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Summary

With the Anthropocene epoch causing massive environmental shifts, natural resources are being depleted at a faster rate than ever. Countries all over the world are setting ambitious goals in the domains of climate change, energy and circularity transitions on a national and city level. The concept of smart cities is also gaining momentum with cities adopting digital ways of achieving the same, some even scaling down to the neighbourhood scale. The Netherlands has been working on neighbourhood level circular projects extensively as well, however, mostly from the perspective of managing waste or water and not energy. Although energy itself is transitional in nature, energy systems in a neighbourhood also influence circularity systemically. This research takes a multi-disciplinary systems perspective towards neighbourhood circularity and energy systems by studying about the impact of the development and implementation of decentralized smart energy systems on neighbourhood circularity, thus aiming to have an integrated approach towards energy and circularity. Using the case of Schoonschip, an ambitious circular neighbourhood in Amsterdam, this explains the conditions (drivers and barriers) under which the development and implementation of DSES accelerate neighbourhood level circularity and simultaneously fill the literature gap in assessing neighbourhood level circularity.

The study took a two way approach with firstly conducting a literature review to set the theoretical foundation to gain insights on neighbourhood circularity and the conditions for DSES development such as technological, economic/market, institutional/policy, political, socio-cultural and environmental conditions and their connections to circularity. Based on the conceptual framework formed from it, the indicators deduced are tested against Schoonschip neighbourhood. Taking a predominantly qualitative approach, interviews were conducted and a survey along with content analysis was also done to support the findings.

The results from that showed that Schoonschip is doing well in circularity, with high scores in 'innovation' and 'environment and GHG emissions' but scored relatively lower in 'circular input' and 'circular activities', however, with all four of them still being on the positive side. An interconnection among these indicators was also established through systems mapping. A big contribution of DSES was observed from technological, socio-cultural and institutional conditions. Technological conditions have a direct impact on Schoonschip's circularity. Socio-cultural conditions share a direct as well as indirect impact, influencing circularity through knowledge, participation and willingness. These factors are also accelerated by technological conditions enabling co-producing, sharing and informing. The institutional conditions played an equal role in facilitating other conditions such as environmental and economic conditions to pull of an advanced social, technical and economic innovation such as DSES, thus also reinforcing the systemic connection between the conditions.

Overall, Schoonschip exhibits a societal role in circularity, showing how technologies, specifically DSES can help support living as a community. The study proved that circularity in urban areas incorporates a major social aspect dealing with people's habits, daily practices and lifestyle, thus starting from the lowest scale of consumer and going on to building design (meso) and finally the neighbourhood as a whole. The barriers deduced from the data analysis further guided in providing recommendation to improve the circularity of Schoonschip through technological, socio-cultural, economic, environmental and institutional improvements. On a broader scale, policy coordination, consideration of legal frameworks on a neighbourhood scale for more innovation as well as flexibility in institutional systems was presented as a way forward.

Keywords

Circular Economy, Circularity, Neighbourhood Circularity, Decentralized Smart Energy Systems, Systems Thinking

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Abbreviations

AI	Artificial Intelligence
CE	Circular Economy
DSES	Decentralized Smart Energy Systems
EMF	Ellen Mac Arthur Foundation
EPC	Energy Performance Coefficient
EU	European Union
IoT	Internet of Things
ITWM	Fraunhofer Institute for Industrial Mathematics
ML	Machine Learning

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Chapter 1: Introduction

1.1 Background Information

We are currently living in the human influenced anthropocene era. With a lack of knowledge about earth's boundaries and its ecological footprint, natural resources are being exploited at a growing rate, thereby accelerating climate change. Energy, also a product of other resources, is often called the currency of life, being primary to not only our economy, but to society and our environment as well. This dependence on energy is seemingly evident and growing with urbanization and the digital transformation of urban systems and human lifestyle, leading to increased resource use as well. Cities account for more than half the total world population but consume two thirds of the global energy (United Nations, 2018). At the same time, this energy consumption is responsible for 73% of greenhouse gas emissions worldwide, the biggest source of human generated greenhouse gas emissions due to excessive use of fossil fuels (Ge and Friedrich, 2020). Despite the alarming warnings by the Intergovernmental Panel on Climate Change for controlling the GHG emissions to prevent further exacerbation of climate change consequences, these emissions are still ever increasing.

Countries all over the world are tackling climate change by setting visionary goals and introducing sustainable approaches to achieve an efficient, low carbon energy transition. The European Union had already established a long term strategic transition that would lead to net zero GHG emissions by 2020 (European Commission, 2018), which they were unable to achieve. Accordingly, despite being the farthest in the renewable energy share in the EU, the Netherlands has also set an ambitious target of 49% reduction in GHG emissions and 27% share of renewable energy by 2030, compared to its emissions in 1990 while aiming at being completely carbon neutral by 2050 (Ministry of Economic Affairs and Climate Policy, 2019). This transition can only be attained with a radical social, technical and institutional transformation of the current linear approach to resource consumption in the country to a resource efficient, circular one that is rooted in the principles of giving back to nature. Interestingly, the Netherlands has been, in parallel, working extensively with the regenerative model of the circular economy (interchangeably used with circularity) since a considerable amount of time. This model relies highly on a systems thinking approach where systems are analysed holistically with interconnections between different parts instead of focussing on one part at a time. This CE model implies the continual reuse of resources and a shift towards the use of renewable energy, replacing the 'end-of-life' concept with a more restorative one, thereby reducing plausible environmental impacts on the system (Ellen MacArthur Foundation, 2013), and is being used all across scales and sectors, from material products to business organizations to cities and nations. In the Netherlands' circular economy 2050 strategy, the key priorities for CE interventions are biomass, plastics, manufacturing industry, construction sector and consumer goods (Ministry of Infrastructure and Environment et al., 2016).

It can be seen that energy transition is dealt with separately from CE transition even though the broader aim of both energy transition and CE is ultimately achieving sustainability. With energy being one of the primary resource flows at any scale of the built environment, an integrated approach may go a long way in ameliorating both the transitions, while attaining sustainability simultaneously. Although energy cannot be fully circular in its physical character (such as heat dissipation), energy systems (including the social fabric that comes with them) can play a major role in circularity when they are seen from a systems approach. From energy generation to consumption and storage as well as empowering citizens by changing old ways of fossil-based power plants, all can contribute to accelerated circularity. For instance, reducing energy demand, using energy from renewable sources, utilizing waste heat from one source for heating up another, sharing locally produced energy among a community can all reduce greenhouse gas emissions and

induce circularity at the same time. Also, low-carbon energy alternatives and efficiency can also encourage solutions for clean water and less waste recovery. Moreover, according to the latest Circularity Gap Report 2020, in over-consuming 'shift' countries (for example, the Netherlands) where fossil fuel extraction is relatively high, one of the primary pathways to achieve circularity is the renewable energy transition (Circle Economy, 2020).
As a matter of fact, the energy transition and smart city swing are causing a socio-technical transition currently (Dang-Ha et al., 2017), replacing traditional fossil-fuel based energy systems in Europe with cost- effective, sustainable smart energy systems that transform the infrastructure as well as services through smart technologies. A smart energy system has varying characteristics around the world, some of which are capable of integrating renewable resources and infrastructure in the energy grid system (Smart Energy Networks, 2015; Lund et al., 2017), while facilitating energy storage and efficiency using citizen engagement and state of the art technology, that can be leveraged to approach zero energy wastage (O'Dwyer et al., 2019). Additionally, due to innovative technologies, smart energy grids can further evolve into decentralized microgrids which are self-sufficient and can function on their own even when detached from the main grid, increasing flexibility from the bottom-up (Metabolic, 2018). Accompanying this is a major factor of active consumerism. The technologies used in these energy systems also support social cohesion by enabling energy production and sharing within communities, thereby also accelerating circularity of the neighbourhood by adhering to the principles of CE (Metabolic, 2018).

Although it is not a smooth transition, countries like Denmark and the Netherlands have already started implementing these decentralized smart energy systems (DSES) in their different forms and components. The Netherlands, renowned globally for its extraordinary engineering accomplishments in sustainable infrastructure, has a handful of projects with these DSES in action at the moment at different scales, mostly at a district or neighbourhood level but getting ready to be upscaled at municipality level (Metabolic, 2014). One such energy system got recently unveiled in the Schoonschip neighbourhood in Buiksloterham area of North Amsterdam. Deemed as the most sustainable floating neighbourhood in Europe, Schoonschip is an extremely forward thinking neighbourhood aiming for a sustainable living (Image 1). The idea for this was initially thought of by a current inhabitant, Marjan de Blok, who got inspired after learning about a self-sufficient houseboat. A group of people joined later on as a CPO (collective private commissioning). Started in around 2008, it took almost 10 years to build Schoonschip, from obtaining the tender from the municipality, getting all permits and implementing everything. The firm Space&Matter designed the neighbourhood (urban planning) while Metabolic gave inputs on and executed the sustainability solutions. The CPO also led people to have their own architects for their houses, which resulted in different house designs (but the same base, of course). All in all, the residential neighbourhood comprises of 105 inhabitants living in 46 households spread out on 30 water plots, with green roofs, 500 solar panels and 30 heat pumps.


Image 1. Schoonschip neighbourhood, Source: Isabel Nabuurs

Many new experiments have been taking place in the neighbourhood, ranging from the advanced DSES to water systems and sustainable mobility, thus exhibiting bottom-up self-sufficiency and neighbourhood circularity. Besides, Schoonschip is also part of the bigger Buiksloterham circular manifesto which aims to make the Buiksloterham district sustainable using circular principles. Together, they signed this manifesto that confirmed their commitment to sustainable living through reducing, reusing, recycling and sharing, thus helping in achieving circular systems. With the technological interventions and inhabitants' involvement at every step, Schoonschip's energy system implementation was also facilitated by some economically viable market conditions, institutional and political support and environmental consideration. Combined together, the output was enhanced circularity of the neighbourhood.

1.2 Problem Statement

The idea of DSES in the Netherlands is being given adequate consideration. Specifically, at the neighbourhood level, where energy flows are comprehensive, pilot projects for circular neighbourhoods are being or have been implemented as test labs (Metabolic, 2014). Nonetheless, circularity in itself is an extensive subject, however, most research on circularity till now focuses on appropriate waste management through technologies for reducing, recycling and reusing waste flows (Kirchherr et al., 2017) but not from an energy point of view. There is limited literature on how energy systems (forming energy communities) that abide by circularity principles can change the resource flows and accelerate circularity, despite the clear umbilical link between circular economy and energy transition mentioned above. Using a systems thinking approach, that is one of the primary foundations of CE, studying the multi-dimensionality of these energy systems involving social, institutional, political and environmental aspects, feedbacks and externalities can aptly explain their relationship with circularity (Giezen, 2018; Hoppe et al., 2019; Rolnick et al., 2019). Another important research gap in academic literature is the addressal of circularity at the neighbourhood scale. Neighbourhood scale has energy, water and waste resource flows which are large and heterogeneous enough to not be considered small-scale but small enough compared to the resource flows in a city or country. While there have been many CE strategies and monitoring and evaluation frameworks developed for products, businesses, cities and nations (EMF, 2015; EC, 2018; Prendiville et al., 2018), measuring the neighbourhood level circularity is not yet explored properly.

This research will therefore dive into the various conditions under which DSES implemented in the selected neighbourhood of Schoonschip accelerate circularity of that neighbourhood. Taking a systems approach, these factors will not just be limited to the system performance, but also the external factors like technological, social and behavioural perspective, economic, institutional, political and environmental capacity (Mosannenzadeh et al., 2017; Giezen, 2018; Ceglia et al., 2020). Further, the proposed study also aims to assess the level of circularity at neighbourhood level by formulating circularity indicators based on comprehensive literature review of existing indicators and their gaps. The modified indicators, such as circular input, circular activities, innovation and environment and GHG emissions (EMF, 2015; Moraga et al., 2017; Konietzko et al., 2019), will aid in concluding insights into the DSES factors that maximise or block full circularity in the neighbourhood.

1.3 Relevance of the Research Topic

Due to the lack of literature on the correlation of energy systems with circular thinking, this study is pertinent in exploring this connection theoretically and empirically. The theoretical analysis will give relevant insights on how a circular transition in a neighbourhood/urban area can be operationalized via DSES by finding the opportunities and barriers for the same, while the

empirical part would apply these insights to a real-life example DSES at neighbourhood level, in this case, Schoonschip.
The study will also be contributing by building on the existing discourse in regards to circularity at the neighbourhood level by finding the indicators to measure circularity at that level and simultaneously draw several drivers and barriers to accelerated circularity in the DSES context. Additionally, further opportunities and findings can be deduced for better implementation of larger scale circularity in energy systems that could facilitate the energy transition and vice versa, which is also the need of the hour to combat climate change.

1.4 Research Objectives

The main objective of the research is to explain the conditions (drivers and barriers) under which the development and implementation of DSES can accelerate neighbourhood level circularity in Schoonschip, Amsterdam, Netherlands. Therefore, the specific objectives are:

- Examine how the Schoonschip neighbourhood with DSES developed and implemented measures against circularity indicators.
- Assess the drivers and barriers of DSES development and implementation in Schoonschip that enable or hinder circularity at the neighbourhood level.

1.5 Main Research Question and Research Sub Questions

Overall research question:
"Under which conditions do the development and implementation of DSES at Schoonschip, Amsterdam, the Netherlands accelerate circularity at the neighbourhood level?"

Sub questions:

1. How does Schoonschip neighbourhood (with DSES developed and implemented) measure against circularity indicators?
2. What are the drivers and barriers in the development and implementation of DSES in Schoonschip that enable or hinder circularity at the neighbourhood level?

1.6 Scope and Limitations

The scope of the study is limited to neighbourhood level circularity and predominantly looks into DSES conditions in the neighbourhood circularity context. Furthermore, a limitation to this study is that the implementation of DSES is fairly new with recent project implementation. There is also not enough literature on neighbourhood circularity, therefore the researcher takes a deductive and iterative role in developing circularity indicators. Most importantly, the research faced many hurdles throughout due to the ongoing global pandemic.

Chapter 2: Literature Review/ Theory

2.1 Circular Economy

Circular Economy (CE) is often linked with sustainability as a (necessary) condition for sustainable development (Geissdoerfer et al. 2017). The concept of CE represents a model for socio-technical change, shifting from the linear production-consumption-disposal systems to a circular one where waste is eliminated and economic growth is decoupled from ecological and environmental degradation, resulting in a harmonious society (Ghisellini et al., 2016; Hobson, 2019; Friant et al., 2020).

The origin of CE is ambiguous and can be traced back to different ideologies in early academic literature, ranging from environmental economics to general systems thinking and industrial ecology, but all converging at the common idea of closed loop systems (of materials, resources and energy) (Ghisellini et al., 2016; Murray et al., 2017, p.372). A prominent contributor, the Ellen MacArthur Foundation (EMF) later on rebranded the concept of CE by linking it with more recent theories such as cradle to cradle (separation of biological and technical cycles), biomimicry (imitation of natural systems), performance economy (sharing) and regenerative design (EMF, 2013, p. 26-27; Ghisellini et al., 2016, p. 15; Murray et al., 2017; Wautelet, 2018). Presently, the CE approach is being widely used in varying disciplines and contexts by governments and businesses as means to tackle climate change and achieve sustainability by taking up resource efficient pathways. Notwithstanding, there is still no universally agreed definition of CE yet. The most commonly used definition is formulated by the EMF (2013), describing CE as “an industrial system that is restorative or regenerative by intention and design” (p. 7), but it is still deemed incomplete and differs from other definitions because of CE’s varying conceptualisations, exploratory nature and diverse spatial dimensions with reference to China and Europe (Kirchherr et al., 2017; Homrich et al., 2018). Kirchherr et al. (2017) in their analysis of 114 CE definitions observed that CE literature prioritizes the economic growth aspect more, contrary to the equal importance given to economic, social, environmental and future generation aspects in sustainable development.

Consequently, literature states three levels/ scales where interventions can be applied for a CE transition. These levels include micro (product, company or consumer), meso (building, eco-industrial parks) and macro (regions, cities or neighbourhoods) (Ghisellini et al., 2016; Kirchherr et al., 2017; Pomponi and Moncaster, 2017). While there have been ample amounts of studies accomplished on the micro-level in contemporary literature, studies on macro-level CE are only growing (Prendeville et al., 2018). Nonetheless, the scope of macro-level CE differs to great extents in literature. Authors such as Kirchherr et al. (2017) suggest that macro-level goes beyond national level whereas Ghisellini et al. (2016), Prieto-Sandoval et al. (2018) limit it to cities, regions and nations. The meso-level CE is covered predominantly by authors from China and focuses on industry/production plants (Geng et al., 2012; Ghisellini et al., 2016). The neighbourhood level or urban area scale, which lies between a building/industry (meso) and a city (macro), is not specified under any level in most studies except by Pomponi and Moncaster (2017) and Marin and de Meulder (2018), in which they merely acknowledge neighbourhoods under macro-level. Maintaining this and also acknowledging that there has been barely any research done on meso-scale beyond industrial settings, CE in neighbourhoods will further be studied from a multi-disciplinary macro perspective in this research. Although it is to be considered that a neighbourhood is essentially a group of buildings (meso) and a group of people (micro) with distributed resource flows unlike a city which is much more complex.

2.1.1 CE and Circularity

As noted above, CE has a broad focus on economic prosperity in general. Research also shows that CE is more applicable on a regional level (Kirchherr et al., 2017). In addition to CE, 'circularity' is also used, either interchangeably with CE or focusing more on closing resource loops and value creation. The latter is often seen in discussions about circularity in the built environment (van Stijn and Gruis, 2019; Geldermans, 2020). Indeed, this may also explain the parity seen in CE definitions and frameworks. It can be said that circularity is a subset of CE on smaller scales and ultimately leads to a CE on a bigger/global scale where economies are involved. To sum it up, from a systems perspective, circularity on any level can lead to a CE on a macro level and by following CE principles, i.e. economic, social and environmental considerations and strategies, circularity is automatically achieved by the system.

2.1.2 CE Principles, Strategies and Frameworks:

A robust circularity framework captures all CE schools of thought and its complex multi-dimensional principles. According to Kirchherr et al. (2017), majority of CE literature covers three main principles of reduce, reuse and recycle. However, more holistic approaches have come to light in recent studies. Contemporary literature consists of distinctive types of frameworks for varying purposes (for example, to conceptualize, evaluate and monitor CE). Kirchherr et al (2017) recommend the R-framework which incorporates the 10R strategies starting from 'refuse' and ending at 'recover' for a fully CE.

Similarly, Konietzko et al. (2019) also came up with a set of circular strategies for products, business models and ecosystem innovation. These strategies are under the categories - narrow (using fewer resources), slow (longer use of resources), close (waste as a resource) and regenerate (renewables), all of which are supported by the use of information technology.

Another popular action framework for CE is the ReSOLVE framework developed by EMF (2015). This framework captures the three main CE principles developed by EMF (2015), namely, preserve and enhance natural capital, optimize resource yields and foster systems effectiveness (p.22). The six actions under them, Regenerate, Share, Optimize, Loop, Virtualise and Exchange provide an extensive outlook on CE which can be applied to businesses and countries and can also be used to monitor CE (Cavaleiro de Ferreira and Fuso-Nerini, 2019).
Consequently, the European Commission (EC) (2018) developed a monitoring framework for CE to identify success factors, areas for intervention and to examine the adequacy of actions taken. The monitoring framework targets key areas such as production and consumption, waste management, secondary raw materials and competitiveness and innovation (p. 4). Apart from that, Levoso et al. (2020) devised a methodological framework to lay out the guidelines for CE implementation in urban systems. Focussing on the production based approach, this framework proposes a strategic plan for CE in urban systems using a four phased process with the first being analysing the context, followed by identifying of the scope in which there is maximum potential for CE implementation, identifying available CE opportunities and areas and finally examining these opportunities to form a roadmap for CE implementation. All these frameworks concentrate on different endeavours of circularity and at different development and implementation levels (Figures in annex 1).

2.1.3 Measuring Circularity at Neighbourhood/ Urban area scale

At the macro-level, a zero waste and resource efficient CE entails integration and redesign of four systems: the industrial system (e.g. phasing out of heavily polluted industries), infrastructure system delivering services (e.g. clean energy, electrical power lines), cultural framework and social system (Ghisellini et al., 2016, p. 22). Additionally, since macro-level studies predominantly focus on urban metabolism, many authors have also suggested a co-creation approach incorporating site-specific living labs to facilitate the transition to a CE (Metabolic, 2014; Amenta et al., 2019). Descending at the neighbourhood level, Metabolic (2014) claims that a systemic intervention like living labs are imperative to aid the application of future-oriented niche technological and management measures in neighbourhoods for enhancing circularity (p. 11). As the scale increases, the number of stakeholders increase as well, therefore this method incorporates the dual approach of top-down and bottom-up public-private-people stakeholder partnerships (including researchers and experts) in achieving circularity, the importance of which is highlighted by Prendeville et al. (2018) as well. For example, collective approaches such as locally produced energy or wastewater management can have a large impact on the circularity of the neighbourhood.

Nonetheless, it is evident from the above-mentioned frameworks that a majority of studies are done to develop strategies to reach circularity/CE and as the scale increases, these strategies get more ambiguous. In general, due to the discrepancies in the scope of the meso/macro level as mentioned in the first section, there is a lack of coherence in evaluative frameworks (Parchomenko et al., 2019; Levoso et al., 2020). Moreover, much needed is the assessment of circularity of urban areas, not just in the form of total outputs but more of a system performance perspective. The EC monitoring framework is used widely to measure circularity, however, they are chiefly designed for the national/city level macro scale and not suitable for an urban area. Moraga et al. (2019) in their analysis of the EC CE Framework further point out that the framework does not take into account the 'function' aspects like multi-functionality and sharing which reinforces the 'circularity' and 'CE' distinction too. These systemic performance aspects, while difficult to measure, still form an integral part of measuring circularity specifically at the neighbourhood level due to a greater involvement of consumers.

Another common measurement technique is the Life Cycle Analysis (LCA) which is already being used for product level circularity and can also be used in buildings of an urban area. This environmental management tool, although giving accurate results for resource loops, unfortunately misses the mark in a more comprehensive measurement of circularity. Similar to the EC framework, LCA does not cover crucial aspects of what a consumer/user could contribute to on a smaller scale, such as sharing, reuse, innovations etc. Moreover, EMF (2015) uses the term 'baseline circularity' to express the level of circularity of a country/territory/region, often used to find the strong or weak points to prioritize in the area. The indicators used by EMF to measure the baseline circularity are resource productivity (both material and energy), circular activities (such as sharing), waste generation and energy and greenhouse gas emissions (p. 42). They are based on EMF's three main circularity principles: design out waste, keep products and materials in use and preserve natural capital (EMF, 2013, p.22). These indicators along with the other evaluative frameworks mentioned above, although not entirely suitable for neighbourhood scale, can be modified and omitted by adding the findings from above to cater to the urban area circularity.

Neighbourhoods are junctions of flows involving energy, water, materials, waste and people. Circularity in urban areas is a process, concerning operational/functioning elements along with the amount of resources in the cycle. In other words, circularity in urban areas incorporates a major social aspect dealing with people's habits, daily practices and lifestyle, thus starting from the lowest scale of consumer behaviour (micro) (Hobson, 2019). It then goes on to building design (meso) and finally the neighbourhood as a whole. Therefore, while assessing circularity of a neighbourhood, all scales should be considered as they are interrelated and interdependent.

Based on this and also supported by EMF (2015), EMF (2016) and Moraga et al. (2017), an undisputed indicator is circular inputs (for circular design) in the area development, in terms of materials and energy loops. Assessing the material management with respect to its reusability/ recyclability and the renewable energy sources in the buildings of the neighbourhood is crucial and is the very base of circularity. Followed by this is the inclusion of the various circular strategies discussed above, not only from a technical perspective but also from a consumer involvement perspective, as was missing in other frameworks. Under circular activities, EMF (2015) and EMF (2016) emphasize on the circularity principles of recycling, reuse, regeneration and sharing which are rather functional and can be measured by exploring the circular interventions on a rather smaller scale, like reducing demand of different flows (energy, water, waste) in the neighbourhood, resource sharing and reuse/recycling/recovery of waste) (Fusco Girard and Nocca, 2019). EMF (2015), Moraga et al. (2017) and Konietzko et al. (2019) also mention innovation as a supporting aspect of a circularity transition. With material and technological innovation being the core enablers of circularity, innovative business models for economic benefits and socio-institutional innovation for knowledge and value creation also come under this category (Potting et a;., 2017). In fact, innovation reflects a better health and wellbeing of inhabitants too. Lastly, on an urban scale, it is important to consider the self-sufficiency of the neighbourhood with regards to resource flows when it comes to the environmental impact reduction and natural capital regeneration. Similarly, GHG emission reduction also acts as a direct indicator to see if the circular strategies made a difference (EMF, 2015; Moraga et al., 2017). Combined together, this set of indicators represent a systems perspective to circularity and can be appropriately applied to an urban area/neighbourhood to measure circularity (Table 1).

Table 1 Circularity Indicators at Neighbourhood Level, Adapted from EMF (2015), Moraga et al. (2017) and Konietzko et al. (2019)

Circularity Indicators at Neighbourhood Level	**Sub-Indicators**
Circular Inputs	Circular materials in buildings, renewable energy sources
Circular Activities	Effective demand reduction, resource sharing, recyclable/recoverable waste generated in the neighbourhood
Innovation	New innovations coming up in the neighbourhood
Environment and Greenhouse Gas Emissions	Resource self-sufficiency, CO_2 emission reduction

2.2 Decentralized Smart Energy Systems Enabling Circularity

2.2.1 Decentralized Smart Energy Systems and Circularity

Circularity and energy transition are essentially a part of a systemic entanglement as energy has both a direct (energy production and consumption) and indirect (energy communities) relationship with circularity. Energy systems when part of a community (neighbourhood) /city act as a leverage point to achieve circularity at a macro level (Giezen, 2018). EMF (2017) states that localised, distributed energy systems play a major role in reaching macro-level circularity. Similarly, the use of smart enabling technologies has been continually mentioned for optimization of resource flows and for a circularity transition (EMF, 2017). With the smart city movement and energy transition gaining momentum, new 'smart' innovations in energy systems are causing a revolution in the energy landscape (Geels et al., 2017). Technological, social and knowledge innovation has enabled distributed, decentralized approaches in the energy production and supply aspect while intelligent assets like Internet of Things (IoT) are providing solutions to the clean energy dilemma. Smart energy systems, which rely on active consumer participation are continuously evolving in literature. Although they are often used synonymously with smart grids (Lund et al., 2017), Lund et al. (2017) and Lammers and Hoppe (2019) define them from a systems integration perspective, where prominent focus is on not just renewable sources integration but also the integration of multiple energy carriers (electricity, heat, gas) where energy flows are balanced through energy storage technologies and ICT features enabling energy efficiency. In totality, due to the different technical components involved in a smart energy system, Lammers and Hoppe (2019) claim that the energy system gets smarter with more 'smart' components.

Authors like Ceglia et al. (2020) and Mosannenzadeh (2016) use DSES as essential at different scales to explain smart energy communities and smart energy cities (also including buildings, blocks, districts and cities) respectively, establishing a broad connection to urban development. These smart energy communities act as a social unit with the key principle of active consumerism, and take up a cooperative approach with the use of distributed, renewable DSES, thus also benefitting being sustainable (Ceglia et al., 2020; Schweiger et el., 2020). Building up on that, it is evident that DSES act as an enabler in the phase out of large, pollution emitting fossil fuel plants, improve the current infrastructure with better distribution and cause a cultural and social shift with decentralization, awareness and active consumerism, thus facilitating Ghisellini et al.'s (2016) viewpoint of assimilating CE at a macro level. Resonating with this, among the many circularity discourses present in literature, Friant et al. (2020) discuss transformation of the society through bottom-up (consumer initiated) approaches and environment friendly technologies under the transformational circular society discourse. DSES fit well under this discourse by creating a socio-cultural and socio-economic change. Therefore, although energy itself can never be completely circular like water and waste due its heat and CO2 conversions, however, these flexible, resource efficient energy systems when they form an energy community can certainly accelerate circularity as they follow numerous other principles of CE that could fasten the circularity transition not just on a neighbourhood level but on building and consumer levels too.

2.2.2 Conditions for DSES Development and Implementation that Enable Circularity

According to Schweiger et al. (2020), DSES being complex systems, numerous elements are needed to be taken into consideration for their successful development and implementation. These elements involve the tangible ones such as the technical and physical environmental aspects, along with the intangible elements like economic and social aspects. However, another major aspect which was not considered by them was the institutional and political conditions. Still positioned in the niche/grassroot stage, DSES also require considerable structural and institutional changes for their implementation, as they not only change the source and means of energy, they also change the ownership of the energy from large scale utilities (Warneryd et al., 2020). These conditions are coherent with the circularity dimensions, and will be studied in the form of drivers and barriers which also influence circularity, thus, incontrovertibly demonstrating the correlation between DSES and circularity simultaneously. It is to be noted that due to the varying names of DSES throughout contemporary literature, literature from decentralized energy systems and smart energy systems (including microgrids and advanced technologies like blockchain, storage etc. used) are reviewed and combined to get extensive results.

2.2.2.1 Technological Conditions

Technological innovation suitably fulfils the three key principles of smart energy systems, namely, decarbonization, decentralization and digitalization (Andoni et al., 2019). Smart energy technologies in DSES, typically used in smart cities increase energy efficiency and renewable integration, fulfilling the goals of energy informatics (Gimpel et al., 2020). Artificial Intelligence (AI), also known as the new electricity (Rolnick et al., 2019) and Machine Learning (ML) are used in demand-side management and to improve the renewable energy generation forecast and automatically detect disturbances in the grid in a secure way, saving up a lot of time (IRENA, 2019; Rolnick et al., 2019; O'Dwyer et al., 2019). Moreover, the use of blockchain technology with web-based apps for digital transactions facilitates prosumers and consumers in energy transactions and exchange, simultaneously improving the flexibility of the system (Hassan et al., 2019).

Correspondingly, Antikainen at al. (2018), Okorie et al. (2018) and EMF (2016) highlight technology as a major driver for achieving circularity. Okorie et al. (2018) assert that collaborative technological infrastructure and digital intelligence facilitate the 'restorative' and 'regenerative' characteristics of a circular approach which thereby leads to a CE. The technologies used in DSES enable many key action areas and synergies to reach circularity. Boon and Dieperink (2014) suggest that decentralized renewable energy technologies, blockchain etc. empower users to be more self-reliant and not so dependent on big top-down centralized energy companies using the concepts of prosumption and energy storage. Apart from that, the flexibility and reliability needed in a circular system can only be achieved through technological interventions in energy systems, such as balancing supply and demand from renewable energy sources, which further ensures resilience in the system (Metabolic, 2018).

On the other hand, according to Ravindra and Iyer (2014), these new technologies are not so easily available and usable everywhere, especially in developing countries. High technical standards are needed to implement these complex systems. Moreover, Boon and Dieperink (2014) and Andoni et al. (2019) also argue that the success of these technologies depends highly on the maturity and reliability of them. Since technologies in DSES are fairly new, a socio-technical lock-in may occur, causing a drag between the development and diffusion, which can act as another barrier to the implementation of DSES.

2.2.2.2 Economic/Market Conditions

Economic factors like investments and energy markets play an important role in any energy system to emerge (Giezen, 2018). Cost effectiveness of the system is also an important aspect/action for circularity at any scale (Williams, 2019). DSES provide many financial benefits such as cost savings on old infrastructure, fuel savings and ancillary services (Hirsch et al.,2018) that is also an integral factor towards a CE. Moreover, the rising demand for renewable energy led to lower cost of renewable sources of energy compared to traditional energy sources (Giezen, 2018; Soshinskaya et al., 2014), which further aids in provision of more incentives for lower costs to reach stability (de Jesus and Mendoca, 2018). Innovative finance mechanisms involving incentives from different stakeholders is an important driver for improvement of DSES market and in turn, its development (Mosannenzadeh et al., 2017). Apart from that, Giezen (2018) opines that liberalising the energy markets is a crucial step in transforming the traditional energy market to a more decentralized one. With the liberalization of markets, more and more private companies are encouraged to develop DSES (Kirchhoff et al., 2016), thus, initiating the top-down bottom-up aspect of circularity.

For instance, the modification of the European Union Renewable Energy Directive (RED II) as part of the Clean Energy for all Europeans Package puts consumers at the centre of the energy landscape by providing them the right to produce their own energy. Combined with the Electricity Market Directive (EMD) under the same package, the energy markets are liberalised with consumers being able to participate actively in markets in electricity generation, consumption, selling and storage, either individually or in communities (Lowitzsch et al., 2020). This strong support will result in encouraging users, local communities and start-ups to adapt to these energy systems better while providing investments, simultaneously increasing implementation of DSES in Europe (Giezen, 2018).

However, these drivers can turn into barriers to the successful development and implementation of DSES as well. Even with a low cost of renewable energy and operations, there is a need for DSES as a whole to be economically feasible for more investment and further to apply economies of scale for future lower costs (Ravindra and Iyer, 2014; Metabolic, 2018). Due to the advanced technologies and smart infrastructure, the system could incur large capital costs, installation, construction costs and hidden costs along with an uncertain return and profit (Mosannenzadeh et al., 2017). Therefore, investments from various stakeholders is an essential element for their success.

2.2.2.3 Institutional/Policy Conditions

A crucial driver cited throughout the smart energy literature is policies/regulations which aid the niche innovation (clean and smart energy) substitute the previously inefficient institutional environment (Wolfe, 2008; Hende and Wouters, 2014; Soshinskaya et al., 2014; Geizen, 2018; Mengelkamp et al., 2018; Proka et al., 2018). Institutional conditions can highly influence the emergence of disruptive/upcoming technologies and their diffusion in the social fabric. Legislative rules and regulations decide how microgrids and local energy cooperatives are implemented properly and integrated well into the traditional energy market (Mengelkamp et al., 2018). These top-down approaches such as subsidy and business support schemes, tax initiatives, energy efficiency norms etc. are necessary to support and encourage consumers and companies to make the shift to renewable energy systems (Mosannenzadeh et al., 2017; Lammers and Hoppe, 2019). For instance, national policies can assist in upscaling decentralized energy systems at a local level with disincentivizing fossil-fuel sources and the installation of low-carbon technologies (such as microgrids) (Chmutina et al., 2014).

Another potential driver to DSES implementation is the presence of a regulatory frameworks such as to tackle privacy and cybersecurity concerns. These privacy concerns could range from identity theft to acquiring information on individual behaviours of consumption (Mylrea, 2017). Even though some of the new technologies (such as AI and blockchain) are well equipped to provide secure connections (Mengelkamp et al., 2018), adequate policies are still imperative for users to trust the system. Additionally, an important institutional factor highlighted by Lemmers and Hoppe (2019) is the involvement of and clear communication between diverse stakeholders (public and private) for decision-making processes. For example, transparency in agreements about cost sharing can result in clarifying positions and therefore speed up the implementation of the DSES.

Conversely, current tariffs on the traditional fossil fuel based main grid are extensively subsidized (Kirchhoff et al., 2016), which also explains their low market price (Hvelplund et al., 2012), acting as a major barrier to DSES implementation and thereby hindering circularity. Additionally, while regulatory frameworks act as a driver, lack of these frameworks for optimum incorporation of new technologies can act as a barrier as well (de Jesus and Mendoca, 2015; Mosannenzadeh et al., 2017).

2.2.2.4 Political Conditions

The development and implementation of new regimes with the integration of clean and decentralized smart energy systems is also driven by political support (Ravindra and Iyer, 2014; Lund et al., 2017; Mosannenzadeh et al., 2017; Wouters, 2015). Political factors play a bigger role in large-scale projects (district or city) as compared to neighbourhood projects (Mosannenzadeh et al., 2017). Nevertheless, as energy and circular transition is on a lot of countries' political agenda with ambitious goals to be energy efficient and circular, the political competition and will to achieve that becomes a significant pressure point in the smart energy system implementation (Mosannenzadeh et al., 2017). Impactful policy changes require political support which can be shown via lobbying for clean energy systems and implementation of regulations supporting energy efficiency and environmental conservation (Chmutina et al., 2014; Geels et al., 2017). For example, political preferences towards liberalization of energy markets are growing as bottom-up initiatives are gaining more and more political importance, especially with the shift towards neoliberalism and the emergence of consumers as actors (Lösch and Schneider, 2016). This in turn, is helping in mainstreaming of DSES too (Geizen, 2018). While all these factors can act as drivers for DSES development and implementation, lack of political support and lobbying for fossil fuel energy systems often become barriers as well.

2.2.2.5 Socio-Cultural Conditions

Social innovation acts as a key in developing decentralized energy systems (Geels, 2017; Hoppe and de Vries, 2018). In a smarter DSES, the consumer is no longer just a consumer, but actively a prosumer. This top-down with bottom-up characteristic of DSES is particularly beneficial for societal innovation, which in turn facilitates circularity. Schot et al. (2016) claim that user participation is an integral driver in achieving sustainable and efficient energy systems. With the increasing capacity of local energy cooperatives, start-ups and prosumers exhibiting ownership and control of a democratized energy system (Giezen, 2018), these bottom-up initiatives create a sense of belonging to further reinforce the importance of participation in successfully implementing DSES (Ceglia et al., 2020). Furthermore, the social and behavioural elements of energy systems are crucial for transition to smart energy systems (van der Werff and Steg, 2016) and are often overlooked or dealt with at a later technical development stage, which cultivate the challenge of social acceptance (Hoppe and de Vries, 2018).

New technological ways of collaboration and information in smart energy systems like turning consumers into prosumers, daily energy usage data and management, and peer to peer energy trading enabled by easy to use applications tend to increase social awareness (about the environment and energy) and user's willingness to adapt to these changes and shift user preferences to a more efficient and environmentally friendly one (Lavrijssen and Parra, 2017; Mengelkamp et al., 2018; Hoppe and de Vries, 2018) and therefore enable successful implementation of DSES. However, at the same time, lack of interest, rigidity in user preferences due to existing practices, values and lifestyles can act as a major barrier for DSES to be implemented for circularity (Mosannenzadeh et al., 2017; Williams, 2019; Ceglia et al., 2020). Lastly, as DSES require visual changes in the community as well as new technological dependence, lack of trust in the system and local commitment can also become potential causes for hindrance in implementing new energy systems for circularity (Soshinskaya et al., 2014; Williams, 2019).

2.2.2.6 Environmental Conditions

Since DSES reduce fossil fuel emissions to a great extent, the opportunity for DSES implementation increases. This also becomes a major driver in achieving circularity as it directly focuses on the principle of preserving natural capital (EMF, 2015). Contrastingly, Ahl et al. (2019) throw light on the detrimental environmental impacts of non-recyclable storage batteries and other hardware (such as metals in solar panels) which could act as a barrier for DSES for environmentally aware consumers. Therefore, it is imperative for DSES to be in line with environmental regulations (Ceglia et al., 2020). Increasing regulations safeguarding the environment also support the circularity principles to a great extent (de Jesus and Mendoca, 2018).

To conclude, Table 2 summarizes the drivers and barriers for DSES implementation enabling/hindering circularity.

Table 2 Conditions and their respective drivers and barriers for developing and implementing DSES (while enabling/hindering circularity)

Conditions	Drivers	Barriers
Technological	Availability and proper integration of advanced technologies for resource efficiency and integrated energy (Ravindra and Iyer, 2014)	High technical standards Socio-technical lock-in due to technology maturity (Boon and Dieperink, 2014; Andoni et al.,2019)
Economic	Cost effectiveness (Hirsch et al.,2018) Liberalization of energy markets (Giezen ,2018) Rising demand for renewable resources resulting in increased financial incentives (Giezen, 2018; Jesus and Mendoca, 2018)	Large capital/production costs (Mosannenzadeh et al., 2017) Lack of investments/funding (Ravindra and Iyer, 2014; Mosannenzadeh et al., 2017) Uncertain return/profit (Mosannenzadeh et al., 2017)

Institutional	Regulatory framework for privacy and cybersecurity and new technologies (Mylrea, 2017; Mosannenzadeh et al., 2017) Involvement of and clear communication between diverse stakeholders for decision-making (Lammers and Hoppe, 2019)	Tariffs/Incentives on fossil fuel sources (Hvelplund et al., 2012; Kirchhoff et al., 2016) Lack of regulatory framework (Mosannenzadeh et al., 2017)
Political	Political support via lobbying for clean energy systems (Chmutina et al., 2014; Geels et al., 2017) Political attentiveness to achieve long term energy efficiency and circularity goals (Mosannenzadeh et al., 2017)	Lack of political support (Mosannenzadeh et al., 2017)
Socio-cultural	Community/user participation, collaboration (Ceglia et al., 2020) Social awareness, willingness to adapt and ease of use (Werff and Steg, 2016; Mengelkamp et al., 2018; Hoppe, 2019)	Rigidity in user preferences (Mosannenzadeh et al., 2017, Ceglia et al., 2020) Lack of trust and commitment (Soshinskaya et al., 2014)
Environmental	Environmental standards and policies (Ceglia et al., 2020)	Detrimental environmental impact (Mosannenzadeh et al., 2017; Ahl et al., 2019)

2.3 Conclusions

The previous sections discussed the theoretical background on the two primary concepts of this research - circularity and DSES. The first section briefly traversed through the varying origins and definitions of CE, the principles it entails and exploring the three scales (micro, meso, macro) these principles can be applied to. This showed the discrepancies not only in CE conceptualizations but also its three scales, therefore asserting the fact that CE is still under exploration and its characteristics keep changing. The basis of this study, i.e. neighbourhood/urban area scale is considered macro-level based on literature. Another discrepancy observed was that the concept of CE and circularity are used interchangeably but have different goals where CE is more economy oriented and circularity towards closing resource loops. This could also explain the difference in definitions, strategies and principles of a CE. Diving into the macro-level circularity, different types of CE frameworks were cited, out of which the evaluative frameworks were studied and it was found that CE frameworks predominantly focus on the country/nation level circularity or product level circularity and will therefore have to be adapted to fit the scope of this study, the neighbourhood level.

To evaluate/measure circularity at the neighbourhood level, frameworks and indicators from EMF (2015), Moraga et al. (2017) were studied together and taken as a base. Gaps were found from each framework and were incorporated in the newly developed indicators. These include- circular input, circular activities, innovation, environment and GHG emissions.

The next section explained how the energy system and circularity are entwined in a systemic entanglement through explaining what DSES are and how they influence circularity through causing a societal shift led by an active consumer participation through the use of smart energy technologies. This was followed by a literature review of the DSES development and implementation conditions under which circularity is influenced. The conditions deduced are: technological, economic/market, institutional/policy, political, socio-cultural and environmental. These conditions were further classified into DSES development drivers enabling circularity and barriers hindering circularity.

Combining DSES and circularity suggests a paradigm shift and can open new pathways for the integration of energy transition and circularity transition on a local level. There is an extensive gap in the CE literature connecting energy systems and how they influence circularity. The theoretical relationship studied between the two variables, conditions for DSES development and implementation, and circularity demonstrate their interrelation and interdependence. The derived drivers and barriers effortlessly exhibit this interrelation and can be further applied on a neighbourhood for achieving a circularity transition, ultimately leading to the main research question for this thesis, discussed below.

2.4 Conceptual Framework

Based on the literature review, the researcher formulated a conceptual framework to empirically answer the research question, "under which conditions do the development and implementation of DSES at Schoonschip, Amsterdam can accelerate neighbourhood circularity".

The framework in Figure. 1 shows how the independent variable, conditions for development and implementations of DSES, influence the dependent variable, accelerated neighbourhood circularity. The conditions for the independent variable found from academic literature are categorized under technological, economic/market, institutional/policy, political, socio-cultural and environmental, as established above and were also studied in relation to circularity. Likewise, for the dependent variable, indicators devised to measure circularity circular input, circular activities, innovation, environment and GHG emissions. These indicators will be used to measure the circularity of Schoonschip neighbourhood for an in-depth analysis. Based on this assessment, the conditions for DSES development and implementation are put into the context of this neighbourhood to find the DSES barriers and drivers that accelerate/hinder circularity so future suggestions could be given on which conditions to work on for accelerated neighbourhood circularity.

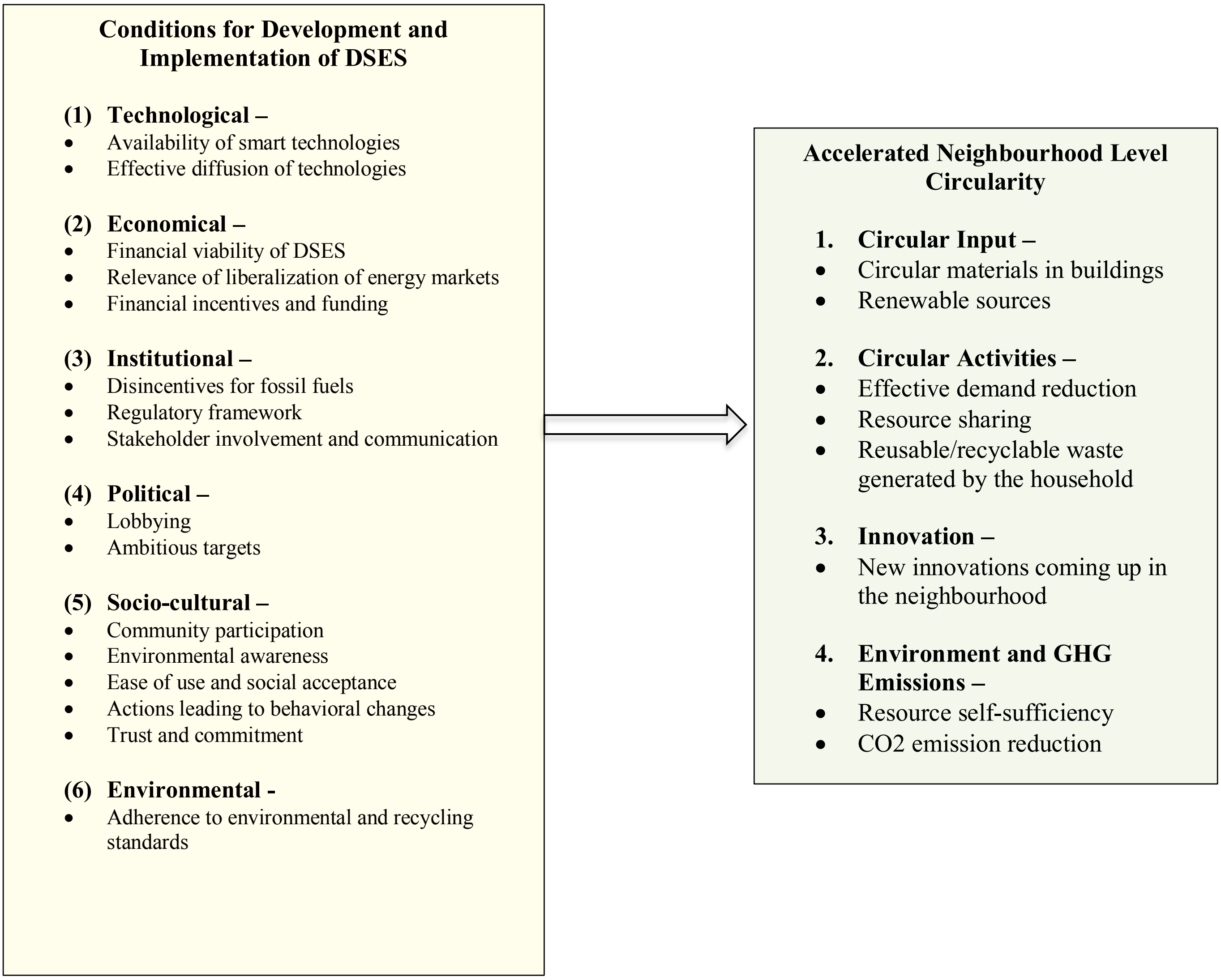

Figure 1 Conceptual Framework, Source: Author, 2020

Chapter 3: Research design, methods and limitations

3.1 Introduction

The major aim of the research is to explain the conditions under which DSES development and implementation can accelerate neighbourhood circularity - which gives the research an explanatory nature. However, since it was found from the literature review in the previous chapter that measuring neighbourhood circularity has not been studied extensively and also considering the exploratory systemic connection between DSES and circularity, the research also adopts an exploratory facet to it. The next section will focus on the numerous approaches taken in the research design for data collection and analysis to ultimately answer the research question empirically.

3.2 Research Strategy

The research strategy used to answer the main research question is case study. A case study research is based in a contemporary real-life setting where an empirical investigation is carried out on rather unique subjects with either interesting aspects to them or due to their first-time occurrence nature (Thiel, 2014). Reinforcing this, case study strategy is often used when the number of units of analysis (e.g. neighbourhoods) are fairly small and the variables influencing them are large. This strategy is particularly relevant in this research because of its exploratory and explanatory nature along with its rich attribute of providing the researcher with a much needed in-depth, holistic knowledge on the complex, contextual relationship between the variables by exploring, describing, and explaining how the independent variable (conditions for DSES development and implementation in a neighbourhood) affects the dependent variable (accelerated neighbourhood circularity) through its several subunits involved. Categorizing the case study strategy further, a causal-process training (CPT) approach is used. CPT approach works on the assumption that an outcome is a result of the combination of the deduced causal factors (Blatter and Haverland, 2012, p. 85). Focusing more on how the independent variable influences the outcome or dependent variable, CPT approach is suitable for this research, giving the researcher a comprehensive explanation from a systems thinking perspective of how the DSES were developed and implemented over time and their underlying mechanisms leading to accelerated circularity in the neighbourhood.
Moreover, the selection of the number of case studies is crucial to any research design. This research takes a single case design approach. As discussed in the previous chapter, DSES have a number of characteristics and technologies and the more components/technologies these energy systems have, the smarter they are. While different variations of DSES have been implemented in the Netherlands on different scales, the most appropriate one which fits this research would be on a neighbourhood level. Therefore, the only neighbourhood level case, Schoonschip, where a wide range of DSES components are already working is chosen. This further supports Thiel's (2014) recommendation of choosing a single case due its extreme exhibition of the phenomenon (DSES) and also CPT analysis of a rare case, with Schoonschip being an innovative pilot neighbourhood case in the Netherlands. Its large number of subunits will be studied in detail and in combination with each other. Additionally, due to the short amount of time for data collection, it is a single moment measurement.

3.3 Operationalization

The major concepts deriving from the research are ‘Circularity’ and ‘DSES’. This section will cover the operationalization part of the research, i.e. the transition of these theoretical concepts to an empirical research where they can be measured and observed (Thiel, 2014).

Table 3. List of variables and their definitions. Source: Author, 2020

Concept	Variable	Definition	Sub-variable	Definition
Circularity	Neighbourhood Circularity	A localized community/urban area within a larger district or city where water, energy and waste resource flows are circular and other innovative circular interventions lead to a low carbon, sustainable society.	Circular Input	Deals with circularity in design stage, involving material circularity (sustainable materials and design for disassembly) and renewable sources required to make the system circular.
			Circular Activities	Activities happening in the neighbourhood which satisfy circularity principles.
			Innovation	Experimentation and new business models that cause technological, social and knowledge transformation and direct it towards circularity.
			Environment and GHG Emissions	Deals with the environmental aspect of circular neighbourhoods by measuring self-sufficiency of the neighbourhood considering the natural capital, and the total amount of GHG emissions reduction by the neighbourhood.
Decentralized Smart Energy Systems	Conditions for DSES development and implementation (enabling circularity)	This variable represents the conditions, further amalgamating into drivers and barriers to the development and implementation of DSES that simultaneously accelerate neighbourhood circularity as well.	Technological Conditions	Refer to the 'smart' layer of infrastructure in energy systems and the conditions needed to implement them, which in turn help in satisfying circularity principles.
			Economic/Market Conditions	Economic and market conditions which allow the development and implementation of DSES (and to enable circularity).
			Institutional/Policy Conditions	Top-down administrative/regulatory and policy conditions favoring the development and implementation of DSES.
			Political Conditions	Conditions dealing with a desirable political environment to encourage implementation of DSES (and for circularity).
			Socio-cultural Conditions	Subjective social patterns in the neighbourhood related to acceptance, awareness and trust, which allow mainstreaming of DSES.
			Environmental Conditions	Conditions enabling preservation of the natural ecosystem through environment-friendly product use.

Table 4. Operationalization of variables and indicators. Source: Author, 2020

Concept	Variable	Sub-variable	Indicator	Sub-Indicator	Unit of Measurement	Data Collection Method	Data Source	Data Type
Circularity	Neighbourhood Circularity	Circular Input	Extent of reusing and recycling building materials in the household (design phase)	N.A	N.A; Likert for survey	Qualitative and Quantitative	Documents, Semi-structured Interviews with project developers, inhabitants, survey	Primary, Secondary
			Extent of using renewable energy sources in the household	N.A	N.A; Likert for survey	Qualitative and Quantitative	Documents, Semi-structured Interviews with project developers, inhabitants, survey	Primary, Secondary
		Circular Activities	Extent of effective demand-side management	Extent of reducing energy demand in the household	N.A; Likert for survey	Qualitative and Quantitative	Documents, Semi-structured interviews with project developers, inhabitants, survey	Primary, Secondary
				Extent of reducing water demand in the household				
				Extent of reducing waste in the household				
			Extent to which neighbourhood residents are sharing resources	Extent of sharing energy	N.A; Likert for survey	Qualitative and Quantitative	Documents, Semi-structured interviews with project developers, inhabitants, survey	Primary, Secondary
				Extent of sharing transport				
				Extent of sharing other materials				
			Extent of reusing/recycling/recovering waste generated by the household	N.A	N.A; Likert for survey	Qualitative and Quantitative	Documents, Semi-structured interviews with project developers, inhabitants, survey	Primary, Secondary
		Innovation	Extent to which the neighbourhood is a part of or stimulates an innovative environment	Extent to which new innovations come up in the neighbourhood	N.A; Likert for survey	Qualitative and Quantitative	Documents, Semi-structured interviews with project developers, inhabitants, survey	Primary, Secondary
		Environment and GHG Emissions	Extent of neighbourhood self-Sufficiency	Energy self-sufficiency in the household	N.A; Likert for survey	Qualitative and Quantitative	Documents, Semi-structured interviews with project developers, inhabitants, survey	Primary, Secondary
				Extent of water self-sufficiency in the household				
			Extent of annual GHG emission reduction by the neighbourhood	N.A				

Concept	Variable	Sub-variable	Indicator	Sub-Indicator	Data Collection Method	Data Source	Data Type
Decentralized Smart Energy Systems	Conditions for DSES development and implementation enabling circularity	Technological Conditions	Availability and use of smart technologies enabling energy sharing and efficiency	N.A	Qualitative	Semi-structured interviews with project developers/experts	Primary
			Extent of effective diffusion of smart technologies with high technical standards (maturity)		Qualitative	Semi-structured interviews with project developers, inhabitants	Primary
		Economic/Market Conditions	Extent of economic viability of DSES implementation	Extent of economic viability of DSES capital costs	Qualitative and Quantitative	Semi-structured interviews with project developers, inhabitants, survey	Primary
				Extent of economic viability of DSES operational costs			
				Extent of cost savings/ profit made with DSES implementation			
			Relevance of liberalization of energy markets	N.A	Qualitative	Semi-structured interviews with experts and institutional actors	Primary
			Extent to which financial support/incentives were provided	Extent of financial support provided by public sector (subsidies)	Qualitative	Semi-structured interviews with project developers	Primary
				Extent of financial support provided by the private sector			
		Institutional/Policy Conditions	Extent of disincentives for fossil fuel use	N.A	Qualitative	Semi-structured interviews with experts and institutional actors	Primary
			Presence of robust regulatory framework	Extent of robustness of present regulatory framework for privacy and cybersecurity	Qualitative	Semi-structured interviews with experts and institutional actors	Primary
				Relevance of other regulatory frameworks encouraging DSES			
			Extent of involvement of and communication between different stakeholders for decision-making	Extent of diverse stakeholder involvement and collaboration	Qualitative	Semi-structured interviews with experts and institutional actors	Primary
				Extent of clear communication between involved stakeholders			

		Political Conditions	Extent of lobbying for clean energy/ circularity that led to development of DSES	N.A	Qualitative	Semi-structured interviews with experts and institutional actors	Primary
			Presence of ambitious overall targets that facilitate political support for DSES				
		Socio-cultural Conditions	Participation of inhabitants	N.A	Qualitative and Quantitative	Semi-structured interviews with project developers, inhabitants, survey	Primary
			Ease of use by end users				Primary
			Environmental awareness raising of residents				Primary
			Availability and relevance of actions related to inducing behavioural change (lifestyle, values etc.)				Primary
			Trust and commitment by residents				Primary
		Environmental Conditions	Presence of environmental and recycling standards to adhere to	N.A	Qualitative	Semi-structured interviews with project developers/experts	Primary

3.4 Data Collection Methods and Sampling

3.4.1 Data Collection Methods

This research uses a mixed-method approach, although it is predominantly qualitative in nature with major emphasis given to semi-structured interviews. However, quantitative data is also used to support and get a deeper understanding of the qualitative data. Apart from that, secondary data collection with the help of documentation are also used to provide the researcher with an in-depth examination of the selected case as well as to solve the issue of validity and reliability in case study strategy (discussed in length in the next section) with data triangulation.

For the qualitative part, the data collection method for this research relied largely on in-depth semi-structured interviews with key stakeholders. Interviews add the flexibility in data collection as the researcher can ask additional supplementary questions to gain a deeper understanding of the response given by the respondents to strengthen their case (Thiel, 2014). The end product of interviews provides a series of non-factual, subjective data as well as some factual objective information supporting quantitative analysis (for triangulation) (Thiel, 2014). Moreover, this data collection method helps in finding new insights into the variables as well, which could well explain the relationship between the two variables.

A two-step non-probability sampling approach involving purposive and snowball sampling was adopted in this case. The purposive sampling from extensive desk research resulted in shortlisting of three groups of stakeholders/respondents for interviews - project experts/project developers, institutional actors and community. Experts represented the individuals/organizations working on the selected case study (consultancy, NGO, academia). Institutional actors consisted of individuals from the municipality or the ones who had an administrative role in the implementation of DSES in the selected neighbourhood whereas the community represented the key informants living in the neighbourhood. Therefore, three separate interview guides were prepared simultaneously based on the operationalization of variables (annex 2). The snowball sampling approach further helped in reaching out to community members and other related experts with respondents referring to new useful respondents. Furthermore, the size of the sample was not defined firstly as the number of stakeholders involved in the case study were limited. It was also dependent on the 'saturation' principle, which is used as a criterion for discontinuing data collection when no additional information can be found (information starts getting repetitive) (Saunders et al. 2017). In total, 15 stakeholders were approached for the interview. However, the final number of interviews was 10. A list of all interview respondents is attached in Annex 2. Although most interviews were semi-structured as mentioned above, a couple of additional open interviews were conducted with experts after getting referred to them for a broader project information.

Apart from semi-structured interviews, content analysis method to study policy and legal documents, websites, webinars and podcasts etc. was also used in the data collection that further helped in data triangulation. Additionally, experts/stakeholders were also consulted on the selection/provision of documents. This data collection method is used predominantly for proving facts and opinions and also to reconstruct arguments (Thiel, 2014). A list of all documents referred is attached in annex 2 for reference.

The quantitative part to support the qualitative part of this study used a questionnaire. A survey method fits this research due to the community perspective, attitudes, behaviour at power in this research as well as in the context of the selected case which is relatively new and not much researched upon (Thiel, 2014). It was also helpful as the selected case had many houses with differing designs. Due to the corona pandemic, an online 5-point Likert survey (starting from 1, denoting 'poor' to 5, denoting 'excellent') was prepared instead of going to the neighbourhood. The sampling was done by mixing convenience sampling and self-selection sampling methods.

The people who were interviewed were approached to further distribute the survey within their neighbourhood online group and through their newsletter, which resulted in individuals to voluntarily choose to participate. With the neighbourhood population of 105 inhabitants living in 46 households, the total number of respondents came to 26 out of those (n=26) or 56% of the neighbourhood population (in terms of households). Out of those, a little below half (42.3%) had lived in Schoonschip for more than a year while the rest (57.7%) had lived less than a year there, thus incorporating views from both residents who were there since the beginning and the ones who joined later. While these sampling techniques may form a sampling bias in the research, they are effective due to people's willingness to give more insights and also save time.

3.5 Validity and Reliability

Validity and reliability are considered important aspects of a scientific research (Thiel, 2014). There are two kinds of validity: internal and external. Internal validity examines whether the researcher has successfully measured what they planned to measure through effective operationalization while the external validity explores the extent to which the research findings can be generalized (Thiel, 2014). Reliability on the other hand investigates the accuracy and consistency with which the variables have been operationalized (Thiel, 2014). Additionally, research lacking in reliability lacks in validity as well.

A case study approach may have issues of validity and reliability as limitations due to its characteristic of analysing a small number of units, which need appropriate measures to be managed properly. Due to the comprehensive in-depth information collected in a case study approach, the internal validity of the research remains high. To further instigate the high internal validity, data triangulation plays a crucial role in this research. Therefore, the use of documents, podcasts etc. in secondary data mixed with interviews provided adequate data triangulation. Apart from that, theoretical triangulation was also achieved by interviewing three different groups of stakeholders, generating three different points of views to the variables. The external validity of this research is also high due to the use of surveys. Moreover, the aim of this research is to study the relationship between DSES implementation and neighbourhood circularity in a particular context (of Schoonschip), which may serve as a basis for developing this relationship as well as the concept of neighbourhood circularity further theoretically (Thiel, 2014). This is known as theoretical generalization. As many neighbourhood projects with DSES in the Netherlands are in the conceptual or construction phase currently, conclusions from this research may guide them further. Moreover, to deal with the reliability of the research, the researcher was transparent throughout their research and documented all steps and data sources in the form of a database, as suggested by Thiel (2014). The case study protocol was used to make the data collection and analysis process more systematic (Thiel, 2014). Finally, the interview manuals for each group ensured a structured and consistent flow of questions.

3.6 Data Analysis Methods

This study used multiple methods for data collection, therefore different analysis methods were used on them. For the qualitative data analysis resulting from semi-structured interviews and content analysis, which also covers a major portion of this research, the software, Atlas.ti was used. The collected data was further divided into smaller sub categories and appropriate codes were assigned to each after reviewing, comparing and grouping the text from different interviews, podcasts, videos and documents to ensure theoretical saturation. The findings were used in the form of most recurring codes, co-occurrence tables and network diagrams (systems mapping) to show the relationship among and between the sub-variables. The quantitative data was analysed through descriptive statistics and was carried out manually due to the low number of variables regarding that. The survey was in Likert scale form. By measuring the mean (average), median (central tendency), mode (frequency)and standard deviation (dispersion) of the responses, trends regarding circularity in the neighbourhood were calculated. This was simultaneously supported by interview data.

3.7 Challenges and Limitations

The research faced many challenges during data collection. Firstly, the case study chosen started operating last year only, therefore there was no numerical yearly data recorded till now in terms of circularity indicators. The operationalization had to be modified to accommodate this fact and the study collected new data through surveys and interviews and supported it with secondary data. It was expected to conduct the survey face-to-face however they had to be done online due to pandemic lockdown followed by Schoonschip not entertaining tours or survey requests. As a result, a 100% response rate was not met (only 56% which is more than half nonetheless), with a slight possibility of multiple respondents from a household. This may have affected the reliability of the results, however this was solved by data triangulation, by interviewing key informants and also through podcasts and launch events that included perspectives of many residents from different households. Because of the pandemic, a second case study was also not chosen for cross comparison as lesser number of people would've been accessible for interview and surveys. Additionally, majority of the interviews were conducted online through video call. Due to this, some respondents also preferred to answer the questions textually. It is to be noted however that all questions for analysis were sufficiently answered.

Chapter 4: Presentation of data and analysis

4.1 Introduction

In this chapter, theory is challenged and confirmed by practice using the selected case study. The variables and indicators deduced from the literature review are used against the neighbourhood Schoonschip and the data is presented in a concise form. The following section will answer the sub-questions based on the results of the data collection and analysis, while subsequently answering the main research questions by comparing and connecting the two variables.

4.2 Neighbourhood circularity – Measuring Schoonschip against circularity indicators

4.2.1 Circular Input

Extent of reusing and recycling building materials in the household (design phase):

The choice of building materials during the design of each house was a major focus point for Schoonschip during its development. Substantial emphasis was laid on circular material management with the use of low-impacting, recycled and reusable materials in the construction phase. The community members with the help of Metabolic did ample research and made themselves aware of different options for environmentally friendly natural materials. A material passport was prepared by Metabolic that not only looked at the end material information but also the total material throughput, incorporating their local context, extraction, manufacturing and toxicity assessment (Secondary data source 4) . These materials were then coded into red, orange and green based on their appropriateness and circularity, which was particularly useful due to the difference in architecture of each houseboat. This way the architects and the residents could choose from a uniform set of materials while keeping them sustainable simultaneously (Material passport shown in annex 1).

However, despite the high ambitions and extensive research, Schoonschip missed out on being 100% circular in its design. According to the conducted survey (n=26), 38.5% (10 out of 26) of the respondents rated the extent of reusing and recycling building materials as ‘very good (4)’, 30.8% (8) of them rated it as ‘satisfactory (3)’, while 23.1% (6) and 7.7% (2) picked ‘fair (2)’ and ‘excellent(5)’ respectively (Chart 1).

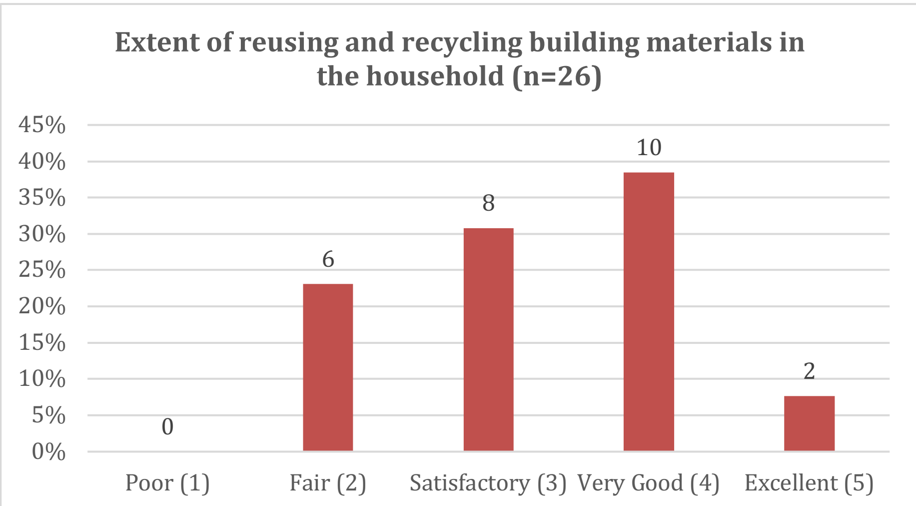

Chart 1. Survey results for extent of reusing and recycling materials in the household

This resulted in the total mean for the indicator to come to 3.31, indicating the average result of the material indicator to be 'satisfactory' (Table 5).

Table 5 Descriptive statistics for extent of reuse and recycling building materials in household

Question	Total (n)	Mean	Median	Mode	Standard Deviation
Extent of reusing and recycling building materials in the household	26	3.31	3	4	0.928

The reason for this score was reflected in the interviews and secondary data. As per an inhabitant and project developer (Interviewee 1), lack of time (as municipality had deadlines and rules), finances and knowledge played a role in the satisfactory score for material circularity. For example, relatively sustainable materials like in the case of insulation were opted out due to their labour intensiveness, extra space, aesthetics and time consumption while some materials were just not always affordable. Some natural materials had lower carbon footprint but were not that efficient (Interviewee 3). Moreover, even though the material passport helped the residents greatly, it was not realistically possible for them to assess all the materials, combined with their lack of building design background. There were often debates about using certain materials coded orange or green. As an example, even though recycled concrete was used as the base of each house, it still accounted under unsustainable. Lastly, some advanced design for disassembly techniques were also not advanced enough or easy to adopt by the architects as well, adding to the whole process being extremely complex (Interviewee 8).

Extent of using renewable energy sources in the household:
Local renewable energy sources such as solar panels and solar PV were also included in the design. Moreover, since energy is also produced from and used in materials (input energy, performance, recycling etc.) consideration was also given to choosing materials from renewable sources in the material passport (Interviewee 3). Most houses have passive house standards and are oriented in an optimal way to take maximum advantage of sunlight. Energy is self-generated by the 500 solar panels installed in all houses with only one connection to the main grid. Even so, Schoonschip houses do draw power from the main grid at least during winter time due to shortage of sunlight then. Correspondingly, the survey (n=26) analysis showed the same, with the average result for the extent of using renewable energy sources coming to 4.35, i.e. 'very good (4)' (Table 6) with 15 out of 26, which is more than half of the respondents (57.7%) choosing 'very good (4)', 38.5% (10) choosing 'excellent (5)' and just 3.8% (1) of them going for 'satisfactory (3)' (Chart 2).

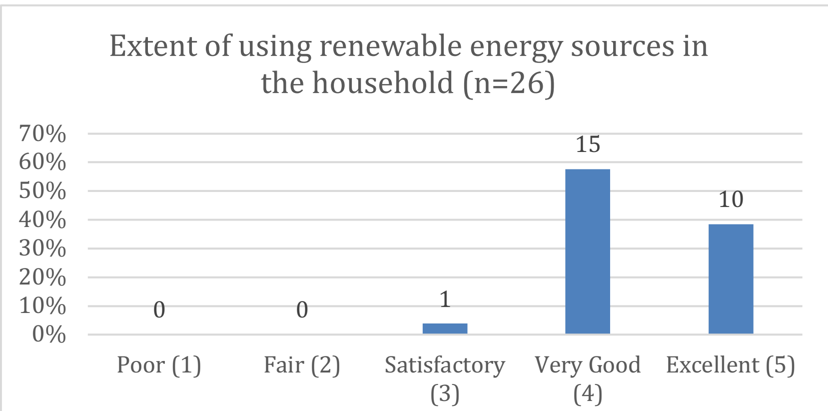

Chart 2 Survey results for extent of using renewable energy sources in the household

Table 6 Descriptive statistics for extent of renewable energy sources in the household

Question	Total(n)	Mean	Median	Mode	Standard Deviation
Extent of using renewable energy sources in the household	26	4.35	4	4	0.562

4.2.2 Circular Activities

Extent of effective demand-side management:
Schoonschip has a multi-faceted outlook on reducing resource demand in households with the help of not only advanced technologies but also through awareness.

a) Extent of reducing energy demand in the household:
Reduction in energy demand is interlinked with Schoonschip's circular design, in terms of using energy efficient electrical installations such as lighting, microwave, dishwasher etc. that do not put much load on the energy grid (Secondary data source 1). Moreover, the energy management system with the smart grid gives them energy consumption predictions on their smart dashboard that further aids in energy conservation through awareness (Secondary data source 3; Interviewee 1,2). With respect to energy, statistics from the survey (n=26) show that the average answer for 'extent of reducing energy demand in the household' was 'very good (4)' with the mean of 4.12 (Table 7). Although the majority of the respondents (42.3% with 11 respondents) went for 'excellent (5)', 34.6% (9) chose 'very good (4)', whereas 15.4% (4) and 7.7% (2) of them chose 'satisfactory (3)' and 'fair (2)' respectively (Chart 3).

b) Extent of reducing water demand in the household:
For water demand reduction, a lot of houses have their own rainwater collection systems which they use to water their rooftop gardens. The toilets also use rainwater and by installing vacuum pumps in toilets, the water consumption is minimal. In addition to that, majority of the houses have recirculating showers where water is recirculated via smart systems that not only help in reducing water consumption but also save up energy (Secondary data source 4; Interviewee 1). Reflected equally in the survey results, the average for the extent of water reduction also was close to 'very good (4)' (Table 7), with 46.2% (12 out of 26) of respondents choosing 'very good (4)', while 26.9% (7) and 19.2% (5) of them went for 'satisfactory (3)' and 'excellent (5)', leaving just 7.7% (2) of them choosing 'fair(2)' (Chart 3)

c) Extent of reducing waste in the household:
The lowest mean within this indicator was observed in the case of extent of waste reduction, reaching a 3.1 which indicated it to be 'satisfactory (3)'. 50% (13 out of 26) of the respondents leaned towards rating it as 'very good (4)', 23.1% (6) of them went for 'satisfactory (3)' and 'fair(2)' each, while none rated it as 'excellent (5)' (Chart 3).
It is mostly the residents applying waste reduction practices in their daily lives by buying food together at times, one household cooking for the community every week, growing some food on rooftop gardens etc. (Interviewee 1). However, while these solutions are being used by most residents, not all residents have opted for these solutions especially the water systems such as the rainwater collection systems. But an inhabitant (Interviewee 2) also pointed out that gradually more and more residents are getting interested through smart systems and group involvement.

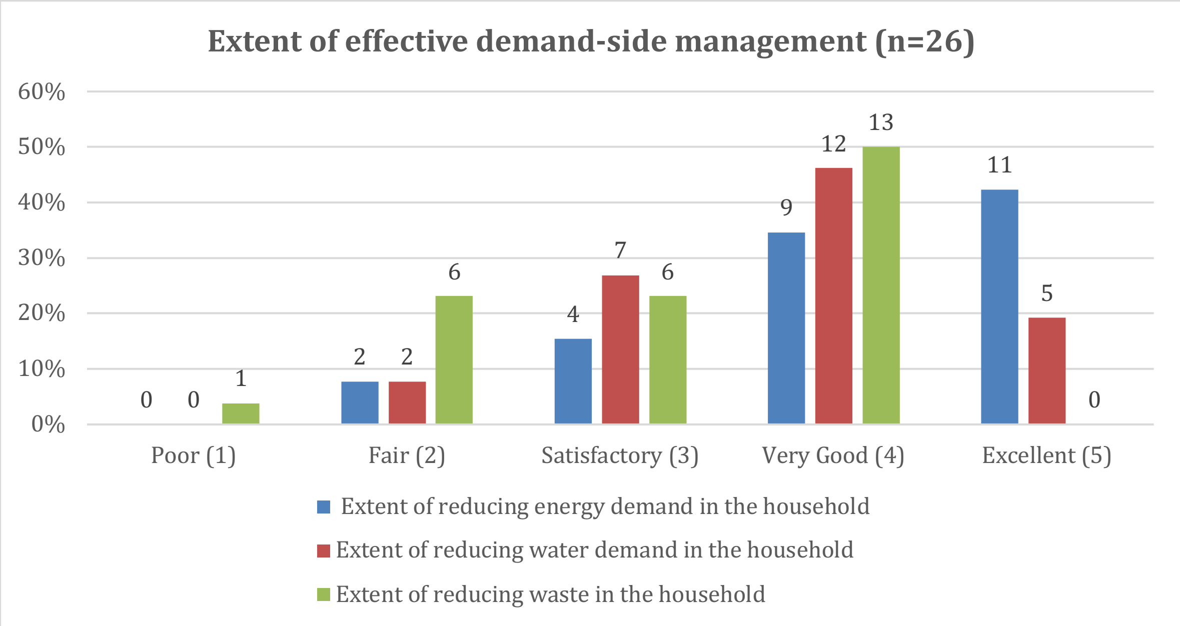

Chart 3 Survey results for extent of effective demand-side management

Table 7 Descriptive statistics for extent of effective demand-side management

Question	Total(n)	Mean	Median	Mode	Standard Deviation	Average Mean
Extent of reducing energy demand in the household	26	4.12	4	5	0.952	3.7
Extent of reducing water demand in the household	26	3.77	4	4	0.863	
Extent of reducing waste in the household	26	3.19	3.5	4	0.939	

Extent to which neighbourhood residents are sharing resources:

a) Extent of sharing energy:

For the extent of sharing energy indicator, a high average of 4.4 was calculated. More than half of the respondents (53.8, i.e. 14 out of 26) went for 'excellent (5)', while 34.6% (9) chose 'very good (4)' and only 11.5% (3) rated it as 'satisfactory (3)' (Chart 4). This is well resonated in the interviews and secondary data which reinforce the strong concept of sharing energy between households with the help of the advanced smart energy systems developed by Grid-Friends[1]. The AI enabled smart grid, while drawing energy from the solar panels also allow surplus energy to be passed on to neighbours without any human intervention. Moreover, the community is in process

[1] Grid-Friends is a consortium of researchers and project partners, comprising of CWI, Fraunhofer Institute (ITWM) and Spectral. Together they developed Schoonschip's DSES that optimized flexibility through autonomous agents with the local energy management system, microgrid coordination platform and decentralized energy market.

of connecting its smart grid to other smart grids around Schoonschip where people can exchange energy on a local energy market platform under the EU funded project, ATELIER[2].

b) Extent of sharing transport:
With the sustainability ambition among community members, shared mobility played an important role. Schoonschip partnered with a private company Huub to experiment with the idea of mobility as a service. Huub provided them with electric modes of transport (EV, E-bikes etc.) for them to share among each other and the municipality gave them the land for experimenting (Interviewee 1,2). The neighbourhood also is currently experimenting with electric boats. Consequently, they also come across some issues related to charging those vehicles in regard to their charging time consumption and other technical points (Interviewee 1). Reiterating that, the survey statistics (n=26) show that 50% (13) of the respondents picked 'very good (4)' for the extent of sharing transportation. Following that, 42.3% (11) picked 'excellent (5)' whereas only 3.8% (1 respondent) picked 'satisfactory (3)' and 'fair (2)' each (Chart 4), bringing the mean to 4.31 (Table 8).

c) Extent of sharing other materials:
Schoonschip inhabitants practice sharing as a lifestyle. The community has an extremely useful mobile application called 'Schoonschip Marktplaats' where they can exchange/give away products, clothes, art etc. among each other. Residents are also developing a big kitchen in their clubhouse so they could make food there and open a food service. Moreover, although the initial development plan involved residents to share washing machine appliances as well, this could not come to fruition and at the moment they have their own washing machines (Secondary data source 3). Likewise, residents selected 'very good (4)' for the extent of sharing products the most, with a percentage of 46.2% (12 out of 26), followed by 34.6% (9) going for 'excellent (5)' and 19.2% (5) picking 'satisfactory (3)' (Chart 4). The average score is calculated to be 4.15 (very good) (Table 8).

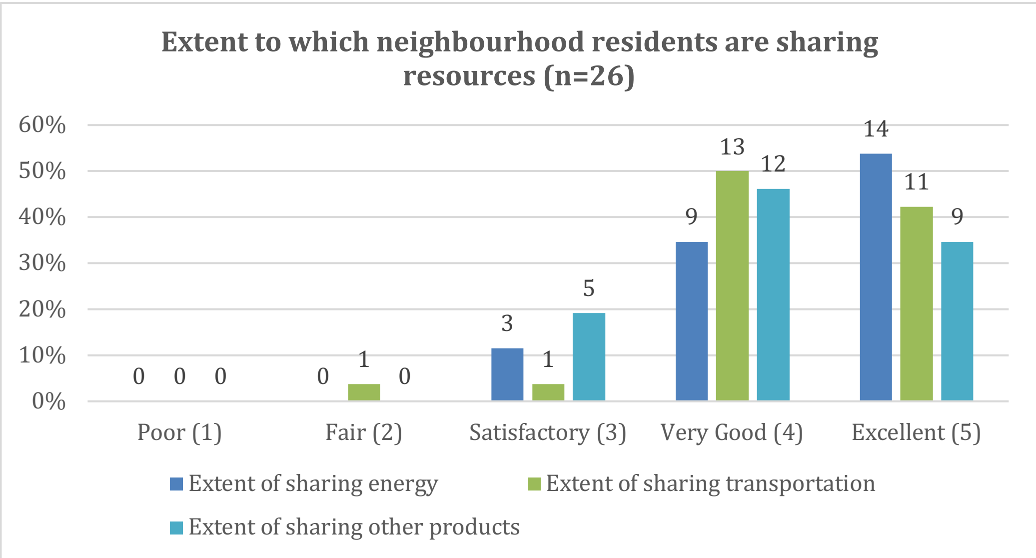

Chart 4 Survey results for extent to which neighbourhood residents are sharing resources

[2] ATELIER is an EU funded, AmsTErdam and BiLbao cItizen drivEn smaRt cities project currently developing citizen-driven Positive Energy Districts (PEDs), where different neighbourhood smart grids will be united into one energy community/market to ensure local exchange of energy.

Table 8 Descriptive statistics for extent of sharing resources

Question	Total (n)	Mean	Median	Mode	Standard Deviation	Average Mean
Extent of sharing energy	26	4.42	5	5	0.703	4.3
Extent of sharing transportation	26	4.31	4	4	0.736	
Extent of sharing other products	26	4.15	4	4	0.732	

An additional observation was also made in the aspect of sharing resources. Based on the community sharing mobility through a common parking space and their plan to use common clubhouse kitchen for food sharing, it can be said that there is some level of sharing of space among the residents as well.

Extent of reusing/recycling/recovering waste generated by the household:
The relatively lower score in waste reduction is followed by a similar average score in the extent of reusing/recycling/recovering waste generated by the households. While none of the respondents from the survey rated it as 'poor (1)' or even 'excellent (5)', 26.9% (7 out of 26) of them chose 'fair (2)', 30.8% (8) of the sample picked 'very good (4)' and 42.3 (11) of them chose 'satisfactory (3)' (Chart 5), thus bringing the average to 3, denoting 'satisfactory (3)' (Table 9).

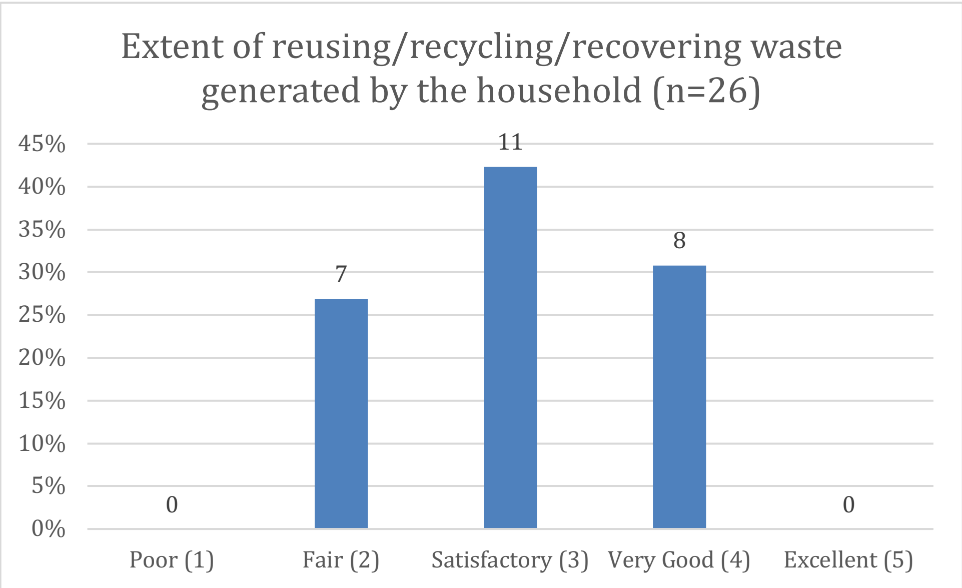

Chart 5 Survey results for reusing/recycling/recovering waste generated by the household

Table 9 Descriptive statistics for extent of reuse/recycling/recovery of waste by the household

Question	Total (n)	Mean	Median	Mode	Standard Deviation
Extent of reusing/recycling/recovering waste generated by the household	26	3.04	3	3	0.774

The community firstly separates out different kinds of waste, from which the organic waste is often used in composting pits present in Schoonschip (Interviewee 1). In the case of wastewater, biogas is distilled from the black wastewater coming from the vacuum toilets and a rare fertilizer, phosphate is extracted by Waternet, the regional water supply company (Secondary data source 4; Interviewee 3). The waste heat from showers is also recovered. Nonetheless, according to interviewee 1, there is still large quantities of waste generated by households which are stored in the municipality containers. To further study the waste flows, this was asked in an interview with a municipality representative. It was, in point of fact, indicated that the majority of the waste collected by the municipality gets incinerated, but waste-to-energy systems have come up that provide heat and electricity to a major part of the city from burning waste (Interviewee 6). Other remaining household waste gets recycled. This contradictory information shows that waste recycling and recovery does happen but on a larger city scale and not neighbourhood scale and stipulates that residents may not be fully aware of what happens to their waste once they dispose it.

4.2.3 Innovation

Extent to which the neighbourhood is a part of or stimulates an innovative environment:
The highest score attained by Schoonschip is for its innovation, with an average of 4.5, indicating its performance in the extent to which it stimulates an innovative environment towards 'excellent (5)' (Table 10). Undoubtedly, Schoonschip acts as a living lab, continually experimenting with new technologies, business models and social innovation and is also a part of the district level innovation of Buiksloterham. More and more countries are following the new innovations at Schoonschip despite its smaller scale. With 53.8% (14 out of 26) and 46.2% (12) of the respondents rating the ' extent to which new innovations come up in the neighbourhood' as 'excellent (5)' and 'very good (4)'in the survey (n=26), none of the respondents picked the remaining choices (Chart 6).

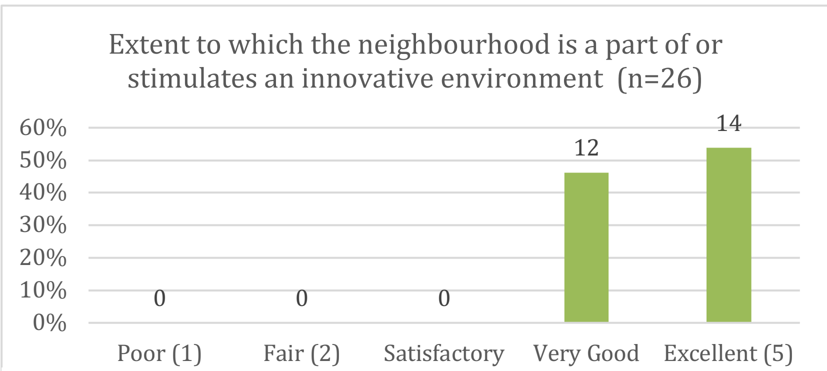

Chart 6 Survey results for extent to which the neighbourhood is a part of or stimulates an innovative environment

Table 10 Descriptive statistics for extent of new innovations coming up in the neighbourhood

Question	Total	Mean	Median	Mode	Standard Deviation
Extent to which the neighbourhood is a part of or stimulates an innovative environment	26	4.53	5	5	0.50839

In the words of a interviewee 6, Schoonschip is 'learning by doing'. As a matter of fact, Schoonschip inhabitants have established a separate foundation, the Pioneer Vessel (VVE) in 2019 to just focus on new innovations for sustainability. The inhabitants who actively contribute to this give extra economic benefits such as discounts on energy or mobility costs. The neighbourhood has been experimenting with various new business models and technologies like shared mobility, smart energy and water systems etc. There was also no project developer for the development of Schoonschip, it is the community participation which brought them to this level of sustainability, though it took longer than anticipated. Governance within the community is also innovative, with each household having their vote for any decision for the whole neighbourhood. Knowledge is disseminated not just through smart dashboards, but also among community members and beyond them through guided tours, podcasts and their website. New sustainable projects on biodiversity, positive energy districts are in process there and in general the neighbourhood sets an exemplary example of technological and social innovation, thereby providing social and economic advantages.

4.2.4 Environment and GHG Emissions

Extent of neighbourhood self-sufficiency:

a) Extent of energy self-sufficiency:

Schoonschip has received well deserved attention for its innovative ways to make the neighbourhood as energetically self-sufficient as possible. The neighbourhood does not use any natural gas. The use of heat pumps to extract energy from surface water, converting wastewater into energy, recovering waste heat from showers, smart grid that allows the use of renewable energy sources fully with excess power generation in summer months and a battery storage system to store it are just to name a few. Combined with the building design and efficient installations, their drive to be sustainable and their advanced smart energy dashboard monitoring their real time energy use while helping in limiting energy demand, the neighbourhood has achieved self-sufficiency to a tremendous extent. The EPC (Energy Performance Coefficient), which is a measure of energy efficiency is 0.0 for each building in Schoonschip, despite the national maximum level of 0.4 (Interviewee 5,6; Secondary data source 4).

Moreover, as explained by an inhabitant and project developer (Interviewee 1), while houses are not completely autarkic and still need to draw power from the main grid in winter, the energy demand and supply is managed well among the residents. In fact, his house was able to achieve net zero energy use for a whole year as well. While it is noteworthy that this is not be the case for every household, another inhabitant (Interviewee 2) mentioned that people are gradually learning and applying. This level of self- sufficiency also came at the cost of some compromise, in regards to not having big terraces (to use more solar energy), windows, aesthetics etc. Furthermore, as per the interviewee from Metabolic (Interviewee 3), the energy systems could have been optimized even more if there weren't some stringent rules by the municipality. Also, the electric vehicles still use energy from the grid and are not connected to Schoonschip's smart energy system, which was the ideal plan.

Naturally, the survey results (n=26) show the same, with 34.6% (9) respondents rating the extent of energy self-sufficiency in the household as 'excellent (5)' and the remaining 65.4% (17) going for 'very good (4)' (Chart 7), bringing the mean to 4.35 (Table 11).

b) Extent of water self-sufficiency:

For water self-sufficiency, the ambitions were high during the planning of Schoonschip. However, with many experimentations, discussions and debates, some solutions were not used (Secondary data source 4). The water supply is connected to Waternet, the regional water supply company because the initial plan of using canal water did not work out due to brackish water concerns (Secondary data source 4). Regardless, all houses have recirculating showers and the wastewater from toilets is treated for resource recovery. Only a few households have the rainwater collection systems which are connected to flushing toilets (Secondary data source 4). There were debates on the feasibility of these systems if the vacuum toilets anyway use minimum amount of water. Additionally, one of the inhabitants in the survey mentioned that there is still a lot of extra water usage in watering plants and showering after swimming the water channel (which is poisonous). Referring to creating more awareness and staying informed about water shortage, one respondent also wrote, "One feels arrogant asking neighbours to use rain water for watering plants".

Building up on that, the mean from the survey (n=26) was calculated to be 3.5, showing that the extent of water self-sufficiency in the neighbourhood is between 'satisfactory (3)' and 'very good (4)' (Table 11). 50% (13) of the respondents voted 'very good (4)' while 38.5% (10) and 7.7% (2) went for 'satisfactory (3)' and 'fair (2)' respectively (Chart 7).

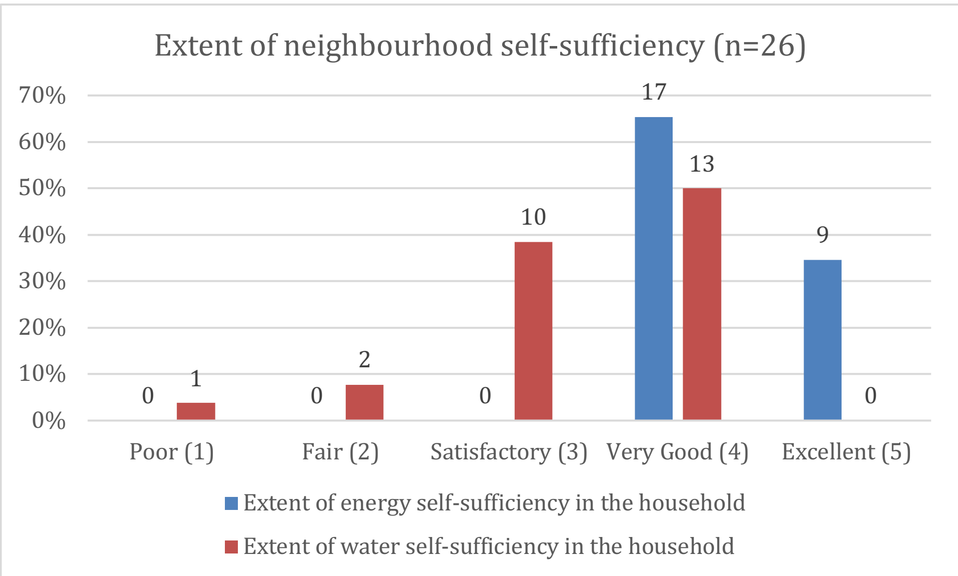

Chart 7 Survey results for extent of neighbourhood self-sufficiency

Table 11 Descriptive statistics for extent of neighbourhood self sufficiency

Question	Total	Mean	Median	Mode	Standard Deviation	Average mean
Extent of energy self-sufficiency in the household	26	4.35	4	4	0.485	3.9 (4)
Extent of water self-sufficiency in the household	26	3.50	3.5	4	0.797	

Extent of annual GHG emission reduction by the neighbourhood:

On being asked to rate the extent of reducing greenhouse gas emissions through the above-mentioned activities in the neighbourhood, more than half the respondents (14 out of 26) rated it as 'very good (4)', 30.8% (8) of them rated it as 'excellent (5)' along with 15.4% (4) going for 'satisfactory (3)' (Chart 8). The mean calculated comes to 4.15, indicating the average answer to be 'very good (4)' (Table e). Information from secondary data is in line with this, with Spectral and Metabolic in their annual impact report informing that the total GHG emissions of the area were reduced by 20% annually (Secondary data source 7). Quite self-explanatory from the above-mentioned activities, whether it is the passive house standards, or the innovative energy reducing/reusing smart grid with information on energy usage and CO2 emission reduction per household or even the mobility project leading many inhabitants to sell their cars (Interviewee 2), a combination of all these has led to a significant decrease in the GHG emissions of the neighbourhood. Biodiversity (bees and plants) and local materials are additional enablers.

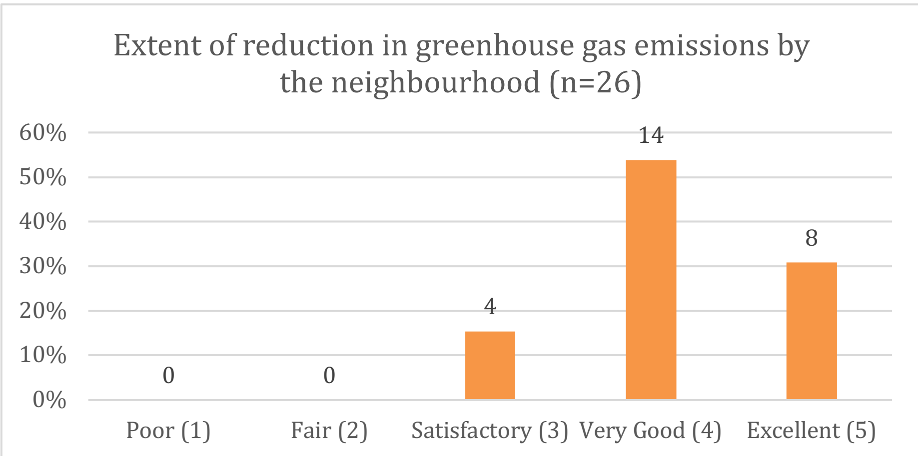

Chart 8 Survey results for extent of reduction in GHG emissions by the neighbourhood

Table 12 Descriptive statistics for extent of GHG emission reduction by the neighbourhood

Question	Total	Mean	Median	Mode	Standard Deviation
Extent of reduction in greenhouse gas emissions through the above-mentioned activities by your neighbourhood	26	4.15	4	4	0.675

4.2.5 Discussion

In descriptive statistics for a 5-point Likert scale, a mean score above 3.5 is seen as a positive result. Schoonschip is able to achieve a positive score in majority of the indicators. Table 13 shows an overview of the average from all circularity indicators.

Table 13 Average circularity scores of Schoonschip per sub-variable

Sub-variable	Indicator	Mean per indicator	Mean
Circular Input	Extent of reusing and recycling building materials in the household	3.31	3.8
	Extent of using renewable energy sources in the household	4.35	
Circular Activities	Extent of effective demand-side management	3.70	3.7
	Extent of sharing resources	4.30	
	Extent of reusing/recycling/recovering waste generated by your household	3.04	
Innovation	Extent to which the neighbourhood is a part of or stimulates an innovative environment:	4.50	4.5
Environment and GHG Emissions	Extent of neighbourhood self-sufficiency	3.90	4
	Extent of annual GHG emission reduction by the neighbourhood	4.15	

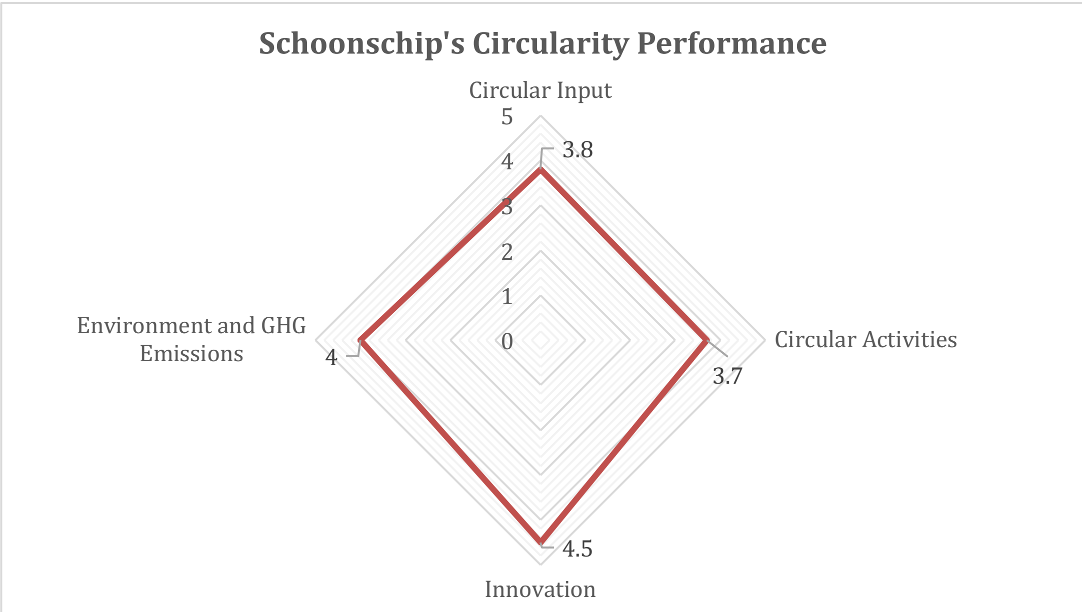

Figure 2 Schoonschip's circularity performance

While Schoonschip performs extremely well in the 'Innovation' and 'Environment and GHG Emissions' sub-variables with an average of 4.5 and 4 respectively, it performs the least in 'Circular Activities' with a score of 3.7, followed by a close 3.8 for 'Circular Input' (Figure 2). The overall score for Schoonschip is calculated to be 4, denoting the circularity of the neighbourhood to be 'very good (4)'. It can be seen that even the lower performing sub-variables are still on the positive side and there is not a great difference between the highest and lowest performing ones. The low score of 'Circular activities' is mainly due to the waste reuse/recycle/recover indicator (scoring a 3) within that sub-variable while it is the material reuse/recycle indicator (scoring 3.31) in the case of 'Circular Input' score. The interviews and secondary data, as presented above, align with majority of the survey results, also validating the low score for 'Circular Input' (through material circularity). A discrepancy found between interviews and survey was in the case of 'Circular Activities'. The indicator 'extent of waste reuse/recycling/recovery by the household' within it, scores the least even though the municipality uses the waste to generate energy on a bigger city scale (Interviewee 6). The inhabitants may not have known of what happens to their waste afterwards which shows a gap in perception/knowledge between the inhabitants and the municipality. In totality, in order to improve the circularity of Schoonschip, emphasis should be given more on 'Circular Input' and 'Circular Activities'.

Through the interviews, another interesting finding was the systemic connection between the sub-variables of circularity through their indicators. The co-occurrence table coded between the sub-variables is shown in Table 14. It can be seen that all sub-variables are related to one another, with the most recurring interrelation being that of 'Circular Activities' and 'Environment and GHG Emissions'.

Table 14 Co-occurrence table between circularity sub-variables, Source: Author 2020

	NC: Circular Input	NC: Circular Activities	NC: Innovation	NC: Environment and GHG Emissions
NC: Circular Input (CI)	-	7	2	7
NC: Circular Activities (CA)	7	-	5	23
NC: Innovation	2	5	-	3
NC: Environment and GHG Emissions (EGHG)	7	23	3	-

For the systemic connection between the sub-variables, the indicator level plays a role. As an example, energy efficient renewable installations (Circular Input, CI) help in reducing energy demand (Circular Activities, CA), which further makes the neighbourhood energy self-sufficient (Environment and GHG Emissions, EGHG). Another example is the innovation in business models (Innovation) which enabled resource sharing (CA). The visualization of this systemic connection is shown in Figure 3.

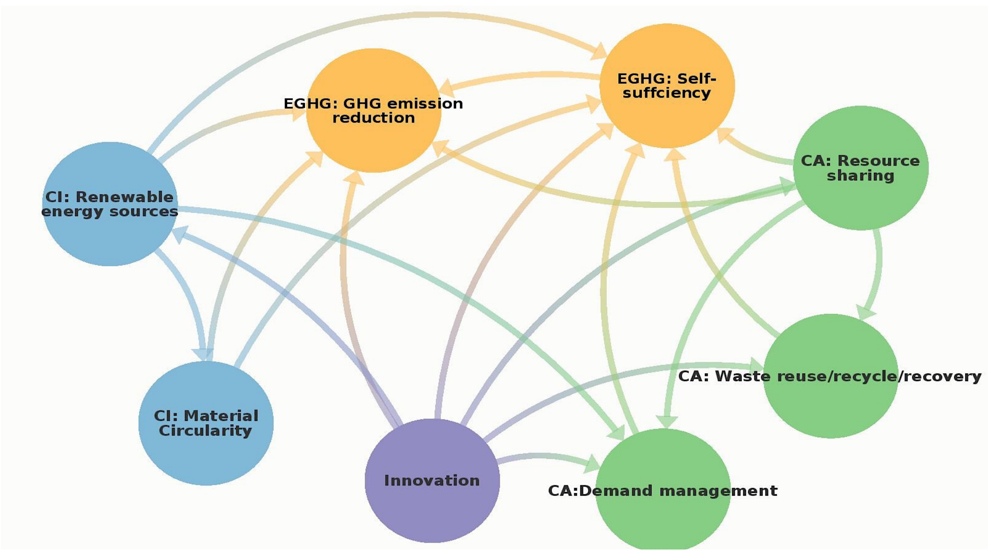

Figure 3 Systems mapping diagram for circularity indicators

4.3 Conditions for DSES development and implementation enabling circularity in Schoonschip

4.3.1 Technological Conditions

Availability and use of smart technologies enabling energy sharing and efficiency:
Schoonschip basically acts as a testing ground for cutting edge technologies in the energy domain, ranging from energy efficient installations to advanced smart grids. Grid-Friends developed a DSES for the residents with the use of state-of-the-art smart technologies such as AI, IoT, battery storage and blockchain. To put this statement in context, Philip Gladek, the CEO of Spectral in a presentation to Schoonschip explained, "While everyone is talking about putting more solar and wind [in energy systems], that's only half the equation because if you have these volatile sources of supply, you need to be able to store energy too so that when the sun isn't shining or the wind isn't blowing, you can use it later and you also be able to need to keep the network in balance" (Secondary data source 3). This is where these technologies come in. Grid-Friends representative in an interview further expanded, "Since renewables fluctuate their consumption requires storage or demand response. While both can incur losses, demand response can often be more efficient, and both storage and demand response need automatic intelligent control. Developing intelligent automatic control is part of AI/ML R&D" (Interviewee 4). Correspondingly, the so called private smart grid of Schoonschip allows a balance by sharing energy from appliances, solar panels, heat pumps, batteries etc. among households based on excess and deficit of energy (looked after by Spectral) (Secondary data source 4). Moreover, the smart grid incorporates an energy management system, called myPowerGrid, that works on these technologies to integrate energy sources and predict a household's energy generation and consumption patterns, battery storage, forecasts etc. on an online platform while providing the residents with strategies to limit their energy use along the way. Additionally, Schoonschip is getting one step ahead soon by getting involved in ATELIER. However, the smart grid is still yet to be integrated with transport/EV.

It is to be noted that the availability of such avant-garde technologies is due to Schoonschip's experimental character and commitment, private organizations' involvement and drive for innovation, as well as municipality to national to EU level stimulation in the form of research opportunities, exemptions and funding, which will be covered in the later sections.

Extent of effective diffusion of smart technologies with high technical standards (maturity):
Some technologies such as decentralization of energy systems and battery storage have already reached maturity and were easy to diffuse. But even the above-mentioned advanced technologies with high technical standards diffused well in the neighbourhood, although through some legal exemptions, and are now being considered by the municipality to replicate in other neighbourhoods (hence, increasing maturity) (Interviewee 6). Being aware and committed, residents were quite open to new technologies, although one inhabitant and project developer (interviewee 2) did bring up the long group discussions/meetings to convince all residents why a specific technology was best suited. On being asked if the technologies have diffused well in the neighbourhood, he answered, "Definitely, I am not a technical person, [still] it is very interesting to see how it actually works and to try to understand a bit of the technicalities but more interesting to see how it works within a community and I think we're all in just one year now so in the coming years to get to know much more about how it works and how this whole idea of balancing this, the net with our network and trading energy within our project and maybe to the outside world as well". Supporting this, interviewee 4 also maintained that for these technologies to be compatible on a community level, a 'tightly integrated approach and co-development of all interacting components' is required, which was achieved by continuous (re)planning and monitoring. He also

added that the process of it was more tedious due the decentralized nature of the neighbourhood, compared to a centralized one. Furthermore, in another interview with an academician working in the field of circularity, strategic management of technologies so people are aware that these work for the common good and not just to profit a few individuals was emphasized for them to work well and towards circularity in a neighbourhood (Interviewee 8). All in all, the technologies in Schoonschip are working efficiently at the moment with a few ups and downs in terms of technical difficulties, but community's willingness to learn and their participation has not let a socio-technical lock-in form in the neighbourhood.

4.3.2 Economic/Market Conditions

Extent of economic viability of DSES implementation:

Schoonschip as a whole is sometimes considered a 'wealthy project' although the interviewees did point out that the prices are affordable when compared to the usual housing rates of Amsterdam. Nonetheless, according to the inhabitants interviewed, the smart energy system component of Schoonschip was relatively easier in installation but equally complex in finances. The extent of economic viability of Schoonschip's energy systems received mixed answers among the inhabitants in the survey (n=26). There was a competition between them choosing 'very good (4)' and 'satisfactory (3)' with 53.4% (14) and 38.5% (10) respectively (Chart 9). Only 3.8% (1) of them picked 'excellent (5)' and 7.7% (2) picked 'fair (2)', bringing the mean to 3.5 (Table 15).

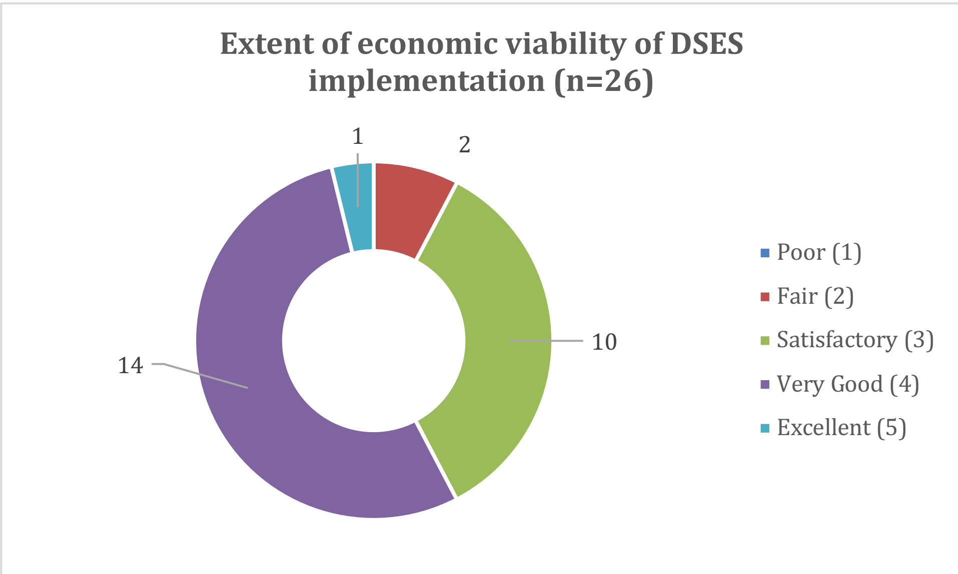

Chart 9 Survey results for extent of economic viability for DSES

Table 15 Descriptive statistics for extent of economic viability of DSES

Question	Total	Mean	Median	Mode	Standard Deviation
Extent of economic viability of DSES implementation	26	3.54	4	4	0.706

a) Extent of economic viability of DSES capital costs:

The upfront/capital costs for these energy systems were quite high as they included buying solar panels, battery installation, heat pumps and solar PV as well as energy efficient appliances over traditional ones, hence the ‘satisfactory’ and ‘fair’ scores by some people (Secondary data source 8). However, Spectral has justified the investment costs well with the lower operational costs (covered below).

b) Extent of economic viability of DSES operational costs:

In their business case as well as their presentation at the opening of Schoonschip, Spectral compared the smart energy system to the status quo where all residents had their own connection to the grid with a solar panel on the roof over 20 years (Secondary data source 4,8). It was estimated that the payback period for Schoonschip’s DSES would be between 5-7 years already (Figure 4).

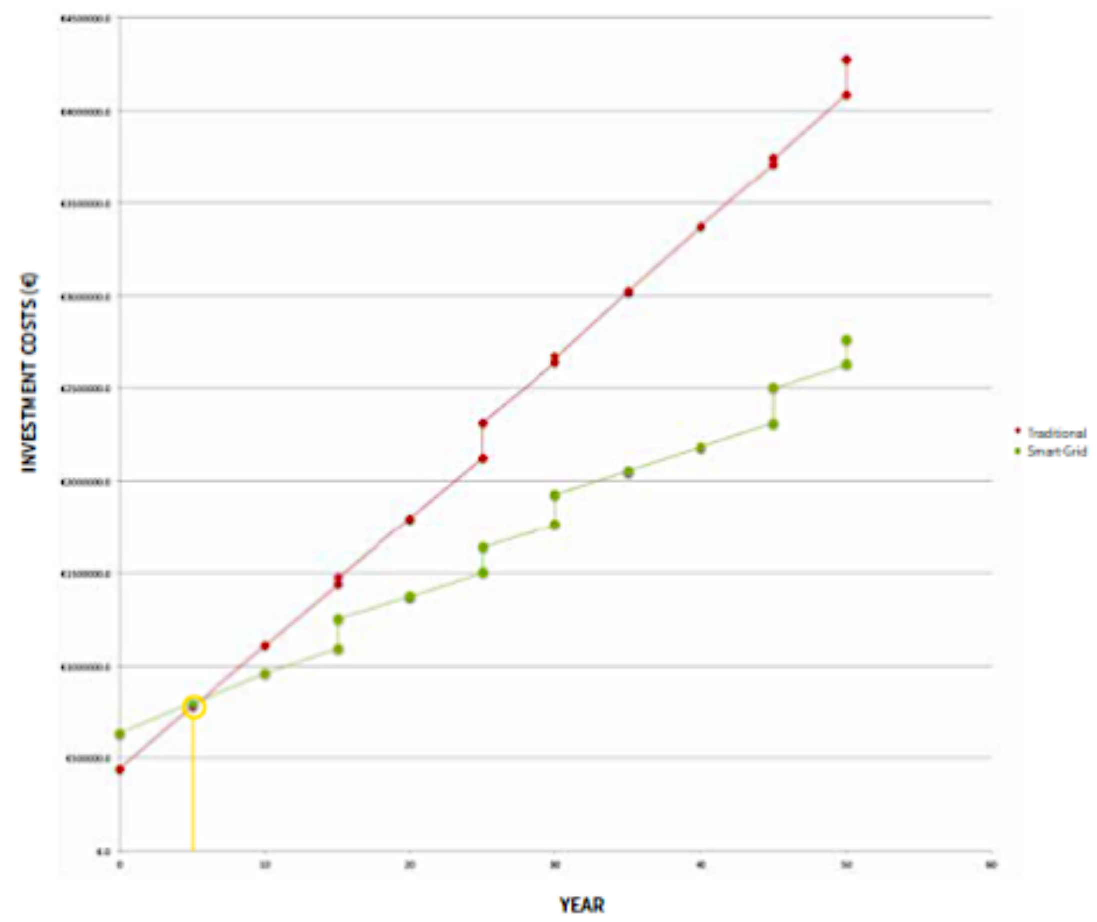

Figure 4 Spectral's business case comparing payback periods for DSES and traditional energy system

c) Extent of cost savings/ profit made with DSES implementation:

Spectral also estimated relevant profits over time with these DSES (Figure 4). A household owner (interviewee 1), showed that his house has already managed to do some cost savings and get money back, albeit insignificant, after a year of generating more energy than consuming from the grid, and it will only keep increasing. Additionally, a direct cost saving technique is to reduce energy consumption and it has already been established how DSES encourage that.

“And then you see it appear (on the dashboard) at the end of the year, I even got 30 euros, you know, normally, it's not minus 30 but if you live in a normal house, you’d pay 800 euros.” – Interviewee 1, Inhabitant

In the near future, as mentioned above, Schoonschip will also start buying and selling energy on local energy markets once it forms a local energy cooperative with its other neighbouring areas, thereby making DSES more profitable in the longer run.

Relevance of liberalization of energy markets:
For Schoonschip's DSES, the inhabitants are not only the owner of the smart grid, but they have their own energy cooperative/company (due to a legal exemption, Experimenten Elektriciteitswet regeling[3]), of which all inhabitants are clients. This implies greater transparency with the community doing its own administrative work and not depending on the centralized energy suppliers. A relevant thing to note is that this efficiency and payback, in fact the 'prosumer' and 'selling energy' concepts as a whole regarding DSES would not be possible without liberalization of energy markets. Interestingly, the European Union has just recently passed the bill allowing energy self-production. During Schoonschip's development, project developers had to apply for a legal exemption with RVO in order to be able to be their own grid operator. Similarly, the Electricity Market Directive for being able to sell energy has also been passed very recently and will help Schoonschip go on to the next level of selling energy.

Extent to which financial support/incentives were provided
a) Extent of financial support provided by public sector:
Referring back to the high investments in DSES, Schoonschip had some external help in funding. Most importantly, the energy management system (research and licensing) was covered under a one-million-euro fund provided to Grid-Friends by ERA-Net Smart Grids Plus initiative under EU through winning their competition. Interviewee 4 stated, "Given the participation in various pilot projects, some capital costs were shared/reduced. The amount of custom work for this community could have not been done commercially at this stage, which is why it was involved in the R&D". Additionally, Schoonschip also benefitted from various subsidies provided by the municipality, ranging from solar panels, heat pumps, battery systems to energy neutrality in buildings.

b) Extent of financial support provided by private sector:
As per the inhabitants, substantial amount of money came from the inhabitants themselves under a collective budget (Interviewee 1). This was particularly difficult, especially as it was around the financial crisis, so many people had to take loans and taking loans was also difficult at that time due to other technical reasons. However, during the times when financing became an issue, crowdfunding campaigns from Greencrowd helped them to a great extent as well (Secondary data source 4).

4.3.3 Institutional/Policy Conditions

Extent of disincentives for fossil fuel sources/use
The disincentivizing of fossil-fuel based sources and legal frameworks conditions conjoined. Starting from a larger scale, funding for DSES R&D as well as the liberalization of energy markets aiding investments (that is more recent) was a direct result of the clean energy ambitions set by the EU. On the national level, disincentives for fossil-fuel based sources come in the form of switching from natural gas to alternative renewable sources through regulations and exemptions.

[3] The goal of the experimental regulation is to identify legal impediments for the development of new energy projects due to technological developments and societal needs (Interviewee 7).

For example, an RVO representative (Interviewee 7) in an interview focused on the importance of the experimental regulation that Schoonschip got for its smart grid, “The goal of the experimental regulation is to identify legal impediments for the development of new energy projects due to technological developments and societal needs”. He further added, “Although it is of minor importance compared to the big emitters of CO2 such as the industry and transport sector, the democratization of the energy transition plays a role [in giving the exemption]”. Narrowing down, the municipality of Amsterdam, as explained by their representative, is highly ambitious with sustainability and circularity, hence they have a wide set of targets outlined for the city to be a frontrunner in these areas. There are numerous projects/innovations (such as Schoonschip itself) done on circularity and energy transition in the city such as waste to energy plants, natural gas phasing etc., a major cause of which is the municipality’s flexibility and its role of acting as a facilitator.

Presence of robust regulatory/legal frameworks

a) Relevance of regulatory frameworks encouraging DSES:

There are no direct regulatory/legal frameworks encouraging DSES except the above-mentioned experimental regulation. But a product of other regulations encourages DSES implementation indirectly. For example, the national government has set energy efficiency target, or EPC for each building to not exceed 0.04. Moreover, the municipality of Amsterdam is using a circular tender for new buildings to come up and was particularly strict with the rules and regulations for Schoonschip. The municipality representative (Interviewee 6) mentioned that they are stricter than other cities in the Netherlands, especially areas like Buiksloterham (of which Schoonschip is a part). A downside of that was also noted while talking to the inhabitants and consultants. Some legal issues were ensued during Schoonschip’s development which caused a delay. For the municipality to give land to Schoonschip members, there was a competition but it took a while longer due to internal bureaucracy (Interviewee 3). Due to an external legal matter (Schoonschip’s competitor suing the city on some technicalities), the municipality was more sensitive on completing all the targets, most importantly the energy self-sufficiency one. Therefore, the municipality had some tight rules focusing more on the techniques/methods and not the final result which did not leave them with a lot of flexibility in some decisions and slowed down the process.

Apart from the legal frameworks se by the public sector on different scales, Schoonschip has its own legal framework, which is quite a contemporary one. Being a completely people driven project, Schoonschip organized itself into many entities (foundations) which handled things like financing, implementation, innovation etc. Predominantly in the case of energy systems, Schoonschip had many legal frameworks with other private sector organizations working on it.

b) Extent of robustness of present regulatory framework for privacy and cybersecurity:

The privacy and security policy for DSES was formed by Spectral and it keeps changing. There are also debates within the community to work more on the privacy policy in case Spectral grows commercially, which will be covered in detail under socio-cultural conditions (Interviewee 1,2). But broadly, even this policy is supervised/under the Dutch Data Protection Authority guidelines.

Extent of involvement of and communication between different stakeholders for decision making

The most important driver that came out of almost every interview was the relevance of stakeholder involvement and communication throughout the development and successful implementation of the project.

a) Extent of diverse stakeholder involvement and collaboration:
There was effective involvement and collaboration between diverse stakeholders, ranging from the public and private sector, research institutions, academicians and especially inhabitants themselves, who got everyone together. "Project partners brought in significant amounts of knowledge. ITWM has been working on energy monitoring and control for years before the project commenced in 2016; similarly, CWI brought in knowledge about cooperation and coordination; Spectral about system integration; and Schoonschip had at that point also already been a community developing their idea for nearly a decade", explained interviewee 4, a Grid-Friends representative. This collaboration also resulted in innovative solutions and varying point of views to tackle a certain problem.

Collaboration is indeed fundamental. CE is a multi-disciplinary approach and then to collaborate, to cooperate for the common good is the only the only possibility, the only way to go I would say." - Interviewee 8, researcher and professor

b) Extent of clear communication between involved stakeholders:
Specifically, with regard to DSES, Treedelft's representative (Interviewee 5) stated, "We were well informed of all the discussions what it should do and what were the problems, where should be the demarcation of what should the clients do and what would Schoonschip do as a whole. So, we were really quite involved in all the discussions going around". Nonetheless, such coordination also stemmed due to Schoonschip not having any project developer for itself, but just inhabitants learning from other stakeholders. Things may have been different if that was not the case. Additionally, as interviewee 4 pointed out, Schoonschip benefitted from a lot of goodwill from various stakeholders (city council, banks etc.) as it was new, unique and had a pioneering role. He also mentioned that even the internal cooperation and communication (among inhabitants) played a role in its success.

"Neither pioneering nor the cultural DNA of this community are easily replicable or scalable, albeit some principles such as a clear mission and organization may be." – Interviewee 4, Grid-Friends representative

With so many stakeholders involved, interviewees acknowledged that some people worked a lot more than others and were the driving force of the project. However, interviewee 4 stated a valid point for not considering the 'amount of collaboration' as we may fall prey to survivorship bias.

4.3.4 Political Conditions

Clearly explained by an inhabitant, Schoonschip is a 'showcase project'. More than 100 people living on water in a sustainable way using modern technologies undoubtedly was something the City Council could showcase.

Extent of lobbying for clean energy/circularity that led to development of DSES:
Schoonschip did a lot of lobbying for this project to keep going. Fortunately, the mayor and the councilors at the City Council during that time were already very much involved in sustainability, therefore they highly encouraged and helped in Schoonschip's development through finances etc. Moreover, some inhabitants also had a few connections with some influential people in the City Council that helped speed up the process. Apart from the local politics, national level politics was not directly involved but still an essential part for the successful implementation of the project in terms of exemptions and working towards clean energy targets.

Presence of ambitious overall targets that facilitate political support for DSES:
Reiterating the above-mentioned case, political involvement specifically for DSES was indirect. The energy and circularity transition targets in the Netherlands call for automatic political support to become a front-runner in the EU. Therefore, the mayors in the municipality of Amsterdam were also interested in sustainable projects, in this case, Schoonschip.

"The experimental regulation itself is the result of the new political reality in the Netherlands where there is a strong focus on environmental policies. During the lifetime of the regulation (since 2015) certain political parties requested updates concerning the existing projects." – Interviewee 7, RVO Representative

4.3.5 Socio-cultural Conditions

Participation of inhabitants
Being a close-knit community, Schoonschip devours many advantages from active participation of inhabitants in general and also during the development and implementation of DSES. The inhabitants made a lot of effort to learn about new technologies and had discussion groups to share their knowledge and understand what was happening. Having no central authority due to being a CPO and building their own houses, they were heavily involved in decision-making. There was also an online forum created to share ideas, discuss issues and solutions together. Although, interestingly enough, it was also stated by inhabitants and consultants in the interviews that some people were more involved in the energy systems than others and acted as a "driving force" or "steering wheel" behind their success.

In the survey (n=26), on being asked to rate their involvement in DSES development and implementation between 'Poor' (1, not at all active) and 'Exceptional' (5, very active), their responses were mixed. While 38.5% (10) and 23.1% (6) picked 'satisfactory (3)' and 'fair (2)' respectively, 19.2% (5) of them picked 'poor (1)' and 11.5% (3) and 7.7% (2) of them picked 'exceptional (5)' and 'very good (4)' respectively (Chart 10).

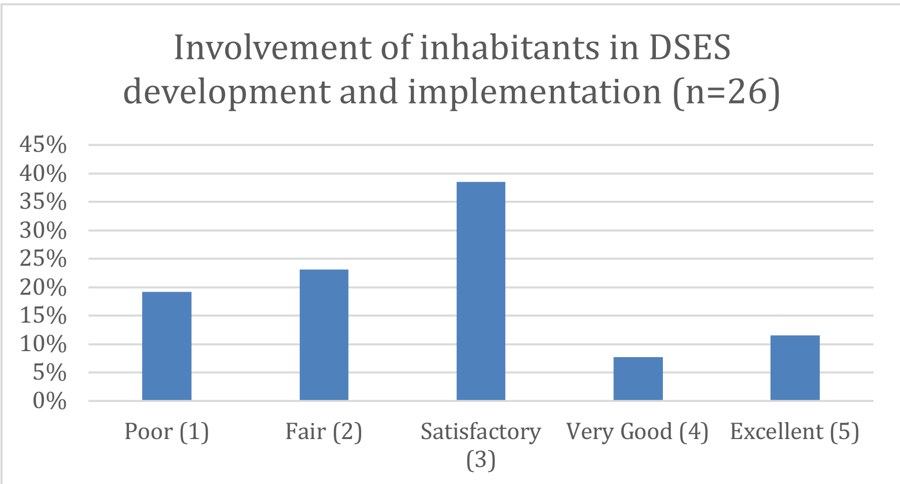

Chart 10 Survey results for involvement of inhabitants in DSES development and implementation

The survey shows a contradiction to the data from interviews and secondary information as well. This can be explained from the division of working groups within Schoonschip where a selected number of inhabitants work more on certain topics like energy, water, finance etc. Nonetheless, inhabitants' active participation attributed to their passion for a sustainable community and their willingness to provide their time, knowledge and effort to achieve that. In contrast, Metabolic representative (Interviewee 3) additionally emphasized on the growing complexity due to so many people involved. She stated that constant interactions and bringing them up to speed about things was heavily time consuming as people wanted to know everything and were opinionated towards a bigger ambition which sometimes fell short for reality. While the concept of bottom-up participation is important, she suggested that hiring a professional developer to oversee the whole process would have been better for management.

Ease of use by end users
Learning how to use these energy systems (heat pumps, management system) was a task for inhabitants. However, sharing information among each other, more specifically learning from and with each other through meetings and online forums (where they could ask anything) helped. One inhabitant mentioned that he did not come across many issues so far and further explained,

"I am not a technical person, but it is very interesting to see how it actually works and to try to understand a bit of the technicalities but more interesting to see how it works within a community." – Interviewee 2, Schoonschip inhabitant

Supporting this, the survey rating to DSES ease of use reflected that majority of the respondents (65.4% i.e., 17 out of 26) rated it as 'very good (4)'. These observations also show a relationship between ease of use of DSES with community collaboration/participation.

Environmental awareness raising of residents
A further relationship seen is with inhabitants learning to use DSES and increase in their environmental awareness. Environmental awareness was also found to be directly interlinked with their behavioural changes in terms of lifestyle and values. Using these DSES is raising inhabitants' environmental extent to some extent. As per the survey conducted, majority of the respondents (61.5%, i.e. 16 out of 26) stated that the use of DSES is helping in increasing their environmental awareness to some extent while 34.6% (9) of them said it is helping to a great extent. Some inhabitant stated that DSES are helping them reduce/save energy use through the dashboard/ monitoring system that shows all generation and consumption patterns. This does not just help the inhabitants but also on a larger scale to aggregate energy flows. Other activities like recycling shower heat, best time to use electrical devices etc. were also mentioned by them when asked how DSES are raising their environmental awareness.

"That's the interesting part, at least for people who have never been dealing with such issues and never heard of this demand side management, for them it's very interesting to see and that you know we are now part of this, and you [the energy working group] get questions like what is the best time to put on my washing machine or how does it actually work if we take energy or electricity from the grid… So it does work and it does raise awareness within the group of people." - Interviewee 2, inhabitant working in the energy working group of Schoonschip.

Availability and relevance of actions related to inducing behavioural change (lifestyle, values etc.)

Stemming from that is the inhabitants' behavioural changes. In the survey (n=26), 53.8% (14 out of 26) of the respondents chose that their lifestyle/behaviours changed to some extent due to DSES while 34.6% (9) said that it changed to a great extent (Chart 11). DSES, according to one person 'opens up the mind to new possibilities'. With being more aware of their impacts on the environment, and knowing what causes it, they are trying to change those habits in their daily routine. A house owner (interviewee 1) gave an example of how his household changed the size of their fridge to a smaller one seeing the amount of energy it consumed. They are also using natural ways of drying their clothes instead of using machinery. Other households are also starting to use electrical appliances at certain times of the day to conserve energy, although the intensity of these changes differ from household to household. Spoken in lengths about this, the inhabitant stated, "I think, more and more people within the project are getting interested because on a very simple dashboard, they can see they can see what's going on during the day into night. And then it's interesting to see possibilities of trading energy". A direct and useful implication that can be made out of these statements is that these hi-tech solutions in DSES are, in fact, changing people's mindsets and causing them to also seek low-tech solutions to energy and other sustainability initiatives in general.

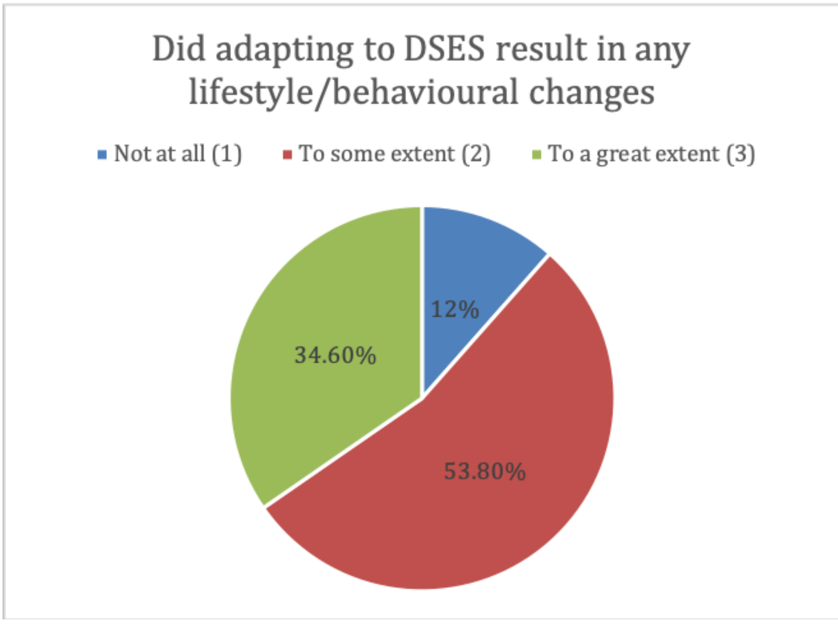

Chart 11 Survey results for adaptation of DSES resulting in lifestyle/behavioural changes

Trust and commitment by residents

When asked the extent to which inhabitants trust the energy systems with their data between 1 and 5, maximum number of them (76.9%, 20 out of 26) went for 4 followed by 15.4% going for 5. Both the inhabitants interviewed also claimed that they fully trust the companies involved (Spectral and Fraunhofer Institute) with their energy data. Additionally, every household has control over their energy data and privacy statement. They can either keep the information private, or visible to the community or even the public. On the other hand, they are also simultaneously keeping in mind that things may change over time with regards to Spectral getting bigger, therefore they are constantly working on the privacy policy.

"Well we trust them a 100%, because we've been working together [with Spectral] from the very beginning and, as I said, you know, this was also like a special situation because Spectral was, was also starting up. Like, we grew up together and so we trust them" – Interviewee 1, Schoonschip inhabitant

"As they [Spectral] become a very interesting party for the big utilities, of course there's some fear that one day they will be taken over by one of the big utilities or energy companies. So, we are just in the midst of debates on how we can actually make sure that we have at least always will be able to have access to our data and it's protected, and that we have a say in the future of Spectral for instance". –Interviewee 2, Schoonschip Inhabitant

All in all, inhabitants are fully committed to DSES in their neighbourhood. While some people did not know about these hi-tech innovations in the beginning and were relying on low-tech ones, they are now learning and getting more involved. What's also important to note in their increased involvement is the community aspect, making them experiment with technologies together.

4.3.6 Environmental Conditions

Presence of environmental and recycling standards to adhere to

Environmental standards were kept in proper check during the implementation of DSES in Schoonschip, with a substantial emphasis given to energy neutrality standards. While Schoonschip's DSES are doing well in integrating heat and power sources, using sustainable circular materials and generating synergies in circularity, there is not much research about the materials/metals used in batteries, solar panels etc. Although the batteries used are good quality lithium-ion ones with a life expectancy of 20 years, it is not clear how these metals will be used later on, beyond their life expectancy. Even the material passport formed does not fully cover the recycling part for these. But broadening the scope, the municipality of Amsterdam with the Dutch government is doing great in coming up with policy mandates regarding recycling of e-waste and also has it as one of their major topics to cover under circularity.

4.3.7 Discussion

Energy systems in Schoonschip were not treated as a separate entity but were integrated with other circular components of the whole neighbourhood throughout in every way, from discussions to planning and design to finance and implementation. Every condition played a crucial role in its own way.

Interestingly enough, the most recurring conditions (in Atlas.ti) in the interviews and secondary data were the institutional/policy conditions. Certainly, all the conditions under this sub-variable had a major role to play for the success of DSES development and implementation, either directly or indirectly. The government, at different levels, foster innovation and because of the ambitious targets set by EU, Netherlands and Amsterdam, there is more support for these kinds of small scale urban initiatives through permits/exemptions and investments, allowing a blend of top-down and bottom-up approach. As stated by the inhabitants, it would not have been possible to go ahead with an innovative DSES in the first place had there been no scope for experimentation in energy ownership. Moreover, the whole institutional setting with ups and downs in collaboration and coordination between the many stakeholders involved was also a driver as well as barrier for the success of DSES. It was indicated that the municipality focussed a lot on 'how' instead of the final result (Interviewee 3). This caused delays and change of plans, possibly some compromises on the efficiency part of the project.

The second most recurring was the technological conditions followed by socio-cultural conditions. Technological conditions also played a major role for attaining circularity through the use of different technologies that allowed users to generate and store their own electricity and informed them about their consumption patterns. Though certain technologies were used only because the government allowed it, thus connecting technological conditions to institutional ones. Socio-cultural conditions formed an intrinsic part of DSES. Whether it was learning to use new technologies (diffusion), participating in all activities, lobbying for financing or dealing with other institutional actors for permits, inhabitants formed a central pivot. With the willingness to make changes clubbed with the information they were able to receive from the DSES about their energy patterns, there was an increase in their environmental awareness and behavioural practices that further guided them in being sustainable. Out of all conditions, environmental conditions were the least recurring ones while coding, as not much emphasis was laid on the consideration of recycling standards for the components of DSES and other environmental considerations were out of regulations.
Apart from the recurrences seen for each condition, their correlation was also observed. A strong systems approach was seen in Schoonschip's DSES development, with all conditions linking to each other in some capacity. For example, it was established that the economic conditions with energy markets and investment enable technological conditions. These economic conditions as well as environmental conditions with building standards are driven by institutional conditions. Similarly, political conditions (such as lobbying done by inhabitants) impact institutional conditions by facilitating in speeding up institutional processes and investments. Furthermore, technological conditions are also directly associated with socio-cultural conditions by enabling participation, awareness, behavioural changes etc. To simplify, Table 16 shows the direct relations between sub-variables through the co-occurrence table while Figure 5 visualizes the systemic connection between them.

Table 16 Co-occurrence table for DSES conditions, Source: Atlas.ti

	DSES: Technological Conditions	DSES: Economic Conditions	DSES: Institutional Conditions	DSES: Political Conditions	DSES: Socio-cultural Conditions	DSES: Environmental Conditions
DSES: Technological Conditions	-	7	5	0	13	1
DSES: Economic Conditions	7	-	21	4	10	0
DSES: Institutional Conditions	5	21	-	8	9	4
DSES: Political Conditions	0	4	8	-	1	0
DSES: Socio-cultural Conditions	13	10	9	1	-	0
DSES: Environmental Conditions	1	0	4	0	0	-

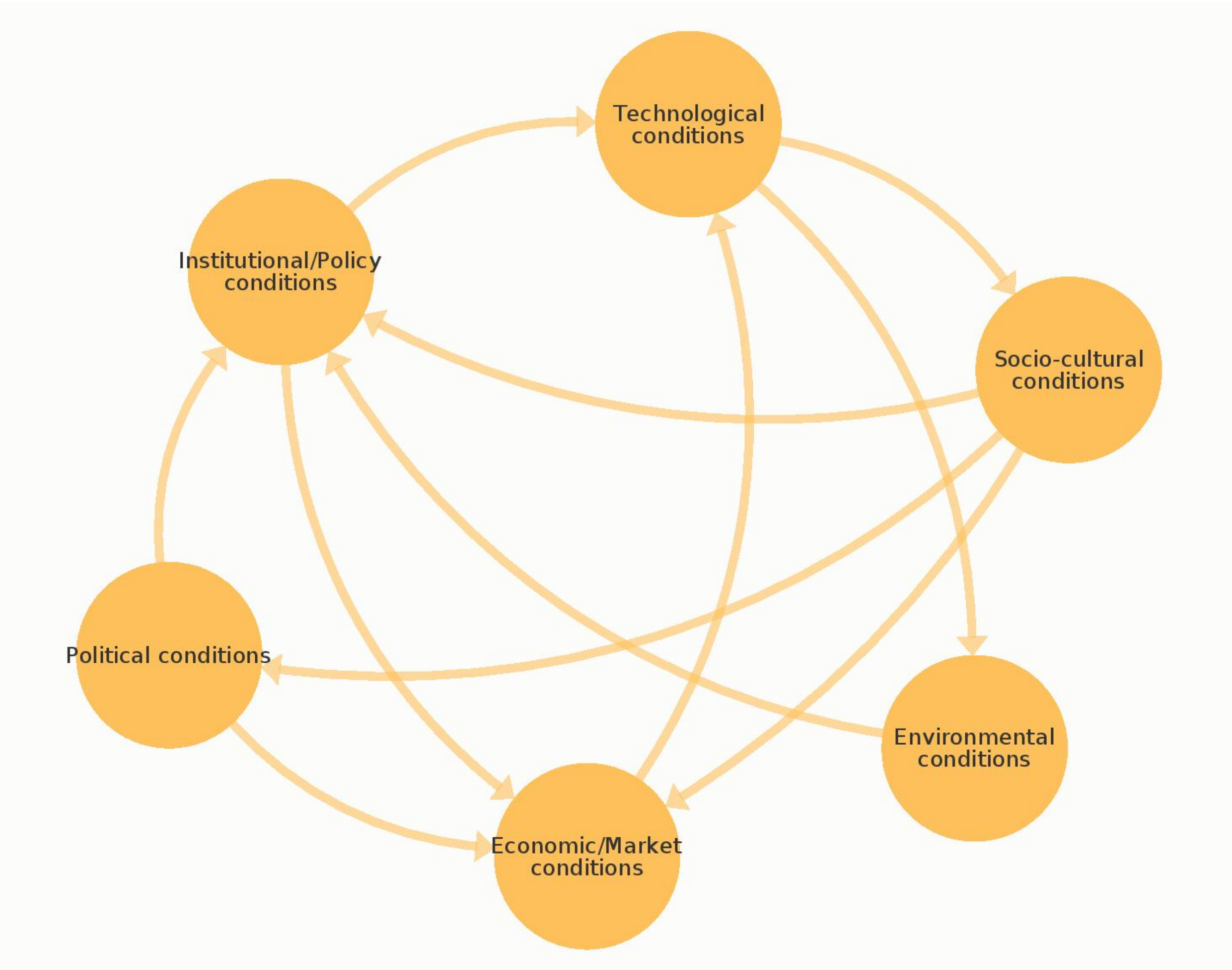

Figure 5 Systems mapping diagram for DSES development and implementation conditions

4.4. Cross-connecting the variables and further discussion

With community involvement at the forefront, decentralization and collaborative structures combined with innovative open source technologies, Schoonschip is already in the direction of achieving a CE transition. There is a fairly direct as well as indirect relationship between energy systems and circularity which is reflected well in this study, despite the physical properties of energy transformation and dissipation. More importantly, the fundamental aspect of community is what binds them.

When both neighbourhood circularity and DSES conditions are analysed together, it brings out many more connections between the two. Table 17 shows the co-occurrence table between the independent and dependent sub-variables, deduced from Atlas.ti.

Table 17 Co-occurrence table to show interrelation between DSES conditions and circularity indicators, Source: Atlas.ti

	NC: Circular Input (CI)	NC: Circular Activities (CA)	NC: Innovation	NC: Environment and GHG Emissions (EGHG)
DSES: Technological Conditions	8	30	7	12
DSES: Economic Conditions	3	1	9	0
DSES: Institutional Conditions	2	2	8	1
DSES: Political Conditions	0	0	1	0
DSES: Socio-cultural Conditions	3	14	6	5
DSES: Environmental Conditions	4	4	0	1

It can be seen from Table 15 that the maximum co-occurrence happens with the DSES technological and socio-cultural sub-variables and circular activities. The technological interrelations are fairly direct in nature, such as one impacts the other. For example, that DSES incorporate renewable sources (CI), reduce energy demand reduction (CA), enable energy sharing (CA), decrease GHG emissions and make the neighbourhood more energy self-sufficient (EGHG). This is directly linked to and is caused by the presence and relevance of technologies which enable innovative ways for renewable energy production and storage while simultaneously helping inhabitants become more aware through the energy dashboard. In the case of water reduction and self-sufficiency, DSES technological conditions are partially involved due to the integration of heat and electricity sectors.

Moreover, it was also observed that DSES technologies help increasing inhabitants' environmental awareness which further leads them to make conscious changes in their lifestyle and experiment/innovate more to be sustainable. As energy itself is also a product of all resource usage, becoming more aware of the energy patterns is, in turn, assisting in the inhabitants paying more attention to water reduction and self-sufficiency. This brings socio-cultural conditions to play a central role in accelerating circularity. Moreover, with the collective production and energy sharing, there is also an increased participation and willingness to learn observed among the inhabitants. Apart from the direct relations, these two sub-variables also accelerate circularity indirectly. For instance, as indicated in survey, the DSES technologies open the mind to new possibilities. Socio-cultural conditions like increased awareness can also affect inhabitants' awareness and consciousness towards other circular activities such as waste and water reduction, resource sharing and recycling waste as well as circular input such as being aware about using more circular/sustainable and energy efficient materials in the household, therefore taking care of the low scoring sub-variables in circularity. Also, as observed from interviewee 1, inhabitants are already aware of not being able to use DSES for mobility sharing and acknowledge that it would have been ideal, indicating knowledge awareness in other realms of circularity too, but a technological restriction. However, it is also important to consider that this awareness aspect is subjective and will vary from inhabitant to inhabitant and also that pre-existing commitment to sustainability by the inhabitants acts as an amplifier to awareness from DSES usage and may influence this finding (Visualization of this in annex 1).

Additionally, while the institutional conditions were most recurring from the previous discussion, not much of a direct relationship is seen when compared against the circularity sub-variables (except innovation) (Table 17). This is because circularity sub-variables show more of functioning and outputs of the neighbourhood while institutional conditions act like a facilitator during the development stage for other conditions to be brought in and play a role which has already been discussed in the previous section. In other words, conditions which have a direct relationship with circularity sub-variables, such as technological conditions providing self-sufficiency, environmental conditions enabling energy efficient buildings and low GHG emissions, economic conditions creating new business models for innovation etc., are all driven/influenced by institutional conditions and they are further impacted by political conditions on a broader scale.

Figure 6 shows the interconnections between circularity and DSES conditions sub-variables for a better understanding. While the solid lines denote a direct connection, the dotted ones show indirect connections.

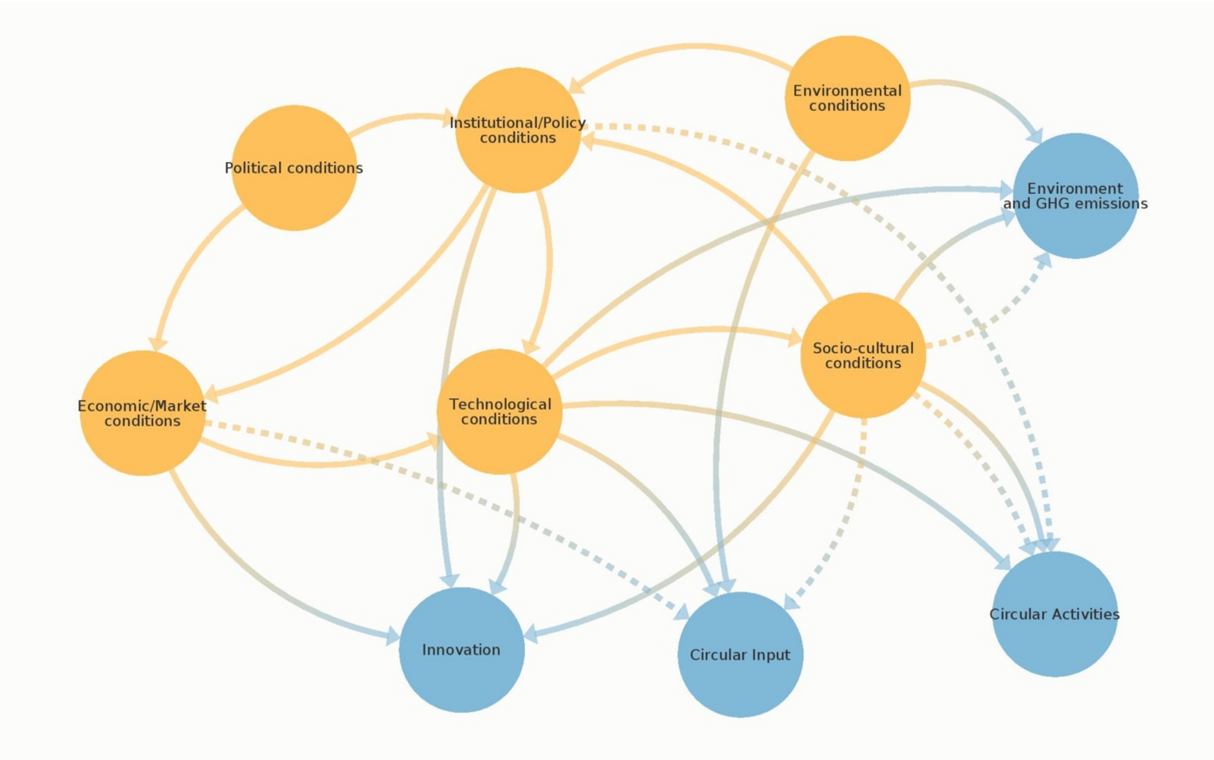

Figure 6 Systems mapping showing interrelations between DSES conditions and circularity indicators

This visualization further shows that every DSES development and implementation condition had some role to play in accelerating/ hindering Schoonschip's circularity, whether directly or indirectly, irrespective of their sequence.

Chapter 5: Conclusion

5.1 Introduction and answering research questions

The aim of this study was to explore and explain the conditions under which decentralized smart energy systems accelerate neighbourhood circularity, using the case of Schoonschip, Amsterdam. Through this study, the researcher was able to shed some light on neighbourhood circularity and DSES. The next section will answer the main research question through the formulated sub-questions while simultaneously connecting the results with theory and thereby providing recommendations for future research and policy changes.

How does Schoonschip neighbourhood measure against circularity indicators?

To answer this question, circularity indicators were formulated from previous literature and their gaps. On applying these indicators to Schoonschip, it was found that Schoonschip is faring well in neighbourhood circularity with high scoring indicators such as new innovations, resource sharing, energy self-sufficiency. Even still, it is not completely circular and has a few shortcomings, such as building material circularity and waste related circular activities. Likewise, the neighbourhood scored the highest in 'Innovation', with a 4.53 and a 4 in 'Environment and GHG Emissions', followed by relatively low score of 3.8 in 'Circular Input' and 3.7 in 'Circular Activities', bringing the total score to 4 on a 5-point Likert scale, also indicating improvements needed in the latter sub-variables.

Nonetheless, an essential finding made with the help of interviews was the interconnection between these indicators, often one affecting the other. In general, Schoonschip's circularity is attained not just on a neighbourhood level but is, in actuality, an amalgamation of circularity at the building level and consumer level. This finding is a reiteration of the literature on circularity, validating Kirchherr et al's (2017) assertion that it is when circularity is taken care of on all three levels of micro, meso and macro, a system can reach towards a holistic CE. Another major factor that ties up all the sub-variables at a smaller scale is the knowledge and commitment by inhabitants, which also proves Hobson's (2020) claim of CE being a socio-technical in nature and that community participation, their acceptance and willingness to adopt new daily circular norms and experiment are essential to achieving circularity on any bigger scale.

What are the drivers and barriers in the development and implementation of DSES in Schoonschip that enable or hinder circularity at the neighbourhood level?

Technological, economic/market, institutional/policy, political, socio-cultural and environmental conditions, were well reflected in Schoonschip. Based on the analysis, a strong systemic relationship between the conditions was deduced. Technological, institutional/policy and socio-cultural conditions were the most recurring ones in data and played the role of encouraging/reinforcing other conditions to come into play. Table 18 summarizes the drivers and barriers found in the development and implementation of DSES in Schoonschip that accelerate or hinder circularity.

Table 18 Drivers and Barriers for DSES development and implementation (leading to circularity) in Schoonschip, Source: Author (2020)

Conditions	**Drivers**	**Barriers**
Technological Conditions	Use of cutting edge technologies fostering greater energy efficiency and renewable integration Effective diffusion of technologies in the neighbourhood (through learning), no socio-technical lock-in	DSES technology not advanced enough to integrate transport/ EV
Economic/Market Conditions	Low operating costs, payback period less Grid ownership through exemption Investments in the form of subsidies and crowdfunding	High capital costs (possible short-term disappointment) Active participation in energy markets was not allowed until very recently
Institutional/Policy Conditions	Investments and willingness due to the clean energy ambitions Disincentivizing fossil fuels with no natural gas Innovation capacity and freedom Collaboration and coordination of diverse stakeholders Effective regulatory and legal frameworks	Too rigid in rules and regulations about efficiency standards Miscoordination causing delays and knowledge gap
Political Conditions	Benefits from goodwill of actors due to Schoonschip's pioneering role Sustainability awareness among the political actors Internal connections of inhabitants within the city council	

Socio-cultural conditions	Effective community participation, learning from each other Knowledge about high tech solutions through discussions and learning, no rigidity in user preferences Increased environmental awareness Daily lifestyle and behavioural changes towards sustainability, increased involvement Trust and commitment towards DSES	Project was a long process, some people opted out due to stagnation at a point Too many people joining at different times and having different queries was too time-consuming Resulted in a few people making more efforts than the rest Shifting from low-tech to high tech solutions as well as gaining new knowledge took time and efforts
Environmental conditions	Consideration of environmental standards while developing and implementing DSES	Lack of emphasis on end life of DSES components (solar panels, batteries etc.)

Main research question - "Under which conditions do the development and implementation of DSES at Schoonschip, Amsterdam, the Netherlands accelerate circularity at the neighbourhood level?"

Combining the abovementioned sub-questions, the main research question is answered proficiently, validating the conjecture that DSES accelerate neighbourhood circularity under certain conditions. Referring back, Kirchherr et al.'s (2017) assertion that holistic circularity happens on all three scales resonates well in the context of DSES in a neighbourhood, particularly Schoonschip in this case. To put things in perspective, firstly it is important to bring up the systemic relationship between the six DSES conditions again. All of them had some role or the other to play, but juxtaposing them with circularity assessment, the most prominent conditions that come up are the combination of technological and socio-cultural conditions. Undoubtedly the technological conditions are permitting distribution, renewable integration, sharing and energy-efficiency through state-of-the-art technologies. But more than that, they are also acting as a factor to make people involved and aware. As explained by Ceglia et al. (2020), smart energy communities such as Schoonschip, which are formed as a result of DSES installation, put consumers/society in the centre. With the principle of active consumerism, DSES gave Schoonschip inhabitants the ability to know, understand and change their energy generation and consumption patterns. As it was found from the analysis, the environmental awareness is then not just limited to energy savings, but can also be applied to all kinds of resource consumption. Being able to co-produce and share resources, inhabitants' interests and participation are accelerated towards being more sustainable. From this, it is evident that DSES forms an energy community causing a social shift, make use of technologies to keep the building energy efficient and affect individual consumer's mindset about their consumption patterns, thus also incorporating Hobson's (2020) social circularity and aiding/mediating a change on all three levels. Apart from these two conditions, another indisputable condition is institutional/policy. A top-down approach acts more of a facilitator for other conditions and is equally needed in being able to pull off such an advanced technical, social and economic innovation. The governments played a facilitating (sometimes even commanding) role in the development and implementation of DSES with the help of subsidies, phasing out natural gas, maintaining environmental standards (environmental conditions), grid ownership exemptions (economic/market conditions), political support and permits. Additionally, with high capital costs of DSES (economic conditions), lower operational costs and cost savings act as a major incentive for inhabitants to invest in DSES. All these DSES conditions form an integral part of Schoonschip's circularity. One cannot say that DSES are the only reason why Schoonschip is circular (as explained from the analysis), but DSES implementation is surely adding to its circularity heavily. Figure 7 shows the conceptual framework in the context of Schoonschip incorporating the DSES development and implementation drivers (deduced Chapter 4) that accelerate Schoonschip's circularity.

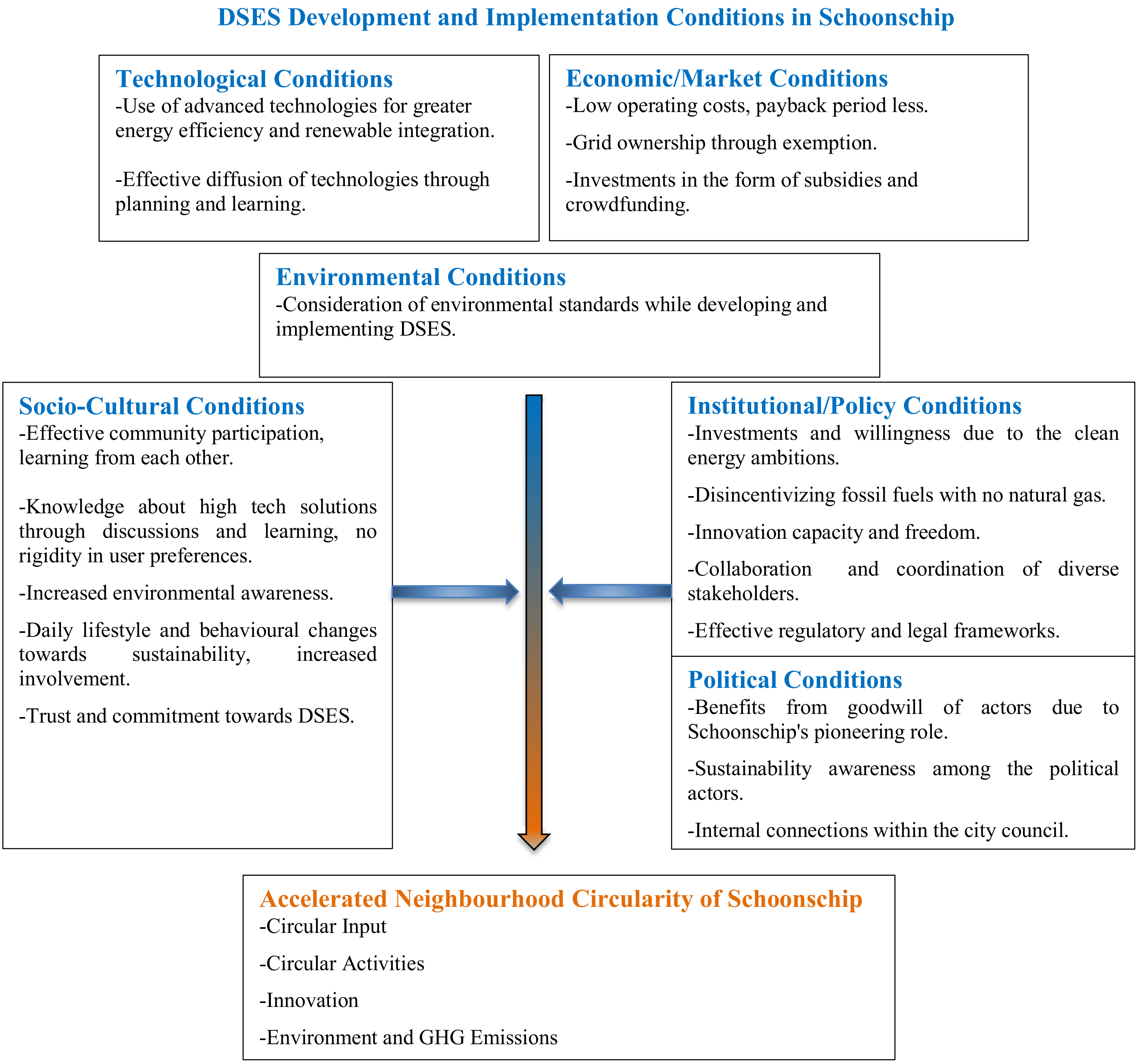

Figure 7 Conceptual framework applied to Schoonschip

5.2 Recommendations

Schoonschip exhibits a societal role in circularity, working on the concept of sharing and showing how technologies, specifically DSES can help support living as a community. But Schoonschip is also a unique example, an experiment and a dream come true for its initiator. Its replicability is difficult although lessons can be learned from it. The barriers in DSES development and implementation found in Chapter 4 can be worked on effectively to further accelerate circularity in Schoonschip and other neighbourhoods in general. The community engagement aspect of Schoonschip proved to be a major driver for accelerated circularity however it also caused delays, confusion and stagnation. This could be prevented by proper management and coordination at the residential level. Even in the case of circular materials, Metabolic did a great job at making the material passport but coordination of that with inhabitants and their choices could have prevented from going for a few unsustainable materials. Further, although DSES are already advanced enough, a further scope of improvement is observed in case of connecting the grid to electric vehicles for mobility sharing, thus making the neighbourhood more self-sufficient. Moreover, co-production with sharing of energy and increase in environmental awareness through information provision by DSES dashboards can also lead the inhabitants to reduce other resource flows in the neighbourhood as well as increase their willingness to invest in technologies and innovations.

Equally important is the top-down, governmental role. The driving force which would bring community's creative inputs and ideas to fruition is ultimately from top-down. Even though experimenting opens new directions, it is the right management that could make citizens trust that it is for the common good. While the government may have high ambitions, it needs to be transparent with the citizens and keep them informed. This could particularly help in filling up the knowledge gap for waste recovery between the inhabitants and municipality. Moreover, as suggested by interviewee 3, things would have worked better if the municipality had expectations about the final outcome and not on how it would happen. This could prevent delays and five innovative partners to be flexible. Additionally, the inhabitants of Schoonschip had to apply for various permits and legal exemptions in order to break the system and innovate. The whole process for DSES could have been easier if there was enough flexibility in the system already, without the need to apply for exemptions. Regardless, the EU is already working on making energy markets more flexible with respect to ownership and selling energy. This will be particularly useful in the broader implications of the project ATELIER in Buiksloterham, of which Schoonschip is part of. The broader implications of DSES may also help in reducing the higher capital costs of these systems in future projects, thus truly attaining eco-economic decoupling, the very concept of CE, although equal attention should be given to the circularity of the metals and other materials used in DSES.

5.3 Policy Recommendations

The study on neighbourhood scale circularity is scarce in literature, especially when it comes to evaluating circularity. As a result of this or supporting this, there are not many examples of a circular neighbourhood in real life. Some of them are conceptually there but are still not completed. Even on a policy level, while there is a lot of work going on building and city level circularity, there is no policy work on neighbourhood level circularity. In the case of Amsterdam, a circular tender for building level exists already. Such things may also become useful on a neighbourhood scale. Moreover, government sees energy projects and circularity projects as two separate components. The policy documents also indicate a fragmentation within policy arrangements. This in turn, makes the whole transition more complex. After concluding this study, the need to have better coordination within the energy transition and circularity transition is well reflected. Especially for a neighbourhood/urban area scale, even though there are exemptions and investments, there should be a greater role of the local government in energy markets than the national government or EU. The role of society/ consumers is proven to be equally important and solutions facilitating sharing economy in policies can act as a way forward. Lastly, on product scale, even though DSES prevent waste from electric grids, there should be proper policies for disposal and reuse/recycling of metals from solar panels and smart batteries too.

5.4 Future Research

From an academic perspective, more research needs to be done to explore neighbourhood circularity. Since this study looked at a smart energy neighbourhood, other smart components that make up the neighbourhood could also be brought into circularity context. Schoonschip particularly introduced a rather brilliant and elaborate material passport that covered major aspects of material circularity and acted as a guide for residents. The passport comprised of a number of important factors such as their recyclability, life cycle impact, local and sustainable sources etc. More research can be done specifically on a material passport like that and to what extent it impacts the neighbourhood circularity. A comparison can also be carried out between circularity of houses which used all ‘green’ marked materials and the ones that missed out. Additionally, the societal basis in neighbourhoods could be used to further study the role of each scale in detail. The assessment method used in this research was restricted due to time constraints and the newly developed characteristic of Schoonschip. In future research, this assessment could be combined with LCA to get objective/numerical results along with subjective results. Furthermore, it would also be interesting to research about just the role of institutions in facilitating neighbourhood circularity, i.e. the right blend of top-down and bottom-up approach for circularity.

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Annex 1: Additional Figures

Circular Economy Frameworks

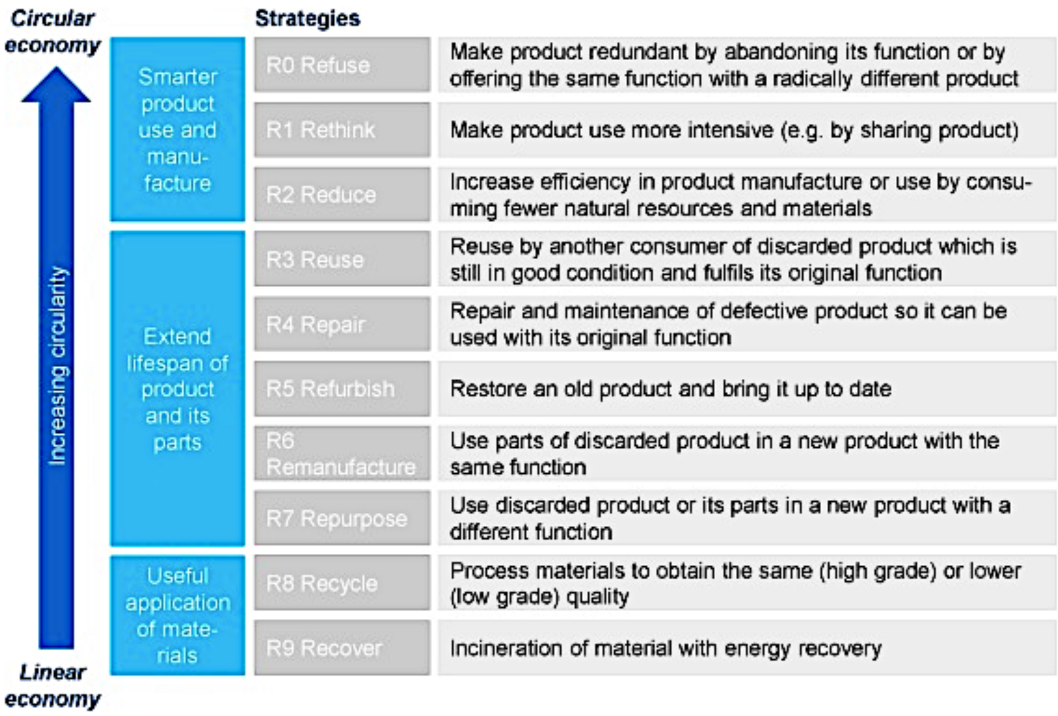

Figure 8 R-Framework developed by Kirchherr et al. (2017)

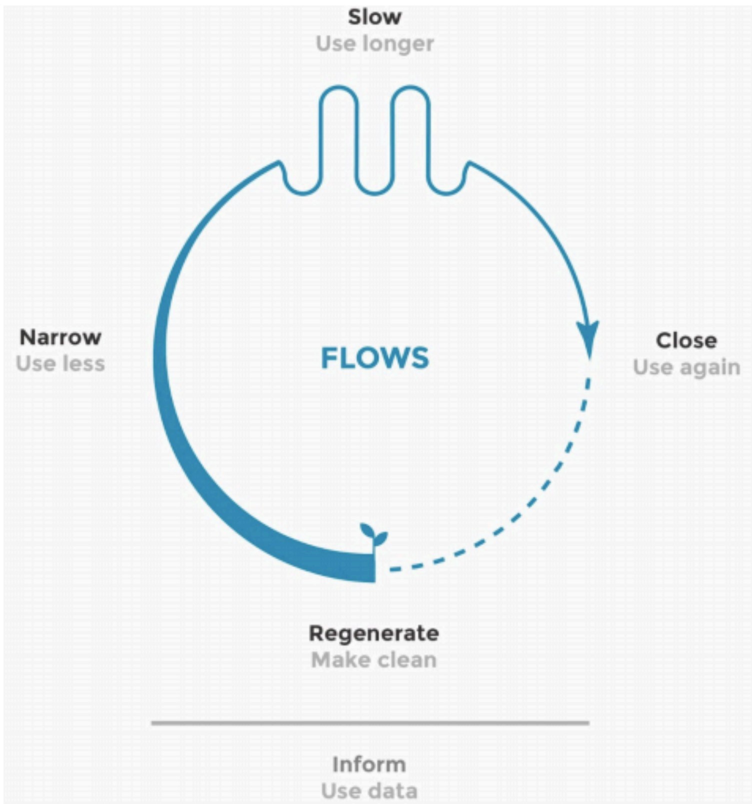

Figure 9 Circular strategies developed by Konietzko et al. (2019)

Figure 11 ReSOLVE framework developed by EMF (2015)

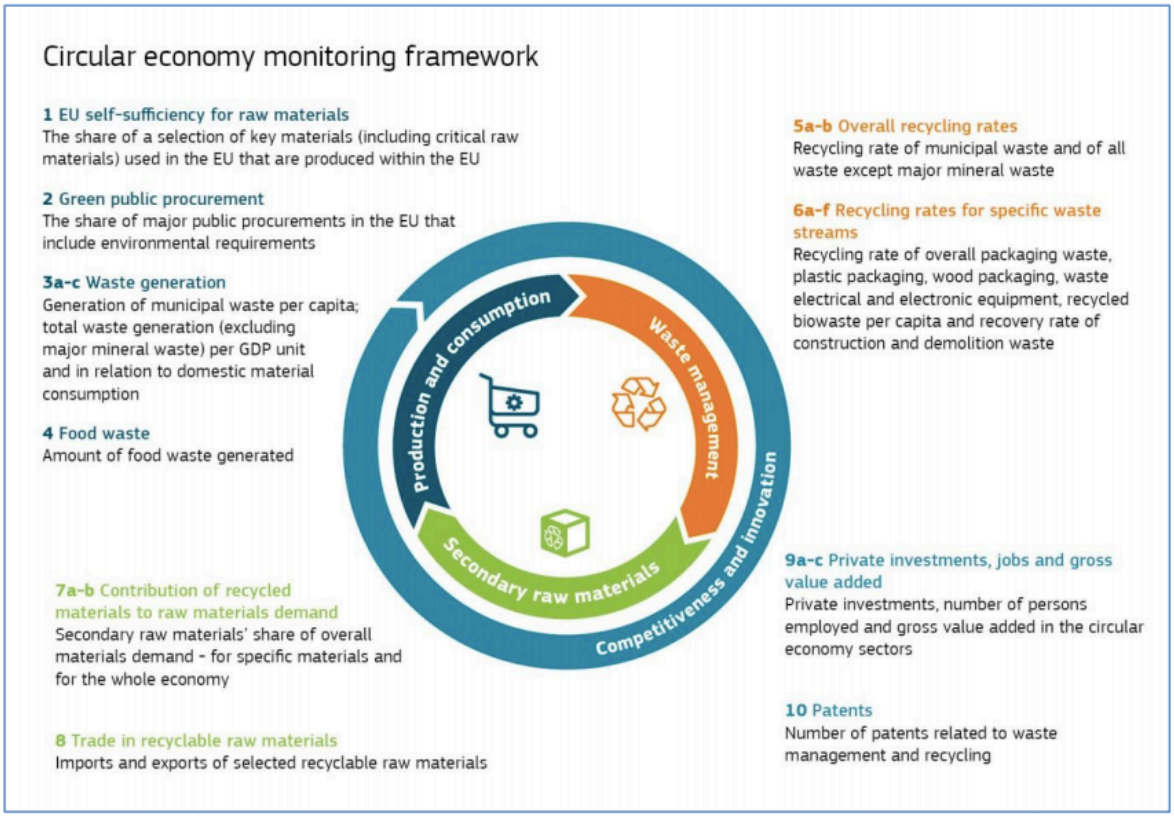

Figure 10 Monitoring framework developed by EC (2018)

Material Passport for Schoonschip

Building layer	Component group	Component / material	Material specification colour indicates sustainability class	Notes / additional conditions	Theoretical recyclability Good / medium / bad	Current recyclability Good / medium / bad
			colour indicates sustainability class			
Structure (primary)	Float / pontoon	Walls / floors	Concrete*		Good	medium
			Fiber reinforced polymer with expanded polystyrene [EPS]		Good	bad
	Massive	Walls / floors slabs / roofs	Concrete*		Good	medium
			Rammed earth		medium	medium
			Earth and rubber tires		Good	bad but second life mater
			Adobe and loam (leem)		bad but degradable	bad but degradable
			Limestone		medium Downcyclable as aggregate	bad [economical]

recycled fract. in current supply Percentage	Compostable / biodegradable Yes / no	Rewable resource Yes / no	Life cycle impact Low / medium / high	Durability Good / medium / bad	Material health Good / medium / bad	Locally sourced Near / intermediate / far	Reused / Recycled / upcycled / downcycled [colour]	Sustainable sources Good / medium / bad
13,7% cement and aggregate, 70% for reinforcement steel	no	yes	medium	medium / good [some times to permanent]	good [some radiation]	intermediate	Recycled / downcycled butt small fraction	medium
1.00%	no	no	high	good	good	far	no [EPS recycling industry is developping though]	medium
13,7% cement and aggregate, 70% for reinforcement steel	no	yes	medium	medium / good [some times to permanent]	good [some radiation]	intermediate	Recycled / downcycled butt small fraction	medium
0% but mostly degradable	yes	yes	low	medium / good [some times to permanent]	good	near	no	good
0,1% but second life material	no (tires) but second life material	yes	low	good	good	near [sourced from waste]	Recycled / Reused	good
0% but degradable	yes	yes	low	good [to impermanent for some purposses]	good	near	good [straw or other organic]	good
1%	no	yes	low	good	good	near	no	good
1%	no	yes	low	good	good	near	no	good
1%	no	yes	medium	good	good	near	no	good
0 % but second life material	no	no	low	good	bad [a lot of radiation]	near [sourced from residual]	no	medium
0 % but degradable	yes	yes	low	good [to impermanent for some purposses]	good	near	good [straw]	good
8,99% but degradable	yes	yes	low	good	good	near / intermediate	no	good

indicator 2. varies	density kg / m^3	Performance indicator physical quantity	Performance indicator unit	Performance indicator Description
40.9	3100	22.070	Gpa / m3 (no reinforc)	Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
N/A	19.9	0.035	W/mK;	λ
40.9	3100	22.070	Gpa / m3 (no reinforc)	Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
N/A	N/A	N/A		Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
N/A	N/A	N/A		Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
N/A	N/A	N/A		Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
31.6	2320	13.601	Gpa / m3	Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
23.7	2440	5.456	Gpa / m3	Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
32.4	2290	14.852	Gpa / m3	Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
N/A	N/A	N/A		Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
0.001	123	N/A		Young modules^3 / density (E^3/ρ). Value for wall and floor slabs.
13	570	3.854	Gpa / m3	Young modules^3 / density (E^3/ρ). Value for wall and floor

Figure 12 Material Passport developed by Metabolic for Schoonschip

Systems Mapping for DSES Conditions and Circularity Indicators

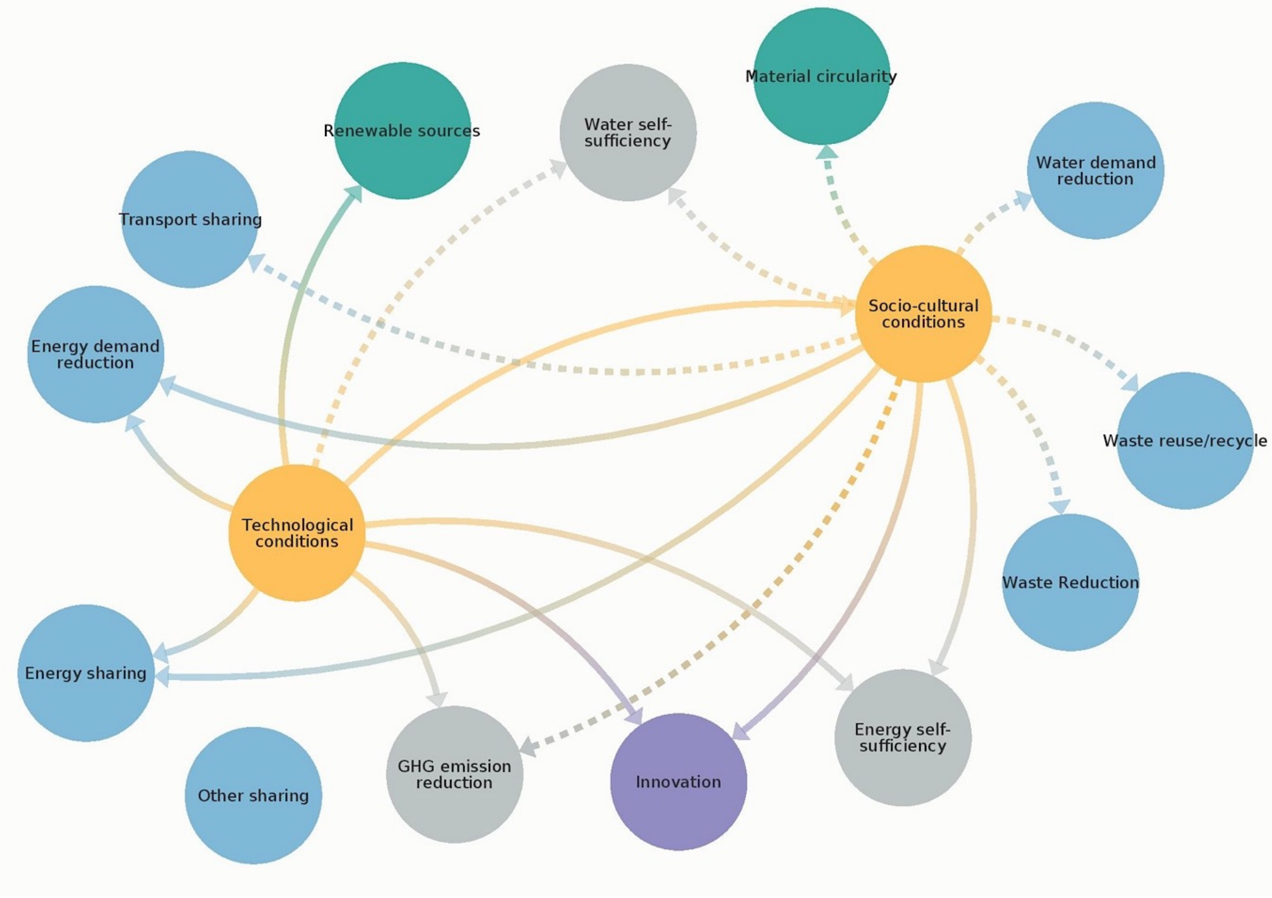

Figure 13 Systems mapping showing interrelations between socio-cultural and technological DSES conditions and circularity sub indicators

Annex 2: Research Instruments

List of Interviewees

S.No	Group	Organization	Contact	Area of Expertise
1	Project Developer/Inhabitant	Schoonschip Inhabitant	Markus Schmid	Members involved in Schoonschip project
2	Project Developer/Inhabitant	Schoonschip Inhabitant	Peer de Rijk	Members involved in Schoonschip project
3	Project Developer/Expert	Metabolic	Eva Gladek	Developed a vision deployment masterplan for Schoonschip, guided the community on sustainability throughout the project
4	Project Developer/Expert	Grid-Friends	Michael Kaisers	Developed advanced smart gird control platform in Schoonschip
5	Project Developer	Treedelft	Joep Brouwers	Part of implementation of Schoonschip
6	Institutional Actors	Gemeente Amsterdam	Iris Voorwerk	Involved in Schoonschip project management
7	Institutional Actors	RVO	Vanand Meliksetian	Gave legal exemption for energy ownership
8	Expert	TU Delft	Piero Medici	Expert working on neighbourhood circularity (with knowledge about Schoonschip)
9	Expert	Waag	Socrates Schouten	Working on a broader project of Atelier, of which Schoonschip is part
10	Expert	AMS Institute	Paul Voskuilen	Working on a broader project of Atelier, of which Schoonschip is part

Interview Guides

1. Interview guide for project developers/experts for Schoonschip:

Sub-variable	Questions
Background	Can you tell me about your organization's work?
	How did you personally get involved in Schoonschip project?
Neighbourhood Circularity	How well do you think Schoonschip performs in circularity in terms of its metabolism? Can you also expand on the different circular activities happening there? (like recycling, reusing, sharing etc.)
	Following up, how often do new innovations keep coming up in Schoonschip?
Background	Please explain how DSES came about, from the idea stage to implementation. What role do you think DSES play in making Schoonschip circular (or sustainable)?
Technological Conditions	Can you elaborate on the availability and role of upcoming and disruptive technologies like IoT, ML, AI in DSES? Did they in any way act as enablers to the development of DSES and in turn, circularity?
	Schoonschip is one of the first few areas which introduced the concept of blockchain for energy trading. Can you elaborate on how it came about and its progress till now? How is it relevant to CE?
	Since the technologies used in DSES are fairly advanced and recent, were there any difficulties in terms of their diffusion in the neighbourhood? If yes, kindly explain.
Economic, Institutional Conditions	Were there proper regulatory frameworks in place that accelerated the development and implementation of these energy systems? Please elaborate. Are you also aware of different kinds of subsidies etc. that enabled their development? (liberalization of energy markets, clean energy and battery storage subsidies etc.)
Political Conditions	Was there some kind of political backing as well? If yes, then how so and at which stages?
Institutional conditions	To what extent did the national disincentives towards fossil fuel based sources help the development and implementation of DSES?
	Were there proper regulatory frameworks in place that accelerated the development and implementation of these energy systems? Please elaborate.
Economic Conditions	What were the different means of financial support that the project received throughout its timeline? (municipality, city govt, PPP --follow up questions on their extent)
Institutional conditions	How were different stakeholders involved in the DSES project of Schoonschip? Please explain how they got involved timewise.
	Was there clear communication between you and other actors involved in this project?
Economic Conditions	How viable is the whole energy system economically? Kindly consider the capital costs stage as well as the operational costs stage.
	Do DSES enable cost savings in any form? Please elaborate on the different sectors it could enable cost savings.
Environmental Conditions	Were there any environmental standards kept in consideration during the development of DSES?
	Were the environmental standards considered while implementing them? If yes, then to what extent?
	Were there initiatives to increase environmental awareness of the community on DSES?

2. Interview guide for community members/informants living in Schoonschip.

Sub-variable	Questions
Background	How did you come to know about Schoonschip and how long have you been a member here?
	Please elaborate on how this neighbourhood came about, from idea stage to a fully functioning stage, focusing on the sustainability initiatives.
Neighbourhood Circularity	Can you explain how the neighbourhood is circular/sustainable, in terms of energy, water, waste? Please elaborate on different activities happening here.
Background	Specifically, how did the idea of installing these DSES start? Was it a product of some other broader initiative?
Institutional, Socio-cultural Conditions	How involved were you (or your fellow neighbours) in the implementation of DSES? Was there an increased participation of any kind at any stage of developing and implementing these energy systems?
Institutional Conditions	Was there clear communication between you and other actors involved in this project? Can you explain how the whole process worked?
Economic Conditions	Can you talk about the economic viability of DSES and if they benefit you economically in any way?
Circular Activities; Technological Conditions	To what extent are you using energy sharing platforms? Are you sharing or reusing energy in other ways as well? Please elaborate
Technological, Socio-cultural Conditions	How well did you adjust to the new technologies used in DSES. What kind of problems did you encounter? Did that or any other activity result in changes in your lifestyle or values? Please elaborate.
Socio-cultural, Environmental Conditions	Following up on the above question, can you tell me if these new systems helped you become more environmentally aware? If yes, then how?
Socio-cultural Conditions	To what extent do you trust these systems with your daily energy data?
Socio-cultural Conditions	Lastly, how would you rate your commitment to DSES (and the neighbourhood)?

3. Interview Guide for institutional actors involved in Schoonschip.

Sub-variable	Questions
Background, Neighbourhood Circularity	Can you tell me about your role?
	What was your agency's role in making Schoonschip circular? Please explain the involvement of your agency from start to finish.
Neighbourhood Circularity	In terms of circularity, how do you think Schoonschip performs in terms of resource productivity, waste management, energy and GHG emissions and circular activities?
	Specifically, what role did you play in the development and implementation of DSES in Schoonschip?

Institutional Conditions	What kind of interactions happened between you and different stakeholders before/ during the development of DSES? Was there clear communication? Please elaborate on PPP and other businesses too.
	What are the different city level/national circularity/sustainability goals that were kept in mind while implementing DSES?
	What kind of subsidies or policies in the clean energy and circularity sector enabled the development of DSES in Schoonschip? Let's start with local energy cooperatives (clean energy etc. later on).
	Are there currently any disincentives for fossil-fuel based energy sources? If yes, the please elaborate on their role in accelerating the development of DSES in Schoonschip specifically.
	What other regulatory frameworks were put into place/ considered/ strengthened for DSES to be a success?
Political Conditions	Can you explain the political involvement? Was there any kind of lobbying done for these energy systems to pass?

Sources used for Content Analysis/Secondary Data

Source	Title	Actor Involved	Type	Description
1	**Cleantech Playground**	Metabolic	Document	Vision and deployment plan for de Ceuevel and Schoonschip https://www.metabolic.nl/publications/cleantech-playground/
2	**Trading power with neighbours**	Philip Gladek (Spectral)	Podcast	Implementation of blockchain technology in de Ceuevel and Schoonschip. http://podcast.montelnews.com/257968/1709380-trading-power-with-the-neighbours
3	**The Making of Schoonschip**	Sascha Glasl (Space&Matter); Philip Gladek (Spectral); Community members	Event; Online recording	Opening event of Schoonschip with Pakhuis de Zwager. https://www.youtube.com/watch?v=bBuw9NczWTA&t=37s
4	**Schoonschip Website**	Community	Website	Website with an open source explaining all sustainability initiatives within Schoonschip and relevant actors, policies involved. https://schoonschipamsterdam.org/#site_header
5	**Spectral Business Case for DSES**	Spectral, Community	Document	Spectral's research on the viability and justification for using DSES in Schoonschip
6	**Schoonschip Organization**	Community	Document	Community's personal documentation of the development of the neighbourhood, actors involved and working groups with timelines
7	**Het Groene Hart podcast**	Community	Podcast	Initiator Marjan de Blok's experience with Schoonschip's development with Sophie Hilbrand (another inhabitant)
8	**Spectral DSES Privacy Statement**	Spectral, Community	Document	Privacy statement for inhabitants using DSES
9	**Schoonschip Tender**	Community, Munipality	Document	Schoonschip's tender entry for getting land from municipality

Survey

Master's Thesis on Neighbourhood Circularity

My name is Rhea Srivastava and I am a master's student at Erasmus University Rotterdam. I am conducting an academic research on the various conditions for the development and implementation of smart energy systems that accelerate neighbourhood circularity in Schoonschip. The aim of this research is to show an umbilical connection between energy and circularity transition and to gain more insights into neighbourhood circularity. This survey will help me with the same. All the information collected will be used only for academic purposes and kept confidential. The survey has 2 main sections, all with multiple choice questions and will take 5 minutes of your time.

I am grateful for your help in completing this survey.

* Required

Assessing Schoonschip's Circularity

Circularity (or circular economy) is a regenerative concept that involves the continual reuse of resources, elimination of waste and a shift towards the use of renewable energy, replacing the 'end-of-life' concept with a more restorative one, thereby reducing plausible environmental impacts.

1. How long have you been living in Schoonschip?

Mark only one oval.

- ◯ More than a year
- ◯ Less than a year

Please rate the extent of the below-mentioned activities on circularity as per your household practices.

2. Extent of reducing energy, water and waste demand in the household *

Mark only one oval per row.

	Poor	Fair	Satisfactory	Very good	Excellent
Extent of reducing energy demand	◯	◯	◯	◯	◯
Extent of reducing water demand	◯	◯	◯	◯	◯
Extent of reducing waste	◯	◯	◯	◯	◯

3. Extent of reusing/recycling/recovering waste generated by your household *

Mark only one oval.

- ◯ Poor
- ◯ Fair
- ◯ Satisfactory
- ◯ Very good
- ◯ Excellent

4. Extent of reusing and recycling building materials in the household *

Mark only one oval.

- Poor
- Fair
- Satisfactory
- Very good
- Excellent

5. Extent of sharing resources *

Mark only one oval per row.

	Poor	Fair	Satisfactory	Very good	Excellent
Extent of sharing energy					
Extent of sharing transportation					
Extent of sharing other products					

6. Self-Sufficiency *

Mark only one oval per row.

	Poor	Fair	Satisfactory	Very good	Excellent
Extent of energy self-sufficiency in the household					
Extent of using renewable energy in the household					
Extent of water self-sufficiency in the household					

7. Extent of reduction in greenhouse gas emissions through the above-mentioned activities by your neighbourhood *

Mark only one oval.

- Poor
- Fair
- Satisfactory
- Very good
- Excellent

8. Extent to which new innovations come up in the neighbourhood *

Mark only one oval.

- Poor
- Fair
- Satisfactory
- Very good
- Excellent

Energy Systems of Schoonschip

This section predominantly covers questions related to the advanced energy systems installed in Schoonschip. These energy systems include the smart grid, battery system, solar panels, heat pumps, smart energy monitoring platform etc.

9. How would you rate your involvement in the development and implementation of Schoonschip's energy systems? *

Mark only one oval.

- Poor (Not at all active)
- Fair
- Satisfactory
- Very good
- Exceptional (Very active)

10. How would you rate the economic viability of these energy systems? *

Mark only one oval.

- Poor
- Fair
- Satisfactory
- Very good
- Exceptional

11. How would you rate their ease of use? *

Mark only one oval.

- Poor
- Fair
- Satisfactory
- Very good
- Exceptional

12. Did adapting to these energy systems result in any lifestyle/behavioural changes/activities? *

Mark only one oval.

- ( ) Yes, to a great extent
- ( ) To some extent
- ( ) Not at all

13. If yes, please mention the activities (e.g. energy saving, reusing etc.)

____

14. Did the energy systems (including energy monitoring) help in increasing your environmental awareness? *

Mark only one oval.

- ( ) Yes, to a great extent
- ( ) To some extent
- ( ) Not at all

15. To what extent do you trust these energy systems with your energy data? *

Mark only one oval.

	1	2	3	4	5	
I do not trust them	( )	( )	( )	( )	( )	I trust them completely

16. How would you rate your commitment to these energy systems? *

Mark only one oval.

	1	2	3	4	5	
Barely committed	( )	( )	( )	( )	( )	Fully committed

17. Other relevant information that you would like to provide

____
____
____
____
____

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