describe in a free-text format any additional thinking that might not have been conveyed in the survey. The evening routine was selected because it presents the greatest challenge in terms of the peak load reduction [28, 39]. Photos were found to be able to convey both social and spatial context, that otherwise may be overlooked [15]. The third stage involved interviews with participants in both Glasgow and Bristol, with 11 conducted to date.

For the purposes of this paper, the discussion will focus on survey and interview data. The survey responses were initially organised into analytical categories, utilising empirical context, SPT, SIT, and rhythm analytical dimensions drawing upon the project's conceptual approach. Subsequently, the responses were grouped according to significant parameters identified as crucial in peak load scenarios within each category. Initially, these parameters included grouping responses by characteristics found to be critical to energy use practices such as house type, energy system, age, employment type., whether participants spent most of their day at home or away, number of appliances and social reach. Analysis across these groups revealed the key parameters that shaped the characteristics (both temporal, spatial, and social) included time at home, number of appliances and social reach.

The interview data were thematically coded into four emergent archetypes (1-4) based on their characteristics derived from the project's conceptual approach. All the transcripts were read and grouped into Archetype groups (1-4). Descriptive memos were written following the protocol sequence to capture the key aspects of each interview. In the second phase, the memos were analysed in relation to insights obtained from the survey. Key thematic details were discussed to further expand upon findings from the survey.

V. Findings – 4 Archetypes

Key findings emerged from the analysis grouped under four themes – named archetypes – they denote key social relations collective characteristics that emerged from the survey and interview analysis. This included – Theme 1 (Generous Belongers); Theme 2 (Aware Belongers); Theme 3 (Distributed Belongers); and Theme 4 (Disengaged Belongers). (See Figure 1)

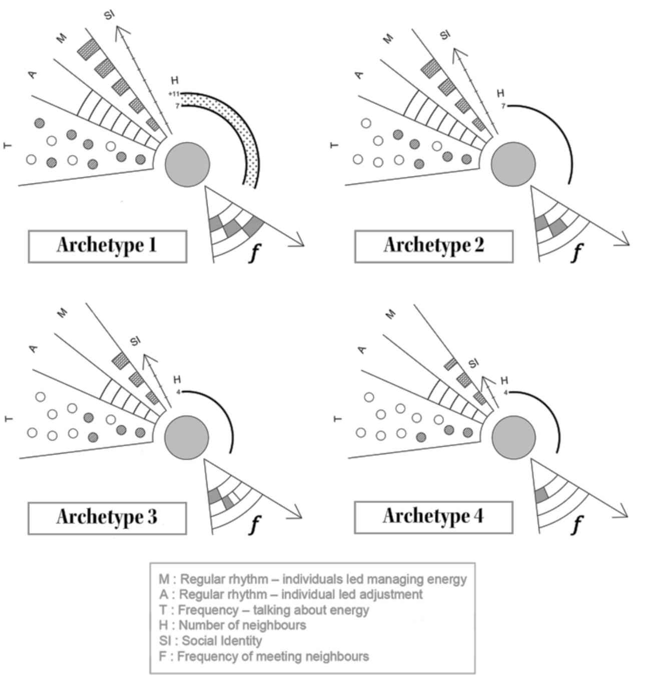

Fig. 1. Archetypes 1 to 4 interactions between social identity, social relations parameters, and consumers' actions in HEM.

The first theme (Generous Belongers) includes 114 consumers, who are characterised by very high social identities and very high community ties. They have a broad social reach (knowing 7-10 neighbours) and engage with their neighbours on a daily basis. The consumers in this archetype regularly help their neighbours and frequently share information related to energy. They strongly identify with their neighbourhood and consider neighbourhood issues highly important.

The second theme (Aware Belongers) includes 80 consumers, who are characterised by high social identities and high community ties. They have a wide social reach (knowing 5-7 neighbours) and engage with their neighbours a few days a week. The consumers in this archetype regularly help their neighbours and frequently share information related to energy. They have a strong sense of belonging to their neighbourhood and consider neighbourhood issues important.

The third theme (Distributed Belongers) includes 120 consumers, who are characterised by moderate social identities and moderate community ties. They have a moderate social reach (knowing 3-5 neighbours) and engage with their neighbours on a weekly basis. The consumers in this archetype regularly help their neighbours and have a moderate frequency of sharing information related to energy. They have a moderate sense of belonging to their neighbourhood and consider neighbourhood issues moderately important.

The fourth theme (Disengaged Belongers) includes 313 consumers, who are characterised by low social identities and low community ties. They have a low social reach (knowing 0-3 neighbours) and engage with their neighbours on a monthly basis. Consumers in this archetype irregularly help their neighbours and have a low frequency of sharing information related to energy. They have a low sense of belonging to their neighbourhood and consider neighbourhood issues of low importance.

In summary, four key archetypes were identified to represent the collective capabilities of HEM (Home Energy Management) that could be simulated during an energy crisis, such as demand response to peak load reduction events. Each archetype was distinguished by its social identity and practice characteristics. There was no discernible differentiation between the archetypes in terms of their social profiles (predominantly consumers, owner-occupiers, and full-time employees aged 25 to 34), physical home characteristics (mostly bungalows and maisonettes), or energy systems (electricity and gas supply with most households possessing 20 or more appliances).

Following the analysis of the initial themes, the energy management and rhythms for each archetype were explored in a baseline (no change) and a peak load energy crisis scenario. In the baseline, archetypes exhibit their typical characteristics during an evening peak load (as reflected in the survey and interview) over a year, without any modifications. The peak load energy crisis scenario assumptions are derived from the expected 'change' behaviours of each archetype, considering principles from SIT on how consumers behave in collectives related to conformity, social status, and social influence. These assumptions reflect how each archetype would change its time of energy use in a typical evening peak load over a year. The parameters within each archetype were determined by insights drawn from the conceptual framework.

In a baseline scenario, Generous Belongers interact with 7 consumers (100% value), on a regular (daily) basis. They also provide regular assistance to other consumers (100% value) over a year. In a peak load scenario, these interactions are expected to increase to 10 agents. They continue to engage with these consumers daily, at the same time each day, thus establishing collective characteristics. Moreover, they maintain their regular pattern of helping other agents, with a 100% value, even considering the increased number of agents during peak load energy crisis scenarios.

Aware Belongers interact with 7 consumers (75% value), on a regular (a few days per week) basis in a baseline scenario. This is somewhat less than generous Belongers but still strong. They also provide regular assistance to other consumers (75% value) over a year. In a peak load scenario, these interactions are expected to increase to 8 consumers. They continue to engage with these consumers a few days per week, thus establishing collective characteristics. Moreover, they maintain their regular pattern of helping other agents, with a 75% value, even considering the increased number of agents during peak load energy crisis scenarios.

In a baseline scenario, Distributed Belongers interact with 4 consumers (50% value), on a regular (weekly) basis. They provide regular assistance to other consumers (50% value) over a year. In a peak load scenario, these interactions are expected to increase to 6 consumers. They continue to engage with these consumers once a week, thus moderately establishing collective characteristics. Also, they maintain their semi-regular pattern of helping other agents, with a 50% value, even considering the increased number of agents in peak load energy crisis scenarios.

In a baseline scenario, Disengaged Belongers interact with 2 consumers (25% value), on an irregular (monthly) basis. They also provide irregular assistance to other consumers (25% value) over a year. In a peak load scenario, these interactions are expected to increase to 3 consumers. They continue to engage with these consumers once per month, thus establishing collective characteristics. Moreover, they maintain their semi-regular pattern of helping other agents, with a 25% value, even considering the increased number of consumers during peak load energy crisis scenarios.

In a specific context of a peak load energy crisis scenario, based on SIT insights, consumers with high social identities would further strengthen their social relations and engagement with other community members over the course of the year. Generous Belongers individually commit to not using energy for 30 min each day during peak load times. They encourage others to monitor and regulate their energy usage, and after 8 months in year 1, they extend this commitment to daily energy conservation. Aware Belongers individually commit to not using energy for 30 min a few times a week during peak load periods. They encourage others to monitor and regulate their energy usage and, after 8 months in year 1, extend this commitment to a few times a week.

Distributed Belongers individually commit to not using energy for 30 min once a week during peak load times. They influence others on a weekly basis to monitor and regulate their energy usage at home. After 8 months in year 1, they extend their commitment to 30 minutes per week. Disengaged Belongers collectively commit to not using energy for 30 min, perhaps once a month, on an irregular basis during peak load times. They influence others monthly to monitor and irregulate their energy usage at home as a collective effort. After 8 months in year 1, they extend this commitment to once a month.

The research findings emphasise the significant role of social identity perspectives and social relations in shaping collective capabilities, especially in energy crisis scenarios. It becomes evident that heightened social identity and relations are manifesting a regularity in energy practice rhythms. Among different consumer groups, those in the Generous Belongers category exhibit very high social identities and relations, and a very high commitment to responsible energy management in their homes. This commitment is reflected in their daily and regular energy management practices. In addition, the Aware Belongers group demonstrates high social identities and relations, aligned with a high commitment to responsible energy management. Their commitment is evident through regular energy management practices carried out several days a week. Furthermore, the Distributed Belongers group features consumers with moderate social identities and relations, along with a corresponding moderate commitment to responsible energy management. They engage in semi-regular energy management practices, occurring once a week. The Disengaged Belongers group consists of consumers with low social identities and relations, resulting in a low commitment to responsible energy management. Their irregular energy management practices take place once a month.

Understanding the dynamics of social identity sheds light on effective strategies that can enhance collective capabilities and promote energy-related practices. This insight has the potential to contribute significantly to boosting the resilience of socially smart grids. By capitalising on the intrinsic link between social identities, relations, and energy management practices, innovative interventions can be developed to encourage conscientious energy use and management behaviours.

VI. Conclusion

The implications of this research are twofold, offering valuable insights into the characterisation of collective consumer behaviours as shaped by their social identities enables a new understanding of ways consumer profiles may be modelled in smart grid operations at the domestic level. First, knowledge of consumers' social reach and community ties could enable a better understanding of their energy management rhythms and the ways of responding in a peak load scenario for the collective good. This expands research on social relations and energy systems, specifically work by Hargreaves et al., [23] in providing empirical evidence of the dynamics of social relations and energy management [16-18]. Expanding the scope of inquiry, these insights carry implications that extend beyond consumer households. They hold the potential to inform energy management strategies on a national and regional scale, potentially even varying across different cities due to diverse socio-cultural contexts. This could potentially involve the integration of novel methods that aimed at comprehending social relations in greater detail, leveraging these relations in the context of future energy research, and enhancing the principles of socially smart grid systems.

Second, there are implications for computational studies focused on modelling peak load scenarios and smart grid operations by incorporating an empirically and theoretically informed approach to collective social profiling of consumers [43-45]. While social science research has explored social dynamics, there has been little empirical detail or methodological guidance on how to do this at a collective scale. In addition, there are policy implications [25] whereby policymakers could design and implement interventions that prioritise social relations, and neighbourhood interventions that promote social cohesion and collective responses [53]. Future studies could broaden their scope beyond the current geographical locations. Understanding other UK as well as international contexts, will provide a more comprehensive understanding of socially smart energy systems and inform the development of tailored approaches to different regions. It is important to acknowledge the dynamic nature of social relations and collective capabilities identified in this research. Consumers may change neighbourhoods, potentially leading to shifts in their archetypal characteristics. Additionally, archetypes themselves can exhibit fluidity and evolve over time. Longitudinal field studies that track consumers' HEM and behaviours and the manifestations of archetypes over an extended period are needed to fully explore these dynamics.

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