Towards Systematic Specification of Non-Functional Requirements for Sharing Economy Systems

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***Abstract*—Sharing Economy (SE) systems use technologies to enable sharing of physical assets and services among individuals. This allows optimisation of resources, thus contributing to the re-use principle of Circular Economy. In this paper, we assess existing SE services and identify their challenges in areas that are not technically connected to their core functionality but are essential in creating trust: information security and privacy, personal data protection and fair economic incentives. Existing frameworks for elicitation of non-functional requirements are heterogeneous in their focus and domain specific. Hence, we propose to develop a holistic methodology for non-functional requirements specification for SE systems following a *top-down-top* approach. A holistic methodology considering non-functional requirements is essential and can assist in the analysis and design of SE systems in a systematic and unified way applied from the early stages of the system development.**

***Index Terms*—Sharing Economy, Security, Privacy, Data Protection, Trust, Economic Incentives, Requirements Specification**

I. Introduction

Circular Economy (CE) represents a novel paradigm shift that promotes a sustainable and environmentally-friendly future. It moves from the traditional *linear* economy (*produce-use-dispose*) to a more sustainable *life-cycle*. It facilities the re-use of resources and physical assets, followed by the recycling and regeneration of new goods, while minimizing waste production levels (*design-reuse-recycle-regenerate-redesign*) [1], [2]. CE covers the entire aspect of our everyday lives, from using renewable energy sources, reusing our assets and services, to sharing them with others while they are not in use by individuals (i.e., owners). The latter is known as Sharing Economy (SE), a (sub)case of CE. SE focuses on maximising the utilisation of physical assets and services by multiple people. It advocates for and incentivises collaborative rather than individual utilisation of assets and services [3]. Figure 1 illustrates the relation between CE and SE.

SE systems use emerging information and communication technologies (ICT) to provide individuals with information that enables optimisation of resources through the re-use of physical assets and services. There are many examples of successful and well-regarded services following the SE model. Uber, Airbnb, Zipcar, TaskRabbit and the original, eBay, are some of the household names. Uber ($120 billion) and AirBnB ($31 billion), the two flagship companies, attained astronomic valuations in late 2018. It is worth noting the mechanics of these businesses, essentially matching demand and supply (for a fee) in distinct areas of daily life such as transportation or temporary housing.

Another example of an SE service that has been gaining attention is smart mobility (vehicle sharing). The worldwide number of users of vehicle sharing services has grown by 170% from 2012 to 2014, reaching 5 million in total [4], and is expected to reach 26 million by 2021 [5]. Several companies including Volvo, BMW, Toyota and Apple have already invested in such SE services. Furthermore, the energy sector has also been undergoing a substantial transformation with the realisation of the smart grid vision [6]. Peer-to-peer electricity markets where users trade their excess electricity directly with each other are redefining the way electricity is generated, delivered and consumed [7].

Innovative SE services are possible due to advancements in ICT. These advancements have allowed users (and companies) to connect to, collect and analyse data from, share their physical assets with, and deliver services to others. A prominent example is Internet of Things (IoT) devices (and their sensors) which allow remote access, monitoring and control of virtually everything connected to the Internet, ranging from houses, cars, fridges, TVs, bicycles to toys for kids. Advancements in computational power and technologies such as Artificial Intelligence (AI) and Machine Learning (ML) enable efficient analysis of large data-sets collected from connected IoT devices utilised for automatic decision making. In addition, blockchain and smart contracts could provide the means to digitally facilitate, verify, and enforce the negotiation of contractual (and possibly legally binding) agreements between users [8].

An SE system usually requires the involvement of a number of users (a priori unknown to each other), as well as the collection of a considerable amount of (mostly personal and potentially sensitive) user data by the SE service provider in order to support various services and be flexible in providing (personalised) services to users. This can result in the emergence of a complex SE ecosystem, with many SE services available to users. Intuitively, the more flexible the

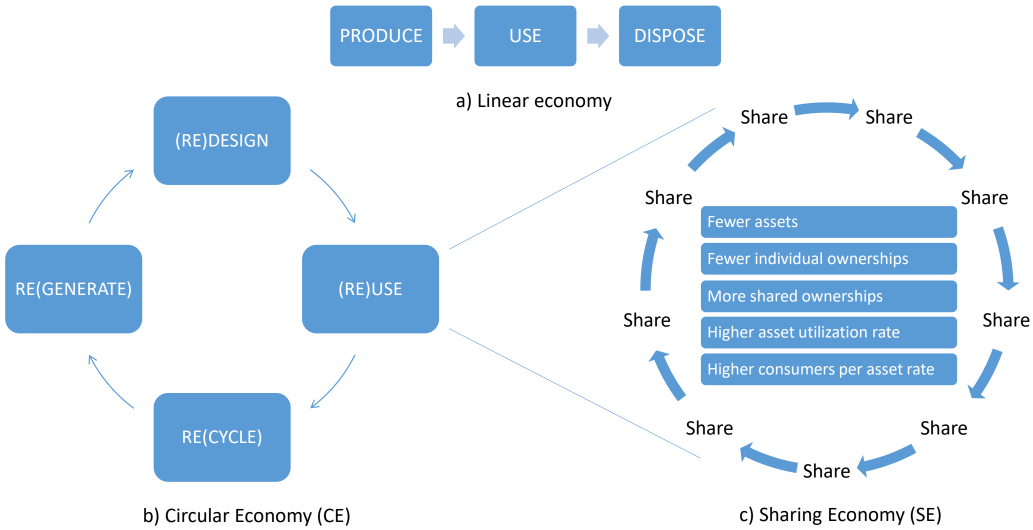

Fig. 1. Relation between different types of economy models: a) Linear Economy, b) Circular Economy and c) Sharing Economy.

SE services are, the more attractive they can become for users, thus contributing towards the primary goal of SE (CE): sustainable and environmentally-friendly future through the efficient re-use of assets.

Inevitably, higher service flexibility commonly requires more personal data being collected, processed, analysed, stored and shared by various SE service providers. This raises concerns about how to (i) provide trust and accountability in SE systems, (ii) ensure the security of SE systems and protect the privacy of users, (iii) ensure that such systems are compliant under the legal frameworks and (iv) design and integrate appropriate and fair economic incentives to encourage users to engage with SE systems proactively. To address these concerns, one should design SE systems in such a way that, in addition to the functional requirements needed to provide the core functionality, the crucial non-functional aspects, i.e., information security and privacy requirements, data protection regulation compliance and appropriate economic incentives, are also considered in the analysis and design stages of SE systems. To the best or our knowledge, there exists no established unified methodology for non-functional requirements specification, let alone one specifically tailored for SE systems.

Our contributions related to SE systems in this paper are: (i) we analyse and identify challenges in four core areas aiming at establishing trust: information security and privacy, data protection and fair economic incentives, (ii) we highlight the lack of a systematic approach to non-functional requirements specification and justify the need for such, and (iii) we take the first steps towards building a unified methodology, while providing future research directions that can be utilised by the industry and the academic community.

The remainder of this paper is organised as follows. Section II reviews various categories of SE services and emerging ICTs and identifies common features of SE systems. Section III analyses the challenges of SE systems in terms of security, privacy and economic incentives; and highlights the lack of a systematic approach for non-functional requirements specification. Section IV describes the limitations of existing frameworks. Section V takes the first steps towards building a unified methodology for non-functional requirements specification and finally, Section VI concludes the paper.

II. Sharing Economy Services and Emerging ICTs

This section provides an overview of the types of SE services available (see Fig. 2) and the emerging ICTs, before attempting to identify the common features of the SE systems.

A. *Sharing Economy Services*

1) Accommodation/space share: This category of SE services allows users to temporary rent (partially) their properties and spaces. In terms of accommodation, this ranges from entire properties, to spare rooms and storage spaces (e.g., Airbnb). Space-related SE services predominantly focus on renting parking and office space. Other examples include services for renting out open spaces used for camping or cultivation.

2) Mobility share: This category of SE services allows users to rent means that would provide them with mobility, i.e., help them move from point A to point B. There are several varieties of mobility sharing, ranging from renting (i) a vehicle such as car (e.g., Turo), van, scooter, bike, and boat, (ii) a ride where the user determines the starting point and time as well as the destination of the ride (e.g., Uber), to (iii) user joining a ride with a predefined route and time (e.g., BlaBlaCar).

3) Food share: This category of SE services allows individuals and restaurants to offer their excess of foot to others. There are also services that provide personalised experience where individuals can host and share a meal with others.

4) Tool share: This category of SE services allows users to share everyday tools, products and equipment such as gadgets, game consoles, DIY tools, gardening tools, and books.

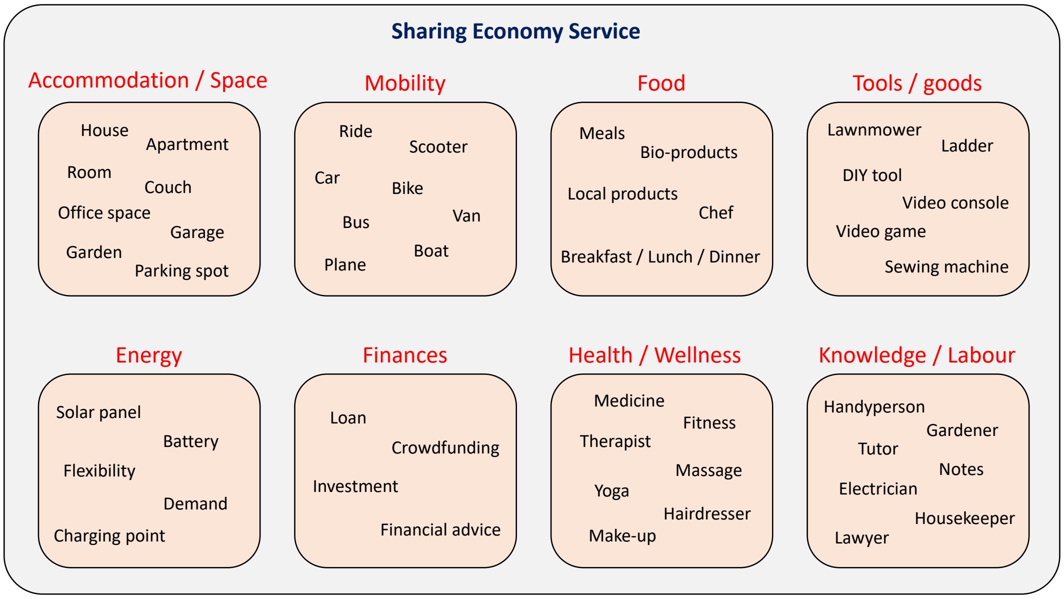

Fig. 2. Sharing economy (categories) of service.

5) Energy share: This category of SE services allows users to trade their excess electricity (generated, for example, from their solar panels) directly with other users (instead of trading with their suppliers) as well as trade their flexibility (i.e., ability to shift their consumption patterns) to suppliers and/or grid operators. The most popular services are peer-to-peer electricity trading as well as offering Demand Response to electricity suppliers, operators or third-party aggregators.

6) Finance share: This category of SE services allows users to lend money to others or invest in others' loan and start-up companies. Borrowers can get lower interest rates compared to borrowing directly from banks or lending institutions, and lenders could get a higher rate of return on their capital.

7) Health/wellness share: This category of SE services allows individuals to lent medical equipment as well as to connect with relevant certified professionals, such as beauticians, dietitians and fitness trainers, to get personalised advice.

8) Knowledge/labour share: This category of SE services connect users with (mostly local) experts and professionals, ranging from mechanics, gardeners, babysitters, to lawyers, tutors and freelancers.

B. Emerging ICTs

Nowadays, the IoT paradigm - connecting everything to the Internet - is already a reality with a growing tendency [9]. There are already a large number of *IoT devices*, with multiple sensors, operating in our everyday lives. In most cases, these devices have limited storage and computational capabilities. Essentially, they are collecting and sending data to service providers, i.e., exporting the collected data to the *cloud*. The amount of data collected and available can require the use of services specialised in data analytics. This paradigm is known as the *big data*, which can facilitate insights extraction from rich data sets. That is possible now due to the advancements in AI and ML techniques such as *deep learning* that could find relations and patterns in large and complex data sets.

Distributed ledger and blockchain have also gained enormous attention in the last few years due to their sought after properties such as verifiability, decentralisation, and transparency. When coupled with *smart contracts*, they can facilitate automated and enforceable "contractual" agreements between users without the need of intermediaries.

Secure distributed computing is another technology that is making the headlines due to its promise to overcome the main limitation of centralised systems - the single point of failure. Although fully homomorphic cryptosystems are not fully practical yet due to their computational limitations, somewhat (semi) homomorphic cryptosystems are already being deployed in practice. In addition, Multiparty Computation (MPC) technology overcomes the limitation of (fully) homomorphic cryptosystems by offering relatively efficient computations at the expense of communication overhead and the need for multiple parties.

C. Common Features of SE Service Providers

Since the SE systems have common objectives, to connect users potentially unknown to each other, aiming to maximise the use of certain assets and services, most of the SE service providers share similar features. A non-exhaustive list of common features of SE service providers is given below.

- *Centralised digital platforms*: Most of the SE service providers use centralised digital platforms to provide their customers with bespoke services and user experience.
- *IoT devices*: The majority of the service providers rely on various types of IoT devices to collect vast amounts of (personal) data of users.

- *Artificial intelligent and machine learning algorithms*: Companies deploy advanced AI/ML algorithms to analyse the collected data and obtain in-depth insights into the profile and behaviour of their customers.
- *User-centric interface*: Most of the SE service providers design their user interfaces in such a way that their services are easy to use as well as they encourage user engagement.
- *New technology-friendly*: Companies providing SE services are open to explore, test and adopt emerging new technologies to enhance their services aiming at increasing their market share.

III. Challenges in Sharing Economy

This section analyses some of the main challenges of SE systems: (i) trust, accountability and transparency, (ii) information security and privacy, (iii) data protection compliance and (iv) fair economic incentives.

A. Trust, Accountability and Transparency

Trust is the single most important enabler of the SE. Eloquently defined as "confident relationship with the unknown", trust is the new oil of collaborative consumption. A user of an SE service needs to trust the business proposition, the platform matching supply and demand (if any) and often the other users of the service. Given that SE services (i) are powered by information technology, (ii) deal with massive amounts of personal data thereby falling within the scope of data protection laws, and (iii) have multiple interacting stakeholders with diverging economic interests, *trust relationships are created and maintained via an ensemble of technological, legal and economic mechanisms*. Note that *trust* is also closely interrelated with *accountability* (to guarantee that misbehaviour is punished) and *transparency* (to guarantee fair and non-discriminatory treatment of users). The efficiency of these means relies on the science of (i) information security and data privacy, (ii) law and (iii) economic mechanism design, respectively.

B. Information Security and Privacy

Technical information security and data privacy have a crucial role in SE services. There are many security and privacy aspects of SE services. First, in scenarios where users share their physical assets, such as vehicles or properties, cyber-physical security is of utmost importance. For instance, if an unauthorised user obtains access to another user's property or vehicle, substantial financial damages for the latter may incur. Second, SE services use platforms for their operations, and the platform itself should be secure and transparent in its mechanisms. Most platforms run on public cloud infrastructure, inheriting its security issues. Also, if the platform handles payments it usually utilises a third-party financial provider to process transactions, thereby being vulnerable to attacks on the financial provider. For example, in a breach of security 57 million Uber customers' and drivers' information were compromised [10]. Third, SE service providers collect a vast amount of user sensitive data [11]; a by-product of the immense amount of data generated by users and transferred to these providers. This changes completely the adversarial model currently used – only the users and the outsiders are seen as a threat, but not the providers. Nowadays, SE service providers are also seen as a threat considering the amount of user data they collect. For example, vehicle sharing service providers collect personal data such as user and vehicle identity, vehicle location, user preferences, rental time, duration, pickup location, and when, where and with whom someone is sharing a vehicle [12]. SE service providers can even attempt to infer additional sensitive information about users from the data they already hold on them – such as racial and religious beliefs [13] or their health-related information, by identifying users who regularly visit specific hospitals [12].

C. Data Protection

Owing to the massive amounts of personal data handled, compliance with *data protection law* plays a central role for SE services. Note that, multiple user data sets can be acquired and *fused* by a single data broker such as Cambridge Analytica [14] and Palantir [15]. Such big data-silos can contain rich information about individuals' everyday lives and habits. That enables profiling and micro-targeting of users such as in political elections. The General Data Protection Regulation (GDPR) [16], that became applicable as of May 2018 reinforces the earlier European framework by creating more stringent requirements for data controllers and processors. As the data processed by SE services is often related to an identified or identifiable person, and the SE providers either are established within the European Union, or their activities relate to the offering of services to persons who are in the European Union, the GDPR is applicable. Therefore, the SE service providers, as the legally responsible entity (controller), have to comply with the requirements of the GDPR and especially have to safeguard data subjects' rights. For instance, the GDPR establishes the protection of individuals against automated-decision making, profiling and discriminatory practices based on profiling.

Compliance with these rules must be transparent for the individual. For example, art. 13 and 14 of the GDPR provide that the data subject must be informed about the existence of automated decision making or profiling, and should receive "meaningful information about the logic involved, as well as the significance and the envisaged consequences of such processing for the data subject."[1] Furthermore, the data subject has the right to object against profiling (art. 21 GDPR) and has the right not to be subject to automated decisions or profiling if it would produce a legal effect for the data subject (art. 22 GDPR). This right, however, does not apply if the profiling is either authorised by Union or Member State law, or necessary for concluding a contract between the data subject and the controller, or if the data subject gives explicit consent. For the

[1] art. 13 (g), art. 14 (g) GDPR. Which article applies depends on whether the personal data was obtained directly from the data subject, or indirectly from another source.

last two cases the GDPR specially reiterates the obligation for the controller to implement suitable measures to safeguard the data subject's rights and freedoms (which includes that not only the right to data protection, but also other rights such as the right to privacy, needs to be taken into account), and that the data subject has the right to obtain human intervention from the controller. The human intervention should help to express the point of view of the data subject and provide a possibility to contest the decision. Supervisory authorities monitor the application of the GDPR, and in case a lack of compliance becomes known it can result in heavy fines from the supervisory authority. Furthermore, in case an infringement of the Regulation results in damage (material or non-material), the person who suffered the damage could get compensation from the SE provider.

D. Fair Economic Incentives

As SE services are built on the principle of involving multiple stakeholders with their own incentives, proper *economic mechanism design* is essential for their success. Broadly defined, economic mechanism design can be seen as a type of inverse game theory: while the desired outcome of a multi-party decision problem is given, the incentives and game mechanisms that take the system under study there need to be systematically engineered [17]. Lately, proper incentives have been shown to make or break successful and efficient systems such as secure computer networks [18], online social networks [19] and even legal frameworks (see art. 83 GDPR on monetary penalties – an incentive for compliance [20]).

Most SE services operate as two-sided (or multi-sided) markets, providing the means (a platform) to match service providers (supply) and customers (demand) [21]. Two-sided markets, if operating efficiently, have the potential to amplify and transfer the network effects from each side to the other. Hence, in addition to the inherent benefits of utilizing ICT, demand-side economies of scale (more customers attracting more providers and vice versa) can boost transaction density, revenues and the value of the platform. To operate SE services efficiently, incentives for all three stakeholder types should align well [22]. In such environments, there are two key issues that are universal in distributed systems in general, specifically in the SE sector: fairness and efficiency.

Providers care about their monetary revenues; this implies a fair share of exposure in crowdsourced systems translating into equal income opportunities. Furthermore, owing to the two-sided network effects, if the SE system is fair, more providers and hence more customers will join, resulting in less idle time and more steady demand. Furthermore, as most SE services utilise review mechanisms, providers' incentives include delivering good service in order to get favorable ratings and get selected by customers in the future. For customers, receiving adequate service for a reasonable cost is the foremost objective. Customers should also care about a fair (to providers) SE system, as a fair matching mechanism ensures that many providers join and stay in the system. That, in turn, means a higher availability of the service in case of peak demand (such as national holidays for accommodation or Saturday night for ride-hailing services). Additionally, as SE services can be much more flexible than their centralised counterparts, customers might be willing to receive worse service (e.g., wait longer for a car) if given the right monetary incentives (e.g., discount fare). Such type of micro-incentive strategies show potential in keeping the whole service running efficiently and in a balanced manner [23]. Platforms themselves need to attract both providers and customers. The larger the pool on either side, the more resilient the SE service is to societal or economic effects. It could already be seen that societal movements such as #DeleteUber can cause more than just a temporary dip in demand [24].

As far as efficiency, in most SE applications there are natural limits on the extent to which the resources can be shared [25]. In ride-hailing, each vehicle has a fixed capacity for passengers, accommodations have a fixed size, and so on. Therefore, participants have to be organised in groups of limited size so that individual resources are shared near-optimally. From the economic mechanism design perspective, a straightforward goal would be to allocate users into sharing groups that extract the maximum amount of overall utility; corresponding to the socially optimal allocation. In a distributed SE environment, such computation is impractical to carry out centrally: information on individual preferences is scarce and a central authority may not even exist (or has only a limited power, e.g. setting incentives). Therefore, game-theoretical investigations into a revenue-distribution mechanism inducing a near-optimal, self-organizing group allocation are needed. Early theoretical work [25] in this area proves that welfare distribution based on the Shapley value [26] shows promise; however, embedding such theoretical results into an actual SE application is far from trivial.

E. Lack of a Unified Methodology

The above examples indicate the complexity of each domain, i.e., information security and privacy, data protection, and fair economic incentives. Thus, it needs to be systematically considered for a SE system design, providing system designers with the essential *non-functional requirements*. Although existing SE systems provide us with the core functionality, which is usually a platform that helps people match demand and supply of various assets and services, they either neglect such non-functional requirements or treat them in an ad-hoc manner. This lackadaisical approach may result in failing services, legal problems, decreased revenues and disappointed users.

IV. LIMITATIONS OF EXITING APPROACHES

Regarding non-functional requirements analysis, there are several methodologies for system analysis and design [27], [28]. However, they are domain-specific and heterogeneous in their focus. For example, system engineering methodologies such as secure software design (i.e., SDLC) [29], do not consider privacy threat analysis and elicitation of requirements.

LINDDUN, a framework regarding privacy and legal requirements for data protection [30], considers GDPR [16] and ePrivacy (Directive 2002/58/EC [31]) only as high-level policy requirements but not as technical ones. Existing domain-specific frameworks for system protection such as for smart metering systems [32] have only focus on the security and privacy challenges from a technological perspective. Existing work on economic mechanism design is highly theoretical and considers general system models [17]. Therefore, a methodology for the elicitation of non-functional threats and compilation of requirements is yet missing and not a trivial task for real-world SE systems. Most importantly, aligning all the analysis and compilation of requirements from technical information security and privacy, data protection law and incentive mechanism design perspective to a single methodology is a challenging task which has not been undertaken yet.

Existing solutions for SE services only partially have tackled the challenges mentioned in Sect. III. In the vehicle sharing service domain, for example, Dmitrienko and Plappert [33] designed a secure free-floating vehicle sharing system. However, their system contains a centralised fully-trusted SE provider that collects and stores all the information exchanged within the system. Symeonidis et al. [34] performed security and privacy analysis of such systems and designed a solution for secure and privacy-friendly vehicle access provision [35]. Complementary to [35], Madhusudan et al. [36] proposed a solution for the booking and payments functionality of a car sharing system using smart contracts. However, payment information is public and a privacy-preserving solution is missing. Similarly, in the energy sharing domain, use case specific (but still generic) security and privacy analyses have been performed [37], [38], as well as concrete privacy-friendly solutions for different functionalities have been proposed [39]–[42]. However, none of these solutions (i) cover the entire asset and services sharing process, (ii) are fully GDPR-compliant (even though they are privacy-preserving from a technological perspective) and (iii) provide fair mechanisms based on proper incentive-based economics analysis. The H2020 project Ps2Share studied participation, privacy, and power in SE [43]. Although valuable as a reference, this project had an economic policy focus and did not adopt a system design analysis.

V. Unified Methodology for Non-functional Requirements Specification

This section sets the first steps towards building a unified methodology for non-functional requirements specifications for SE systems. In building this methodology, we propose to take a *top-down-top* approach, i.e., start with a generalised initial methodology, apply it to a concrete SE service, and then generalise the results to a wide range of SE systems. More specifically, we propose the following steps.

- Step 1: *Develop an initial methodology for analysis and identification of non-functional requirements, focusing on security and privacy, data protection law and economic incentives*. One should identify non-functional requirements methodologically collected from relevant and broad range of real-world SE systems and the corresponding literature. The focus should be on per-domain best practices and their interplay following the recommended *security-by-design, privacy-by-design, legal compliance, and economic incentive-based mechanism design* frameworks. The systematization yields a preliminary (but extendable) compilation of non-functional requirements for SE systems and a methodology for such analysis.
- Step 2: *Design a secure, incentive-compatible and data protection compliant SE service.* One should validate the initial methodology by applying it to a proof-of-concept SE system, for example for vehicle sharing. The goal should be to design and implement a concrete solution that satisfies the requirements identified while still retaining its core functionality. In the design phase, system designers should pay special attention to (i) offering accountability, conditional privacy, data protection, and forensic evidence provision, (ii) being compliant under the GDPR and the upcoming ePrivacy regulation, and (iii) designing proper economic incentives for all stakeholders. Various advanced technologies such as distributed ledgers, smart contracts, and multiparty computation can be combined to offer technical guarantees for satisfying the identified non-functional requirements. In addition, the designer should also create a list of all non-functional requirements and a catalog of the corresponding solutions for satisfying these requirements.
- Step 3: *Generalise, re-apply and extend the initial methodology to another category of SE systems and services.* One should consider the devised lists of requirements and existing solutions and generalise, re-apply and extend them such that they are valid for the majority of SE systems under the same category or an inter-group of SE systems with common features. Ideally, the devised requirements should be applicable to each SE service under the same category. If this is not possible, SE systems should be grouped based on their system model and features specification. Such an approach can allow designers to provide per category or inter-group tailored list of requirements and corresponding solutions.

VI. Conclusions

Sharing Economy services are already broadly used. However, if such services are to contribute substantially to Circular Economy, a systematic approach to the elicitation and specification of their requirements is needed. This paper positions for a systematic approach to non-functional (yet crucial) requirements specification for SE systems. We highlighted the lack of such an approach focusing on three distinct but intertwined branches of requirements stemming from technical information security and privacy, data protection regulation and economic incentive design. We showed the shortcomings of existing (partial) requirements specification frameworks, and set forward a research agenda based on a *top-down-top* approach. In a nutshell, the aim is to analyse a wide range of SE systems capturing all common features and devise an initial methodology; apply the initial methodology to an SE system and obtain tangible outcome for the specific service; and finally generalise the results to be applicable to broader categories of SE systems.

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