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ORIGINAL ARTICLE

Theory as a source of software and system requirements

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Abstract

Today, when undertaking requirements elicitation, engineers attend to the needs and wants of the user groups considered relevant for the software system. However, answers to some relevant questions (e.g., how to improve adoption of the intended system) cannot always be addressed through direct need and want elicitation. Using an example of energy demand-response systems, this paper demonstrates that use of grounded theory analysis can help address such questions. The theories emerging from such analysis produce a set of additional requirements which cannot be directly elicited from individuals/groups, and would otherwise be missed. Thus, we demonstrate that the theories generated through grounded theory analysis can serve as additional valuable sources of requirements for software and its wider system. This paper extends our previous work by demonstrating how several theories can be constructed and utilised for a single system analysis.

Keywords Grounded theory · Elicitation method · Requirements elicitation · Demand-side response · Energy service, Energy transition · Case study · Systemic concerns, Tacit knowledge

1 Introduction

Requirements engineers are charged with the task of elicitation and specification of the needs and wants of the prospective software system users. The current predominant requirements elicitation methods are those based on agile methodology [1, 2], centered on the practical, incremental delivery of useful functionality, whereby the intended users actively participate in the formulation of roles and functions that the software system should support. This method ensures that the intended users are engaged with helping to define and test what the intended software will do.

The contrasting methods to active user engagement into the requirements elicitation process are ethnographic and observational methods [3–6]. These methods underline a need for third party analysis for elicitation of tacit knowledge (i.e., knowledge that cannot be easily identified, conceptualized, or verbalized by those who possess it [7, 8]). While immensely rich in detail and context provision, these methods require prolonged situating of the researchers into the context of study, and often result in too large volumes of data which could be difficult to analyze and utilize within the constraints of a single software system development project.

As agile practice has taken root in Software Engineering (SE), reliance on closer interaction with intended users, and their direct input for software system requirements elicitation has grown. The ethnographic and observational practices in SE have focused instead on explanation of processes and practices within development teams and ecosystems [9, 10], leaving it to the social scientists to engage with questions of societal practices and operation. Yet, given that the software systems are to be situated and operated within the societal fabric, requirements engineers are aware that societal concerns, norms, and beliefs will drive additional requirements for the software system to be [11].

This paper presents the process which *accommodates elicitation of some of such societal requirements alongside the use case elicitation process*. The process emerged as we worked to elicit requirements for a new household energy management system, while also thinking about fostering wider adoption of this intended system.

To understand how to foster adoption, we drew on the grounded theory (GT) analysis technique which helped us unveil how prospective users of a software system perceive their role within the socio-technical system facilitated by this software and their skills-related constraints. We then observed that our conceptualization of the adoption process

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(formulated as the adoption theory) that emerged from the grounded theory analysis motivates a set of additional socio-technical requirements which cannot be directly elicited from individuals/groups, and would otherwise be missed out. *Thus, this paper illustrates that a theory generated through grounded theory analysis can serve as an additional valuable source of software and its wider system requirements.*

Thus, based on the experience of the demand-side response (DSR) energy management system's study:

– We suggest that the theory building practice (through the grounded theory (GT) method) can be integrated into the requirements elicitation practice, and carried out alongside such established RE methods as use case elicitation. The grounded theory method provides a tool for theorizing on the research questions at hand, particularly when such questions relate to systemic concerns. The validated theories (which explain the questions) can then serve as a source of new socio-technical requirements for the system-to-be.
– Our approach is not restricted to addressing one specific question. Instead, it provides a process for setting pertinent questions relevant to a given system. Nevertheless, as each question may require new data collection, the value of the answers must compensate the committed effort.
– We demonstrate the use of this process with iterative analysis for two theories through a case study for an energy demand-side response management system. A number of such systems for business users are already in operation around the world [12–14].

The background concepts and related work for this paper are presented in Sect. 2. Section 3 reports on the study design and analysis. The study findings are presented in Sect. 4. Section 5 discusses how our findings compare with the related work in this domain. Section 6 discusses implications of the theory constructed as part of this study to requirement elicitation. The lessons learned through this study are summarized in Section 7, and Section 8 concludes the paper.

2 Background and related work

Our contribution to the research in RE is, thus, in using the GT analysis to form an inter-subjective theory that is of central interest to a software system-to-be, and *deriving new requirements due to this theory*.

2.1 Grounded theory method

Grounded theory (GT) [5, 6, 15] is a method for qualitative analysis of data aimed at providing a systematized approach for constructing a theory about phenomena or a question of interest firmly grounded in (i.e., linked to) the collected data (e.g., via observations, interviews, reports, etc.). Here, a theory "states relationships between abstract concepts and may aim for either explanation or understanding" [5] (p. 228). Briefly stated, the key notions of GT [5, 6, 15] relate to:

– *Theoretical sampling:* Purposeful selection of sources and collection (i.e., sampling) of additional data for analysis which is expected to be relevant to the notions under analysis.
– *Coding:* The process of examining the data, breaking it down into small portions (e.g., from individual text lines to a few sentences) and assigning labels (called codes) to each portion.
– *Constant comparative analysis:* The codes are continuously compared/contrasted with each other, as they emerge when data is examined. As a result of this process, data is collated into conceptual categories, and links/relationships between the categories are identified. Unlike many other qualitative analysis approaches, there is no restriction on what themes/categories are considered relevant, so all emerging categories are acknowledged and considered. Throughout the analysis process, the reflections on the analysts are recorded into memos.
– *Conceptualization and abstraction:* Development of theories that emerge from the abstraction and review of the coding results and memos.

Presently, there are three main strands of GT in practice, which differ substantially in philosophical worldview (e.g., objectivist [6] vs. constructivist [5]) and processes (e.g., could the researcher study the relevant literature prior to data analysis). A recent study by Stol and colleagues has proposed a set of good practice guidelines for GT in Software Engineering [16], suggesting that each study that uses GT should detail which specific strand it draws on and how it carries out data collection and analysis, as well as theory building and evaluation.

2.2 Use of grounded theory in requirements engineering

GT has already been applied in various areas of RE, but primarily as a tool for an abductive data categorization.

For instance, Sharma et al. [17] used GT to group functional requirements into categories, while Dupree et al. [18] used it to group stakeholders into categories to be represented as personas in privacy and security profile designs. Others directly utilize the categories that arise through GT analysis for software modeling. For instance, Wurfel et al. [19] first categorized the requirements data then map GT conceptual categories directly onto use case specifications, while Halaweh [20] builds an information model and a class diagram from GT conceptual analysis. Rashid et al. [21] used GT to integrate the reports of multiple similar security incidents into a single analysis and categorization process, and (by learning from past incidents and constructing incident fault trees as part of the GT analysis) theorize as to how these security threats can be neutralized.

The above efforts demonstrate that GT analysis could be helpful for a number of RE activities: from structured stakeholder categorization, to grounding use cases in interview data, and helping to model the information content. Yet, the key power of the grounded theory approach is in supporting *theory building* for explaining/understanding "relationships between abstract concepts" of interest. In requirements engineering, the concepts and relationships of interest are, unavoidably, the socio-technical system and the in situ interactions with the software system. Thus, where a *systemic question of interest* (i.e., a question that relates to a broad set of actors and their interactions within the given socio-technical system) is to be considered, we advocate use of GT to *theorize* about this question of interest and to *inform the system requirements through such theories*.

This differs from the widely used RE techniques in that theories are constructed by the analyst (underpinned by the evidence from the empirical data): (a) alongside the more established RE activities (such as use case elicitation), and (b) with the explicit intention to use the theories to derive additional requirements for the system-to-be. These theories would aim at *elicitation of inter-subjective*[1] *tacit knowledge*, i.e., knowledge that the majority of the intended system users would tend to agree upon, if it were verbalized. Moreover, extending our previous work [22], this paper demonstrates that more than one such theory can be derived and utilized alongside each other. Furthermore, such theories can complement and extend each other.

[1] A valid theory can be derived for a small sub-set of the respondents as well. However, such a theory is unlikely to have good *resonance and usefulness* [5], i.e., have a significant impact on the overall socio-technical system requirements, as discussed in Sect. 8.

2.3 Energy demand-side response management

Related work on energy demand management has observed that the "public wants and expects change with regard to how energy is supplied, used and governed" [23]. Yet, while some scenarios of automated appliance governance are acceptable (e.g., 78% of respondents accepted automatically turning off a TV from standby), the others are less so (e.g., only 30% of respondents accepted the idea of automatically turning off a fridge/freezer for short periods during the peak demand). Overall, the scenarios that allow householders some control are preferable and interventions that assist people in shifting their own energy use patterns are viewed positively. Yet, most elements of demand management are unfamiliar to the public and need explaining [23, 24].

Several studies have focused on understanding the factors that affect energy consumption at home. For instance, Jones et al. [25] identified 62 factors that affect energy consumption in households from an extensive literature review. These factors were related to 3 key areas; those most often repeated in (several) studies are:

- *Socioeconomic factors,* e.g., more occupants, teenagers and higher income and disposable income, all contribute to significant increases in electricity consumption. The presence of children or elderly people and education levels show no conclusive effect.
- *Property factors,* e.g., age and size (number of rooms, bedrooms and floor area), all contribute to increased consumption as does electric heating, electric water heating and air conditioning.
- *Appliance-related factors show a clear effect in increasing consumption*, e.g., the more appliances a household has, the higher is its energy consumption.

Boomsma et al. [26] categorized consumption by contexts: morning, evening, regular, important, most energy consuming, summer or winter. Kavousian and colleagues [27] suggest that the daily minima of consumption is explained by constant factors (e.g., house size, numbers and type of devices), whilst daily maxima relate to the number of occupants and high-consumption intermittent-use appliances. It is suggested that there are four groups of factors affecting energy use: (i) external conditions (weather, location), (ii) physical characteristics of the building, (iii) appliances, and (iv) occupant behavior.

Others have studied the effectiveness of information provision to households on their energy consumption either through smart meters, or via in-house displays [28, 29], concluding that, by themselves, these are insufficient for motivating any action or change in energy consumption behaviors.

A study by Whitmarsh et al. [30] notes that the ability of households to change their behavior in support of carbon reduction is limited, because carbon footprint (and hence, energy consumption) is not a driving force in everyday behaviors even when individuals are knowledgeable and motivated to act. Gabe-Thomas et al. [29] concurred that the fact as to how much energy an appliance consumes is not at the forefront of a householder's consideration when utilizing an appliance; instead the domestic practices take priority. As noted by Shove and Walker [31], energy consumption is a by-product of the activities of society; "demand and the means to consume constitute each other", where means to consume include such things as grids, power stations, networks, and devices with which end-users engage.

In summary, it is evident that energy consumption is intertwined with the habits and preferences of households, the stock and capability of their appliances, the physical properties of their dwellings, and the social and personal values and norms. Given that the problem is inherently multi-faceted [32], it is necessary to provide a solution that tackles as many facets of this problem as possible.

3 DSR study

3.1 Case study and research questions

This research was formulated through work on a case study of an energy demand-side response (DSR) management system. The study to design this system was commissioned for a DSR service trial by the Bristol City Council (BCC), Bristol, UK [33]. The **overall brief** is that: to use this system users register their energy generation (e.g., roof-top solar PV) and consumption (e.g., washing machines, dishwashers, water heaters, etc.) assets with the DSR service provider. The service provider monitors the supply and demand conditions on the energy market and schedules the device runs when energy prices are most suited (e.g., run dishwasher at midday when renewable generation is in excess, and so energy prices are low). This system would be used by households to help reduce pressure of the peak time energy consumption (i.e., when consumption threatens to overrun available generation) and foster better use of the local renewable energy.

The system owners wanted to know:

RQ1: What did the households wish the system to do? Moreover, they were concerned about reports of poor adoption of similar systems elsewhere [34]. Thus, they also asked us to consider

RQ2: What could foster better adoption of the intended system by the households? Furthermore, as our research progressed in addressing the two above-noted questions, an additional research question was set:

RQ3: What skills and training do householders require for better adoption of smart local energy services (like the present DSR service)?

This last question was motivated by the fact that the said demand-side response system was to be part of the transition envisioned by the BCC for Bristol's energy ecosystem—from the traditional fossil-based centralized generation and delivery to that of a low-carbon smart local energy system (SLES), and as previously noted [28, 29], simply informing the householders of their energy consumption is insufficient for motivating any action or change of behavior.

3.2 Study design

As the present study required both understanding of the key functional requirements of the system (i.e., RQ1), as well as of the adoption considerations (i.e., RQ2 and RQ3), we opted for data collection via semi-structured interviews and co-design workshops which would allow for exploration of both the expected functionality (through use cases) and the contextual issues (through study of householders' routines and perceptions) of the intended system through the same data collection activities.

The study was structured into three cycles. In the *first cycle* an interview study was set up to collect requirements for use cases as well as build an initial theory [5] that would address the question of the DSR system adoption.

The grounded theory approach used in this study draws on the work of Charmaz [5] and guidelines by Stol et. al [16], whereby the *initial research question* for the study is set, but can evolve throughout the study. Although this research did not commence with a full *literature review*, the authors had previous familiarity with the literature of the DSR domain, most of which had focused on reporting how prospective users (or pilot study participants) responded to specific stimuli for DSR (such as time-of-use energy pricing, i.e., pricing based on time of energy consumption as opposed to the flat rate which is commonplace today; notifications of price change/high demand periods, etc.).

The interview was first piloted, then carried out as a full study. The results of the interviews were analyzed and a set of use cases as well as an initial theory to address adoption question were derived.

In the *second cycle* two co-design workshops were planned and executed to validate both the use cases elicited from the interview study and the *resonance* [5] of the developed theory (i.e., checking if the theory makes sense to the study participants).

The *third cycle* commenced as the initial results of the findings from the previous cycles were reported upon, and a new question on skills and training needs was posed. This cycle led to an additional analysis and theory building activity over the data collected in cycles 1 and 2.

It is relevant to highlight here that RQ3 is concerned with the skills and training needs for SLES services and solutions, of which DSR is one representative example. Yet, the adoption theory developed in previous cycles was centered specifically on a DSR system. Thus, while the coding and categorization work from previous 2 cycles could be used in study of RQ3, limiting skills and training needs to the DSR only adoption theory could have restricted understanding of the training needs and skills for the (more general case of) SLES. Thus, in addressing RQ3, an additional theoretical coding cycle had to be undertaken over the cycles 1 and 2 data.

The set of all data collection activities is detailed below:

3.2.1 Interview: pilot study

The interview study was piloted by two requirements analysts (see [35] for details). The interview questions were prepiloted with 2 individuals, to check the clarity and utility of the set questions. The updated questions were then used for a pilot. Using *convenience sampling* [36], 7 interview participants (4 male and 3 female) were recruited from non-single occupancy households, as these households have a richer context of interactions around the use of shared devices. The pilot study interviewees presented a mix of professionals (a lecturer, a researcher, an investment banker, a medical practice manager) and students. The number of interviews was limited to 7 due to the time constraints of the pilot study and available researcher time (4 weeks altogether).

All interviews were carried out in English and face-to-face, they were recorded, transcribed, and analyzed for both use case elicitation, and for grounded theory analysis.

The pilot validated the suitability of our data collection instrument and the process for both DSR requirements use case elicitation and for an adoption theory-building exercise. Most significantly, we trialed the objectivist [6] GT approach, and observed that our study constraints and context are best aligned with the constructivist [5] strand of GT. The pilot also helped us improve the structure of the questions by splitting them into topic-specific sub-groups.

We noted that use of convenience sampling threatened the relevance of the pilot study findings, as the stakeholder sample was too biased toward the university members, and not representative of the population at large. Yet, this is an acceptable trade-off, as the pilot was specifically aimed at the validation of the interview instrument as well as the refinement of the data analysis process.

Thereafter, the full interview study was carried out.

Table 1 Characteristics of study participants

		Int	WS1	WS2
Gender	M	11	7	4
	F	19	4	8
	N/A			
Age	16–25	1		
	25–49	17	7	4
	50–65	10	1	3
	N/A		3	5
Income	< 25K	13	3	4
	25K–50K	10	1	1
	> 50K	5		1
	N/A		7	6
House type	Semi/Detached	4		
	Terrace	20	7	3
	Flat	4	1	4
	N/A		3	5
Household size	Single	4	2	3
	Couple	3		
	House-share	4	3	
	1 parent, adult kid	1	2	
	Couple, adult kids	3		1
	1 parent, young kids	4		2
	Couple, young kids	9	1	1
	N/A		3	5

3.2.2 Interview: full study

The full interview study was carried out with 28 households (with two interviews carried out with couples, a total of 11 male, 19 female) during November 2018–February 2019. The interview questions were split into 3 sections:

- Participant background details;
- Current practices of appliance and energy use;
- Responses to the idea of automation for energy management.

Interviewees were drawn from households that had received smart appliances from BCC as part of the smart city initiative (16 in total) and households with no direct relationship to BCC (12 in total). In the participant recruitment, an active effort was made to obtain a representative sample of participants, balancing for both demographic and owned/occupied property characteristics of the households. We stopped the interview process when no new significant use cases or code categories emerged from the last 3 interviewees (i.e., *theoretical saturation* was deemed achieved[2]).

The participants' demographics are summarized in Table 1 (see column *Int*, short for Interview):

Here too, as for the pilot study, interviews were carried out face-to-face in English; these were recorded, transcribed, and analyzed for both use case elicitation, and theory building (following the process validated through the pilot study). The collected data were analyzed and a set of use cases as well as DSR system adoption theory were formulated. These were further refined and validated through two co-design workshops and a questionnaire, respectively.

3.2.3 Use cases: co-design workshops

Two, 2-hour-long workshops were held in March and April 2019 with a total of 23 participants. Participant demographic details are shown in Table 1 (see columns WS1 and WS2 for workshops 1 and 2, respectively). The workshops were used to validate the findings of the analysis from the interview-based data collection for the DSR requirements. Half of the workshop participants were also interviewees; others were recruited through the wider BCC smart city project or via a register of energy champions (a different pool of potential DSR system users from those recruited for the interview study).

The set of activities carried out at the workshops included:

- Co-designing a DSR automation system interface to accommodate the participants' personal routines and preferences (as previously elicited through interview study);
- Reflecting on how an energy management system might deliver maximum gains;
- Walking through the process of DSR sign-up and use;
- Discussing the use of rewards or savings for personal or community gain.

The activities were carried out in groups of 3–5 participants. Each group had an assigned scribe, responsible for taking notes of the discussions, although most activities also had accompanying forms to be filled either individually or in pairs/groups. The notes from the workshop participants and the scribes were then collected and treated as supplementary materials to those of the interview transcripts, helping to validate/refute the suggested DSR requirements and design choices.

3.2.4 RQ2 theory validation: questionnaire

To validate/refute the resonance [5] of the proposed theory for RQ2, a questionnaire was designed to seek agreement/disagreement with the premises of the theory, along with the justification for own opinions, from the intended users (see Appendix 1).

The questionnaire was distributed for completion at the second (April) co-design workshop, as an additional activity. The demographics of the questionnaire respondents are presented in Table 1 (see column WS2).

Since the results of the GT analysis for RQ2 (as discussed in Sect. 4) suggested that a key theme of the dataset was an expectation of business partnership, the more formal notion of a partnership in business organization was drawn upon [37]. Thus, a partnership arrangement requires that:

- Individuals contribute to a common goal or enterprise;
- Pool resources (e.g., skills, money, etc.);
- Share profit and loss (in accordance with terms of the partnership agreement).

The workshop participants were asked to explain (by completing a questionnaire) if and why, as DSR service users, they agree/disagree to committing to the above three points, though no reference to a formal "partnership agreement" was made in the questions (see Appendix 1).

It should be noted that the theory of Partnership itself was not shared either with the respondents, or with the broader community to which the respondents could have access. Only the small group of 3 researchers knew what the theory was and how the questionnaire was related to it. The respondents were simply told that findings from previous data collection activity were being validated and there were no right or wrong answers—the key aim of the exercise was to find out what the respondents, as potential users of DSR, think with respect to set questions.

3.2.5 On RQ3 theory validation

The theory on the skills needs for RQ3 was developed at a later time, after the coding and analysis for RQ1 and RQ2 were carried out, and workshops 1 and 2 were already concluded to validate the previous RQ findings.

Thus, to validate RQ3 findings, we:

- Demonstrate (see Table 4) that the findings of the skills needs theory of RQ3 are:

[2] We note here that the coding was carried out and saturation deemed achieved when only RQ1 and 2 were set. RQ3 was set later, when the initial data collection and analysis were already complete. Yet, given that the analysis for RQ3 was carried out over the already defined primary categories (i.e., no new primary category was identified for RQ3), we consider the data sufficiently saturated for RQ3 as well.

– Consistent with the functional requirements identified and previously validated through use case analysis (as per Sect. 3.2.3), as well as extend these with relevant safety and similar use cases;
– Reinforce the partnership theory of DSR adoption, which is validated as discussed in Sect. 3.2.4,
– Are consistent with the related work, discussed in Sect. 5.

We note that for a full proof of validity of the skills needs theory a large scale survey with the citizens of Bristol would be required. However, given that this theory is consistent with the previously validated work we deem it sufficiently validated for our purposes as well.

Further limitations and treads to validity of the present theory are discussed in Sect. 3.4.

3.3 Data analysis

3.3.1 Use case elicitation

To elicit the relevant use cases, the interview transcripts were analyzed to identify the actors and their interactions with the intended DSR software expressed by the interview participants [38]. These were aggregated and summarized into a use cases diagram.

3.3.2 GT analysis

As previously noted, this study used the constructivist strand of the grounded theory (GT) analysis [5], as the initial (broad) research question was set for the study and the researchers could not expect to objectively forget their previous knowledge of the DSR literature. The line-by-line text analysis resulted in a set of codes, during the initial coding stage (e.g., wash for immediate use, noise from washing machine, etc.), which were then integrated into a set of 8 main categories during the *focused coding* activity in addressing RQ2 (these are: Practices, Appliances, Data, DSR Automation, Motivations, Concerns, Knowledge, Smart). The *theoretical coding* then helped to establish relationships between these categories and formulate a cohesive Theory of Partnership in response to RQ2. While the detailed description of the Theory of Partnership derivation is not presented in this paper, the overview of the process as well as a subset of sample codes are summarized in Table 2; the code book for main categories is available at [39].

RQ3 was set out for the researchers after all GT coding activities for addressing RQ1 and RQ2 were completed. Fortunately, the GT practice fosters theory-independent categorization in open and focused coding activities. Thus, we were able to draw on the already defined categories for addressing the question on skills and training needs (i.e., RQ3).

Here, we had to carry out additional theoretical coding activity, to establish the relationships between these categories that define the skills and training needs. The theoretical coding for RQ3 resulted in a causal dependency model for DSR automation, where the software feature, and training needs for maximizing positive impacts and minimizing negative ones were defined for each identified relevant factor (see Sect. 4.3).

In choosing this approach to addressing RQ3, we rely on the guidance for grounded theory construction as a study of processes championed by K. Charmaz ([5], chapter 9). When taking a process-based approach to theory construction, an analyst conceptualizes the relationships between experiences and events reported in data. Thus, several large processes could be identified when a complex phenomenon is analyzed. However, "collapsing multiple different processes into one would be over-simplification" as people experience multiple different processes at the same time. K. Charmaz recommends reporting on all relevant processes to "reveal the complex variations" of reality.

Correspondingly, we suggest that *Transition to smart local energy systems* is a complex phenomenon. The present study has analyzed two semi-independent processes (the theories for which are reported in this paper):

– The *business model formation* on the one hand, which is conceptualized as the partnership theory, and
– *Citizens' capacity building* (i.e., developing awareness and skills for engagement with the transition to SLE) on the other, which is conceptualized in skills needs theory.

3.4 Validity and limitations

Given that this is a qualitative study, based on data obtained through interviews and co-design workshops, we do not claim that the findings (either of the use cases, or of the adoption theory) are generalizable beyond the scope of this DSR case study. Given that our GT results are grounded within the studied context and collected data, this is an expected limitation.

Although qualitative studies can be designed to validate the obtained results for a more general population (as indeed is our intention for future work), findings from such additional studies will not change the validity of the study for this given context. While we have made a best effort to engage with a representative sample of participants for both the interview study and the workshops, it is only representative to the community living in the city of Bristol, UK.

Table 2 Grounded theory analysis extract: DSR system

Initial Coding Eg.	Focused Coding Eg.	Theoretical Coding Eg.
Filling machine: "...we always try to pack it as full as possible..."; *Wash for immediate use*: "There's some stuff in the laundry that I'd like to wear today or tomorrow";	*Appliances*/Washing machine/Practices of washing/filling machine *Appliances*/Washing machine/Practices of washing/wash for immediate use	Householders possess a set of appliances, which they have invested into both financially and in terms of learning and getting used to time and effort. They have developed a set of *Practices* around these *Appliances*. The *Appliances* can generate *Data*, which is also important to the Householders.
Doing good: "if the main aim is to save energy, it's about doing something good"; *Financial gain*: "And save me money."); *Data ubiquity*: "...everybody has got our data anyway!"	*Data*/acceptance; Data/acceptance/financial gain *Data*/acceptance/data ubiquity	Householders have *Appliances* which generate *Data*; the householders are supposed to be the owners of the data, but many are aware that their data is passed on and used by 3rd parties. Some householders are willing to share this data for common good (such as minimizing environmental impact from energy use), but others are worried about privacy and security, and see use of data by *3rd party* as a *loss* to themselves.
Loss of control: "...you're kind of losing control over what it's doing"; Loss of convenience: "...would make life slightly less convenient or comfortable"; Damage to appliances: "if I had sort of assurances that it wasn't going to wear out the appliances"	*Concerns*/loss of control *Concerns*/loss of convenience *Concerns*/damage to appliances	While considering use of automated control of their *Appliances* by a *3rd party*, the *householders* foresee a number of *losses* that they are likely to incur. The different types of losses are relevant to different degrees to different households, but they all would be deterred from engaging into the DSR if these perceived losses were not perceived to be compensated for by some *gains*.
Reduced cognitive load: "just get it done at some point in the next few hours" *Efficient use of resources*: "this is a more efficient use of energy. Can't really object to that."	*Automation*/acceptability/benefits/convenience/reduced cognitive load *Automation*/acceptability/benefits/efficient use of resources	Householders see *DSR automation* as a process that can lead to both *benefits* and *losses*.
Energy consumption: "could do more awareness around you know, energy use on a machine" *Personalized advice*: "maybe sort of tailored to you, rather than just random"	*Knowledge*/energy consumption *Knowledge*/personalized advice	Households would like to learn more about the impact (both in terms of *gains and losses*) that the *DSR Automation* would have on their activities, environment, grid as a whole and alike.
Not technical: "I'm a bit more low tech man." *Flexibility*: "I don't mind really as long as it's safe "	*Practices*/beliefs/energy consumption *Practices*/flexibility	Householders follow a number of own *Practices and routines* which are dictated by their work/life timeline, habits and preferences. Some of these cannot be changed, but some *Practices* can be adapted, if the householders are willing to do so. Change of *Practices* requires effort and sometimes investment

In addition, the pool of participants was limited to those who responded to our invitation, and we note that this may imply a certain self-selection and self-reporting bias—those interested in energy management and energy efficiency coming forward more prominently. This concern, however, is mitigated to some degree by the fact that these are also the very same households that would likely take up the intended DSR service.

To further the validity of our findings, we draw on the notions of data, investigator, method and theory triangulation [40]:

- For data triangulation [40] we reached out across both the *space* (i.e. areas of the city) where BCC had initiated the activities related to the demand-side response project (16 households) and to those areas that are completely independent of this BCC initiative (12 households). We also ensured that the participants of varying demographics were engaged (see Table 1) across a 6 months period (4 months of interviews and 2 of workshops).
- For investigator triangulation two researchers worked on the GT coding and analysis, continuously double-checking and verifying each other's work, and discussing and resolving disagreements.
- For data collection method triangulation, we used interviews and co-design workshops, ensuring that data for both sets of outputs (i.e., the use cases and the GT theories) had been acquired through two methods each. GT, as a data analysis method was, however, not triangulated.
- Finally, for theory triangulation we compared the derived theories against the independently published related work (see Sect. 5). We also checked the consistency of the skills needs theory with that of the partnership theory of adoption, as well as with the use cases analysis. Given that both the partnership theory and the use cases have already been validated, and the findings of the Skills theory are consistent with both of the above, we suggest that implications of the Skills theory can be considered sufficiently validated as well.

We must, however, note three further relevant points on the limitations and validity of this study. As noted in Sect. 3.3.2, this paper reports on two processes for which theories were built (i.e., business model formation and need for skills acquisition):

1. Both of these processes, clearly, exist within a larger socio-technical phenomenon, that of a systemic transition of a city to a smart local energy setup. This transition comprises a number of other processes which have not been addressed in this study (e.g., technological change, change of governance of the infrastructure, etc.). If studied, all these processes together would likely form the theory of a City-Wide Transition to SLES. This, however, is outside of the scope of the present paper, which is set out by the initial research questions.
2. Furthermore, it is also clear that the partnership and skills processes will interact where skills are needed for (effective) participation in the partnership business model. A further iteration of the GT process would help refine and map out points at which these processes and their theories interact. This, again, is considered outside of the initial research questions set for the present paper.
3. Finally, one may note that the analysts have first engaged in the full GT process in studying RQ1 and RQ2, and only then considered RQ3. Thus, it is possible that the analysts could have developed a biased perception of the data (colored by the already constructed partnership theory), which would then impact the construction of the novel Skills theory. This, indeed, is accounted for in the constructivist strand of GT by both:
4. Acknowledging that the theory is ”constructed by” the analyst who cannot escape his/her prior knowledge, background, and values and
5. Calling for examination and review of how this background knowledge impacts the analysis and theory construction.

Thus, following these principles, while developing the Skills theory, we have acknowledged our prior knowledge of the partnership theory and made a concerted effort to take a broader view of skills needs analysis.

4 Study findings

4.1 Addressing RQ1: use cases

Figure 1 presents the summary use-cases diagram[3].

As expected, the use cases depicted in Fig. 1 seem to suggest that the prospective DSR clients are interested in practical management of their devices through DSR software. Furthermore, several somewhat unusual use case are also identified, such as *Foster Social Interaction*, which captures the respondents' desire to interact with like-minded individuals outside of the software sphere, or *Set Shared Goals* (a sub-goal of *Set Goals* not shown in Fig. 1).

In *cycle 2* the above identified use cases were discussed with the prospective users as part of the co-design workshops. The users were asked to walk through their most recent instance of a smart appliance use as well as their customary

[3] Most of the use cases are to be refined into specific sub-use cases, e.g., *Inform on Gains and Losses* would include *Propose Alternative Settings*, and *Report Per-month Consumption*, *Set Goals* would include *Set Personal Goals*, and *Set Shared Goals*, etc.

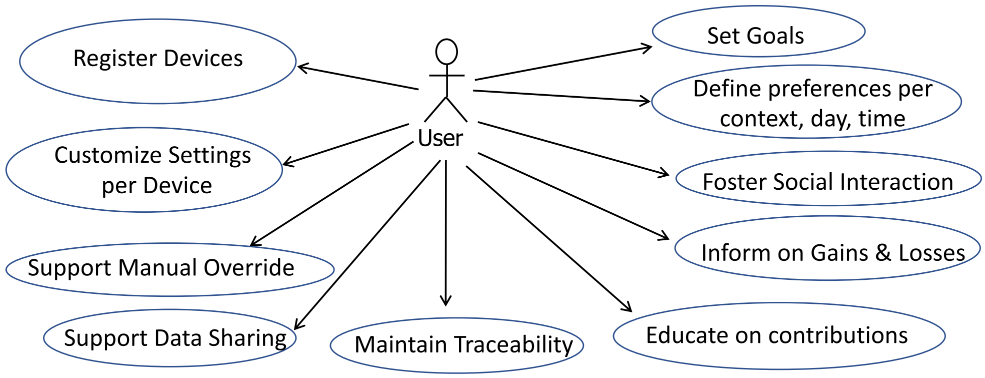

Fig. 1 DSR use cases

use of appliances (which could differ from the last specific use instance). They were asked to explain why it was used at a particular time, in a particular way and how they would be able to manage their preferences and practices given the suggested outline DSR preference setting designs for automation. They also walked through the issues that either currently or potentially may prevent or complicate use of DSR for themselves; and discussed how DSR automation could support them.

The groups identified a number of relevant refinements to the proposed use cases (e.g., need to define more than one preferred slot for appliance use, need to differentiate between individual days of the week, ability to set default preferences, etc.), but the overall set of use cases was both considered relevant and appeared to cover all the expected needs. Thus, this addressed RQ1 set out for the present study.

Yet, this view of the software system did not provide specific perspectives on whether or not the DSR service would be well adopted by the intended users or what skills and training needs might the prospective users have.

4.2 Addressing RQ2: theory for DSR adoption

The theory derived from the users' interviews and feedback analysis suggests that the key theme that relates all other key categories is that of implied business *Partnership*, as illustrated in Fig. 2.

The **Theory of DSR Partnership** suggests that: *The Prospective DSR-participant households have a set of Assets (such as appliances, data, flexibility of own practices/routines) which they could consider contributing towards the DSR Business, if a 3rd Party (which satisfies qualities and processes expected by the households) provides a DSR platform and a risk/benefit sharing agreement. In this agreement, the selected 3rd party will act as a General Partner of a business, while each participating householder will be a Limited Partner.*

The *Assets* include both physical (e.g., energy generation and consumption appliances, such as PVs and washing machines) and non-tangible resources (such as data on energy use, processes to be followed, etc.). Thus, the concept of assets integrates the categories of appliances and data, DSR automation along with (sub-categories of) smart (which together make up the Platform), as well as practices (as the flexibility of practices is a necessary asset for feasibility of the DSR service). Furthermore, a number of sub-categories from knowledge (e.g., provision of information), concerns (e.g., loss of control; accountability), and motivations (e.g., sharing information) form the process category under the assets group in the partnership theory, as processes would be expected to be put in place to address the issues raised by these sub-categories.

The assets are used by the general and limited partners to generate return upon their investment. The *Return* (which is differentiated as *Benefits*, constituted primarily from the sub-categories of the Motivations category, and *Losses* which includes many of the *Concerns* sub-categories) is shared by the partners, in accordance with the partnership agreement. However, the limited partner only incurs losses of prospective earnings, if the business fails to generate income (as

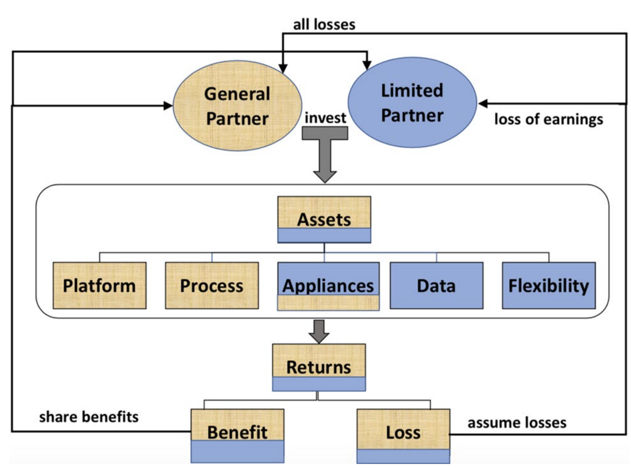

Fig. 2 Partnership theory of DSR

Table 3 Responses to partnership theory validation

	Joint goal	Pool resources	Share profit/ loss
Yes	8	8	7
No	4	3	3

his/her losses are limited to what she/she has invested and/or agreed to in accordance with the partnership contract), while the general partner will assume all other losses. The gains from the DSR service are also shared by the partners, in proportion to the investment and risks assumed. Both the general partner (i.e., the DSR service providing business) and the limited liability partners (i.e., each household participating in the DSR service delivery/use) contribute their own assets. The assets can also be both separately and jointly owned. For instance, a PV array can be owned by a group of households, or be co-invested into by a household and the DSR service providing business.

As noted above, this theory was checked for *resonance* through a dedicated questionnaire which asked the prospective DSR participants if they feel that the households and the DSR services providers:

- Would be contributing to a common goal or enterprise;
- Would be pooling resources (e.g., skills, money, etc.); and
- Should be sharing profit and loss.

Table 3 summarizes the responses (note, not all participants responded to all questions), demonstrating that at least two-thirds of the prospective users would expect to have the partnership relationship with the DSR service providers, not just act as simple service consumers. This demonstrates that the theory has a good resonance (i.e., makes good sense to the substantial majority of the study participants).

The general sentiment of the respondents can be summarized by the statement of one respondent that "People buy ideas not products. So potential users need to have bought into the mission of the ...service provider".

This is in conformance with the theory itself, as participation in a DSR service does mean that the households:

- Agree with the need to manage energy demand (either for financial, environmental, or other reasons);
- Are willing to make some up-front investment, to either buy smart (i.e., externally controllable) appliances and/or generation/storage equipment, or invest time and effort for setting up appliance user preferences, or adjusting own routines and practices, etc.;
- Are, at least implicitly, sharing in gains and losses of the DSR service provider—if the service provider goes out of business, the (time or financial) investment that households planned to recoup through DSR savings will not materialize either.

We must underline that the questionnaire respondents who did not say "yes" to the resource and profit sharing options of the partnership theory, did not disagree with these premises either. Instead, they pointed out that the set questions were somewhat simplistic since:

- A service user is likely to have more than one goal (while the question in the set questionnaire was formulated in terms of one single goal);
- Any sharing needs to be guarded by privacy concerns;
- The service users must be protected against the service provider passing his/her losses onto the citizens.

This was noted as a limitation of the presented theory, and also highlighted the need to have additional (not just yes/no) options in questionnaire design. These points were integrated into the *theory review*, which was updated to account for the *"limited liability partnership"* type (as presented in Fig. 2), instead of the full partnership theory where equal liability would be normally expected. The privacy concern, as well as ethical behavior, accountability and other principles of behavior that the households expect of the prospective service provider partner, had previously been identified to be a part of the theory. However, for the sake of keeping the key message of the validation exercise simple, these additional parts, were not integrated into the questions asked for theory validation.

4.3 Addressing RQ3: theory for skills and training needs

While the partnership theory formulated in response to RQ2 provided a structured model in which the DSR service is likely to be adopted and operated with mutual benefit for both householders and the service providing businesses, RQ3 is concerned with skills and training needs, irrespective of a particular service delivery model. Thus, drawing on the primary and focused coding categories obtained from the previous GT analysis—and by undertaking a new theoretical coding activity—we formulated the causal model of adoption of automation by Bristol's citizens.

The model is shown in Fig. 3[4]. It emerged through the theoretical coding process, where the analysis converged to

[4] URL https://energysystems.blogs.bristol.ac.uk/2021/01/08/citizens-bristol/ can be used to simulated this model.

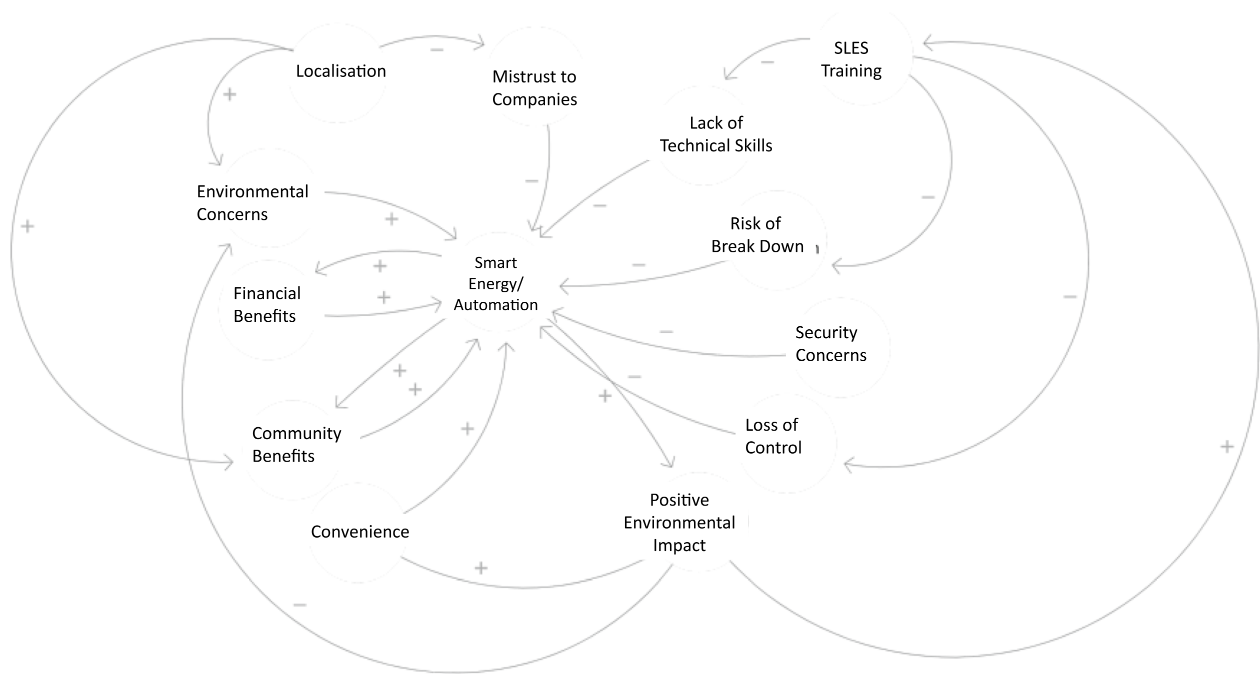

Fig. 3 Causal model of the Bristol's Citizens' Sub-system

the conclusion that *there is no single skill or point of training provision. Instead, skills and support need to be provided at each point where the householders face an automation impact factor. The support is needed both where any impediments are expected, and where the positive impact factors can be amplified.*

In accordance with this systemic view of automation adoption by the citizens (see Fig. 3), the expected environmental, financial, and community benefits, as well as personal convenience and trust toward the local authorities and local pro-environmental companies, foster adoption of the DSR services. On the other hand, mistrust toward 3rd party service providers, lack of technical and smart local energy systems skills, as well as safety and security risks, hamper such adoption. The factors and components of the model are briefly explained below:

(1) Environmental and Financial Concerns:

Overall the respondents were motivated by environmental, financial, and efficiency outcomes for signing up to energy management and automation (integrating the majority of content within the Motivations category (such as environmental, financial, energy management, etc.) as well as expected benefits from the automation category (such as Automation/desired properties/financial incentives, etc.).

Many of them said that the **environment was a primary motivator**—they want to be supportive of environmental protection as long as it is practical within their household setup. Some participants said that they were prepared to even cope with disruption and inconvenience *if there were positive environmental outcomes*, e.g.:

> I would be very willing to change the way that I do stuff, even at the cost of convenience or money, if that's really going to make a difference. (PE9, under Motivations/environmental/desire to help environment category)

However, given that the personal impact on environment due to smart energy system use is both intangible and invisible, the respondents worried that their actions were not "...really going to make a difference", and many asked that the system should provide *feedback on their actual environmental impacts*.

Where **energy efficiency** is a core ambition for users, they aim for better use of resources. Here, the respondents consider automation to be a positive force, as the energy management system can make decisions based on availability of renewable energy, which will, in turn, help the grid to be used more efficiently. Some respondents also noted that energy storage for use at peak demand times and ensuring that electric vehicles are charged when renewable energy is plentiful should be part of the future automation.

Most interviewees wanted to have **financial savings**, even when their primary motivation was environmental, e.g.:

I suppose environmental issues which would be the main driver and benefit, save me money as well, that'd probably be a second factor. (PR11, under Motivations/environmental/environmental and financial category)

Several interviewees noted that **financial return** is expected in recognition of the effort invested by the householders, the disruption of their routines, and for getting to grips with a new system:

It doesn't sound like it will be that inconvenient. If it was massively inconvenient, then no. I'd want more of a financial incentive. So yes, it's a sliding scale of inconvenience. (PE6, under Motivations/financial category)

Here they also noted the parallels with other sectors:

That's kind of the standard model for a lot of things isn't it, like flights ...(PR2, under Motivations/financial/pricing/parallels category)

Furthermore, a number of participants recognized a degree of **social responsibility** to engage in managing energy better – both for supporting current users and future generations:

If you're looking socially irresponsible to not do it then that would motivate me. (PE9, under Motivations/social responsibility category)

When addressing the likely benefits and problems envisaged due to use of an automated system, the main issues centered around trust, complexity, risk, and control.

(2) Trust

was discussed in several different guises (primarily under the Concerns and Data categories, as well as under potential problems within Automation):

- *Trusting a system to work properly.* Lack of trust that the *system would work as expected* seems to be backed up with direct experience of technology use and by other people's stories of things going wrong (*Concerns/damage to appliances category*):

  I just don't trust computers generally, and their ability to continue doing the right thing. You know? Because they go wrong, don't they? (PE7, under Automation/potential problems/lack of trust category). ¶I only like to use that when I'm there because recently my friend's dishwasher set her house on fire. (PR6, under Knowledge/stories/what to worry about category)

  Clearly, once such a story is embedded into "common knowledge", it is difficult to change and it gets repeated and spreads.
- *Trust in the operator.* The 3rd party system and service providers must be trusted to make the right decisions for the benefit of the users. But such a trust still needs to be earned:

  I don't think I'd trust an outside authority to make those decisions for me. (PR4, under Concerns/trust/trust into external party category)

  Respondents were more inclined to trust the local authorities or academic research, and less the big business who were seen as chasing profits.

  I'm with Bristol Energy so I trust them. If I was with one of the big six, I might be a bit reluctant to let them have it [energy data]. Yeah it probably depends who's supplying my energy. (PR11, under Data/entrusting data/who is to hold data category)
- *Trust in use of data*. Data privacy was an underlying concern but it was also one that most participants didn't feel that they had much control over. Many respondents accepted the idea that energy companies could hold and use detailed data—especially if it helped them to better manage supply and the grid—doing good for the planet:

  If the main aim is to save energy, it's about doing something good. (PE10, under Data/acceptance/doing good category)

  However, to others, the need to make data available might be a demotivator for participation in energy management:

  I can't say I'm enthusiastic about it, no. It would act as something of a demotivator. If I thought the whole thing was a really great idea, maybe I'd accept that but I don't really like the idea. (PE9, under Data/energy data use/sharing issues category).

(3) Risk

Participants were concerned about several aspects of risks:

- *Risk of Financial Loss.* The respondents wanted to have some assurance that the smart energy system either generated rewards or, at the very least, ensured than no penalties were passed onto the households (Knowledge/personal energy sub-categories).
- *Risk of System Malfunction* (e.g., causing appliance failure, overheating, or damage as per Concerns/damage to products and property sub-category as well as stories/what to worry about sub-categories) or incorrect

operation (e.g., starting up a remotely controlled appliance at inappropriate time of the day as per Smart/using smart controls/obstacles/unwelcome interruptions subcategory) was noted by several participants. To counter this (to some degree), the respondents suggested that the smart system may be able to inform users of various issues which could cause malfunction/failure (e.g., need to deep clean appliance and filters; detection of power surge or burnout; over-capacity loading, etc., as per Knowledge/personal energy/faults and failures info category).

(4) Technical Complexity

The respondents were concerned about technical complexity and their own technological literacy, which impairs their willingness to engage with the smart energy systems, e.g.:

> I'm not techno savvy so I probably wouldn't do it anyway because I just switch things on and let them do their thing. (PR7, under Smart/using smart controls/obstacles/technology knowledge)

(5) Loss of Control

The respondents were worried about loosing control over their daily lives and their ability to use the appliances as and when they wanted, e.g.:

> Like you're kind of losing control over what it's doing, that you don't know. (PE 2, under Concerns/loss of control category)

(6) Provision of information

The participants said they wanted more information—on how much energy is used, on savings, on environmental impact, etc. Feedback is thus really important for engagement. The system should show energy/CO2 savings and potential benefits, enabling users to think differently about their consumption. Greater knowledge should mean that energy is used more consciously, thus enabling people to make changes and improvements to their own practices, e.g.:

> Information about those peak times and how much energy is being used nationally at those times, and my average daily and weekly usage. Information like that would be good, because I haven't got a clue. (PR3, under Knowledge/provision of information/energy consumption)

Other information might include how much energy is wasted using standby or leaving lights on. The system could suggest the best way to use appliances, give an overview of how energy has been used and how these compare with (relevant, comparable) others.

> I think there should be more, sort of, advice about how you can be more efficient and that sort of thing. And maybe sort of tailored to you, rather than just random. (PE7, under Knowledge/personal energy/personalized advice)

4.4 Skills needs for the citizens' adoption of SLES

Focusing on the factors (i.e., nodes that represent concepts of interest) shown in the causal model of Fig. 3, we can now identify which skills needs are relevant to each factor, how these needs relate to the previously identified use cases (Fig. 1) and to the partnership theory (Fig. 2), as well as consider as to what additional software and socio-technical system requirements the casual model would suggest. In Fig. 4, these needs are shown as brief annotations over the previously constructed causal model. These are also summarized in Table 4 and briefly explained below.

The above noted requirements, in their majority, are already integrated into the use cases specification, as outlined in Fig. 1. However, some new use cases have also been identified. These new use cases (underlined and italicized in Table 4) are aimed at supporting households with some skills acquisition (e.g., help and training), or integrate functionality that incorporates some skills-based actions (e.g., those deemed critical for user safety) into the software (e.g., *Turn off Electricity and Water Supply* to be taken up by the appliance in case of Breakdown). On the one hand, such inclusion will liberate the households of some responsibility, on the other, it will quiet some of their worries.

The above noted skills would need to be furnished through training and education of the households. The areas and modes of such training provision are discussed below.

4.4.1 Areas of training needs

- *SLES overview, uses, implications and engagement processes*: what the SLES are, why are they replacing the traditional energy system, what and how could householders do to best benefit from the SLES (e.g., invest into battery or roof-top PV, etc.)
- *Opting in and out of SLES services*: where SLES provide optional services, the households should be able to choose which services to take up or opt out of.
- *Assessment of Impact: Financial, Social, Environmental*: gain accountancy literacy on costs and benefits of smart, renewable energy alternatives, so that the householders can make an informed assessment of do-nothing versus uptake of DSR and other smart energy services. Specific

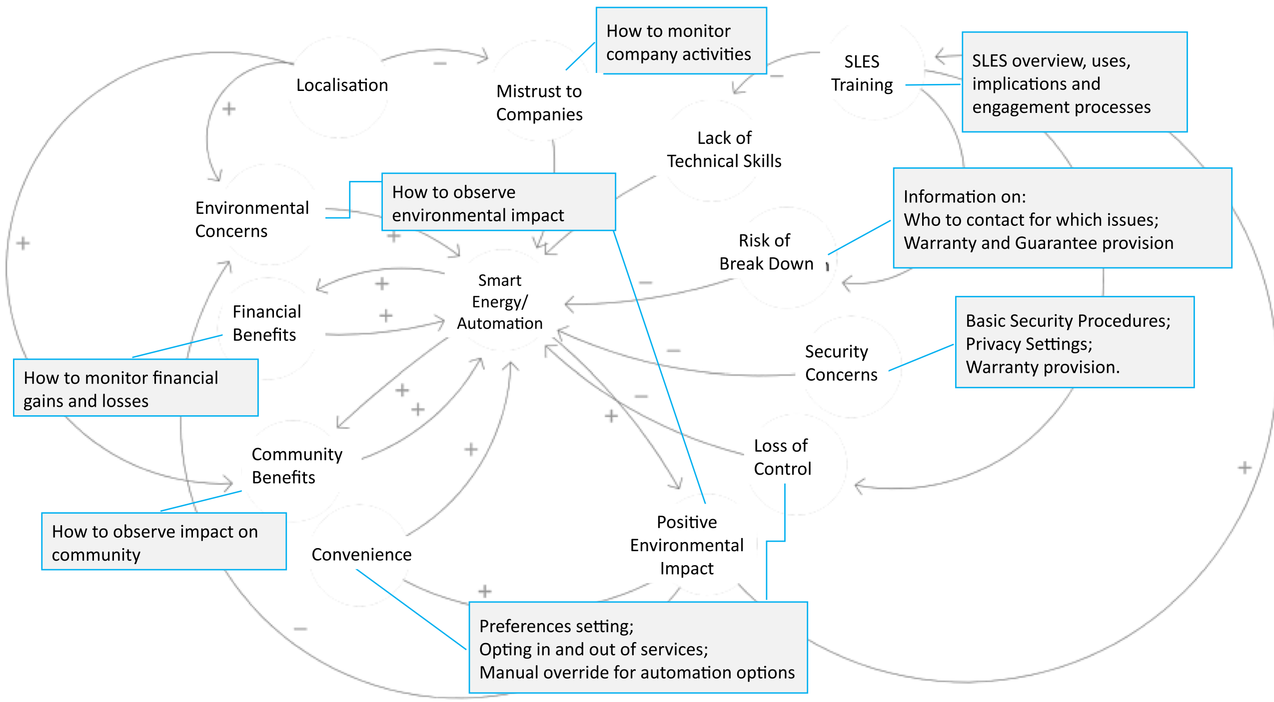

Fig. 4 Skills in the Causal model of the Bristol's Citizens Sub-system

(and simplified) accountancy methods need to be provided for financial accounting, environmental accounting, and societal impact accounting.
- *Preferences setting*: what are the customization options when participating in SLES (e.g., demand side response, peer to peer trading, etc.).
- *Manual override for automation options*: where 3rd parties control any in-house appliances, what and how can be manually overridden, if necessary.
- *Security Procedures for successful SLES participation*: where the security threats are and how to avoid pitfalls.
- *Privacy Settings with SLES technologies*: where the privacy concerns are, how they can be handled (e.g., data sharing and ownership).
- Knowledge on *whom to contact for which issues and where to find this information* is necessary to help alleviate the worries of the householders.
- Knowledge on what *warranty and guarantee provision* is available due to SLES services and activities and how to access these will be equally relevant in alleviating financial loss concerns.
- A set of "How to" procedures to help householders navigate the concerns on how to:
  - Monitor company activities;
  - Observe environmental impact of SLES;
  - Monitor own financial gains and losses due to SLES;
  - Observe impact of SLES on community.

4.4.2 Modes of training

Given that the knowledge of and willingness to engage with the smart, renewable energy and services needs to be communicated to the whole population (including soon-to-be-adult young people, current property owners and investors, as well as tenants of all ages), the training delivery modes must be accordingly adapted. Thus, training could be delivered:

- To all, via media campaigns, explaining the structure and aims of the SLES, overview of technology, opportunities and impacts, as well as where and how to look up further information. This can be achieved through *TV, radio, and social media advertisements* (akin to the recent UK-wide "don't drink and drive" campaign);
- To school children: more detailed understanding of the SLES as a system, its key technologies, their roles and impacts. This can be *integrated within various areas of the school curriculum* (from science to citizenship);
- To property tenants, explaining the available SLES services opportunities, costs and benefits, via *energy service delivery companies, citizen advice services, council website, post and community groups.*

Table 4 Summary Mapping

	Overview mapping between: Concerns of interest from Fig. 3 (Factors heading), Skills needed to propagate positive causal impact as per Fig. 4 (Skills heading), Use Cases for functionality of the Automated energy services system as per Fig. 1 (Req. heading, newly identified use cases are underlined), and how these skills play out in the partnership theory of Fig. 2 (GT heading)
Factors:	Environmental Concerns and Positive Environmental Impact
Skills:	Assess environmental impact of own activities
Req.:	Use Cases: (a) Set Goals—set a goal on reduced emissions/impact; (b) Inform on gains and losses—inform on CO2 reduction/other environmental impacts; (c) Educate on contributions—provide "how to improve" advice/guidelines for maximum positive environmental impact.
GT:	Objectively assess the environmental gains and losses of entering into partnership agreement. Informed environmental choice for prospective Benefits and Losses.
Factors:	Financial Benefits
Skills:	Assess and monitor financial gains and losses
Req.:	Use Cases: (a) Inform on gains and losses—inform on financial gains/losses with current settings of automaton vs a default scenario (b) Set Goals—set a goal on maximizing financial benefits; (c) educate on contributions—provide "how to improve" advice/guidelines for maximum financial benefit, but complement with options on gains for environment and community too.
GT:	Objectively assess the financial gains and losses of entering into partnership agreement. Informed financial choice for prospective Benefits and Losses.
Factors:	Community Benefits
Skills:	Assess and monitor community gains and losses
Req.:	Use Cases: (a) Inform on gains and losses—inform on community gains/losses with current settings of automaton vs a default scenario (b) Set Goals—set a goal on maximizing community benefits (e.g., invest into communal batteries or parks); (c) Educate on contributions—provide "how to improve" advice/guidelines for maximum community benefit, but complement with options on gains for environment and financially too.
GT:	Objectively assess the societal gains and losses of entering into partnership agreement. Informed social choice for prospective Benefits and Losses.
Factors:	Convenience
Skills:	Configure service around own convenience
Req.:	Use Cases: (a) Define preferences per context, day, time—set automation options aligned with own routines/preferences
GT:	Objectively assess the impact of the potential partnership agreement upon expected flexibility. Informed decision on the level of own flexibility contribution.
Factors:	Loss of Control
Skills:	Exercise full control over own devices
Req.:	Use Cases: (a) Support Manual Override—allow termination of automation settings at any time; (b) Customize settings per device—allow change of automation options at any time to aligned with own preferences; (c) Define preferences per context, day, time—keep control over own preferences and update as needed.
GT:	Objectively assess the impact of the potential partnership agreement upon expected flexibility. Informed decision on the level of own flexibility contribution.
Factors:	Security Concerns
Skills:	Assess security implications of automation and data sharing and make informed choices
Req.:	Use Cases: (a) Register Devices—only data for registered devices will be shared and only these devices will be automated; (b) Maintain Traceability—observe who uses household's data and controls his/her appliances and how; (c) Support Data sharing—share data and access to devices/control with only trusted (by household) parties; ensure that the sharing process is secure (e.g., encrypted data exchange, backups in case of failure, access given to approved device only at agreed upon schedule, etc.)
GT:	Evaluate the security and privacy risks of the potential partnership agreement upon personal data ownership and privacy. Informed decision on the level of own data contribution and engagement with the DSR platform.
Factors:	Risk of Break Down
Skills:	Assess risk of breakdown, prevent losses and handle dangers due to breakdown in a safe way
Req.:	Use cases: (a)*Notify of the faults and dangerous states*; (b)*Turn off electricity and Water Supply*in Case of Breakdown.
GT:	Evaluate the likelihood and impact of breakdowns and failures caused due to the DSR service use against the potential expected gains (environmental, financial, societal, convenience). Informed decision on which Appliances to engage with the DSR and to what level of Flexibility.
Factors:	SLES Training
Skills:	Knowledge of SLES services, ways to participate in them, assess the impact of uptake or disengagement with them both financially, socially, and environmentally

Table 4 (continued)

	Overview mapping between: Concerns of interest from Fig. 3 (Factors heading), Skills needed to propagate positive causal impact as per Fig. 4 (Skills heading), Use Cases for functionality of the Automated energy services system as per Fig. 1 (Req. heading, newly identified use cases are underlined), and how these skills play out in the partnership theory of Fig. 2 (GT heading)
Req.:	Use Cases: (a) Inform on gains and losses—inform on community, environmental, financial gains/losses with and without SLES (b) Set Goals—set a goal on maximizing community/environmental/financial benefits; (c) Educate on contributions—provide "how to improve" advice/guidelines for maximum community/environmental/financial benefits along with their trade-offs; (d) Help and Training—learnabout SLES
GT:	Evaluate the potential expected gains and losses (environmental, financial, societal, convenience) from engagement/non-engagement with the DSR service. Informed decision on engagement into the DSR Partnership.
Factors	Lack of Technical Skills
Skills	Configure devices for SLES participation, set preferences, monitor own participation impact; update the preferences and settings.
Req.	Use Cases: As for the above SLES training factors, also*Help and Training*—provide help for the use of SLES with the DSR software and provide training materials.
GT:	Learn to interact with the platform and the process of the DSR service delivery. Learn to (dis-engage) own assets with the DSR service. Informed decision and frictionless integration with the DSR partnership and platform.
Factors:	Mistrust to Companies
Skills:	Assess the impact of uptake or disengagement with services provided by (alternative) company(ies) both financially, socially, and environmentally; Monitor that the use of own data by a company complies with set preferences and agreements; Withdraw participation/consent on data sharing when so preferred
Req.:	Use Cases: (a) Inform on gains and losses—inform on community, environmental, financial gains/losses with and without SLES (b) Maintain Traceability—observe who uses household's data and controls his/her appliances and how; (c) Support Data sharing—share data and access to devices/control with only trusted (by household) parties; (d)*Withdraw participation*—withdraw from all services and data sharing agreements.
GT:	Evaluate the potential expected gains and losses from engagement/non-engagement with the DSR service. Informed decision on engagement into the DSR Partnership.
Factors:	Localization
Skills:	Knowledge of SLES service providers, ability to join local schemes
Req.:	Use Cases: (a) Define preferences per context, day, time—select and sign up with the service provider by geographical locality. (b) Set Goals—set a goal on maximizing interaction with the local service providers/local communities.
GT:	As above, with specifically local impact in mind.

5 Comparison to related work

5.1 DSR and automation

Though, to our knowledge, no previous research has undertaken a study of a DSR adoption with grounded theory analysis, others have trialed DSR services.

For instance, Buryk et al. [41] worked on a 3-week trial to determine whether disclosing the environmental and system benefits of dynamic tariffs to residential customers could potentially increase their adoption, thus, helping to shift consumption to more opportune times. The trial included 160 residents in US and EU out of which 88 received information on environmental and systems benefits from dynamic tariff use, while the rest did not. They found that the respondents strongly preferred environmentally friendly energy consumption and supply mix, and were willing to switch to a cleaner supply, even if it was up to 10% more costly.

These findings are in line with the sentiments categorized under the Motivations/environmental theme in our study. Indeed, many study participants observed that their interest in DSR is driven by the environmental concerns. Yet, we also observe that the socioeconomic circumstances of the respondents have a significant impact on their willingness to take on additional costs. Participants with lower annual incomes were unwilling and unable to incur additional costs. Thus, we consider that the limited liability partnership, which guards those most stressed financially against any losses, while allowing those more able to assume financial risks to take additional challenges on, is well suited to these circumstances. Furthermore, training households to assess the potential gains through participation (vs non-participation) in DSR (or other SLES services) will help foster adoption of such services by both financially and environmentally or socially driven households.

Buchanan and colleagues [42] first ran a workshop to develop concepts for smart meter enabled services and then conducted focus groups to explore consumers' perceptions of how smart meter data can be used to provide services. They considered 3 options: automation of appliance use, community rewards for disciplined use of appliances, and gamification as motivators for peak avoidance and use reduction. They found that automation was consistently the most preferred concept. Participants realized that the proposed system offered them different choices about if and when they would like the system to control their household appliances. Community reward schemes were not very liked, participants stated they would rather receive money off their energy bills than contribute toward paying for a collective benefit. Gamification was not popular, as participants did not have the time to commit.

Our findings concur that automation is a preferred solution to DSR service provision (as indicated by the DSR Automation and Smart themes of our GT analysis, and the Assets category within the partnership theory). While we did not address the notion of gamification at all, we did observe the concerns about additional cognitive load and time requirements emerging from our respondents as well (e.g., as reflected in the concerns about Technical Skills, Risk of Break Down when user is not in the vicinity, as shown in Fig. 3). Automation, however, was considered as a viable and necessary solution for handling the additional complexities of the DSR service use (e.g., as reflected by Convenience factor in Fig. 3). With respect to community vs. individual rewards, we observed a split, whereby 2/3 of respondents were willing to fully or partially contribute their gains to the community cause (e.g., a common battery storage, a community playground, etc.), while 1/3 preferred to keep the additional income to themselves. We noted that the requirements that emerge from the proposed partnership theory advocate for goal setting, allowing each limited liability partner to choose which goal he/she will aim for: from own income maximization, to environmental impact reduction. Thus, we consider that our findings are aligned with those of Buchanan et al. [42].

Customer experience of demand side response with smart appliances and heat pumps is studied in the trial by Capova and Lynch [43] for a small sample of houses in Durham. Here, none of the participants believed that the direct control of the service provider over the appliances had any influence on their decisions about when to do the laundry. All participants thought that they had not changed any of their previous washing regimes.

These findings, again, are compliant with our proposed partnership theory, which suggests that the DSR model would be successfully adopted if the contributions of the Limited Liability Partners are acknowledged, supported, and appropriately rewarded. The DSR provider simply is not able to take a direct control over the necessary Assets for the successful operation of the DSR service, as the flexibility, appliances, and data remain under the householder's control. Thus, unless the householders are motivated to participate in the DSR business venture, the venture cannot succeed. Finally, the training provision for up-skilling the households in DSR and similar smart energy services use is aimed at fostering the support and motivation in households to widen adoption of such provision.

5.2 Skills and training

The need for the skills development and raising awareness of the potential benefits of the smart energy solutions are recognized in the recent literature [44, 45]. However, what specific skills are required for the householders to better engage with the technologies for transition to smart energy system, is still a topic of active study.

Some researchers argue for the need of basic training in energy systems, explaining the benefits of smart solutions to individuals and communities [46]. Others state the need for a range of skills: from reading a smart meter to nuanced choice between different energy providers, tariffs and technologies [47].

The majority of work on energy-related education of householders has, so far, focused on **informing them on energy use via smart meters' feedback**. For instance, some such work [48–50] demonstrates that providing users with tailored feedback on their consumption practices helps to increase householders' awareness of how much energy they are using and encourages them to consider some change in their behavior.

Up-skilling households with respect to **control over own data**, is currently an active area of research. Not so long ago researchers suggested that privacy was of little concern to householders [51], who cared more about credibility of data [52]. Householders were not very concern about the nature of the data collected and analyzed by energy service providers [53] either.

More recently, however, it was shown that when householders were explained what risks are associated with their service subscriptions, 92% either changed their privacy settings or canceled their service subscription [54].

Schwartz et al. [55] found that users are not comfortable sharing their consumption data because they fear being misrepresented. Also, they classified energy data as personal goods, therefore concerned about losing ownership. Concerning the sensitivity of energy data, most participants in a Swedish field study [50] concerning home energy management systems believed that energy data is harmless and poses no threat to their privacy.

However, they were concerned about how companies might exploit their consumption data. Schwartz et al. [55] also found that participants wanted to discuss energy data as collective consumption, rather than fine-grain data.

Two other studies related to our work were conducted by Gürses et al. [56] and Ukil et al. [57] which are focused on privacy-preserving technology for smart meters.

Other efforts on design recommendations for energy data systems mainly focus on changing behavior and conserving energy [55, 58, 59].

6 Implications for requirements

Thus, as previously discussed, both the use cases and the partnership theory for the DSR system were found relevant and valid by the validation workshop participants. The skills needs theory was shown (see Table 4) to inform and support rational choice of participation of the households in the DSR/SLES system, as well as extend the said use cases with support for such informed engagement. What, then, does this imply for requirements of our DSR system?

Clearly, the set of use cases reflects the core functions of practical utility that the DSR system should deliver. Yet, the relevance of the partnership and skills theories to the prospective DSR system users implies that a number of **new requirements must also be considered**, if the DSR service is to be widely adopted by these prospective users. Such requirements would be motivated by these theories, such as, for instance:

– As per *Partnership theory*: *Support setting of shared goals between the DSR service providers and the service subscribers*. There could be several goals set, such as maximize financial return, maximize use of renewable energy, or minimize environmental impact, etc. A participant could choose to join and support one or many of these goals. Each such goal will require a particular DSR scheme design.

  Also, the shared goals between the service providers and the citizens could differ from the goals that the citizens want to set and share with other users (e.g., local or other communities), as noted in the elicited use cases (see Fig. 1). Thus, an additional consideration is to be given to the way that these groups of goals would coexist within the DSR system.

  Simultaneously, the *Skills theory* will complement this requirement with a need for training provision for the assessment/evaluation of the expected gains/losses with respect to the set goals (e.g., how to employ environmental or financial accounting for own context).

– As per *Partnership theory: Explicitly acknowledge, support and encourage various modes of resource sharing*. For example, a prospective DSR customer may not have their own smart device, but may be willing to contribute their own Data and Flexibility, should the service provider (as a general partner) (co-) invest into a smart device with this customer. Similarly, the appliances (e.g., PV arrays, batteries, etc.) that participate in a DSR may be a shared resource of a number of customers (e.g., common investment by a block of flats in a given building). Sharing of other (non-tangible) assets, such as good practice, tips and success/failure stories should also be recognized, attributed and supported across the DSR user communities and with the service provider.

  At the same time, as per the *Skills theory:* training provision will be necessary to evaluate risks and benefits from either uptake of or disengagement with the DSR service partnership.

– *Integrate profit and loss sharing scheme into the DSR service provision contract*. This should recognize that prospective customers will undertake varying degrees of risk (e.g., relying on service provider's funds for devices, vs. investing own funds into device purchase, etc.) and so should receive varying degrees of return on investment.

  As per the *Skills theory:* training on evaluation of the various levels/modes of participation will also need to be provided so as to assess the viable returns (e.g., how much financial return is rationally to be expected if the householder invests own funds into the new battery, vs if she agrees to install the asset owned by the energy provider?)

More importantly, this partnership theory not only brings up a number of new requirements to the software system, but also **changes the framework** within which the DSR service provision business would successfully operate. For such a business to align with the expectations of the partnership theme, it would need to consider a new legal framework, a fresh process for customer relationships management (as what traditionally was a customer now becomes a business partner), and a rather different business model for service provision as well. All in all, the business and the software system that would deliver DSR service and comply with the partnership theory would hardly be confused with the one that would be delivered only with the functionality of the use cases in Fig. 1.

The impact of the Skills theory is equally profound despite its lack of a similar structural change within the service delivery model. In this case, the state changing impact would be seen in the knowledge and level of skills employed by the householders when considering smart energy-related options both in technology, and in societal and environmental settings. The smart local energy system that operates within the framework of applied Skills theory, is an order of magnitude more knowledgeable and engaged, than it is without.

Thus, our three research questions, while separately addressed, must be integrated into the sources of socio-technical system requirements and from all three of these new requirements must arise for the success of a DSR system.

7 Lessons learned

7.1 Interdependence of theory and software requirements

We commenced this study expecting to report on requirements for a DSR system design (as per RQ1, for which use case elicitation was to be carried out), and suggest strategies

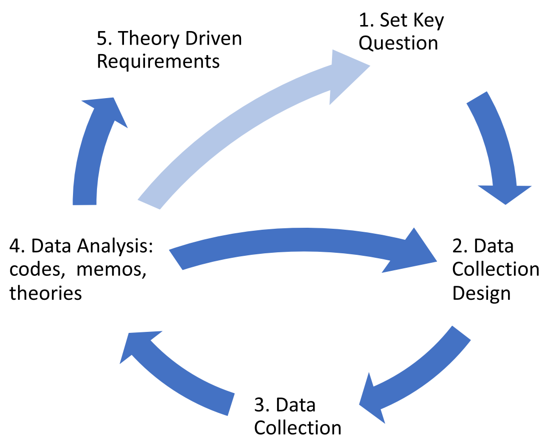

Fig. 5 Method Used

for fostering adoption of this system by the prospective users (as per RQ2, for which a theory of adoption was to be derived). Yet, as we progressed with the study, it became apparent that these two objectives (and research questions) are closely interdependent, and one cannot be addressed without the other. In particular, adoption success not only depends on the useful functionality delivered though the system, but also imposes a set of deeply transformational functional and non-functional requirements upon the target socio-technical system (as discussed in Sect. 6).

Indeed, the same observation was confirmed with treatment of RQ3 which was added at the later stages of the research (when findings from RQ1 and RQ2 were being presented to the key stakeholder). The skills and training provision deemed necessary for the wider acceptance of smart local energy systems by the Bristol households not only concurred with the previously identified use cases (as per RQ1), aligned with the partnership theory of adoption (RQ2), but also posed new functional and socio-technical requirements, expanding the previous set (as discussed in Sect. 4.3).

Furthermore, we note that this observation is not unique to the adoption and skills questions which happen to be posed in our case, but is equally relevant to other issues related to the broader socio-technical system within which the intended software system is to be situated.

7.2 Integrated RE process

We further observe that the process used for our study is well suited for constructing theories for explanation and understanding of various socio-technical concerns, as well as informing the relevant software system's requirements and constraints. This process is therefore represented in Fig. 5. The process starts with **selection of a key question** to address, which is deemed relevant to (most) stakeholder groups. For instance, in our study of demand-side response energy management system, the question of adoption was set as the key issue to be studied. This is because successful adoption (i.e., widespread acceptance and use of the system) is dependent on the majority of all kinds of intended users taking the system up, which still remains a challenge for DSR systems.

In order to address the key question, a set of input data is to be collected, for which a suitable **data collection instrument** needs to be designed. The instruments will vary depending on the set question. For instance, to collect the data for the above set question, we could undertake interviews with the intended system users, and/or run focus group, co-design workshops, user observations, and so on.

Once the instruments are designed, **data collection** would take place. After this, the collected **data** would be **analyzed** using the integrative GT process of data coding. As part of the analysis, the initial theories about how the set question can be addressed would be formed. This could then necessitate new data collection and analysis cycles, as additional data collection instruments would need to be designed and new data collected in order to provide the missing information and/or validate or refute the initial theories.

As a satisfactory theory is developed, it will serve as the basis for new **theory-driven requirements elicitation**.

It must be noted that the theory building, or the theory-driven requirements do not replace the "usual" requirements engineering process, but only augment it with an additional activity, aimed to identify the additional requirements for the noted key question.

Moreover, as shown in Fig. 5, the proposed requirement approach allows for **iterative review of the initially set research question**. Indeed, in undertaking this case study, we were made to undertake an additional iteration when a new question on the set of skills and training needs for the smart local energy systems (of which DSR is an example) was posed. It is worth noting that in addressing this new question, we were able to *reuse both the previously collected data, and its categorizations* constructed through the primary and focused coding activities of the GT. Here:

- The primary and focused coding categories were constructed purely on basis of the data content, and
- The newly set research question (RQ3 on skills and training for SLES acceptance) was sufficiently related to the previously set one (RQ2 on adoption of DSR).

This enabled us to undertake a new cycle of theoretical coding activity without necessitating new data collection and analysis. Yet, we must underline that, had either of the above points differed (e.g., if thematic analysis was used instead of open GT coding for primary analysis, or if the new research question was more divergent and so was not sufficiently addressed by the data collected for the previous one) the need for a new data collection and re-analysis process would have been unavoidable.

Finally, given the integrative, cyclical nature of data collection, analysis and theory development/refinement, we propose that this version of GT analysis could align well with some agile development cycles. Study of such an integration is one of the main directions of our future work.

7.3 Worth of theory development

The overall process of integrated use case and theory development which serves as a new source of requirements was outlined in Sect. 7.2. While this paper presents the theories of a DSR adoption and skills/training needs, the process is not restricted to addressing these specific questions. Any other question pertinent to the concerns of the socio-technical system can be posed and addressed through the same process. Yet, as addressing a set question will most likely require new data collection (though this could sometimes be avoided, as discussed in the above section) and analysis, the value of the answers expected from this process must compensate the committed effort.

This value then is dependent on the degree to which the theory-driven requirements are truly undiscoverable through a typical RE process. While a full answer to this question would require a dedicated measurement study (which is outside of the present paper's scope), some qualifying points to note are as follows:

- Since the theory is constructed from the data collected from the system stakeholders, it is likely that at least some of the theory-driven requirements can and will be identified through the traditional RE practices. For instance, the need for data sharing and so acknowledging that data is a shared resource between stakeholder and the service provider were noted as part of the use case elicitation activity (see Fig. 1).
- On the other hand, a theory construction deliberately engages with the explanation and/or understanding of "what?, how? and why?" of a set research question [60]. This process directs comparative analysis of data, identification of evidence gaps, seeking additional data and questioning the emerging understanding and/or causal relationships. As a result:
  - A systematic process for evidence collection, review and interpretation is followed, which would uncover additional information of import to the set research question (e.g., as noted in Sect. 6 review of the partnership theory pointed out the new requirements for a limited liberality partnership with capped loss sharing between service provider and prosumer, etc.);
  - The constructed theory itself solidifies a conceptual explanation/understanding of the what, how and why and is relevant to the set question. Thus, the requirements engineer can systematically interrogate the requirements that would bolster or deter the processes explained by the theory. E.g., understanding that the prosumers view their behavior/flexibility as an asset helps the service provider justify investment into renewing this asset when considering the financial structure of their business models.

8 Conclusions

In this paper, we report on our experience of requirements elicitation for a DSR system and socio-technical theory development, which led us to recognition that a theory itself must serve as a source of (software) system requirements.

Charmaz [5] suggests that to evaluate the developed theory, one should consider

- *Credibility*, e.g., has sufficient data been collected, was the appropriate process followed, etc.?
- *Originality*, i.e., does the theory offer any new insights?
- *Resonance*, i.e., does the theory make sense to participants?
- *Usefulness*: does the theory offer useful interpretations?

We addressed the *credibility* criterion by undertaking data collection until the theoretical saturation of category generation was observed, and followed the good practice guidelines [16] in undertaking and presenting the study process and product (see Sect. 6).

We address the *resonance* criterion by validating the developed partnership theory with participants (see Sect. 4.2), as well as comparing the findings for both the Partnership and the Skills theories with the related work reported in literature (see Sect. 5). In both cases, we find that the partnership theory is acknowledged as relevant by the prospective DSR participants, and that both theories also align with the findings of researchers working in the DSR domain.

We address the *originality* criterion by considering whether the developed theories noticeably change the requirements of the socio-technical and software systems-to-be (see Sect. 6). Here, we find that integration of the requirements driven by the partnership theory not only substantially expands the software system requirements, but also completely re-shapes the socio-technical system within which the DSR software-to-be would operate. To point out just one of the change impacts: here the notion of DSR customer is completely changed, with each household acting as a business partner within this massively distributed, multiparty DSR business model.

Similarly, integration of the Skills theory both adds new use cases to the previously identified software requirements (see Table 4), and also leads to a notable change within the socio-technical environment of the intended system. Integration of this theory would substantially upskill, engage, and educate the intended users of the prospective software system.

Finally, to consider *usefulness*, we ask if the proposed theories propose useful answers to the questions set forth for their development, i.e., *(a) What could foster better adoption of the intended system by the households?* and (b) *What Skills and Training do householders require for better adoption of smart local energy services (like the present DSR service)?*

On the one hand, these theories can be seen as very useful indeed, as they provide a set of actionable requirements that drive a new kind of socio-technical system; also our partner energy companies are very interested in these. On the other hand, real usefulness of these theories can be observed only when the socio-technical system emerging from their operationalization is implemented, and its results compared to those of more traditional DSR systems. This, however, is presently a long way away.

As it is, we summarize that two good theories (in terms of the above evolution criteria) will, likely, also be good source of new requirements for the relevant socio-technical system.

Appendix: Questionnaire to validate the partnership theory

In order for this energy management system to function well, do you think...

- You/households need to have any common purpose with the energy management service provider? (Yes/No)
  What is the common purpose?
- You/households need to share skills (e.g., how to optimize time management of own devices)/resources (e.g., access to devices) with the energy management service provider? (Yes/No)
  What are the skills/resources?
- You/households need to share in the ups and downs of profit/loss from the energy management service? (Yes/No). Please explain: why?

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