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Smart and Sustainable Off-grid Housing Powered by Vehicle to Anything (V2X)

An exploratory study to understand the innovation readiness and feasibility for off-grid living powered by Vehicle to Anything (V2X)

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by

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Master of Science Thesis TRITA-ITM-EX 2022:189
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Smarta och hållbara off-grid boenden försörjda av en elbil med V2X

av

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KTH Industrial Engineering and Management	**Master of Science Thesis TRITA-ITM-EX 2022:189** **Smart and Sustainable Off-grid Housing Powered by Vehicle to Anything (V2X)** Hanna Borgefeldt Emma Svensson

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Abstract

For the EU to reach net-zero by 2050, an increased rate of renewable energy generation is needed. Off-grid tiny houses serve as a sustainable housing option as they are energy conservative, and their primary source of energy is renewable energy. However, off-grid living is faced with challenges due to the seasonal energy imbalance caused by the intermittent characteristics of renewable energy. This thesis aims to explore the potential of reducing this energy imbalance by using an electric vehicle (EV) to charge the home when there is an energy shortage and charge the EV when there is an energy surplus. This concept is enabled by bidirectional charging, also referred to as "Vehicle to Anything" (V2X). The main research question is to understand if an off-grid tiny house supported by V2X can be self-sufficient on energy and what the prerequisites for usage are. The method for answering this research question is firstly by conducting a general study followed by a case study. In the general study, industry experts are interviewed and surveyed to assess the innovation's technology, market, and regulatory readiness and attributes of the innovation related to potential adoption. Thereafter, a case study with a partner in Sweden offering stays in off-grid tiny houses was conducted. The aim was to understand the system dynamics of the energy balance for an off-grid tiny house with solar panels and a home battery when adding an EV.

Results show that it is regulatory unproblematic to connect an EV to power off-grid living today, and the technology is more ready than the market. To increase the readiness level of the innovation, standardization of equipment and communication is needed. The attributes of the innovation that supports adoption are that the EV is mobile and offers large storing capacity which increases flexibility and hence decreases dependency on renewable energy. However, setting up the off-grid system and following safety regulations can be considered complex. Thereto, the innovation is seen as most applicable for short-term stays and individual usage. Results from the case study show that the EV can theoretically prolong the season for off-grid tiny house living by 1-4 months by reducing the energy imbalance and increasing self-sufficiency. Moreover, the EV can increase the share of renewable energy that is being used by storing energy when there is excess solar energy available.

On a final note, to answer the main research question if off-grid living supported by V2X can become self-sufficient on energy and what the prerequisites are for usage, the study concludes that it is theoretically possible, but the innovation is dependent on all technology components being tested and validated together in an off-grid environment. The EV needs to have bidirectional capabilities and the home needs to be equipped with smart software and an inverter to control the charging and discharging. Thereto, there needs to be a business model that creates value confirmed by the market, both customers and industry actors. Lastly, from a regulatory point of view, the concept is feasible as long as the installation of the energy system follows Swedish safety regulations. The EV can then, according to the model, theoretically help to prolong the season by reducing the energy balance making the energy system self-sufficient on energy. The EV can be discharged as well as charged by the excess solar, and hence the smart bidirectional charging of the EV and the home can increase the share of renewable energy available for use and reduce the energy imbalance. Implications of this thesis suggest increased access to off-grid living as the V2X technology can prolong the season for people living off-grid as well as for off-grid businesses in the hospitality industry. This would allow for increased business value and opportunities within both the housing and tourism industry. The findings also support sustainable development as the innovation increases resource efficiency of the EV as it can serve multiple purposes, including transportation, energy storage, and energy supply.

Key-words: Off-grid, Vehicle to home, V2H, Vehicle to load, V2L, sustainable power generation, renewable energy, technology readiness level, electric vehicle innovation

Examensarbete TRITA-ITM-EX 2022:189

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Sammanfattning

För att EU ska nå nettonoll till 2050 krävs mer förnybar energi. Off-grid tiny houses är små hus som är frikopplade från stamnätet och är ett hållbart boendealternativ då de är energisnåla och deras primära energikälla är förnybar energi. I dagsläget finns det dock flera utmaningar med att bo off-grid till följd av den säsongsbaserade energiobalansen orsakad av de intermittenta egenskaperna hos förnybar energi. Därför syftar det här examensarbetet till att utforska potentialen för att minska energiobalansen genom att använda en elbil för att ladda hemmet när det råder energibrist och ladda elbilen när det finns ett energiöverskott. Detta koncept möjliggörs av dubbelriktad laddning, även kallad "Vehicle to Anything" (V2X). Den huvudsakliga forskningsfrågan är att undersöka om off-grid tiny house med stöd av V2X kan bli självförsörjande på energi och vilka förutsättningarna är för användning. Metoden för att besvara forskningsfrågan är inledningsvis en empirisk studie följt av en fallstudie. I den empiriska studien uppskattas den teknologiska, marknadsmässiga och regulatoriska mognadsgraden av att använda en elbil för att försörja off-grid boenden. Vidare undersöks innovationens egenskaper för att förstå hur lösningen skulle kunna tilltala möjliga användare. Studien gjordes genom att intervjua samt skicka ut en enkät till branschexperter. Därefter genomfördes en fallstudie med en partner i Sverige som erbjuder vistelser i off-grid tiny houses. Under fallstudien modellerades energisystemet bestående av ett off-grid hus, ett hembatteri samt solpaneler för att förstå hur energibalansen förändras när en elbil adderas till systemet.

Resultaten visar att det är regulatoriskt oproblematiskt att ansluta en elbil till ett off-grid tiny house för att förse det med ström, och tekniken är mer redo än marknaden. För att innovationens mognadsgrad ska öka krävs mer standardisering av både utrustning och kommunikationsprotokoll. Egenskaper som uppmuntrar användning av innovationen är att elbilen är mobil och erbjuder stor lagringsmöjlighet vilket i sin tur minskar beroendet av förnybar energi. Det kan dock anses komplicerat att sätta upp off-grid-systemet och följa de säkerhetsföreskrifter som krävs. Vidare ses innovationen som mest användbar för korttidsvistelser och individuellt bruk. Resultaten från fallstudien visar att elbilen kan förlänga säsongen för off-grid tiny houses boende med 1-4 månader genom att minska energiobalansen och öka systemets grad av självförsörjande. Dessutom kan elbilen öka andelen förnybar energi som används genom att lagra energi när det finns överskott av solenergi tillgänglig.

Slutligen, för att svara på den huvudsakliga frågeställningen om off-grid tiny houses med stöd av V2X kan bli självförsörjande på energi och vilka förutsättningarna är för användning, drar studien slutsatsen att det är teoretiskt möjligt, men innovationen är beroende av att alla tekniska komponenter testas och valideras tillsammans i en off-grid miljö. Elbilen måste ha dubbelriktad laddning och hemmet måste utrustas med smart mjukvara och en växelriktare för att styra laddning och urladdning. Därför behöver det finnas en affärsmodell som skapar värde som bekräftas av marknaden, både av kunder och branschaktörer. Slutligen, ur ett regulatoriskt perspektiv, är konceptet genomförbart så länge installationen av energisystemet följer svenska säkerhetsföreskrifter. Elbilen kan då, enligt modellen, teoretiskt bidra till att förlänga säsongen genom att minska energibalansen och göra energisystemet självförsörjande på energi. Elbilen kan både ladda ur energi till boendet samt laddas av överskottet av solenergi, och därför kan den smarta dubbelriktade laddningen av elbilen och hemmet öka andelen förnybar energi tillgänglig för användning och minska energiobalansen. Implikationerna av denna uppsats tyder på ökad tillgång till off-grid boende eftersom V2X-tekniken kan förlänga säsongen för människor som bor off-grid såväl som för off-grid-företag inom besöksnäringen. Detta skulle möjliggöra ökat affärsvärde och möjligheter inom både bostads- och turistnäringen. Resultaten stöder också hållbar utveckling eftersom innovationen ökar resurseffektiviteten för elbilen eftersom den kan tjäna flera syften, inklusive transport, energilagring och energiförsörjning.

Nyckelord: Off-grid, Vehicle to home, V2H, Vehicle to load, V2L, hållbar kraftproduktion, förnybar energi, tekniksmognadsgrad, innovation, elbilar

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Nomenclature

BEV	Battery Electric Vehicle
EV	Electric Vehicle
HEMS	Home Energy Management System
PHEV	Plug-in Hybrid Electric Vehicle
PV	Photovoltaic
SDG	Sustainable Development Goals
SOC	State of Charge
V2H	Vehicle to Home
V2L	Vehicle to Load
V2X	Vehicle to Anything

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Emma Svensson & Hanna Borgefeldt

Stockholm, June 2022

1. Introduction

This chapter first introduces the reader to the background of this thesis. Secondly, the problem is defined as two layers. Thirdly, the problem definition is translated to a research purpose and research questions aiming to investigate solutions to the problem. Lastly, delimitations of the scope are presented followed by a guide explaining the disposition of this report.

1.1 Background

The EU aims to reach net-zero by 2050 (European Commission, 2019) and an increased rate of renewable energy generation is needed to reach climate neutrality (Broom, 2021). The installed capacity and investments in renewable energy have continued to increase, but the world must double the transition rate to renewable energy to be able to reach net-zero by 2050 (IEA, 2021a; REN21, 2021). The building sector is a large emitter and buildings account for 36 % of the global energy demand (Urge-Vorsatz, et al., 2020). More specifically, the portion of energy demand in buildings that comes from renewable energy sources is less than 15 % (REN21, 2021). In contrast, one type of building that has a significantly higher share of renewable energy consumption is off-grid houses, as their primary source of energy often is solar energy or wind power (Pulido, et al., 2019; Volcko, et al., 2015; Ren, et al., 2019; Abuzeid, et al., 2019; Rahimzadeh & Evins, 2019). Therefore, off-grid homes powered by renewable energy can be a way to help mitigate climate change in the building sector (Miyazato, et al., 2017b; Pulido, et al., 2019). Further, the interest in off-grid living has increased due to the reduction in prices for PV panels and battery solutions (Khalilpour & Vassallo, 2015). Moreover, living off-grid in tiny houses, that are energy conservative due to their size, has also increased in popularity (Arias Calluari & Alonso-Marroquín, 2017). Motivations behind wanting to live off-grid and in tiny houses are described to be related to financial aspects, a desire for simplicity and sustainability concerns (Olsson, 2020; Arias Calluari & Alonso-Marroquín, 2017). The interest in off-grid living is also seen to be closely related to the desire for security as well as independence (Khalilpour & Vassallo, 2015).

Off-grid living is, however, faced with several challenges due to the characteristics of renewable energy (Pulido, et al., 2019). Renewable energy depends on uncontrollable meteorological factors varying over season and time of day (Kanoria, et al., 2011). Off-grid homes must hence cope with these intermittent characteristics by having sufficient energy storage (Puranen, et al., 2021). Even though prices of PV panels and storage solutions have decreased (Khalilpour & Vassallo, 2015) it is still expensive and difficult to store all energy that the household generates during summertime as this requires large energy storage systems (Bülow, 2021; Heberlein & Perneby, 2021; Wahlström, n.d.). The alternative to storing the energy produced from PV panels is to sell the excess energy to the main grid, however, this is impossible in the off-grid scenario as the home is disconnected from the grid (Hu & Augenbroe,

2012). Another side of the above-mentioned problem is that during the remaining seasons of the year, less solar energy can be generated (Wahlström, n.d.). During spring, fall, and winter in Sweden, solar energy generation is still feasible (Vattenfall, 2022) but during some months it is too low to supply an off-grid home, and hence a separate fossil fuel-driven generator is often needed (Rowe & Aichele, 2010; Dahlbom, 2020; Elazab, et al., 2021). Concludingly, there is a seasonal energy imbalance when living off-grid.

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Simultaneously, in the journey towards reaching net-zero, there is an ongoing aim to increase the electrification of end-use sectors such as the transportation sector (European Commission, 2020). The transport sector is being decarbonized (European Environment Agency , 2021) and the electric vehicle adoption rate is rapidly increasing (IEA, 2021; COP26, n.d.). With this rapid growth and adoption of EVs, new ideas, concepts, and technologies are emerging to utilize EV batteries in a non-traditional way (Pearre & Ribberink, 2019; Liu, et al., 2013; Blazek, et al., 2020). One of these emerging technologies is Vehicle to Anything (V2X), where the EV serves as an energy storage solution through traditional charging and acts as a power source through discharging (Thompson & Perez, 2020; Noel, et al., 2020). Hence, the EV can both store and supply energy. This presents an exciting research opportunity to explore the concept of utilizing an EV to solve the energy storage and supply problem when living off-grid. In other words, exploring the innovative idea of using V2X to power the off-grid home.

The innovation of using an EV to power off-grid homes and reduce the seasonal energy imbalance has, however, gained little academic research. The use of V2X to power places and loads where other power sources are either not feasible or convenient is currently understudied (Noel, et al., 2020). This thesis aims to explore off-grid housing powered by V2X to reduce the energy imbalance caused by the intermittent nature of renewable energy. In this study, the V2X technology is explored to understand the potential and feasibility to power off-grid housing. Firstly, the innovation readiness level is analyzed from a technology, market, and regulatory perspective. This is followed by an analysis of the innovation attributes to understand potential adoption. Secondly, a case study with an off-grid living provider is conducted to understand the feasibility of an off-grid V2X system. In the case study, a model is developed to analyze different scenarios of the off-grid tiny house operation powered by the EV. Concludingly, this thesis aims to reduce the knowledge gap and explore the solution to understand if it is possible for the off-grid tiny house with V2X to be self-sufficient on energy.

1.2 Problem Definition

As introduced in the background section, off-grid living is problematized by not being able to utilize all renewable energy that is being produced as it requires large and expensive energy storage systems (Bülow, 2021; Heberlein & Perneby, 2021; Wahlström, n.d.). The excess energy cannot be sold to the main grid since the production is off-grid (Hu & Augenbroe, 2012). Moreover, off-grid living is also problematized by not having enough energy generation during the remaining seasons of the year as less solar can be generated (Ahrberg, 2021; Vattenfall, 2022). During certain parts of the year, a backup generator is needed, and these generators are often driven by gasoline, diesel, or liquified petroleum gas (Rowe & Aichele, 2010; Dahlbom, 2020; Elazab, et al., 2021; Rahimzadeh & Evins, 2019; Yilmaz, et al., 2015). Concludingly, the intermittent character of renewable energy causes a seasonal energy imbalance when living off-grid.

Even if there are acknowledged benefits of the V2X technology it appears to be a knowledge gap within this area, especially in the context of powering places where no other power source is available (Noel, et al., 2020). As presented in the literature review below, there were only twelve papers examining the topic of using an EV to power an off-grid home, i.e., off-grid V2X systems. Moreover, the papers that exist often solely focus on the technology as a solution to a specific use case. Hence, there is not much research on the market and regulatory perspective found in the literature today. More research would be needed for an overview of the full landscape of the V2X technology in the off-grid scenario, especially in the Swedish context. Hence, another problem situation is that there is limited academic literature on powering an off-grid home with V2X and its practical implementation. Lack of theoretical and practical knowledge is seen to relate to a lack of decision-making that affects organizational performance (Abubakar, et al., 2019; Yima, et al., 2004).

Concludingly, the three above presented problems could be divided into two different layers: layer one and layer two. The first layer of the problem is that further academic research is needed to provide an overview of the V2X technology in an off-grid setting from a holistic perspective. Additionally, research examining the characteristics and possible benefits that V2X could bring for this specific use case would contribute to a more holistic understanding of the innovation. The second layer of the problem is that there is an energy imbalance: during summer, the excess energy cannot be stored nor sold, and during colder and darker months there is not enough energy generation causing the need for a backup generator which is often fossil-fuel driven. The hypothesis is that the second layer of the problem potentially could be solved by leveraging the EV as extra energy storage and energy source through the V2X bidirectional charging technology in the EV and increase the energy self-sufficiency. V2X is seen as feasible to be used as an energy storage solution and to provide electricity in remote places (Thompson & Perez, 2020; Pearre & Ribberink, 2019; Noel, et al., 2020).

Several possible beneficiaries could benefit from having these problems analyzed. On the first layer, industry actors could use the findings to better understand the innovation of using an EV to power an off-grid home through V2X and its potential market opportunity. This thesis aims to explore the V2X technology in a new setting which poses a potential opportunity for using EVs for more use cases than solely for transportation. Policymakers could likely also be interested in taking part in this study to understand the market and technology readiness in relation to the regulatory landscape for using the EV to power an off-grid home. Similarly, the housing sector could also see interest in prolonging the season for off-grid living with the use of an EV. On the second layer, this thesis also aims to create value for EV users and tiny house residencies. As the EV adoption rate is increasing (IEA, 2021), using the EV to power one's home could be considered an interesting use case that adds value to the homeowner as it can help reduce the seasonal energy imbalance. Concludingly, the interviews with experts and the modeling of scenarios that this thesis will conduct aim to be interesting for several beneficiaries interested in housing, energy as well as mobility.

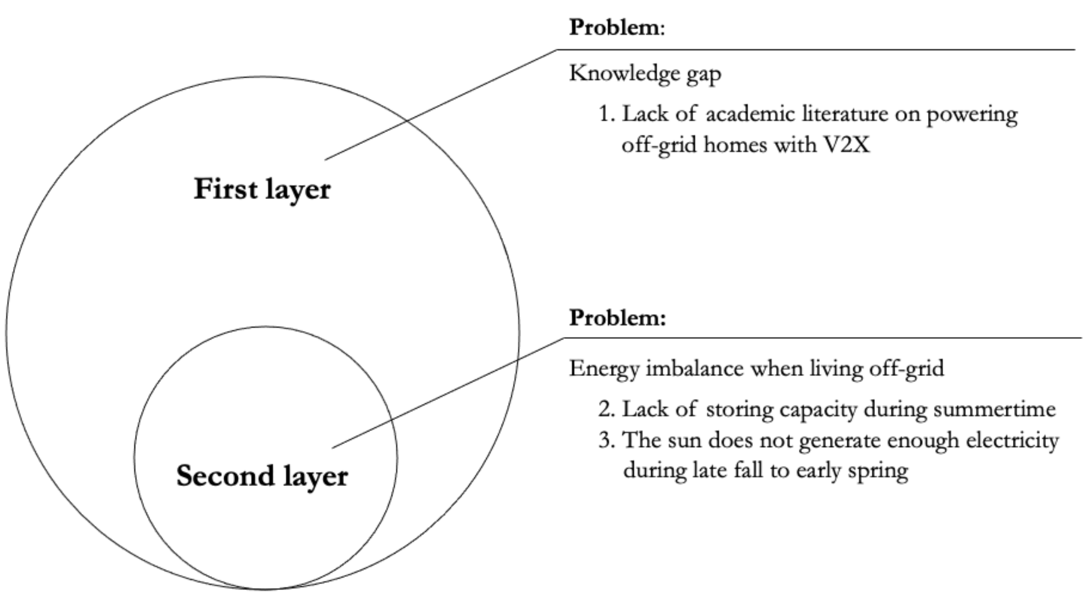

Figure 1 Visualization of this study's problem definition

1.3 Purpose and Research Question

Derived from the problematization above, this thesis aims to help solve both layers of the problem; the first layer being a current knowledge gap, and the second layer being that there is an energy imbalance when living off-grid caused by renewable energy generation. Starting with the problem on the first layer, the purpose is to reduce the research gap on using the V2X technology in an off-grid setting by synthesizing literature, both academic and grey literature, and by interviewing experts on the topic. In the second layer, the purpose is to analyze the potential of using the EV as additional energy storage during summer and to prolong the season for off-grid living. Consequently, this study aims to investigate the potential for smart and sustainable off-grid housing powered by V2X technology. This concept is new, and this study will hence explore the V2X technology to understand both the technology, market and regulatory landscape as well as the potential adoption. Further, the feasibility of V2X to power off-grid tiny houses will be assessed. This innovation of an off-grid V2X system could enable greater flexibility when living off-grid.

The main research question (RQ) will be answered by researching two sub-questions, where RQ1 will be answered by a general study and RQ2 will be answered by a case study with an off-grid living provider in the hospitality industry.

- *Main RQ:* Can off-grid living in a tiny house supported by Vehicle to Anything (V2X) become self-sufficient on energy and what are the prerequisites for usage?
    - *First layer RQ1:* How ready is the V2X technology to power an off-grid home and what could affect potential adoption?
    - *Second layer RQ2:* Can V2X help prolong the season for tiny house off-grid living by reducing the energy imbalance?

1.4 Delimitations

The scope of the general study for RQ1 and the case study for RQ2 will be set in a Swedish context. This delimitation is made as to the market conditions and regulatory landscape differ depending on the country. Moreover, this delimitation is made as the data collection will be fetched from interviews held with Swedish experts as well as using data from a Swedish case study partner active within the hospitality industry for off-grid living. In contrast to the market and regulatory readiness assessment, which is region-specific, the technology as such is more alike regardless of country. Hence, international research journals and literature will be reviewed as the Swedish literature on this new technology is limited. However, once the understanding of the technology as such has been gained, the final assessment of the innovation readiness from a technology, market, and regulatory landscape will be made on a Swedish level. Concludingly, the delimitation to focus on Sweden is made.

Secondly, another delimitation is that this study will evaluate the potential and feasibility of a V2X off-grid system with BEVs and off-grid living, excluding PHEVs, fuel cell EVs as well as on-grid housing. More specifically, the system will consider tourism and the second home market for individuals staying for short and medium terms, hence not evaluating the fully off-grid lifestyle. The case study is based on a company offering stays in off-grid tiny houses and the assumptions made will hence be based on the activities and energy consumption of a tiny house. Heating is supplied by liquified petroleum gas in the case study cabins, and hence the EV will not be used to power the main heating system of the tiny house. Instead, the model only includes the electricity-driven share of the heating as described in the load specification in the "Method" chapter.

Thirdly, the demand for off-grid living as such will not be investigated. Instead, the demand is considered to exist and given this demand, the possibility to connect the EV with V2X technology to power the off-grid home is examined. In other words, the market demand and supply for the off-grid V2X system will be assessed, but the demand for traditional off-grid housing is not assessed.

Lastly, only energy balance will be modeled in the case study. The model will not take into consideration e.g., AC/DC converters and voltage drop. This delimitation is made as the model will aim to illustrate the generation, storage, and flow of energy between the different components in the off-grid system during a year to assess when there is a balance between energy supply and energy demand. However, even if the AC/DC converters are not included in the model, these will be considered by adding a loss factor to the model representing the conversion as this affects the available energy. This delimitation is seen as reasonable as the thesis analyzes the energy self-sufficiency of the home.

1.5 Disposition of Report

Chapter 1 Introduction: This chapter introduces the reader to the background, the problem, and the research purpose and research questions. Lastly, delimitations of the scope are presented.

Chapter 2 Literature Review: This chapter introduces the reader to the previous studies in the field of off-grid energy systems, the V2X technology and the intersect of using V2X in the off-grid setting. The last section of this chapter also presents grey literature on the topic to provide an industry context.

Chapter 3 Theoretical Framework: This chapter presents the chosen theoretical frameworks, the motivation for choosing these frameworks, and how the theories complement each other.

Chapter 4 Method: This chapter presents a description of the research design, system boundaries, method for data collection and data analysis as well as an analysis of the thesis' reliability and validity.

Chapter 5 General Study: This chapter aims to assess the first layer of the problem represented by RQ1. Firstly, the results from the interviews and the survey are presented. Secondly, the results are analyzed by applying the Innovation Readiness Framework and Diffusion of Innovation theory.

Chapter 6 Case Study: This chapter aims to assess the second layer of the problem represented by RQ2. Firstly, the model and the results from the model are presented. Secondly, the model results are analyzed.

Chapter 7 Discussion: This chapter discusses the general study and case study. Initially, the studies are discussed separately and then collectively to understand the implications. Further, the thesis' SDG alignment, as well as the study's limitations, are discussed.

Chapter 8 Conclusion: This chapter presents the conclusion to the main research question as well as supporting RQ1 and RQ2. Thereafter, theoretical contributions and practical implications of this thesis are presented. Finally, future studies are suggested.

2. Literature Review on Off-grid Living and V2X

This chapter introduces the reader to previous studies in the field. Firstly, literature on off-grid energy systems is presented, followed by literature on the Vehicle to Anything (V2X) technology. Thereafter, previous studies on this intersection of using the V2X technology in the off-grid setting are presented. Lastly, this chapter presents an industry focus on the topic including grey literature on which car manufacturers are offering or researching the bidirectional functionality, and commercially available options for smart charging.

2.1 Off-grid Living and Energy Management

The components of an off-grid home vary based on the configuration. However, a common set-up for the system is (1) renewable energy generation by PV or wind turbines, (2) energy storage in form of a battery, (3) a backup generator, and (4) devices that consume electricity (Pulido, et al., 2019; Volcko, et al., 2015; Ren, et al., 2019; Abuzeid, et al., 2019; Rahimzadeh & Evins, 2019). Many off-grid smart homes also include solar collectors and hot water heat pumps (Miyazato, et al., 2017a; Miyazato, et al., 2017b). Moreover, renewable energy sources have attracted attention as they provide realistic off-grid methods of electricity generation and storage which thus can replace conventional fossil fuel energy sources (Abuzeid, et al., 2019). PV panels are a flexible and simple technology that provides renewable electricity without needing a complex electricity infrastructure (Pulido, et al., 2019). For an off-grid home to support daily operation, an energy system must be able to not only generate all energy it consumes but also store the energy short- and long-term due to the intermitted characteristics of the renewable energy sources (Puranen, et al., 2021).

2.1.1 Opportunities and Challenges when Living Off-grid

Off-grid homes can be seen as an environmentally friendly option since they are often powered by renewable energy and thus do not emit carbon dioxide (Miyazato, et al., 2017b). Moreover, off-grid homes are seen as a positive reaction to both energy generation trends as well as climate change impacts (Siegner, et al., 2021). They can also be considered important as off-grid homes can increase access to electricity throughout the world, to remote places and bring flexibility to the grid (Pulido, et al., 2019; Pulido, et al., 2018). In other words, off-grid houses can contribute to solving problems regarding the environment and areas without access to electricity (Miyazato, et al., 2017b). PV systems are important in the off-grid scenario because they are easy to install and customize in an off-grid scenario and they are sustainable (Yilmaz, et al., 2015). The installation cost of a PV system is often less than the connection cost to the grid (Yilmaz, et al., 2015) and a PV-based system is currently the best option from a cost perspective for electricity generation (Puranen, et al., 2021). In addition, prices are expected to further fall, and the popularity of PV panels is hence expected to increase (Puranen, et al., 2021). The trend of off-grid living has grown globally and the reduction in price in solar panels and batteries is one of the underlying reasons (Alonso-Marroquin, et al., 2017). The estimation of continuous reduction in PV prices and battery storage solutions has gained public interest and interest in “leaving the grid” or “living off-grid” has increased (Khalilpour & Vassallo, 2015). Furthermore, the concept of an off-grid system is to create independence between a house’s primary energy system from the public infrastructure and utilities (Alonso-Marroquin, et al., 2017). The interest in off-grid living is the same as the desire for security and independence (Khalilpour & Vassallo, 2015).

However, off-grid electrification of houses is also opposed to challenges. These challenges are high initial investment costs, regulatory uncertainties, tariffs, stranded assets as well as supply and demand mismatch (Pulido, et al., 2019). The supply and demand mismatch, or the energy imbalance, in off-grid houses powered by solar, is highly challenging as both the supply and demand are dependent on unknown surrounding conditions (Hu & Augenbroe, 2012). The intermittent nature of renewable energy sources poses challenges, but these can be combined with a conventional diesel generation and an energy storage system, called a hybrid renewable energy system, to offer reliable energy generation during the darkest and coldest parts of the year (Abuzeid, et al., 2019). However, one main challenge is the trade-off between energy storage and importing diesel (Rahimzadeh & Evins, 2019). Moreover, there is no reliance on the grid for infinite storage when being off-grid, only the local energy storage solution (Hu & Augenbroe, 2012) and to achieve a 100% off-grid house, the storage sizing is a crucial component. Hence, there is another trade-off between power outages and the annual system cost of a PV and battery. If the system cost is to decrease, the frequency of power outages will increase, and vice versa (Miyazato, et al., 2017a). Furthermore, a study implied that it is not feasible to leave the grid, even at the low PV and battery installation costs today (Khalilpour & Vassallo, 2015).

2.1.2 Energy Storage Solutions

Off-grid energy systems may hence require both seasonal and short-term energy storage for the year-round operation to be feasible; especially in northern climates where the intermittency of both solar irradiance and energy consumption patterns is seen to be extreme (Puranen, et al., 2021). However, off-grid living is also seen as an element possibly capable of supporting the integration of having more renewable energy in a country (Pulido, et al., 2019). Many countries are investing in renewable energy as a way to mitigate climate change, and off-grid homes could be part of this integration since off-grid homes tend to keep the generated energy locally (Pulido, et al., 2019). The mismatch between energy generation and consumption over the seasons is seen to be solved either with support from the main grid or by storing the excess for longer seasons during the months when a surplus is available (Puranen, et al., 2021).

The energy imbalance between supply and demand poses a barrier to off-grid living. A study found that using hybrid energy systems with a backup diesel generator would be cheaper compared to using a diesel generator (Rahimzadeh & Evins, 2019). In a Northern setting, another study found that neither a battery nor hydrogen storage would be sufficient to power a year-round off-grid operation (Puranen, et al., 2021). With a small PV size, increased battery storage can increase the household's grid independence, but a 100 % grid independence is seen as not feasible unless a very large PV and battery system are installed, requiring significant costs (Khalilpour & Vassallo, 2015).

As EVs can carry and store electricity they can compensate for the electricity needed as a support operation for the off-grid home (Miyazato, et al., 2017b). The EV battery could serve as an option to mitigate the shortage of power when living off-grid and be used in combination with renewable energy generation, e.g., PV panels, and a battery (Miyazato, et al., 2017a; Miyazato, et al., 2017b). If the EV is charged with renewable energy, this off-grid energy system could consequently decrease CO_2 emissions (Miyazato, et al., 2017a). To further explore this idea, the next section of this literature review will therefore present previous studies on using the EV as an energy source, also known as Vehicle to Anything (V2X). This is followed by a section presenting the limited literature on the specific use case of using V2X in an off-grid setting.

2.2 Vehicle to Anything (V2X)

Electric vehicles (EVs) are interesting for power systems as they can store energy and act as a power source (Corchero & Sanmarti, 2018). Emerging technologies have hence been developed to utilize these abilities. One of these emerging technologies is Vehicle to Anything (V2X). V2X is an umbrella term for services connecting the EV to power loads through bidirectional charging and hence derive additional value from the battery when the EV is not in use (Thompson & Perez, 2020; Pearre & Ribberink, 2019). V2X can also be described as the power transfer between an EV and any external system where bidirectional communication is fundamental (Monteiro, et al., 2019). The main purposes of V2X are to provide benefits to the grid, to reduce, flatten or shift peak energy consumption, or to provide backup power (Thompson & Perez, 2020). Other terms under V2X are Vehicle to Home (V2H) when the EV is connected to a single household, Vehicle to Building (V2B) when the EV is connected to a multiple household building, Vehicle to Grid (V2G) when the EV is connected to the grid by an aggregator or directly to the Independent Service Operator (ISO) (Noel, et al., 2019). V2G can hence be used to provide flexible capacity on wholesale and ancillary service markets (Thompson & Perez, 2020). Vehicle to Load (V2L) connects the EV to power a single load (Thompson & Perez, 2020). Some studies also mention Vehicle to Vehicle (V2V), but this can be considered a redundant subversion of V2L and has hence fallen into disuse (Thompson & Perez, 2020). Vehicle to Community (V2C) is a concept for using the EV to provide storage for a local grid and community (Noel, et al., 2019).

Table 1 V2X concepts and benefits adapted from (Noel, et al., 2019; Elf & Svensson, 2019)

Term	Definition	Benefits	Scale
V2G	Vehicle to Grid: Using the EV to provide storage and support for the electricity grid	High economic value to EV owners that can contribute to decarbonization	5 – 1000 (or more) vehicles
V2H	Vehicle to Home: Using the EV to power and provide storage to a home	Backup power during power outages or during peak hours, peak shaving and higher utilization of solar panels	1 – 3 vehicles
V2L	Vehicle to Load: Using the EV as energy supply to an isolated load	Access to power in areas where the main grid is inaccessible or expensive to connect to as well as power to remote places	1 – 3 vehicles
V2B	Vehicle to Building: Using the EV to provide power to a multi household building	Decrease electricity costs by managing both power and energy demands	1 – 50 vehicles
V2C	Vehicle to Community: Using the EV to provide storage and supply for a local grid	Better resilience and utilization of renewable energy on a community level	5-50 vehicles
V2X	Vehicle to Anything: Catch-all for any imagined use case	Umbrella term and useful for novel use cases for using the EV as a power source and storage	1 – 1000 (or more) vehicles

Derived from the literature presented above, the definition of V2X used in this study will be using an EV to power any load through bidirectional charging. As this study will explore using an EV to power an off-grid tiny house, the focus in the V2X landscape will be at V2H and V2L as these concepts focus on powering a home, and using the vehicle to power areas where the electricity grid is inaccessible or expensive to connect to (Noel, et al., 2019; Elf & Svensson, 2019). Hence, a further definition of V2H and V2L follows below.

2.2.2 Vehicle to Home and Vehicle to Load

Vehicle to Home (V2H) is the technology where the EV can either draw energy from the charger or transfer the energy back to the house through a bidirectional energy transfer (Guo & Zhou, 2016; Sree Lakshmi, et al., 2020; Gudmunds, et al., 2020). Furthermore, V2H is a way to mitigate the pressure on the power system from fluctuations that renewable energy sources contribute with by storing the energy in the EV when renewable energy generation is high. The stored energy can later be utilized by sending it back to the household (Guo & Zhou, 2016). V2H operates with a connection to a central hub or a home energy controller, often together with solar panels installed on the rooftop of the house (Thompson & Perez, 2020). The V2H technology can thus increase the self-generated renewable energy usage (Corchero & Sanmarti, 2018).

In the on-grid V2H use case, the EV is connected to the charging station which in turn is connected to the grid and an Energy Management System (EMS) that is controlling the energy flow (Vadi, et al., 2019). The home load manager is also connected to the EMS controlling the flow to the home loads and to determine whether the EV should be charged or discharged there is a controllable switch communicating with the EMS (Vadi, et al., 2019). An energy management system connected to the home is often referred to as a "Home Energy Management System" (HEMS) which can be defined as a system consisting of several sub-systems that both generate and use energy, connected to a smart meter (Van de Kaa, et al., 2021).

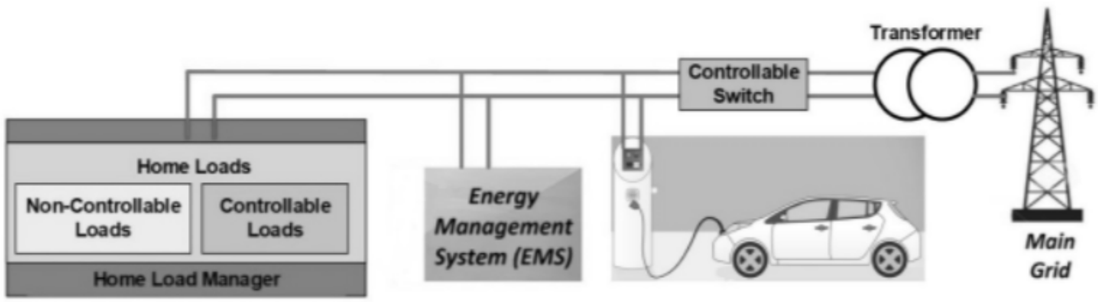

Figure 2 Block diagram of the V2H system (Vadi, et al., 2019)

Vehicle to Load (V2L) technology is the use of an EV to a load that does not otherwise have electric service (Corchero & Sanmarti, 2018). V2L can also be described as any instance of an individual EV battery providing energy to a load (Thompson & Perez, 2020). The benefit of V2L is that it can provide emergency backup energy if needed during power shortages or enable rural areas, or areas with low access to grid connections, to use the car as a source of energy (Thompson & Perez, 2020). V2L can also be useful in non-emergency situations such as construction sites, concerts, or camping (Corchero & Sanmarti, 2018; Thompson & Perez, 2020). Even though V2L technology can provide easily accessible energy from the EV with recognizable value add, it has not gained much academic research (Thompson & Perez, 2020).

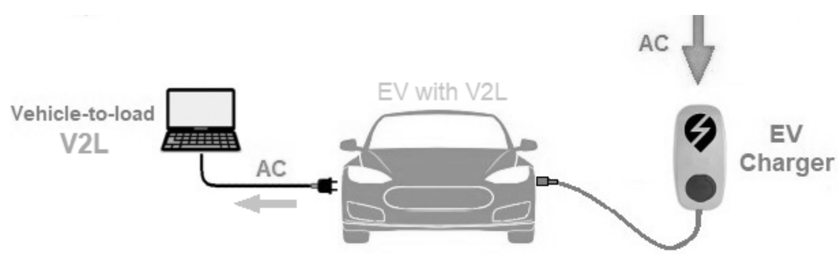

Figure 3 Overview of the V2L system adapted from Svarc (2022)

2.2.3 Bidirectional Charging and Charging Standards

For an EV to be able to participate in V2X, bidirectional capabilities are needed (Noel, et al., 2019). A bidirectional converter allows for the electricity to flow both ways, charging the EV and discharging the electricity back to the house or to a load (Liu, et al., 2013). The bidirectional converter can either be placed off-board the vehicle, i.e., in the charger, or on-board the vehicle (Liu, et al., 2013; Vadi, et al., 2019). The V2L technology does not require a bidirectional charger and instead has an onboard inverter (Sree Lakshmi, et al., 2020; Svarc, 2022b). To charge and discharge the energy in the battery, the car and the charger communicate by sending and receiving signals. This is done through standardized communications protocols (Otsuki & Ogura, 2019). Today, there are four main communication standards between the EV and the charging station, and these are ISO 15118, SAE J2847, CHAdeMO, and GB/T 27930 (Kester, et al., 2019; Elf & Svensson, 2019).

Furthermore, there are several charging standards and plug-in designs currently in use. These depend upon the country the car is manufactured for, the original equipment manufacturer (OEM), and the car model. The current charging standards are Type 1 and 2, CCS Combo 1 and 2, CHAdeMO, Guobiao, and Tesla (Jones, et al., 2021). There is no standard bidirectional charging platform as of now, and this is one of the main barriers to adoption that V2X faces today (Corchero & Sanmarti, 2018). Equipment and communication protocol standardization, along with standardized plugs should be established (Corchero & Sanmarti, 2018). Bidirectional charging is presently available only through EVs with the CHAdeMO protocol and soon with the CCS protocol in 2022 (Zecchino, et al., 2019; Svarc, 2022b). ISO 15118, which is a part of the CCS system, has been developing an updated communications protocol that supports bidirectional energy transfer, called ISO 15118-20 (Mültin, 2021). ISO standards are not a regulation nor an international agreement, but a voluntary standard adopted by car manufacturers and charging standard providers (Kester, et al., 2019).

2.2.4 Smart Energy Management with V2X

With a smart energy management system, using the V2H technology could provide significant cost savings for the household owner (Dargahi, et al., 2014; Turker & Bacha, 2014; Alahyari, et al., 2015). Smart homes can be defined as smart devices and sensors that are integrated into an intelligent system, offering management, monitoring, support, and responsive services (Marikyan, et al., 2019). These systems can be of different kinds, and in the V2X domain, the systems often include demand-side flexibility and management of loads. Li et al. (2017) proposed a HEMS utilizing the V2H technology to coordinate home appliances and a plug-in EV with solar power to optimize home energy cost and improve the demand-side energy efficiency.

The V2H technology can lead to cost reductions by charging through a bidirectional charger compared to a unidirectional charger (Gudmunds, et al., 2020; Guo & Zhou, 2016). In the on-grid scenario, with smart energy management based on the typical price trend of electricity, where low prices occur during the night and the following morning, the EV can be charged when people sleep (Guo & Zhou, 2016). During the daytime when the electricity prices are higher, the EV's surplus battery energy is discharged back to the home. Hence, the EV can serve as a distributed energy storage and the V2H technology can hence help save costs for the household (Guo & Zhou, 2016). A Swedish study used real-time GPS data of vehicles driving pattern and data from households' electricity consumption to model PV electricity generation profiles and applied this to Swedish households (Gudmunds, et al., 2020). Their study showed potential for using an EV as electricity storage for households with PV panels (Gudmunds, et al., 2020).

Similarly, Chen et al. (2020) created a V2H model for different scenarios with and without PV and bidirectional V2H charging. In this model, the V2H technology was seen to increase the utilization rate of valley electricity prices. The study also showed that the amount of energy that can be transferred to the home with V2H depends on the distance the EV has traveled (Chen, et al., 2020). The possibility to save costs has also been identified when examining V2H and V2G as part of a nano-grid (Ajao, et al., 2017). Similarly, by examining a system combining V2B and V2H, peak shaving and cost-saving opportunities were identified by leveraging the EV as energy storage (Borge-Diez, et al., 2021). Additionally, using onboard inverters is seen to be a useful approach to avoid the additional cost for the consumer to purchase an off-board charger for V2X (Kelm, et al., 2020).

Furthermore, EVs could be used to capture renewable energy and hence help balance generation with demand as well as increase independence from the grid (Corchero & Sanmarti, 2018). Renewable energy sources pose different challenges to planning and control of energy systems (Francis, et al., 2014) due to their intermittent nature (Kanoria, et al., 2011). The V2X technology may be a solution to the challenges posed by intermittent renewable energy sources as energy can be stored in the EV and discharged when needed (Guo & Zhou, 2016). The EVs can hence compensate for the fluctuations (Francis, et al., 2014).

2.3 Off-grid Living Powered by V2X

As presented above, most academic papers regarding V2X revolve around on-grid scenarios for cost savings and peak shavings. However, some papers also examine using EV as backup during power outages which can be considered a temporary off-grid mode. Moreover, some studies also analyze the feasibility of using an EV to power fully off-grid homes. These studies are presented below.

2.3.1 Using V2X for Increased Reliability during Outages

EVs are seen as capable of boosting reliability during power outages by using the EV as a home generator (Sree Lakshmi, et al., 2020; Tuttle, et al., 2013). Power outages putting the home in an island mode could be considered a temporary off-grid mode. Tuttle et al. (2013) simulated that a V2H capable vehicle connected to a PV equipped home could enable fully off-grid operation as backup power when needed. They saw that the residential V2H system with a PHEV and rooftop PV could provide backup power from 19 - 600 hours, i.e., approximately 1 - 25 days, depending on the season and vehicle configuration. Building on Tuttle's experiment, another study aimed to prolong the duration to cope with grid failure and made an experimental algorithm to maximize this backup duration (Shin & Baldick, 2017).

Moreover, Mehrjerdi and Hemmati (2020) made a model which had a diesel generator, V2H technology, wind power, and a software demand response program that collaborate to minimize energy cost and improve system resiliency under off-grid circumstances. Battery swapping is also seen to be a viable solution to power shortages, where V2H based on battery swapping is mentioned as a way to maximize backup duration during events and external grid outages by having access to two batteries: the EV and the backup. This has the benefit of people avoiding the fear of running out of energy (Mehrjerdi, 2021).

Another study investigated the reliability and resilience of a micro grid (MG) by connecting EVs to be used as an intelligent energy reserve through V2H (Al-Muhaini, 2020). Four different micro grids were assessed with a population of each MG being between 450-1200 people and an EV penetration of 30 %. The paper found that one of the main benefits of using EVs as an energy storage is the mobility feature. Furthermore, the paper concluded that EVs can contribute to increased reliability during outages through V2H, but that the EV's available capacity might not be sufficient to supply all demand during outages (Al-Muhaini, 2020).

2.3.2 Using V2X to Power Off-grid Living

Tostado-Veliz et al. (2021) conducted a study investigating the optimal electrification of off-grid smart homes considering flexible demand and V2H and found that the EV can effectively play the role of a storage facility. Moreover, it was stated that EVs may bring benefits to off-grid homes and may enable the consumer to avoid the necessity of installing a battery bank and hence save costs (Tostado-Veliz, et al., 2021). V2H can be used to mitigate the shortage of power when living off-grid when used in combination with renewable energy generation, e.g., PV panels, and a battery (Miyazato, et al., 2017a; Miyazato, et al., 2017b).

Moreover, another study developing an off-grid based test platform for V2H tested parameters to be measured with different appliances to see their impact on the parameters. They found that communication between their ordinary appliances and the control system was stable (Blazek, et al., 2020). Shigenobu, Adewuyi, and Senjyu (2017) analyzed the operation of an off-grid smart house and introduced a model for capacity sizing of PV, fixed battery in the smart house, and considered V2H. Their study presented Pareto optimal solutions to their system. Another study illustrated that a home in California, US, with a solar PV system of 7.2 kW, a battery energy storage system, and an EV with an 80-kWh battery could sustain off-grid full operation for at least 72 hours (Gong & Ionel, 2021).

2.4 Industry Context

To set up an off-grid home and power it with V2X, the off-grid home, the EV, and smart charging need to be examined. In Sweden, there are no legal constraints to live off-grid and have solar panels (Wahlström, n.d.). However, safety regulations still need to be taken into consideration, and a professional installer must do the installation even if the house is off-grid (Elsäkerhetsverket, n.d.). To install a photovoltaic system on your house in an off-grid setting, there are specific requirements on the electrical installation that need to be fulfilled to be able to set up the system (Elsäkerhetsverket, 2021). There are no regulatory constraints to live off-grid (Energimarknadsinspektionen, 2017) and neither are there any regulatory barriers to transporting the electricity by charging the EV in one place and then discharging the electricity to another property or location (Power Circle, 2020).

Furthermore, to understand which EVs have the capability of charging and discharging, there are a few V2H and V2L compatible EV models available. The Hyundai Ioniq 5, MG ZS EV, Kia EV6, and Genesis GV60 support the V2L technology, and all these models except Genesis are available on the Swedish market (Hyundai, n.d.a; MG Motor, n.d.; Kia, n.d.; Genesis, n.d.). The car models that support V2H are currently Nissan Leaf and the Mitsubishi Outlander PHEV (Mitsubishi Motors, 2021a; Nissan Global, n.d.). Ford's BEV F-150 Lightning model and Mitsubishi Eclipse Cross PHEV support both V2L and V2H (Mitsubishi Motors, n.d.; Ford, n.d. All Volkswagen ID 77 kWh models will support bidirectional charging for V2H in the future (Volkswagen Newsroom, 2021). Volvo Cars have also announced that they are planning to offer bidirectional charging in the future, starting with the successor of the XC90 (Volvo Cars, 2021). Audi and the Hager Group have researched the V2H technology with their Audi e-tron model (Hager Group, n.d.). BMW is also testing models with bidirectional charging and launched the first BMW i3 models with this feature in a trial in Munich (Press BMW Group, 2021). Moreover, Tesla mentions that the Cybertruck will have power onboard feature (Tesla, n.d.). Polestar is researching the V2X technology in a three-year research project (Polestar, 2021) and Renault made a trial with their model Renault Zoe to test its feasibility for V2G (Renault Group, 2019).

Moreover, Hyundai has conducted a trial to explore the viability of powering an off-grid tiny house with an EV (Hyundai, n.d.b). This project was called "Today's Office" where Hyundai created an off-grid office space of nine square meters located in the forest outside Stockholm, which was powered by the Hyundai Ioniq 5 through the V2L functionality. Today's office was created as an inspiration to show the possibilities of a V2L compatible vehicle (Hyundai, n.d.b). At "Todays Office", the EV Ioniq 5 powers Wi-Fi, sound system, TV, refrigerator, air-sourced heat pump, kettle, espresso machine, and a toilet (Hyundai, n.d.b). Hyundai has also marketed their Ioniq 5 in an off-grid setting when going camping (Hyundai Motor Group, 2021a). Similarly, the Tesla webpage displays a picture on their website explaining that their Cybertruck will have onboard power which can be used for cooking food in the forest (Tesla, n.d.).

In addition, as presented in the literature review, an important component for V2H to function is a smart energy management system. There are smart software solutions available in the bidirectional charger, and one example is the Quasar Wallbox (Wallbox, n.d.a). The second-generation Quasar Wallbox 2 has load management to enable the EV to power the home during a power outage (Svarc, 2022b; Wallbox, n.d.b). Ferroamp is working with Polestar to develop a charging box for bidirectional charging in Sweden (Olin, 2021) and their EnergyHub 2 is under development for a smart home energy system also capable of off-grid usage (Sandberg, 2020). In addition, Ford and Nissan have also developed systems for smart charging. Ford has developed their own charging station for bidirectional charging (SunRun, n.d.). This Ford Charge Station Pro is connected to its Home Integration System available in the US for their V2H offering for the Ford F-150 Lightning (Ford, n.d. Nissan similarly offered their Nissan Power Control System in Asia for the CHAdeMO connector and the Nissan Leaf, enabling a smart home (Nissan Motor Corporation, n.d.; McMahan, 2019). Both Ford and Nissan mention their V2H models Ford F-150 Lightning and Nissan Leaf to be capable of powering the home during a power outage (Ford, n.d.; Nissan Motor Corporation, n.d.).

3. Theoretical Framework

In this chapter, literature on innovation assessments, adoption, and system dynamics is presented. Then, an overview of the chosen frameworks is presented to provide the reader with an understanding of the structure. This chapter is finalized with a motivation for choosing this theoretical framework and an explanation of how the theories complement each other.

3.1 Innovation Theory

Innovation has evolved as a synonym for the development of nations, technological progress, and the driver of business success (Kotsemir, et al., 2013). Rogers (1998) defined innovation as "the application of new ideas to the products, processes or any other aspect of a firm's activities". Schumpeter argued that innovation occurs in cycles and defined a concept of "creative destruction" where innovation prompts a new business to replace the old (Schumpeter, 1936). Innovation can also be described as the creation of new combinations where processes of problem-solving activities constitute building blocks of innovative creativity (Blomkvist, et al., 2016). Moreover, Bower and Christensen (1995) highlighted that companies often aim to provide their customers with what they ask for, yet still, fail to uphold their customer base when competitors offer rapidly improved and more accessible innovation which they referred to as disruptive technologies. Sustaining technologies are the technologies that maintain a steady rate of improvement of the innovation attributes, whereas disruptive technologies offer a very different set of attributes (Bower & Christensen, 1995). The disruptive technologies tend to initially fail in their existing markets and instead enable new emerging markets. Proposals for these emerging markets can also be difficult to assess due to the novelty of the innovation (Bower & Christensen, 1995).

Therefore, several theories for assessing innovation have been established. Innovation can be analyzed as part of a socio-technical system to understand how it relates to different levels of society (Boons, et al., 2013; Geels, 2004). Thereto, Hang et al. (2011) proposed an assessment framework specifically made for disruptive innovation, based on the three pillars market positioning, technology, and favorable drivers. Innovation can also be analyzed on solely a technology level. For technology-specific analysis, NASA developed a nine-point scale to assess the readiness of the technology from idea to flight-ready (National Aeronautics and Space Administration, 2012). This framework is called "Technology Readiness Level" (TRL) and was first created in the 1970s to estimate a technology's maturity on a scale from idea to functional product (Mankins, 2009). This technology readiness level framework has been used by governments and other organizations and is a common framework used to assess innovative technologies (Mankins, 2009).

The TRL framework and the scale as such have further been refined by many academics (Vik, et al., 2021). Kobos, et al. (2018), among others, have developed the TRL framework to also include more perspectives to gain a holistic understanding of the readiness and not solely assess the technology on technical aspects. They included a regulatory and market perspective through a Regulatory Readiness Level (RRL) and Market Readiness Level (MRL) assessment framework (Kobos, et al., 2018). Similarly, Evans and Johnson (2013) created an Innovation Readiness Level Framework for managing early-stage business model innovation. Vik, et al. (2021) further developed the Readiness Level framework based on the work of NASA, Kobos et al, and others and included two more perspectives; acceptance and organizational perspectives. They presented a nine-point scale where each readiness level is built upon a nine-point scale with a description of what each level means and what each level implies in practical terms (Vik, et al., 2021).

For the scope of this thesis, the technology, market, and regulatory readiness levels presented by Vik et al. (2021) are considered a relevant framework to use for assessing the innovation of powering off-grid tiny houses with an EV. The reason why this framework is valuable is that it helps assess the innovation from three perspectives. These three scales, TRL, MRL, and RRL will be jointly referred to as the Innovation Readiness Framework (IRF). This framework is used as it helps create a holistic understanding of the innovation readiness today and answer RQ1. This framework also helps answer the main research question of what the prerequisites are for being able to use an EV to power an off-grid tiny house in Sweden today, or what would be needed for it to be possible.

3.1.1 Innovation Readiness Framework

In the Innovation Readiness Framework (IRF), the Technology Readiness Level (TRL) assesses the technological development similar to the framework presented by NASA, and the Market Readiness Level (MRL) regards the commodification of the technology focusing on the process of adapting the product to the market (Vik, et al., 2021). The lowest level of the TRL scale is level 1, and when an innovation is at TRL 1 only the early technological idea has been formulated. At the highest level of technology readiness, the system has been proven functional in its natural environment (Vik, et al., 2021). MRL is seen as a useful instrument to assess if there is a market willing to buy the product whereas the TRL evaluates the capability to produce the product (Eljasik-Swoboda, et al., 2019). The lowest level of MRL means that there has been a hunch of market need, whereas the highest level of MRL is when there are stable sales, and the market confirms the value offering. Lastly, Regulatory Readiness Level (RRL) regards the legalization of the technology. The lowest level of RRL means that there it is still unclear which regulatory laws that would apply to the innovation, and the highest level of readiness from a regulatory point of view is when no regulatory constraints are hindering the innovation (Vik, et al., 2021). See the complete IRF scale and its set criteria in the figure below.

Table 2 The Innovation Readiness Scale and the three dimensions of readiness level assessment, adapted from (Vik, et al., 2021)

Innovation Readiness Scale (Level 1-9)			
Level	**TRL**	**MRL**	**RRL**
1	Specific technological ideas are formulated	Hunch of a market need	The legal and/or regulatory aspects of the technology is unpredictable or unknown
2	The technology idea is explicitly described	Market and products are described	Use of production will require changes of law
3	Experimental proof of concept	Market need and market supply are explicated	Use and/or production will require change or reinterpretation of regulatory framework
4	Technological elements are tested and validated in labs or simulated environments	Validation of market/small pilot campaign	Use and/or production will require demanding permission or approval
5	Integrated technology is tested and validated in labs or simulated environments	Business model described	Use and or production will presuppose accessible permissions or approvals
6	Technology demonstrated in relevant environment	Products are being launched in limited scope	Necessary approvals are likely
7	System prototype demonstrated in natural environment	Customers confirm progress/improvements	Necessary approvals for use or production are "just around the corner"
8	Product tested and validated, and the functionality is being optimized	Stable sales make income predictions possible	Use or production fulfills general conditions
9	Actual system proven functional in natural environment	Market confirms stability/growth	Use and production are regulatory unproblematic

As part of the framework presented by Vik et al., there are also acceptance and organizational readiness levels (Vik, et al., 2021). These perspectives are however excluded from this thesis due to the novelty of the innovation and also due to this thesis not having an organizational point of view for the analysis. The nine-point scale for each readiness level that will be used to analyze the off-grid V2X system is displayed in the table above. These three dimensions of analysis, TRL, MRL, and RRL, are chosen to understand the technological components as such, the market supply and demand as well as to investigate what regulatory guidelines exist today. Furthermore, the IRF scale is also translated by Vik et al. into a questionnaire to assess and understand the readiness level for each category. Each question is linked to a specific readiness level in reversed order. The questionnaire is formulated as "Yes" and "No" questions for all readiness levels to assess where the innovation readiness is at today (Vik, et al., 2021). The questionnaire is used as the foundation for the survey sent out to industry experts and can be found in the "Method" chapter.

3.2 Adoption Theory

For a technology to offer value, it needs to be socially accepted and used by consumers. A technology will not be adopted if it is not perceived as beneficial by its users (Davis, 1993; Georgiev & Schlögl, 2018). Adoption theory analyses the individual and the choices an individual makes to either accept or reject an innovation (Straub, 2009). Theory of Reasoned Action (TRA) and Theory of Planned Behavior (TPB) focuses on individual motivational factors that determines the likelihood of a user performing a specific behavior (Montano & Kaspryzk, 2015). The aim of the TRA is to explain voluntary behaviors and the connection between attitude, intention, and behavior. The strongest predictor of voluntary behavior is the intention (Hale, et al., 2002; Georgiev & Schlögl, 2018). TPB is an extension of TRA to deal with the limitations regarding incomplete voluntary control (Montano & Kaspryzk, 2015; Ajzen, 1991). TBA introduced a third variable affecting the intention for behavior, the Perceived Behavior Control (Georgiev & Schlögl, 2018; Ajzen, 1991).

Moreover, the Technology Acceptance Model (TAM) is developed by Davis (1993) to answer questions about technology adoption. TAM is based on the principles adopted from Fishbein and Ajzen's TRA and TPB, and TAM was first based on the field of computer science but can be applied to many settings (Straub, 2009). TAM is a commonly used model for analyzing technology acceptance (Georgiev & Schlögl, 2018; Straub, 2009). TAM addresses why users accept or reject an innovation and how user acceptance is influenced by system characteristics (Davis, 1993). Davis (1993) identified two characteristics that influenced the adoption of the innovation, *perceived usefulness* and *perceived ease of use.* Perceived usefulness is defined as the degree to which a person believes that using an innovation would enhance their job performance and perceived ease of use is defined, in contrast, as the degree to which a person believes that using an innovation would be effortless (Davis, 1989).

Diffusion of Innovation theory developed by Rogers provides a foundational understanding of adoption and has been widely used across disciplines (Straub, 2009). The Diffusion of Innovation theory provides a structure for understanding individual adoption and collectively diffusion (Rogers, 1983). The theory has been of particular importance since it has influenced several other theories of adoption and diffusion (Straub, 2009). Diffusion of Innovation theory describes how new ideas become adopted. The main elements in the diffusion of new ideas are described by Rogers (1983) as an innovation, which is communicated through certain channels over time among the members of a social system. The diffusion process described by Rogers focuses on the demand side of an innovation and the adoption takes on the perspective of looking at a society comprised of individuals with free will, and who all have the potential to adopt an innovation (McEachern & Hanson, 2008).

Rogers' Diffusion of Innovation Theory is the adoption theory considered most relevant for this thesis as it's the theory which provides a broad foundation to understand factors that influence choices that an individual makes regarding an innovation. Diffusion of Innovation is a common framework used to understand adoption (Straub, 2009). Further, the theory is descriptive and describes why adoption occurs and not how to facilitate adoption. This can be viewed as a limitation, but for the scope of the thesis which aims to assess what affects the adoption, the theory is well suited. Moreover, the theory can be applied to any discipline, in contrast to TAM which is frequently used to study adoption in formal organizations (Straub, 2009).

3.2.1 Diffusion of Innovation

The rate of adoption is the speed at which an innovation is adopted by the members of a social system (Rogers, 1983). When plotting the cumulative number of individuals that are adopting an innovation, the results are presented as an S-shaped curve. At first, only a few individuals are adopting innovation but soon the adoption rate increases, and the curve begins to climb. Then the rate of adoption starts to decrease as fewer individuals remain left that not yet have adopted the innovation. Lastly, the s-curve starts to stagnate (Rogers, 1983). Five different adopter categories have been specified based on their characteristics: innovators, early adopters, early majority, late majority, and laggards (Rogers, 1983). Innovators are the first to adopt an innovation and are active information seekers. The second group to adopt an innovation is early adopters, and this group of people tends to be influential on other people and can often be seen as role models. Thirdly, the early majority is the group of people that would adopt an innovation before the average individual. This group of adopters is followed by the late majority that tends to be more skeptical and is not expected to adopt the innovation until uncertainties are removed. The last group of people to adopt an innovation is laggards (Rogers, 1983).

Moreover, the Diffusion of Innovation theory claims that the characteristics of an innovation as perceived by the users or members of a social system will determine the adoption rate. The five attributes of innovations are more specifically described as (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability (Rogers, 1983). The (1) relative advantage is the degree to which the innovation is perceived as better compared to prior ideas. This perceived relative advantage can be seen from any perspective, e.g., more economical, higher convenience, or social prestige. This does not need to be objective, instead, the greater the perceived relative advantage, the more rapid the adoption rate will be. The (2) compatibility factor explores how aligned the innovations are perceived to be compared to previous values, old ideas, past experiences, and needs. An innovation that is not aligned with previous norms and values will not be adopted as quickly. The (3) complexity aspect describes how difficult the innovation is to grasp and use. If the innovation can be easily understood by the social systems, then it will be adopted easier. (4) Trialability is the degree by which the innovation can be tried on a limited basis, e.g., the user is given a trial before committing fully can increase adoption of innovation. (5) Observability describes how visible the result of an innovation is to be observed by others. If people can see that the innovation created value for others, it is more likely to be adopted (Rogers, 1983). The attributes of the off-grid V2X system will be analyzed to understand what the potential adoption could be driven by in the future.

3.3 System Dynamics Theory

Systems thinking can help to understand complex behaviors of systems to better predict them and adjust the outcome. Overall, system thinking is used to understand complex systems, and Richmond is credited for coining the term systems thinking in 1987 (Arnold & Wade, 2015). There are many researchers in the field of systems thinking and the term has been defined and redefined in various ways since it was first created. Richmond (1994) defines systems thinking as "the art and science of making reliable inferences about behavior by developing a deep understanding of the underlying structure". Sweeney and Sterman (2000) are other researchers in the field of systems thinking and define it in terms of a purpose to represent and assess dynamic complexity. They further list specific skills related to systems thinking: (1) understand the behavior of a system over time, (2) discover and represent feedback loops explaining system behavior, (3) identify stock and flow relationships, (4) recognize delays and understand the impact of the delays, (5) identify nonlinearities and (6) recognize and challenge the boundaries of models (Sweeney & Sternman, 2000). Senge (2006) defines systems thinking as "the discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots'".

Systems thinking and system dynamics are not quite the same, but the overlap is significant. Richmond views the relationship between systems thinking and system dynamics as systems thinking is the concept of where system dynamics takes place within, and Forrester believes it to be the other way around (Richmond, 1994), which can be interpreted as the terms being interchangeable. System dynamics are closely related to models, which can be defined as a schematic method to analyze a piece of reality (Gårding, 1997). Moreover, models always need to serve a clear purpose to be considered useful (Gustafsson, et al., 1982) and can be argued to preferably describe a specific part of the total system to make the model as accurate and realistic as possible (Sterman, 1991). Hence, the model can be used to describe a part of the system. Moreover, Meadows (2008) describes systems as an interconnected set of elements that are jointly organized in a way that achieves something. A system consists of three types of things: elements, interconnections, and a function or purpose. Elements can be both tangible things and intangibles in the system. The interconnections are the relationships that hold the elements together and can be either physical flows or flows of information. Lastly, is the function or purpose of the system. Generally, the purpose and function of the system can be seen as what it is that drives the behavior of the system (Meadows, 2008).

For this thesis' research aim, system dynamics is hence considered a useful theory to understand the feasibility of an off-grid home powered by V2X. By building a model the system dynamics of the energy system can be modeled and understood. With a clear purpose, the components of the system can help understand if the seasonal energy imbalance when living off-grid could be reduced with an EV by analyzing the system over a full year in different seasons.

3.3.1 System Dynamics Modelling

The system dynamic tools can both be applied to behavior and as well as technological systems (Sterman, 2002). The basis of system dynamics are stocks and flows, where stocks are the accumulation of resources and flows are the in- and outflows from the stocks (Sterman, 2002). More specifically, the concept of system dynamics is grounded on the theory of nonlinear dynamics and feedback control (Sterman, 2002). System dynamics can hence be used both to understand systems as well as be leveraged as an engineering tool when building models (Enqvist, 2005). Computer simulation of the system dynamics is necessary for effective modeling and the behavior is dependent on the system structure (Lane & Sterman, 2011). Forrester states that the human mind is excellent in its ability to observe forces and actions in a system, but computers help estimate the model's dynamic consequences of the system assumptions (Forrester, 1973). Sterman was part of the development of the Stella software used for understanding system dynamics, and the Stella name is an acronym for Structural Thinking, Experimental Learning Laboratory with Animations (Sterman, 1991). Thereto, system dynamics also emphasizes the time aspect, as the dynamics of the system analyze the change process and development of the system over time and in different scenarios (Thelen, et al., 1991). The foundation of stocks and flows in system dynamics is pictured below (University of Bergen, 2022).

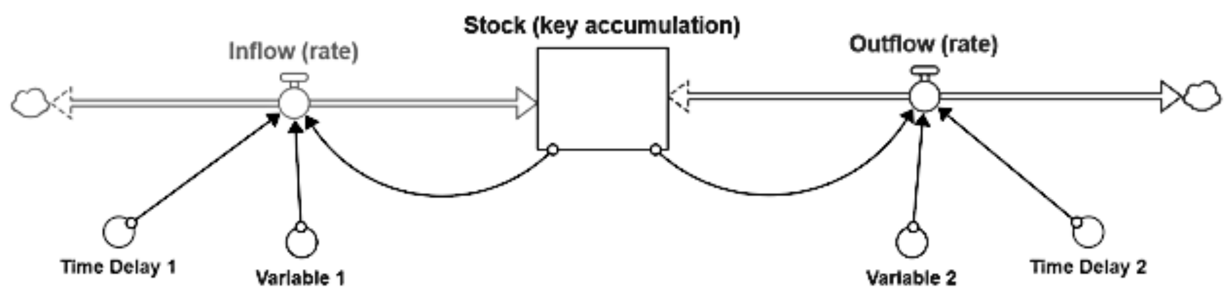

Figure 4 Visualization of a system dynamics model (University of Bergen, 2022)

By using system dynamics as a tool to build a model the system can be understood (Enqvist, 2005). The arrows represent information and feedback loops between the stocks and inflows (Meadows, 2008). To understand the technical feasibility of an off-grid home powered by an EV, the energy system will be modeled based on system dynamics. The model will be built in the Stella program mentioned above, and with the help of human assumptions to create flows and stocks, the model will enable a better understanding of the dynamics in the off-grid V2X system. The purpose of the model is hence to understand different scenarios of the energy balance. The exact structure of the energy system built and analyzed in this thesis work is described in the Method chapter and the output is presented in the Case Study chapter.

3.4 Overview of Chosen Conceptual Framework

To summarize, for this study, The Innovation Readiness Framework, Diffusion of Innovation, and System Dynamics are the three frameworks used. For the first part of this paper, the Innovation Readiness Framework (IRF) adapted from Vik et al. (2021) and the Diffusion of Innovation (DOI) framework by Rogers (1983) will be used to answer RQ1. This approach hence aims to provide a holistic view of how ready the innovation is and understand the potential adoption of the innovation. Firstly, the Innovation Readiness Level will be assessed and then when an understanding of the innovation readiness is achieved, the attributes of innovation from the Diffusion of Innovation theory will be applied to understand the potential adoption. As for the second part of the study, the feasibility of the innovation will be analyzed to answer RQ2. In this part, the system dynamics will be analyzed to understand the relations between the elements in the model and how they interact. Below is a visualization of the chosen theoretical framework.

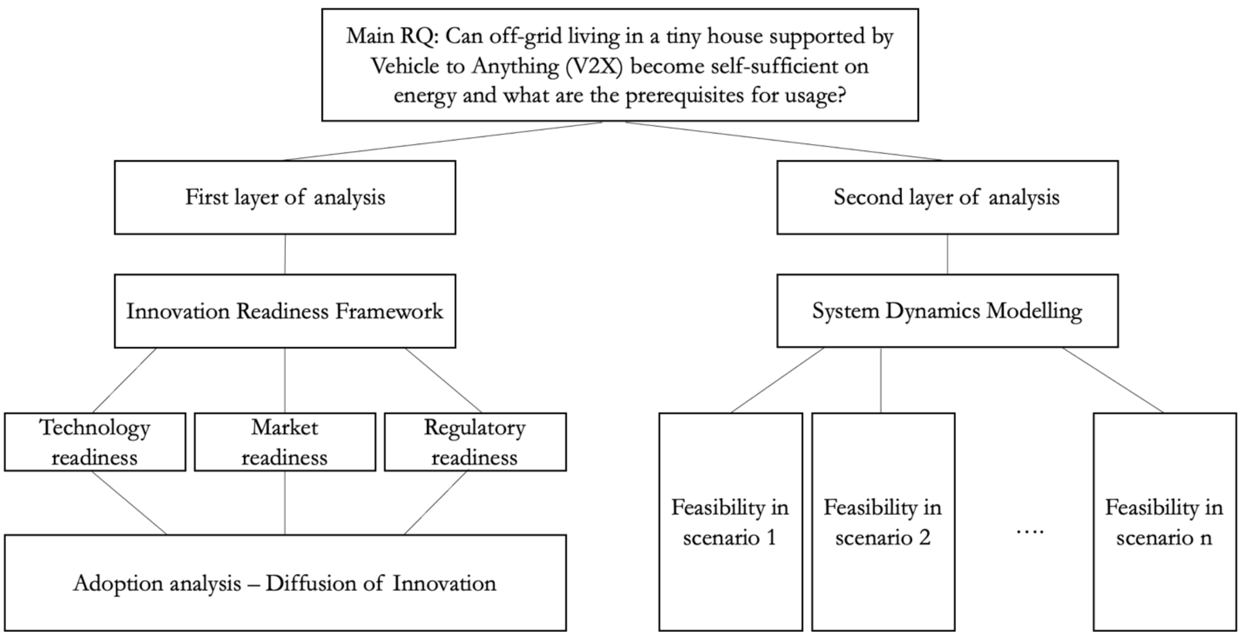

Figure 5 Overview of the chosen conceptual framework for the thesis

3.5 Motivation for Chosen Frameworks

The Innovation Readiness Framework (IRF), Diffusion of Innovation (DOI), and System Dynamics Modeling are chosen since the concepts complement each other. The purpose of the IRF is to gain a holistic overview of how ready the innovation is from the three perspectives and understand what perspective is leading the development and which perspective is lagging the deployment. The framework is centered around innovation and examines technological development, market willingness to purchase the innovation, and if there are any regulatory barriers to the innovation (Vik, et al., 2021). Salazar & Russi-Vigoya (2021) stated that the major limitation of TRL is that it does not address the readiness of the technology for human performance and user satisfaction. In contrast, the Diffusion of Innovation theory is centered around the users, or potential adopters of the innovation, and aims to understand how the innovation will become adopted by the members of a social system. The innovation attributes will be analyzed to understand the adoption of the innovation depending on the characteristics of the innovation (Rogers, 1983). Diffusion of Innovation has also been seen to be useful in the V2G context as it was applied by Noel et al. (2019) to provide an overview of how users could in theory interact with V2G. Hence, the Diffusion of Innovation theory complements the Innovation Readiness Framework well.

The Innovation Readiness Framework also aims to complement the Diffusion of Innovation framework. The Diffusion of Innovation framework has been seen as a useful model when aiming to explore innovation adoption at market levels with a highly technical perspective (Attié & Meyer-Waardenb, 2022). It is, however, also seen as limited in the sense that the theory has been criticized to dismiss details in the diffusion of complex networked technologies needed for collective adoption behaviors (Jan & Lyytinen, 2001). Therefore, Kobos et al. (2018) state that the IRF adds perspectives to the s-shaped curve representing technology transitions and market adoption over time, as the IRF contributes by analyzing factors required before innovations enter the market and during the early stages of market adoption. Hence, the details of the innovation are explored by using the Innovation Readiness Framework which analyzes the components of the innovation from three perspectives during the early stages of market development.

Lastly, System Dynamics will be analyzed. The model aims to complement the first two frameworks in the sense that it views the technical feasibility of the system, and the components of the system can be tested in a simulated environment. Hence, this framework will be used as a foundation when building the model and making scenario testing of the off-grid V2X system based on different inputs e.g., weather data, available solar energy, and the EV state of charge. The system dynamics allow for an understanding of the energy balance of the off-grid V2X system.

The unit of analysis of the Innovation Readiness Framework is the innovation as such, i.e. the use of V2X to power an off-grid tiny house. The unit of analysis in the Diffusion of Innovation framework is the adoption rate of the innovation, hence complementing the first analysis with the user perspective. Lastly, the system dynamics model analyzes the system energy balance. Thereby contributing to the thesis by analyzing how the energy balance is impacted when an EV is added to the residential energy system. Overall, these three frameworks aim to complement each other and help answer the research questions.

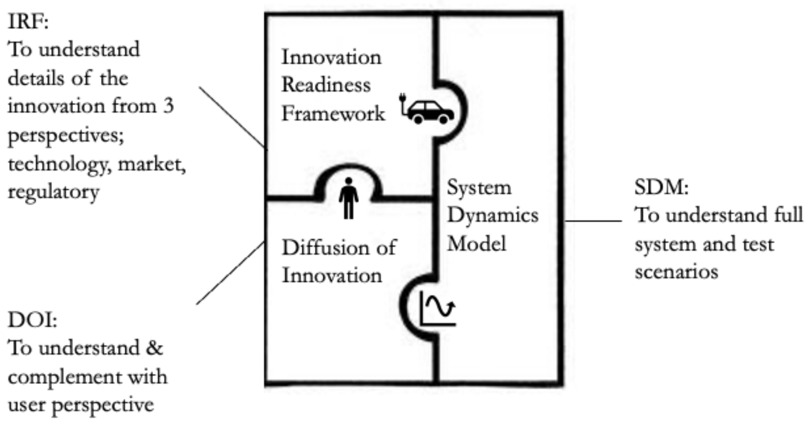

Figure 6 Visualization of how the frameworks complement each other

4. Method

This chapter presents a detailed description of the research design, the set system boundaries, the method for data collection, how the data analysis was made, and lastly an analysis of the reliability and validity of the research. This chapter aims to motivate why the specific methodology was chosen and how it aims to help answer the research questions.

4.1 Research Design

This study was conducted with an exploratory purpose. An exploratory approach is a useful method to understand what is happening, seek new insights, and assess topics in a new light (Saunders, et al., 2007). This approach was considered appropriate for the study's scope and research question to understand how the V2X bidirectional charging technology can be used to power off-grid living and prolong the seasonal stay.

The initial phase was the literature review to create an overview of the off-grid living energy system as well as the current landscape and knowledge of the V2X technology. In this part, a gap was observed in the literature with regards to using V2X in an off-grid setting. From this, part one and part two were formed. The first part, the general study, involved gaining a deeper understanding of the technology, market, and regulatory readiness in the context of off-grid living supported by V2X and analyzing potential adoption. This was done in a qualitative approach by conducting 22 interviews with industry experts and followed by a survey. The last and second part is a case study with a Swedish off-grid cabin stay provider, where a model was built with the aim to test the feasibility of an off-grid tiny house powered by V2X to reduce the energy imbalance. This is a quantitative approach to testing and calculating the results of the different scenarios. Hence, a mixed-methods research design is chosen. The research process is illustrated below.

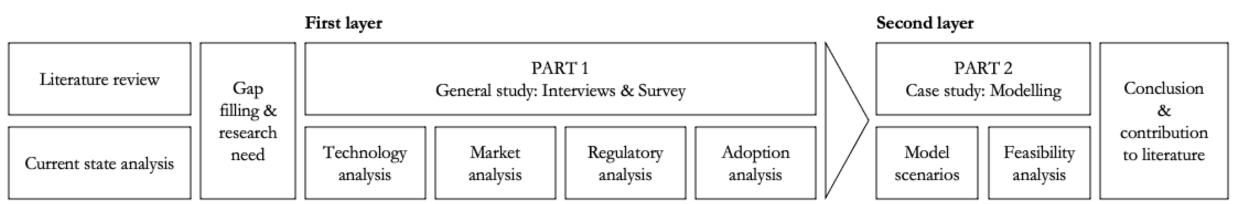

Figure 7 This study's research design

The research approach for the first part, the general study, was inductive. As the area of combining off-grid living and V2X technology is a seemingly new research area, this approach is suitable as no definite hypothesis could be identified in the early stage of the research (Miller & Brewer, 2003). The inductive approach allows for a more flexible structure and allows the emphasis to change along the process (Saunders, et al., 2007). The general study aimed to answer RQ1 and to understand how ready the V2X technology is in an off-grid setting from a technology, market, and regulatory perspective and understand potential adoption. The general study was answered through qualitative interviews with experts in different areas related to the V2X technology in an off-grid setting followed by a survey sent out to selected experts. Firstly, the findings from the interviews and survey were synthesized and presented. Secondly, the findings were qualitatively analyzed, together with literature, by applying the Innovation Readiness Framework and Diffusion of Innovation theory as presented in this study's theoretical framework.

The second part of the study, the case study, was conducted with a deductive approach to understand the relationship between different variables and inputs (Saunders, et al., 2007). The hypothesis that V2X technology could power off-grid tiny houses was tested by creating a model in the software called Stella by service provider Isee Systems. This deductive approach is based on quantitative data and was modeled in Stella to test different scenarios with the V2X technology used in combination with a home battery and PV panels during different seasons and weather conditions. Moreover, different loads were applied to the home to understand the output and feasibility of using the EV as a power source for the home.

4.2 System Boundaries

To conduct the research, the scope and system boundaries needed to be defined. The system boundaries set out in the study are presented in the figure below. Firstly, the study has a focus on the Swedish context. The case study was made based on data from Skövde, which makes the findings from this part of the study relevant for the middle and southern parts of Sweden. The general study and the model as such are however applicable to all of Sweden. The larger Venn diagram in the figure illustrates the bigger system which is defined as the two domains: tourism & housing and mobility & charging. From a housing and tourism perspective, the study will focus on off-grid tiny houses used as second homes within Sweden. Hence, this study does not analyze permanent off-grid residents. Instead, the study focuses on people going to their second home or staying at hospitality service providers e.g., tiny house cabins for short- and medium-term stays. From a mobility perspective, the study will focus on BEVs (battery electric vehicles) with bidirectional charging, which allows the vehicle to both draw energy from the house and send the energy back. The intersection between off-grid living and BEV with bidirectional charging is off-grid living powered by V2X, which is the innovation in question that this thesis focuses on.

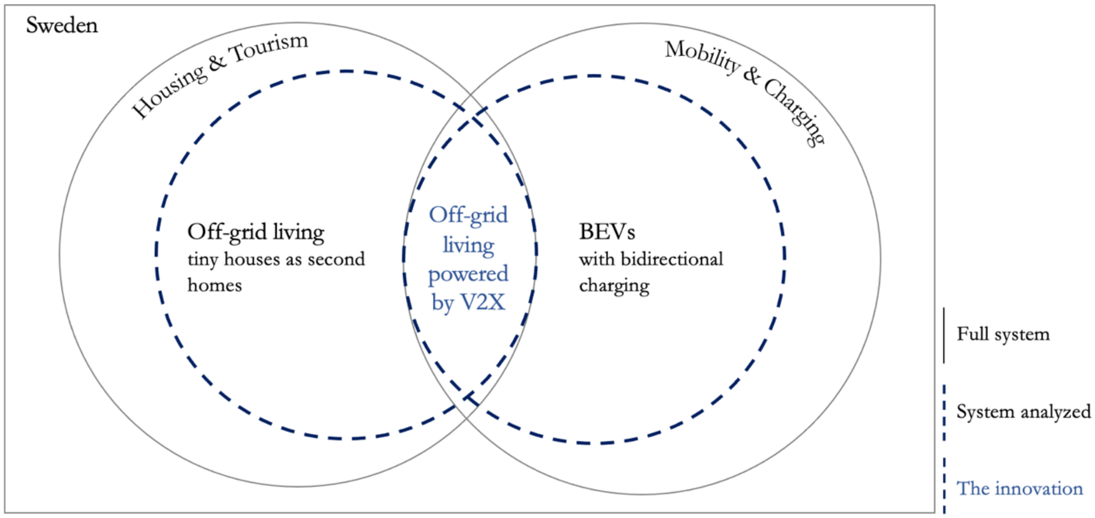

Figure 8 Overview of the system analyzed in the thesis

4.3 Literature Review Approach

Literature was reviewed continuously under the entire scope of the thesis work. At the beginning of the study, a systematic literature review was made. Given the broad scope of the study, the literature review had three main iterations. For the first part of the study, the literature review aimed to get an understanding and overview of off-grid housing. The review increased the understanding of off-grid energy systems and potential challenges with off-grid living. Thereafter, literature on the current state of the V2H and V2L technology was assessed. This review helped increase the knowledge base and form the scope and topic of the project. This literature review revealed that the search needed to be complemented with more specific technical aspects, such as communication standards. For the third and final iteration, the literature review was more focused, critically targeting the relatively unexplored area of off-grid living powered by the V2X-technology. The systematic literature review was made through the search engine Web of Science. Search queries and exclusion criteria were used as listed in the figure below. After the initial screening based on the exclusion criteria, the reading began. When reading the articles, a snowballing technique was applied to identify other articles of interest to the scope through reference and citations (Wohlin, 2014).

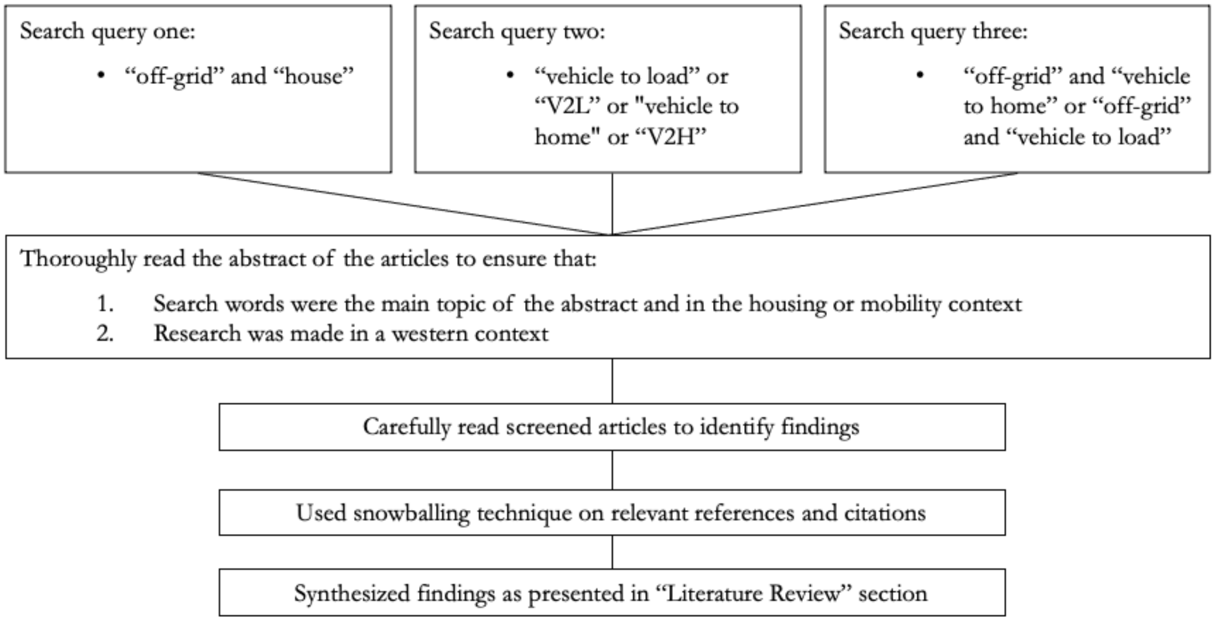

Figure 9 Overview of systematic literature review method

Given the novelty of the innovation of using an EV with V2X technology to power an off-grid home and the limited number of academic papers on the topic, a research gap in the academic literature was identified. The search query presented in the figure above only resulted in twelve papers for V2X in an off-grid setting, as synthesized in the "Off-grid living powered by V2X" chapter of this thesis. Hence, grey literature in the form of white papers, governmental reports, company websites, and industry statistics has also been assessed. These findings were placed under the "Industry Context" chapter in this thesis. This review was made due to the novel state of the technology in an off-grid setting to help understand how ready it is today and the market and regulatory landscape as such. This literature review can be seen as a continuation of the initial systematic literature review and aims to create a research industry context and its main purpose is to answer RQ1 under the general study.

4.4 Data Collection

4.4.1 Interviews

The data collection for the general study was made through interviews with industry experts and sending a following survey to selected interviewees. In total 22 interviews were held with industry professionals from two main domains of expertise: "mobility & charging" and "housing & tourism". The interviews were exploratory in their nature and explored the V2X technology in an off-grid setting. These interviews were conducted over "Zoom" video calls and were 30 minutes long and conducted by the authors. The interviews were held from January to March 2022. The complete interview guide and questions asked during the interviews are attached in the appendix of this thesis.

The first part of the interviews, hereby referred to as part A, was guided and unstructured, meaning that the interviewers introduced the topic and then allowed for the interviewees to give their perspectives and thoughts on the topic (Morse, 2012). When needed, the interviewers guided the interviewee in a certain direction back to the thesis topic but did not demand specific answers to certain content.

In the second part of the interview, part B, the interviewee was asked to estimate where they believe the V2X off-grid solution to be most applicable in the future based on the figure below. The interviewees were asked to estimate whether they thought the innovation would be most relevant either for individual usage or community usage (y-axis) and for short-term stays or long-term stays (x-axis). This was made by asking the respondent to place their pin on the quadrant. This question aimed to result in an overview of where the best market fit potentially could be. On the y-axis, community usage is defined as the EV being shared among multiple off-grid households, and it can be driven to multiple houses to power it when needed. Individual usage is defined as each household having its own EV. The x-axis asks if they think the solution would be most applicable for short-term usage, being a few days up to a week, or long-term usage which would be for multiple weeks to a full season. As this thesis only investigates the usage of second homes, full-time is not part of the assessment. The purpose of this question is to understand where the experts believe the potential for using an EV to power an off-grid home would be the most applicable and to initiate a conversation about potential adopters.

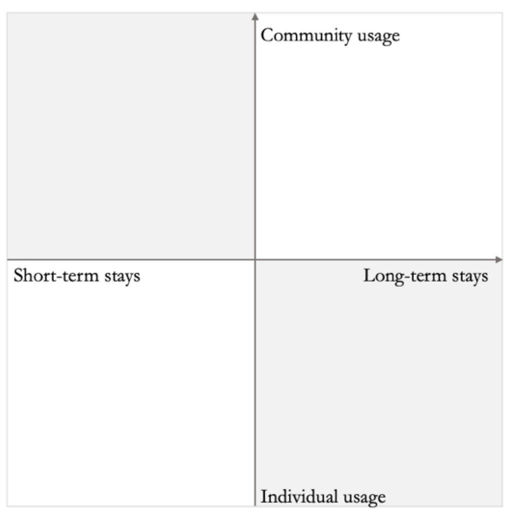

Figure 10 Quadrant used in Part B of interviews to ask interviewees where they find off-grid V2X systems most applicable in the future

Table 3 Interviewees and their expertise

Name in report	Company description	Domain	Survey
Asset Manager	Innovation Hub	Mobility & Charging	
Battery Expert	Battery Manufacturer	Mobility & Charging	
Charging Expert	Automotive Company	Mobility & Charging	X
E-mobility Manager	Energy Company	Mobility & Charging	
Energy Management Expert	Automotive Company	Mobility & Charging	
Energy Policy Advisor	Energy Company	Mobility & Charging	X
Energy Expert	Automotive Company	Mobility & Charging	
Insight Manager	Tourism and Marketing Company	Housing & Tourism	X
Off-grid Living Expert	Off-Grid Cabin Rental Stay	Housing & Tourism	X
Postdoc within Geography and Tourism	Academia	Housing & Tourism	X
Professor within Geography	Academia	Housing & Tourism	X
R&D Manager	Energy Company	Mobility & Charging	X
R&D Portfolio Manager	Energy Company	Mobility & Charging	
Regulatory Advisor	Energy Agency	Mobility & Charging	X
Researcher E-Mobility	Energy Company	Mobility & Charging	X
Senior Analyst	Consulting and Research Company	Housing & Tourism	X
Strategy Director	Automotive Company	Mobility & Charging	X
Sustainability Expert	Automotive Company	Mobility & Charging	
Sustainability Leader	Furniture Company	Housing & Tourism	
Technical Expert	Automotive Company	Mobility & Charging	X
Telecommunications Strategist	Telecom Company	Housing & Tourism	X
Tiny House Manufacturer	Tiny House Manufacturing Company	Housing & Tourism	X

4.4.2 Survey

After the interviews were held, data was also collected through a survey asking the respondents to estimate the innovation readiness based on the Innovation Readiness Framework (IRF). The questions sent out were directly adopted from the questionnaire defined by Vik et al. (2021) created after the technology, market, and regulatory readiness scale. The questionnaire is designed so that level one is first assessed and if the respondents assess the questions to be “yes” they should continue to the next question as far as the answer is to be considered “yes” and check the last box only. A copy of the full survey can be found in the appendix.

Table 4 Questions sent out in the survey to selected interviewees

Level	TRL	MRL	RRL
1	Is a specific technological idea formulated?	Does an idea regarding a market need exist?	Are the legal and regulatory aspects of the technology unpredictable/unknown?
2	Is the idea explicitly described?	Has an idea regarding a need and a technological solution been formulated?	Will use of the technology demand legal changes?
3	Is a concept clearly demonstrated and described?	Has market demand and a product been explicated?	Will use of the technology require regulatory changes?
4	Are the core technological elements tested and validated one by one?	Is the market demand and the idea confirmed by customers and market actors?	Will use of the technology require demanding permissions/approvals?
5	Are core components tested together and validated in lab/simulated environment?	Is there a described business model?	Will use of the technology require easily accessible permissions?
6	Is a prototype tested and validated in a relevant environment?	Has the product been sold in small amounts?	Are needed approvals/permissions likely?
7	Is the technology tested and validated in the natural environment?	Has there been demand for the product in the market?	Are the necessary approvals/permissions close to being given?
8	Is the technology tested and validated on a broad scale?	Is product demand stable or growing?	Does the use and production of the technology fulfill general requirements?
9	Is the technology fully developed and ready to use?	Is the product available in a market through a defined business model?	Is use and production of the technology regulatory unproblematic?

This survey was made by sending a Google Form to 14 interviewees, and these were handpicked from the 22 interviews held to get a balance regarding their professional expertise domain and ensure that they had good knowledge about the V2X technology. To validate what domain each respondent represented, the first question was which area of expertise they have, and this question was asked to ensure alignment between our perception of their expertise and their self-perceived domain of expertise. 11 of 14 people replied to the survey, by which six people were in the "mobility & charging" domain and five people had "housing & tourism" expertise. The next question was from which perspective the respondent was comfortable assessing the readiness level of the innovation. They could choose to assess the readiness either from a technology perspective, market perspective, and/or regulatory perspective. Multiple perspectives were possible to choose if a respondent assessed that they had enough knowledge to answer from more than one perspective.

4.4.3 Data Input for Model

For the model to be built as part of the case study, data was collected from a case study visit and secondary sources available online. The case study was made with a partner offering stays in off-grid tiny houses near Skövde, Sweden. The authors of this study came to visit and live in these off-grid cabins for two nights between the 4th to 6th of April 2022. Between the 5th and 6th of April, load data was measured from the cabin and the data collected was used as an input in the model built. Moreover, data regarding the number of PV panels and their efficiency as well as the capacity of the station battery was provided by the case study partner. The off-grid cabin was powered through PV panels and a home battery. The cabin had six PV panels and a station-based home battery that could store 3 kWh of solar energy.

Solar Irradiance and PV Data

Moreover, to build the model for the case study, data on weather, irradiance, and PV efficiency data were needed. A common approach for obtaining data for power generation is to simulate power generation based on the meteorological irradiation data (Puranen, et al., 2021). Weather data was collected from Sveby for 2019, 2020, and 2021, and the location chosen for the weather data was Skövde, in Sweden (Sveby, n.d.). The weather data was presented per hour for the entire years of 2021, 2020, and 2019 and included solar irradiation in global horizontal irradiance (GHI) in W/m^2. GHI represents power from the sun that hits the surface per unit area. GHI is the total solar irradiance that hits the surface, both directly and after being scattered in the atmosphere (Global Solar Atlas, n.d.). GHI is often used to calculate solar energy from the PV installations (Vaisala Energy, n.d.) and was hence chosen as input for the model. An average of GHI per hour for all three years was calculated to get an accurate estimate for solar irradiation.

Furthermore, the off-grid cabin dimensions and the number of PV panels were modeled after the case model partner's off-grid cabins. The off-grid cabin had six PV panels with an estimated dimension of 1.7 times 1 meter (Solorder, n.d.). The case study partner had placed the cabin south-facing, and at an angle optimizing the energy capturing. However, there are also trees around the cabin as it is situated in the forest. Hence, this needs to be taken into consideration when estimating the efficiency of the PV panels. The efficiency of typical PV panels in Sweden is around 16 – 20 % (Jämtkraft, n.d.). Since the placement of the cabin and the chosen angle of the PV panels have been optimized, this should indicate the highest efficiency of 20 %. However, due to the trees surrounding the home, an efficiency of 18 % was chosen to be used in the model to account for the possible shade that hinders an optimal efficiency. Energy losses that occur in cables and inverters are also accounted for; these losses amount to 3 % of the supplied energy (Vattenfall, 2021). When the irradiance data, PV panel data, and efficiency were collected, the solar power generated per hour by the PVs could be calculated.

Table 5 Solar energy inputs used in the case study model

Solar energy input	
Number of PV panels	6
PV panel size	1.7 x 1 m
Efficiency	18 %
Losses	3 %

EV Capacity Data

In the model, the battery capacity of the EV is used for discharging energy to the home as well as being charged by solar energy. To define what level of the maximum capacity of the EV should be defined in the model, V2H compatible models were analyzed for reference. The Nissan Leaf has a battery capacity of 40 kWh or 62 kWh (Nissan USA, n.d.), Ford F-150 Lightning has a battery capacity of 98 kWh or 131 kWh (Hoffman, 2021) and lastly, Volkswagen announced that their 77 kWh ID.4 models will have V2H (Volkswagen Newsroom, 2021). The calculated average for these models is hence 82 kWh. However, normally the usable share of the total capacity is a few percentage points lower than the total capacity (Voelcker, 2021). Hence, for the stake of this model and its accuracy a lower battery capacity of 78 kWh, five percentage points lower than the calculated average, was used as an input for the model.

It is important to take into consideration that the capacity of the EV battery is affected by the temperature. Temperature data was collected in the same data set as GHI, and an average temperature for each hour for 2019, 2020, and 2021 was calculated (Sveby, n.d.). The battery capacity declines in colder temperatures and the relation between EV battery capacity and temperature were collected from an analysis of the EV performance (Argue, 2020). The percentage point on the y-axis stems from how the EV range declines in relation to its best range, and as the battery capacity can never reach more than 100 % this is put as the maximum battery capacity. To get the percentage capacity per temperature, the data points were interpolated. The estimated capacity per temperature is presented in the figure below.

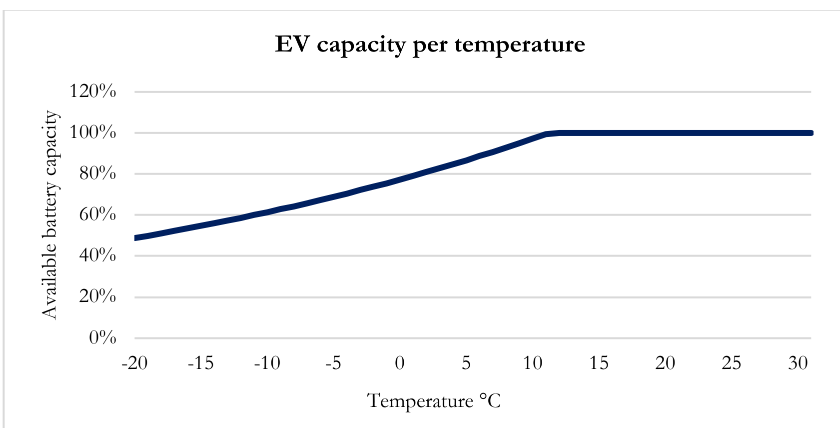

Figure 11 EV battery capacity per temperature

Moreover, the EV owner also needs to be able to travel home from the second home, the off-grid cabin, and therefore causes the need for some energy to be left in the EV. Hence, a state of charge (SOC) limit of 20 % is set. This limit means that the energy stored in the EV battery can never go below 20 % of the maximum capacity. The limit is estimated to be sufficient to reach the nearest charging station which is in a radius of 10 km from the case study location, and 20 % of the lowest available limit of 51 kWh, when it is negative 20 degrees, is 10.2 kWh. Moreover, the EV owner also needs to travel to its cabin to get there, hence the EV does not arrive fully charged. The remaining battery upon arrival is estimated to be 80 %, representing the buffer of energy of 20 % needed to go from the nearest charging point to the cabin.

Table 6 EV inputs used in case study model

Parameter	Value	Definition
SOC limit	20 %	Limit ensuring EV never discharge below this level of the battery capacity
EV capacity at arrival	80 %	The EV needs to travel to the second home which consumes parts of the battery, and this is the level when arriving to the off-grid home
EV battery capacity	51-78 kWh	The EV battery capacity depends on the outside temperature, see figure above

Load Data

The load data that was collected in the field study was used as a base for the loads in the entire model. The data collection only occurred during one day in April, and hence assumptions needed to be made for the remaining time. Load data is often represented by a generalized load profile (Puranen, et al., 2021). To create different load profiles, the year was divided into four seasons: winter, spring, summer and fall. Winter was defined as November to Mars, spring as April to May, summer as June to August and fall as September to October. What differs in the demand profiles are the activities conducted during each season. During summer, more time is spent outside the cabin, which decreases the loads. During winter, this behavior is set to be reversed as people are expected to spend more time inside when it is cold. The load profiles were simplified in the sense that the load demand is the same for each day in each defined season. Activities “sleeping”, “working”, “relaxing”, “cooking”, “breakfast” and “outside” were mapped out for each hour of a typical day for each season. Thereafter, loads were placed for each activity. In the “sleeping” activity, no loads were added except for the idle loads. “Working” and “relaxing” often included mobile charging and computer charging, as these devices are used when working and for some cases when relaxing, and the lamps are turned on. During the “cooking” activity, the kitchen fan is active, but it is not active during “breakfast”, but in both activities the lamps are on. Lastly, in the “outside” activity, no loads are added except for the idle loads.

Since demand data was collected for April in the field study, the load profile for spring was done first. Fall data was assessed to be similar to the spring data and the same activities were chosen for the two seasons, but at various times. The spring and fall data were then used as a base for winter and summer. For winter, the loads during the day were increased due to more time spent inside. For the summer, the loads decreased due to more time spent outside. In order to decide how much the load profile should increase per season, different home loads were identified, presented in the table below. These loads were as well benchmarked with the data collected in the field study to ensure unity. Hence, the estimation for the remaining seasons were based on the activities described above and aimed to represent typical days when living off-grid. 30 W was added to the load data collected during the case study visit to represent the power demand of the inverter itself.

Table 7 Loads and their required power used in the case study model

Home loads	
Active loads	
Kitchen fan	129 W
Mobile charging	20 W
Computer charging	67 W
Lamps when home	30 W
Lamps when away	0 W
Idle activity	
Heating fan and pump	36 W
Fridge and freezer	35 W
Inverter	30 W
Excluded since supplied by gas	
Cooking stove	Liquified petroleum gas
Heating	Liquified petroleum gas
Water heater	Liquified petroleum gas

Active loads are only active when a specific activity is performed that includes that load, whereas idle activities are always running in the background to keep the house functioning. The idle loads are based on the data fetched during the field study, which made the data adapted to two people living in the tiny house cabin. The lamps are turned on when the users are in the cabin, except for sleeping and during the summer. Below is a table presenting the different seasons, the activities and total load demand. The activity and load mapping were made in Microsoft Excel and made for all hours during one day per season and then replicated for all days that season. The full data set was hence, 24*365 = 8760 rows representing all hours of the year.

Table 8 Activities and load demand per winter and spring, total load also includes idle loads described above

	Winter				Spring			
Hour	Activity	Load 1	Load 2	Total load [W]	Activity	Load 1	Load 2	Total load [W]
1	Sleep			101	Sleep			48
2	Sleep			101	Sleep			124
3	Sleep			101	Sleep			65
4	Sleep			101	Sleep			127
5	Sleep			101	Sleep			121
6	Sleep			101	Sleep			123
7	Breakfast			131	Breakfast			154
8	Working	Mobile charging	Computer Charging	218	Working	Mobile charging	Computer Charging	218
9	Working	Mobile charging	Computer Charging	218	Working	Mobile charging		151
10	Working	Computer Charging		198	Working			131
11	Working			131	Outside			131
12	Cooking	Kitchen fan		260	Cooking	Kitchen fan		260
13	Outside			101	Outside			101
14	Outside			101	Outside			101
15	Working			131	Outside			101
16	Relaxing	Computer Charging		198	Outside			101
17	Relaxing			131	Outside			101
18	Cooking	Kitchen fan		260	Cooking	Kitchen fan		260
19	Relaxing			131	Relaxing			131
20	Relaxing	Computer Charging	Mobile charging	218	Relaxing	Computer Charging	Mobile charging	218
21	Relaxing	Computer Charging	Mobile charging	218	Relaxing		Mobile charging	151
22	Relaxing	Computer Charging		198	Relaxing			131
23	Sleep			101	Sleep			84
24	Sleep			101	Sleep			100

Table 9 Activities and load demand per summer and fall, total load also includes idle loads described above

	Summer				Fall			
Hour	Activity	Load 1	Load 2	Total load [W]	Activity	Load 1	Load 2	Total load [W]
1	Sleep			48	Sleep			48
2	Sleep			124	Sleep			124
3	Sleep			65	Sleep			65
4	Sleep			127	Sleep			127
5	Sleep			121	Sleep			121
6	Sleep			123	Sleep			123
7	Breakfast			154	Breakfast			154
8	Relaxing	Mobile charging		120	Working	Mobile charging		131
9	Relaxing	Mobile charging		120	Working	Mobile charging	Mobile charging	151
10	Outside			100	Working		Computer Charging	171
11	Outside			100	Outside			198
12	Cooking	Kitchen fan		229	Cooking	Kitchen fan		131
13	Outside			100	Outside	Computer Charging	Mobile charging	230
14	Outside			100	Outside			188
15	Outside			100	Outside			101
16	Relaxing			100	Outside			101
17	Relaxing			100	Outside			101
18	Cooking	BBQ		100	Cooking	Kitchen fan		131
19	Outside		Mobile charging	120	Relaxing			260
20	Outside		Mobile charging	120	Relaxing			131
21	Relaxing			130	Relaxing			131
22	Relaxing	Computer Charging		197	Relaxing			131
23	Sleep			84	Sleep			84
24	Sleep			100	Sleep			100

4.5 Data Analysis

4.5.1 Qualitative Data Analysis

Coding the Interviews

The data analysis occurred in several steps, firstly in real time during the interviews, secondly during the transcription and lastly by coding and categorizing the transcribed interviews. The results from the interviews were coded to easily structure the findings and create a useful understanding of the results. This was made according to the following four steps: (1) becoming familiar with the data, (2) coding the data, (3) searching for themes and recognizing relationships and (4) refining themes and testing propositions (Saunders, et al., 2012). By following this qualitative data analysis structure, the interviews could be analyzed in an efficient manner. In the first iteration, all interview transcripts were coded on a high level based on if they referred to technology, market, regulatory or adoption aspects using the codes TEC for technology, MAR for market and REG for regulatory or ADP for when the interviewee spoke about potential adopters. Thereafter, the second iteration of coding was to further break down the quotes from the interviews into more specific themes, which resulted in the sub-codes listed in the figure below. These sub-codes were chosen based on categorization of frequently mentioned statements, themes and trends and provided a useful overview of the interview findings. The interviewee's self-introduction and off-topic discussions were not included in the presentation of the empirical findings as it did not relate to the research question. The sub-codes used were then also used as the titles of the synthesized empirical finings presented under general study.

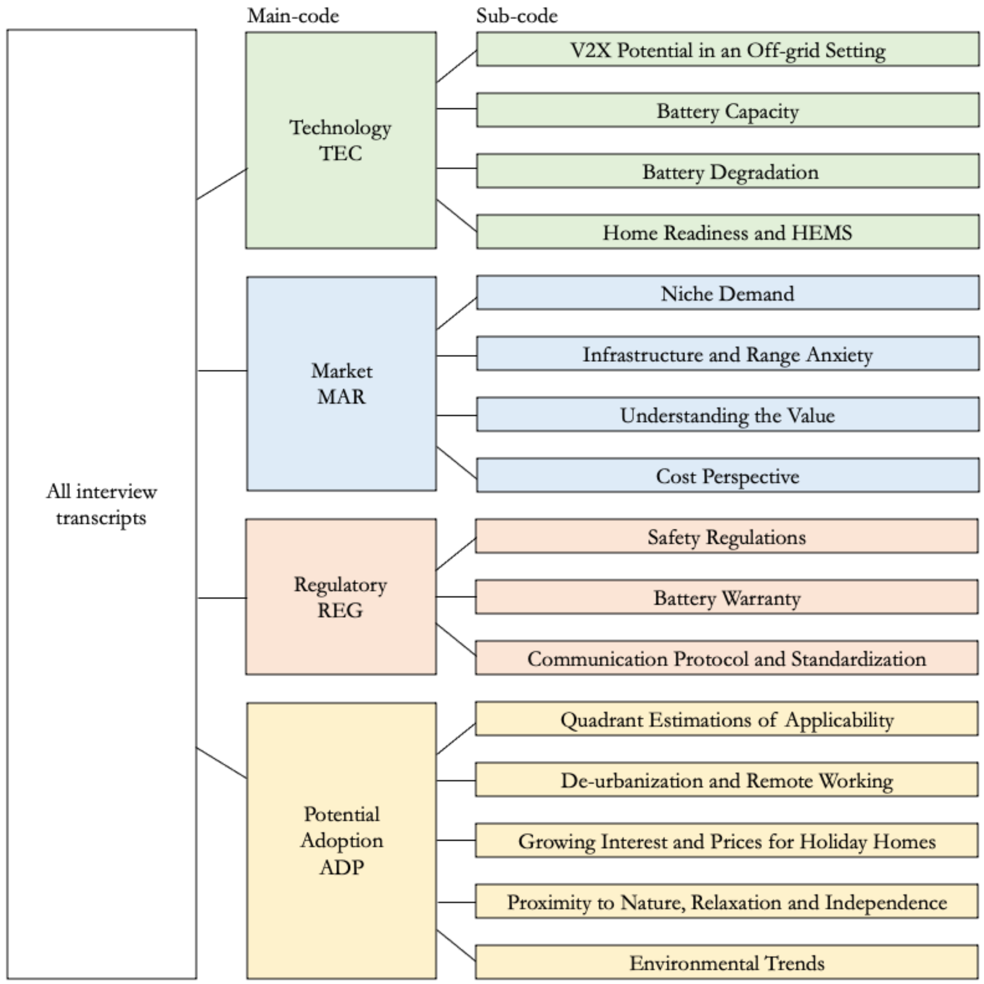

Figure 12 Codes used for analyzing interview results

Applying the Innovation Readiness Framework

When the interviews were coded and synthesized under the different sub-codes, the result was presented in the "Results from Interviews and Survey" chapter. After the results were presented, the analysis of the results was made under "Analysis of Results" where the two theoretical frameworks for the general study were applied. To assess the first part of RQ1, being how ready the V2X technology is to power an off-grid home in Sweden, the IRF framework was applied. The technology readiness was first analyzed, followed by market, and regulatory readiness. For all three perspectives, the first level on the nine-point scale of criteria was initially analyzed. If that first level was deemed to be fulfilled the analysis continued to the second level to see if the criteria had been reached based on the statements made by experts during the interviews. If this level was also deemed to have been fulfilled, the next level criteria on the scale were assessed and this process continued until the level where the criteria were no longer achieved. The full scale of criteria is presented under the theoretical framework section. To understand if the level was fulfilled, the questionnaire developed by Vik et al., i.e., also the same questions as used in the survey, served as a foundation along with the scale. Moreover, when assessing the readiness based on this Innovation Level Framework, the results from the interviews were combined with the literature review and research context to understand if the experts' views were supported by literature, both academic and grey literature.

Moreover, the qualitative assessment of the readiness was combined with a survey. This was made to see more explicitly what the interviewees assess the readiness to be and to see if there was an agreement on the readiness assessment made based on the interviews versus the survey. The survey answers were both assessed on an individual level, to understand what perspective (technology, market, or regulatory) each respondent estimated to have reached the highest readiness, and on a group level by calculating the median for the readiness assessment on all three perspectives. By first understanding what each survey respondent thought had the highest readiness of all three perspectives, this could be compared to the results from the literature to see if there was alignment among the answers. The median assessed readiness formed a more concrete guideline for understanding if there was a consensus between the interviews and survey which helped form the conclusion. After this, a final assessment was made of the readiness level for V2X technology in an off-grid setting from the technology, market, and regulatory perspective.

Applying the Diffusion of Innovation Framework

The second part of RQ1 is understanding the potential adoption. This was made by applying the attributes of the innovation theory as defined by Rogers' Diffusion of Innovation (Rogers, 1983) to the interview findings. This was made by analyzing the interview findings from the five attributes of innovation defined as what is the (1) relative advantage of using an EV to power an off-grid home compared to other energy supply methods, (2) what is the compatibility with previous norms and values, (3) what is the complexity of using the EV to power an off-grid home (4) what is the trialability i.e. how easy it would be for a user to try the solution to power its home with the EV and lastly, (5) observability, how easy it would be for a person to see the perceived value add that this solution could bring. The transcribed interviews were analyzed and synthesized in sections named after the five attributes: relative advantage, compatibility, complexity, trialability, and observability. Moreover, the findings from the previous studies presented in the literature review and the industry context were used to see whether they could support the interviewees' statements and their ideas. In many cases, the literature findings were aligned with the interviewees' thoughts which increased the reliability of the analysis.

On a more detailed level on how the analysis was conducted, the relative advantage analysis was made by synthesizing all interviewees mentioning ways that using the V2X technology as a power source for the home would be better or create additional benefits for the user in any sense, and barriers in the sense that they believed an EV could be a poorer alternative compared to traditional energy supply methods. The compatibility attribute was analyzed by seeing what the interviewees highlighted with regard to human behavior, values, norms, and change in habits. This was made since the compatibility attribute refers to how well aligned the innovation is compared to previous values, norms, and ideas (Rogers, 1983). The complexity attribute was assessed by analyzing the interview findings to see if interviewees mentioned aspects of the innovation that would be complex or difficult to understand for the user. In this category, statements from interviewees stating that the innovation would be easy to use were also synthesized in this section, as a lower degree of complexity is what according to the Diffusion of Innovation theory would mean an increased adoption rate (Rogers, 1983). The trialability attribute was analyzed by assessing if interviewees highlighted ways that would increase entry barriers for the user to try powering the off-grid home with an EV. Lastly, the observability attribute was analyzed by reviewing the interviewees' statements on how easy the value add would be for the user to understand and if the user possibly could see the value that this innovation would bring.

4.5.2 Quantitative Data Analysis

Building a Model and Analyzing Scenarios

The software used for building a model and analyzing the scenarios used in this master thesis is called Stella and is offered by the service provider "Isee Systems" (Isee Systems, n.d.a). The program is an icon-based tool used for system dynamics modeling to understand how different elements and flows interact and affect each other (Isee Systems, n.d.b). In this program, the energy system for an off-grid home with the elements home battery, PV panels, home loads, and an EV is built. These elements will react with system flows being kWh, to see how the energy is transferred between the different components. Converters are also added to define the data input explained above, as the Stella software is compatible with Microsoft Excel data lists. Stocks are icons shaped like squares, which can accumulate and save flows over time (Isee Systems, n.d.c). Converters are circular-shaped icons that convert inputs to outputs (Isee Systems, n.d.e). The connectors are arrow-shaped icons that connect the model entities together and enable information sharing between the different components (Isee Systems, n.d.d). Lastly flows are represented by tubes with tap icons and are used to drain or fill the stocks i.e., the accumulating icons (Isee Systems, n.d.

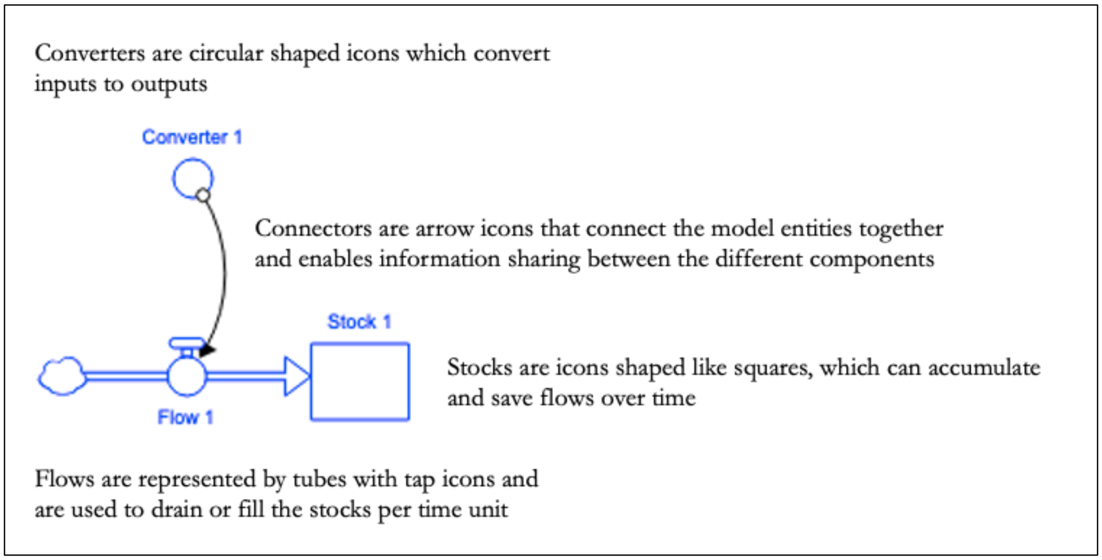

Figure 13 Explanation of system components of Stella software used to build case study model

Hence, the software allows for an understanding on how different components interact which each other; in this case study how the sun irradiance affects the available energy in the home battery and the EV battery depending on the home loads. This software was chosen as the goal of the case study was to understand in which scenarios the EV can reduce the seasonal energy imbalance.

Defining Scenarios

To understand the feasibility of using an EV to power an off-grid home, different scenarios were created. Firstly, the current state of the case study partner in Skövde was replicated. In other words, scenario 0 was created to represent the baseline without an EV. In this scenario, only the home battery, the PV panels and the home loads were included as this is the reality today. In scenario 1, an EV was added to the energy system to help balance the energy supply and demand. Scenario 2 is similar to scenario 1 but the EV is charged every other week at an external charging point, i.e., biweekly charging, during spring, fall and winter. Lastly, in the final scenario being scenario 3, the EV was allowed to be charged once per week during the same seasons. In other words, the EV is charged every seven days during spring, fall and winter. Below is an overview of all scenarios.

Table 10 Overview of all scenarios tested

Scenario	Definition
Scenario 0	System has no EV - trying to simulate baseline today
Scenario 1	System has EV but is never recharged at an external charging point
Scenario 2	System has EV and bi-weekly charging at external charging point
Scenario 3	System has EV and weekly charging at external charging point

Testing Criteria

Each scenario was evaluated by seeing how many days the home loads could be supplied with the energy needed. The testing criteria was hence to see when the supply; the solar PV panels, home battery and the EV, could meet the demand; the home loads, equation 1 and 2. The aim was to reach a system where the difference between the supply and the demand would be equal to 0 or greater than 0, and if there is excess energy it would be used to charge the EV battery. The output from each scenario was compared based on how many days the demand would be fulfilled by the supply. This is aligned with the RQ2 of understanding if the EV can prolong the season by supplying the home loads with its stored energy and reduce the seasonal energy imbalance. Moreover, the excess energy that cannot fit in the battery nor the EV was also measured for all scenarios.

(1) Energy balance test = Supply (kWh) – Demand (kWh)

where

(2) Supply = Energy from PV Panels, Home Battery and EV, & Demand = Home Loads

Model Building

The model building was made in five steps. Step 1 was to create a conceptual model of the flows and the idea as such. Step 2 was finding the relevant and needed input data, step 3 was to set up a first draft of the model structure in Stella without having the correct inputs and functions. Step 4 was refining the first draft by also adding the flows and setting the functions and logic in the flows. Step 5 was creating the different scenarios by deleting parts from the model. In other words, the model was built for scenario 2 and 3 which has the external charging point for the EV. Then to create scenario 1, the external charging was deleted from the model. To create scenario 0, the baseline, the EV components were deleted as well.

To describe in more detail how the model was built, step 1 of building the conceptual model was made in Microsoft PowerPoint and is pictured below. The conceptual model enabled a visualization of the idea and the flow of using PV panels, a home battery and an EV to power the home loads for off-grid living. This conceptual model also included the logic of the energy flows, to visualize the idea of only using the EV for discharging *if* the available sun energy and the stored energy in the home battery was not enough. The conceptual model is pictured below.

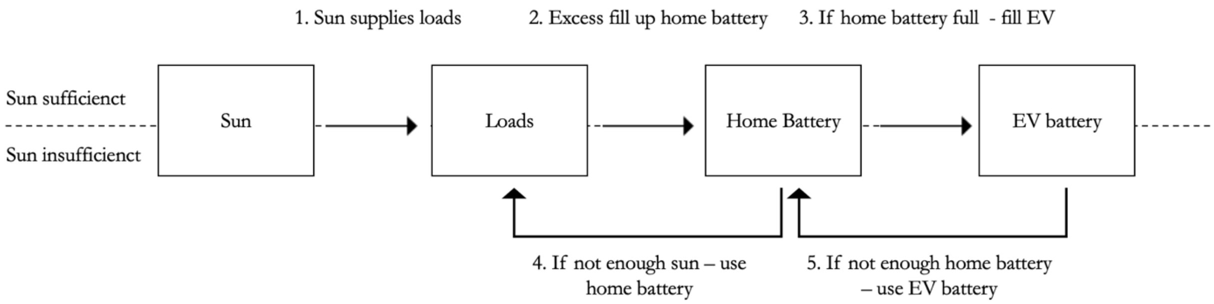

Figure 14 Conceptual model of the actual model later built in Stella

The second step was to collect the data inputs needed, as described above in data collection. The data on solar irradiance, EV capacity, and home loads was gathered in Microsoft Excel per hour, which later could be added to the Stella program to run the model. The third step was to start building the main components, the stocks, as listed in the conceptual model and to add flows as well as the collected data to the program. In this stage, the flows were not yet accurate, but the data was fed into Stella. Thereafter, step 4 was to set up the proper logic and the functions were added to the model. The time horizon in Stella was set to one year, divided into hours. This means that each calculation is made once per hour.

To explain all parts in the model building and how the logic was created the equations and conditional functions determining the flow and the relation between the input and output will be presented in the order of the logic used in the model. Starting with solar power, it was calculated as:

*(3) Solar power = Irradiance * PV_panel_area *(1 - Losses) * PV_panel_efficiency*

The sun energy flows into a stock which checks if there is enough available capacity in the home battery, which has a limit of 3 kWh:

(4) IF House_Battery < Battery_threshold THEN Battery_threshold - True_House_Battery ELSE 0

This energy then flows to power the home loads in the model, meaning that the output from the home battery is the same as the home load demand per that specific hour. There is then a component checking if the supply in the battery is the same as the demanded load, called delta energy, equation 5.

(5) Delta energy = House_Battery - Home_Loads

If the delta energy is negative, this means that the home battery was not enough to supply the loads. In this case, as presented in the conceptual model, the EV is discharged with the amount needed. However, there is a set EV state of charge (SOC) limit on the EV battery defined as 20 % to ensure that the EV is never completely discharged, since the user still needs to be able to travel home or reach the closest charging station. In this model, the assumption is also made that the EV requires a maximum of 20 % to go from the closest EV charger to the cabin, meaning that the EV capacity at arrival is defined as 80 %. This means that the disposable EV capacity at arrival is the capacity that is left once arriving at the house and excluding the SOC limit. Hence, it is defined as:

*(6) Disposable EV capacity at arrival = EV_capacity_at_arrival_% * (1-EV_SOC_limit) * EV_battery_capacity*

The model logic is set to as when the home battery is not enough to power the loads at a certain hour, i.e., delta energy is negative, then the amount of energy needed for that hour is discharged from the EV from this disposable EV battery share. ABS means the absolute value of the energy needed, and this is discharged from the EV, see equation 7.

(7) Energy discharged from EV = IF Delta_Energy < 0 THEN ABS(Delta_Energy)

ELSE 0

Looking at the conceptual model again, this was the case when the sun was insufficient. During summertime, when there is an excess amount of solar energy, the model should charge the EV with the excess energy. Hence, when the model checks if the solar energy is larger than what the home battery can fill, the excess goes to charge the EV, equation 8.

(8) To charge EV with = Excess_energy_control - House_Battery

This energy then goes to the EV. However, naturally, the model also needs to check if the EV battery is already full or how much can fit in the battery. As presented earlier, there is a SOC limit of 20 % that is never used in the model since this is needed to leave the off-grid cabin. Hence, the available capacity in the EV that could be charged is 80 % as this is the disposable share used in the model for discharging. The model therefore checks how much of the battery that can be filled with the excess sun, see equation (9).

(9) How much sun the EV can be charged with =

*IF EV_disposable_battery < (EV_battery_capacity *(1-EV_SOC_limit))*

*THEN (EV_battery_capacity *(1-EV_SOC_limit)) - EV_disposable_battery ELSE 0*

Then the battery is filled up with as much that is needed from the excess solar energy. The amount of energy that was sent to charge the EV with, but cannot fit due to the EV reaching its full capacity is calculated as:

(10) Energy that can't fit battery nor EV = Energy_that_cant_fit_in_battery - How_much_sun_EV_can_be_charged_with

During the seasons that do not have excess solar energy i.e. winter, spring and fall, the EV can also be charged at external charging stations, and to include this in the model, a charging station component is added. The charging logic is built by setting a charging schedule by building a Microsoft Excel sheet as input with ones (1) and zeros (0). This input was named “Away to charge EV” and the logic is made on a yes or no basis with 1 representing yes, and 0 representing no. The maximum amount that the EV could be charged with is the disposable share, once again to highlight that 20 % is always left out of the model to ensure it is possible to reach the charging station. Charging at the external charging point is named external charging in the model, equation 11.

*(11) External charging = Away_to_charge_EV * Disposable_EV_capacity_at_arrival_Wh*

Then the model checks how much the EV can be charged with at this certain hour based on the defined charging schedule with 1 and 0. The model compares how much is left in the battery compared to the disposable battery and how much sun the EV can be charged with at that hour which was calculated above. The model then charges the EV with the remaining need:

(12) Recharging EV at external point =

*IF EV_disposable_battery + External_charging + How_much_sun_EV_can_be_charged_with > EV_battery_capacity * (1 - EV_SOC_limit)*

THEN EV_battery_capacity(1- EV_SOC_limit) - EV_disposable_battery - External_charging - How_much_ sun__EV_can_be_charged_with*

ELSE External_charging

This step is the final component of the model. All the above functions and steps are repeated for each hour of the year. Once the model was finalized and running properly, step 5 was to create the four scenarios earlier presented. Scenario 0 aims to replicate the current state of the case study partner today, i.e., without the EV. Hence in this scenario, all EV related components were deleted from the model. Scenario 1 has the EV but no external charging, hence all external charging components were deleted from the model for this scenario. Scenario 2 was bi-weekly charging, so here the 1 and 0 schedule earlier explained was set to charge the EV once every 14 days. Scenario 3 was weekly charging; hence the charging schedule was set to 1 for every 7 days.

Then the total energy balance was calculated for all scenarios based on the testing criteria defined above. Firstly, by examining the energy balance at all moments and plotting the results:

(13) Energy balance test = Energy_to_power_loads - Home_Loads

Thereafter, an analysis on how much energy the EV can be charged with as well as the excess energy was made. To see how much energy the EV can be charged with the factor “To charge EV with” defined was plotted in a graph. To analyze the excess energy, the factor “Energy that can’t fit battery nor EV" was plotted in another graph. The energy balance and the plotting of the graphs described was repeated for all four scenarios. This allowed for an understanding of the RQ2 to see if the energy imbalance could be reduced. Please find results of the case study model under Case Study chapter.

4.6 Reliability and Validity

Reliability is defined by Saunders et al. (2012) as whether the data collection and analysis would produce consistent findings if they were repeated on another occasion or by another author. Hence, the threats to reliability needed to be taken into consideration when choosing the research design. One of the common threats is a poorly executed coding scheme (Neuendorf, 2019), which can be avoided by making a pilot test of the codes chosen. Therefore, in the coding of the interviews, the chosen codes were iterated by starting with the high-level codes: "technology", "market", "regulatory" and "adoption". Thereafter, the sub-codes were defined during a second iteration more carefully specifying the topic of the quote. These repeated iterations were made with the aim of reading the interview results several times, and as there are two authors of this study, both authors read all results to ensure alignment and hence reduce the risk of making an inconsistent analysis. This might have been more time-consuming, but the analysis was likely more consistent which made it more reliable.

Another threat to reliability is researcher bias where a researcher risk allowing their own subjective thoughts to influence the interviewee (Saunders, et al., 2012). This threat was mitigated by having an unstructured and explorative interview design where the interviewee could guide the conversation and the researchers mainly provided the initial questions. The questions aimed to be as neutral as possible in the sense that they did not influence the interviewees' opinions. Thereto, the interviews were complemented with a closed-ended assignment asking them to place their pin on a template showing a picture of a quadrant. This question was asked to ensure more consistent data collection. As the first part of the interview was unstructured, the interviews tended to be quite different from each other. Therefore, the closed-ended data collection made the final part of the interviews more alike, and regardless of which researcher that would have been asking this question, the template of the quadrant would be the same; hence suggesting that the data collection would be consistent regardless of the interviewer which increases the reliability. Furthermore, another risk for bias was when choosing which candidates to send out the survey to. The survey respondents were chosen based on their industry with the aim to get an even number of responses from the industry domains "charging & mobility" and "housing & tourism" with the aim to limit biases in the survey based on industry expertise. The respondents were picked based on their perceived level of expertise in the V2X subject accrued from the interviews and interviewees both optimistic and pessimistic regarding the subject were chosen to get an accurate view of the solution readiness as well as try to limit bias.

The reliability of the model was also considered, and when the results of the model had been realized and presented, a comparison to previous studies was made. As few studies have analyzed using an EV to power off-grid tiny houses, the comparison to other researchers' assessments was first adapted and compared based on their inputs. As presented under discussion, the findings from this study were weighted by the relative relationship between load demand and available energy storage. These comparisons to previous studies were made to evaluate if the results are reasonable, and this is not the same as reliability but comparing to what other researchers have found can be used as a benchmark to see that similar research has found similar results given the circumstances suggesting consistency

To further ensure the quality of the research, not only does reliability need to be taken into consideration. Validity is an important aspect to ensure good quality of the research (Saunders, et al., 2012). Firstly, construct validity concerns whether the methods measure what is intended to be measured (Saunders, et al., 2012). This has been accounted for in the research by complementing the interviews with a survey to ensure that the interviewees assessed the innovation readiness. Furthermore, the interviews were coded by the authors and hence some of the intentions and meanings could have been missed. By adding a survey which explicitly assesses the readiness of the innovation from the technology, market, and regulatory perspective ensures that what is intended to be measured is being measured. The questions asked in the survey were based on the theoretical framework of this thesis, which further strengthens the construct validity. In addition, the innovation under analysis was clearly defined and described in the survey to ensure that all survey respondents had the same understanding of what kind of innovation is being assessed. Moreover, the survey was sent out to chosen experts based on the initial interviews and the perceived expertise of the interviewees based on their job title. To ensure alignment between the authors perception of the survey respondents' expertise and their self-perceived expertise, the first question of the survey asked the participant to make their own assessment of their expertise. This increases the validity of the innovation readiness assessment by ensuring that what the survey measured truly was what was being intended to measure.

Moreover, external validity regards whether a study's findings and results can be generalized to other relevant settings or groups (Saunders, et al., 2012). The general study aims to understand how ready the V2X technology is in an off-grid setting. However, technical aspects in regard to the innovation are assessed, for e.g., the bidirectional functionality as such. This means that the findings can be used in other settings than solely the off-grid V2X context. Moreover, the case study takes place in Skövde, Sweden, and the result from the model is determined on meteorological data for that location. This shows low external validity. However, the model as such that investigated whether an EV could prolong the season for off-grid living or not could be used in other settings than in the case study. The exact same results will however not be achieved as the model is depended upon metrological data which is dependent on the location making the results representative for mid- and southern parts of Sweden. Overall, these reliability and validity precautions aim to have increased the quality of this thesis.

5. General Study

This chapter presents the first part of this thesis, the general study, which aims to assess the first layer of the problem represented by RQ1: "How ready is the V2X technology to power an off-grid home and what could affect potential adoption?". In this chapter, firstly, the results from the interviews and the survey are presented. Secondly, the empirical findings are analyzed by applying the theoretical frameworks earlier presented, Innovation Readiness Framework and Diffusion of Innovation.

5.1 Results from Interviews and Survey

5.1.1 Technology Perspective

V2X Potential in an Off-grid Setting

During the interviews, the potential of connecting an EV to an off-grid house was discussed. A Sustainability Expert (2022) pointed out that an EV could potentially increase the value for a consumer to live off-grid, but only if the electricity storage in the EV can achieve what solar cells cannot produce at night. A R&D Portfolio Manager (2022) mentioned that the EV can create value if the car is charged and has significant capacity left when arriving at the cabin. An EV is seen capable of prolonging the stay in an off-grid cabin with solar panels and a small battery for several days and still having battery capacity left (Off-grid Living Expert, 2022). Moreover, the EV can serve as a complement that might only be needed on some occasions (Energy Policy Advisor, 2022). Furthermore, during the interviews it was mentioned that there is no problem to live off-grid during late spring, summer and early fall with only solar panels and a battery in the cabin, however during the winter it is not feasible if there is no other energy supply or a seasonal energy storage solution (R&D Portfolio Manager, 2022; Researcher E-Mobility, 2022; Off-grid Living Expert, 2022).

Today backup generators driven by liquefied petroleum gas or gasoline are often used when the PVs do not generate enough electricity and the battery has run out (Off-grid Living Expert, 2022). An EV with bidirectional functionality might be useful and has great potential to prolong the accessibility of off-grid living (Off-grid Living Expert, 2022). Another advantage with an EV is that it is mobile, hence it can be transported to be charged in a different location and transported back to the off-grid cabin (Charging Expert, 2022). However, using an EV to transport electricity can be considered an expensive way to get access to electricity (Strategy Director, 2022). The EV is expected to be capable of also drawing energy from the home when the PV has generated excess electricity (Off-grid Living Expert, 2022).

Battery Capacity

Some experts' express concerns about the battery capacity in the EV and if it is sufficient to power a house. The EV battery will probably not have the capacity to cover a house's energy demand in weeks and some off-grid homes are equipped with hydrogen storage as a backup power which the EV will not be able to replace (Sustainability Expert, 2022; R&D Portfolio Manager, 2022). A Battery Expert (2022) highlighted that an EV battery is constructed so that the car can accelerate, and it is hence not optimal to power a home due to it having a different load demand. Furthermore, there were some concerns regarding the risk of being deserted if the charging infrastructure is far from the off-grid house and that the battery might not be able to provide the cabin with electricity and provide transport to the regular residency (Energy Management Expert, 2022; R&D Manager, 2022).

Battery Degradation

Some of the interviewees mentioned battery degradation as a barrier to the V2X technology (Battery Expert, 2022; Energy Policy Advisor, 2022; Energy Management Expert, 2022). A Battery Expert (2022) stated that the batteries that exist on the market today are adapted after the area of use and that the batteries in EVs are different from batteries used in the home. Furthermore, an expert within policy at an energy company mentioned the issue of how much you are willing to use, or lend out, your EV to provide electricity at the cost of shortening the battery life (Energy Policy Advisor, 2022). When using the V2X functionality of the EV it then becomes even more important for the user to understand the battery health, or state of health (Charging Expert, 2022) and if the user is knowledgeable of how the battery works, it can be cycled it in a gentle way (Energy Management Expert, 2022). But if not, the usage could become a warranty issue for the car manufacturer (Energy Management Expert, 2022). Similarly, some experts pointed out that V2X during power outages and V2L usage will not wear out the battery as much since it is not constant usage, and it is a smaller load that is being supported (Energy Management Expert, 2022; Strategy Director, 2022).

Home Readiness and Home Energy Management Systems

The system will require a lot from the house infrastructure, as things are optimized according to their function (Battery Expert, 2022). A switch is needed on the smart inverter that can decide what to reload (Off-grid Living Expert, 2022). There needs to be a smart discharge, and a Strategy Director (2022) mentioned that the smart software needs to have a boundary condition so that the EV does not discharge after a certain battery limit based on the state of charge. A Charging Expert (2022) mentioned that you can use the car for V2L, but the environment and how the EV is connected to a load independent of the main grid requires a certain frequency and voltage control. This is supported by a Researcher in E-Mobility (2022) that mentioned that the power sources must create frequency and voltage itself with the required power quality and that the power source must be strong enough to deliver to all loads and for safety systems to function. Moreover, there are communication standards to and from the electricity meter, but there is no communication standard for smart hubs, HEMS, in Sweden today (Regulatory Advisor, 2022). As highlighted, the off-grid V2X system will require a lot from the house infrastructure (Battery Expert, 2022) and there are probably some suppliers that can supply all relevant components, but they might not be compatible with all the EVs (Regulatory Advisor, 2022). Off-grid homes are often also equipped with a home battery, and more specifically, an Off-grid Living Expert (2022) explained that off-grid tiny homes in Sweden with an approximate base consumption of 100 W per hour and with a small home battery of 2.4-3 kW is seen as sufficient between the beginning of April and the first half of October long as the battery is charged during the day.

5.1.2 Market Perspective

Niche Demand and "Nice to have" Feature

Many of the interviewees mention that the market for off-grid living and the future market for off-grid living combined with V2X is very niche (Charging Expert, 2022; Off-grid Living Expert, 2022; Professor within Geography, 2022). An Asset Manager (2022) working with strategic projects for an energy innovation hub mentions that the "Customer demand is still niche", which an R&D Portfolio Manager (2022) agrees with, but believes that it is an exciting niche that might grow. This can, however, also be considered an opportunity as the V2X solution is seen to possibly provide value for this specific niche (Postdoc within Geography and Tourism, 2022; Insight Manager, 2022). The bidirectional feature is also considered to be a "nice-to-have" feature, in other words, not a necessity but instead a value-add (Charging Expert, 2022; Sustainability Expert, 2022).

Infrastructure and Range Anxiety

Given that EVs can be charged in one place and discharged somewhere else, powering an off-grid tiny house with V2X is agreed to be an interesting use case among some interviewees (Energy Policy Advisor, 2022; R&D Manager, 2022; R&D Portfolio Manager, 2022). One reason for the slow adoption of V2X is that the EV market is still in an early stage and that the market is now starting to catch up and offer the bidirectional charging functionality (Asset Manager, 2022). In the near future, most of the cars on the market will be EVs (Strategy Director, 2022) and the charging infrastructure is being expanded (Sustainability Expert, 2022). The charging infrastructure is needed to grow in Sweden in order to have easily accessible charging stations on the way to the off-grid tiny house for it to be interesting for people (R&D Manager, 2022; Insight Manager, 2022; Senior Analyst, 2022). Today many EV owners have range anxiety and are worried that the energy will not last as long as needed (Battery Expert, 2022; Insight Manager, 2022). Another aspect that was mentioned during the interviews is that having electricity in the EV could be valued higher than powering the home with that electricity (R&D Manager, 2022). An interviewee also mentioned that even though there is potential for the technology, the off-grid living circumstances make it more difficult to charge the EV when the sun is not shining (R&D Portfolio Manager, 2022).

Understanding the Value

Another factor mentioned during the interviews when discussing the market for an off-grid V2X system is that the customer might not understand the value (Sustainability Expert, 2022; Technical Expert, 2022). There needs to be a business model that creates value for both customers and businesses and there needs to be valuable incentives for the user (Sustainability Expert, 2022). When living off-grid, the EV is seen to possibly be a good value add for the homeowner if it is expensive to connect to the main grid (Strategy Director, 2022). The feeling of increased independence with more energy storage through the EV compared to traditional off-grid housing is also mentioned as a possible value add for the customer (R&D Portfolio Manager, 2022). However, money is mentioned as the most important driver to customer demand (R&D Portfolio Manager, 2022). Moreover, if the EV can allow for a person to live off-grid and not feel the need to connect to the grid, this increased flexibility is also mentioned as a value add from a grid perspective as the grid in Sweden today needs to be expanded. So, the less it needs to be expanded, the better (Energy Policy Advisor, 2022). The EV with bidirectional functionality is seen to possibly make off-grid living easier compared to owning a traditional fossil-fuel car (R&D Portfolio Manager, 2022). However, there needs to be some changes in behavior as the users always need to connect to the EV through the charging port when arriving at the house or cabin (Strategy Director, 2022).

Moreover, the EV is believed capable of helping extend the season for off-grid living (Off-grid Living Expert, 2022). In addition to this, if the EV is charged with green energy from renewable sources, it also serves as a sustainable option for powering the home (Off-grid Living Expert, 2022).

> *We see a great demand to be off-grid, but it is difficult during the winter. You must have a large battery that costs a lot, and it is not so environmentally friendly to buy a large battery to be able to fully upgrade oneself; A car would have been perfect. (Off-grid Living Expert, 2022)*

Cost Perspective

If the house is off-grid, connecting it to the main grid is expensive (Strategy Director, 2022; R&D Portfolio Manager, 2022). Moreover, the cost of a larger home battery is also mentioned as expensive during interviews (Off-grid Living Expert, 2022). One interviewee also mentions that the cost of transportation will decrease in the future as cars become more autonomous (Senior Analyst, 2022). Money and cost savings is also a common incentive for people to try new innovations (R&D Portfolio Manager, 2022) and the solution could be more interesting if the user could get lower energy prices (Strategy Director, 2022). On the industry cost side of implementing the feature, the technology of adding converters is not seen as difficult. One interviewee mentioned that the technology for adding bidirectional converters has not been difficult for the past 20 years, but the cost side and understanding why the OEM should carry these costs has been the question (R&D Manager, 2022).

5.1.3 Regulatory Perspective

Safety Regulations

According to several experts there are no additional legal requirements, and it is even regulatory unproblematic, to use V2X in an off-grid setting (Sustainability Expert, 2022; R&D Manager, 2022; Energy Expert, 2022). An Energy Policy Advisor (2022) highlighted that since it is a smaller energy system that is off-grid, it is doable. Moreover, an Energy Management Expert (2022) mentioned that the difficult part is getting the home disconnected from the grid, but in an already off-grid home there are no regulatory constraints. However, there are still many existing electrical safety requirements for installation and other specific regulations that need to be fulfilled, such as voltage regulation due to fire risk (Researcher E-Mobility, 2022; Technical Expert, 2022; Energy Expert, 2022; Regulatory Advisor, 2022).

As the system that is being analyzed is off-grid, the electricity market requirements are not relevant, however, electrical safety needs to be taken into consideration and a fire fighter needs to understand how to turn off the power (Energy Expert, 2022; Regulatory Advisor, 2022). This has been regulated for PV panels (Regulatory Advisor, 2022). Moreover, in an off-grid mode, it is important to have a balance between the generator and the load otherwise the equipment might get destroyed. In a home, there are many loads, and it is important to make sure that the generator has a capacity as high as the demand from the loads, or a control system that can connect and disconnect the loads (Researcher E-Mobility, 2022). Further, the off-grid V2X system seems regulatory unproblematic, and no permissions are needed to set up the system (Sustainability Expert, 2022; Regulatory Advisor, 2022). However, the electrical installation still needs to fulfil the electricity safety regulations, which might be complex to understand as it is unclear which rules are required for it to be safe (Regulatory Advisor, 2022; Researcher E-Mobility, 2022). This can, however, likely be solved by hiring an electrician to do the installation (Regulatory Advisor, 2022).

Battery Warranty

During the interviews the battery warranty was highlighted as something that might need to be adapted to the additional battery degradation due to the V2H/V2L technology (R&D Portfolio Manager, 2022; Energy Management Expert, 2022). Through the usage of V2X, the battery would be used more times as it would serve multiple use cases; both transportation and V2X. The battery would hence be cycled more than through regular usage, which affects the lifespan of the battery (Charging Expert, 2022). Today OEMs provide a battery warranty to ensure that a specific battery capacity remains for a certain number of years or number of kilometers travelled. If the bidirectional functionality is used, the battery might have degraded more than the capacity limit defined by the warranty, even if the set distance or time has not passed. This is mentioned as something the OEMs need to decide on how to handle (Charging Expert, 2022). Another interviewee mentioned the warranty terms are one of the biggest barriers for V2X adoption (R&D Portfolio Manager, 2022), but some interviewees mentioned that the warranty terms need and probably will be updated and do not view it as a barrier (Energy Management Expert, 2022).

Communication Protocol and Standardization

There are various communication standards for EVs which enable bidirectional functionality, however, the market will move towards more standardization, and for V2X to reach the mass, standardization is needed (Battery Expert, 2022). The reason, and one of the barriers, why cars today do not have this functionality is because there are various standardization protocols for both the EV and the EV supply equipment, and it is up to the OEM if they want to offer this functionality in their cars (Battery Expert, 2022). A Researcher in E-mobility (2022) at an Energy Company mentioned that the communication standards are voluntary, but very practical as it creates compatibility between different car models and different charging infrastructure and the EU directives can be fulfilled by following harmonized EU standards. OEMs can create a proprietary standard, but then the burden of proof to fulfill the EU directives that exists lies with the OEM (Researcher E-Mobility, 2022).

ISO 15118-20 is under development as a European standard (Charging Expert, 2022; Technical Expert, 2022; Strategy Director, 2022). In Europe, car manufacturers will adopt to the ISO standards because they will not benefit by creating a proprietary standard (Energy Expert, 2022). Asian OEMs are following the proprietary CHAdeMO standard that in version 2.0 offers bidirectional DC charging. European EV manufacturers aim for bidirectional DC (and AC) charging control by the new ISO 15118-20 and using the CCS2 interface (Researcher E-Mobility, 2022). However, the testing standard has first to be developed to guarantee interoperability. Regarding electrical safety at bidirectional charging the IEC standards IEC61851-23 Ed2 and IEC 61851-1 Ed4 are still under development (Researcher E-Mobility, 2022). Few OEM in Europe will deviate from the ISO standard that soon will be published (Energy Expert, 2022). The new ISO standard will, as well, solve the issue regarding communication between different car models. That is one of the reasons why many car manufactures are awaiting the approval and release of ISO 15118-20 (Energy Expert, 2022). One interviewee framed their view on the relationship between the technology, market and the regulatory landscape being as the market is less ready than technology and the key is standardization of equipment (Regulatory Advisor, 2022).

5.1.4 Readiness Assessment Survey

The interviews were followed by a survey asking respondents to estimate the readiness of an off-grid V2X system. From a qualitative point of view, the results show that all people who rated the innovation from both a technology (dark blue) and a market perspective (yellow) considered the *technology* to be more ready or equally ready compared to the *market* perspective assessment. This is also true for most assessments made from a technology perspective compared to the market assessment; five of eight technology estimations are assessed higher than all market estimations made. The median for the TRL is 6 and the median for MRL is 3. Moreover, the *regulatory* (grey) assessment was made only by two people. Their estimations put the regulatory readiness at a level six and level four, and in relation to their other assessments, the readiness of the innovation from a regulatory point of view is considered less or equally ready as the technology. The median for RRL is 5.

The survey was anonymous, but the respondents' expertise is presented on the x-axis. One of the respondents added a free text response to complement their assessment saying:

> *Perhaps not the whole system [off-grid V2X system], but V2G and off-grid power supply have definitely been validated separately. Generally, I would say the solutions are available, but the market is not there (Mobility Expert, 2022)*

This comment hence emphasizes that the system components are ready and validated, but not validated together and that the market is lagging. Another respondent with expertise within tourism commented that:

> *While I certainly think this system could be an option among many options in the market for leisure dwellings, I deem it to be a fringe phenomenon reserved for enthusiasts. At least for now. It would always have to compete with "normal" options, such as second homes, caravans and recreational vehicles, which are more established in the market (Tourism Expert, 2022).*

The statement highlights that the option of living off-grid with the V2X technology still would need to compete with more traditional housing options on the market.

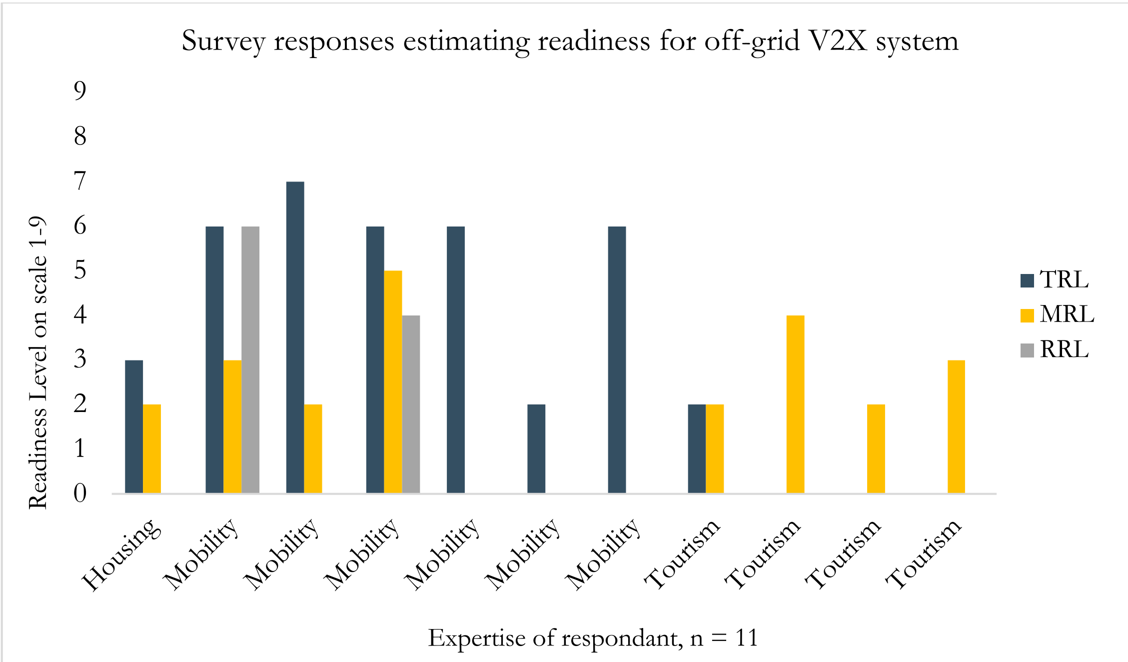

Figure 15 Results from survey estimating the respondents to estimate readiness level on a scale 1-9, n = 11.

5.1.5 Potential Adoption

Applicability of the Innovation

Interviewees were also asked to estimate where they thought the off-grid V2X solution was most applicable for the future. Results show that most respondents think that the solution is most applicable for short-term stays and individual usage.

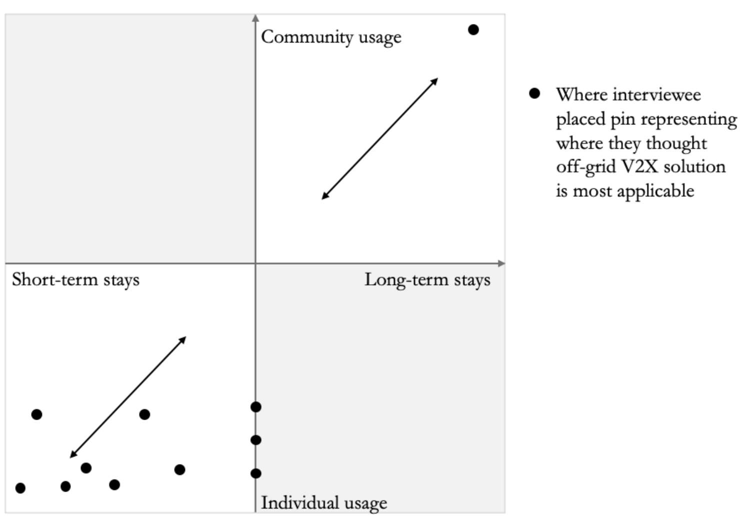

Figure 16 Results of assessment where the interviews assess where they find the off-grid V2X to be most applicable

Most respondents placed their pin on the individual side of the y-axis. People want a convenient lifestyle and tend to use more individual solutions even if community solutions could be more rational from a resource perspective (Postdoc within Geography and Tourism, 2022). If people are part of a community, they might lose the feeling of being alone and having their private space in nature (Insight Manager, 2022). Sweden is seen as an individualistic country which makes the innovation more applicable for individual usage (Battery Expert, 2022). One interviewee made the comparison to today's reality with fossil fuel driven cars; even if your neighbor runs out of gas you are unlikely to share your gas with this neighbor (R&D Manager, 2022). People tend to want to have their own things, e.g., in a regular residential area in Sweden, all households tend to have their own chainsaw instead of sharing it, and this off-grid V2X solution is likely resemble this situation (R&D Manager, 2022). Other interviewees agree that a community solution would be too complicated (Energy Policy Advisor, 2022) and that the individual use case is more likely (Sustainability Expert, 2022; Off-grid Living Expert, 2022; Asset Manager, 2022). As electricity prices increase, the electricity you have in your EV is also going to be perceived even more valuable and hence it is unlikely that people would want to share it with others (Professor within Geography, 2022).

The founder of a company building tiny houses mentioned that the off-grid V2X solution is most likely to be relevant for an individual use case but wishes it would be more community based (Tiny House Manufacturer, 2022). The interviewee presents a vision of having a smaller village of tiny houses with a minimalistic lifestyle and a common plant of solar cells but highlights that this would be more realistic in the future (Tiny House Manufacturer, 2022). The arrow in the quadrant pictured above shows that some interviewees highlighted that for short term stays, individual usage is more likely whereas for long term stays the community usage is more likely (Strategy Director, 2022; Tiny House Manufacturer, 2022).

If solely the EV will be used as the main energy source, it is only applicable for short term stays. However, if the EV is combined with PVs panels the solution is more likely to work for long-term stays (Battery Expert, 2022). The type of loads that the EV is expected to power also affects whether the solution would be more likely for the short or long term, but over time the solution is seen to be more likely to be used for long term stays (R&D Manager, 2022). Today, the technology is considered more likely for the short-term (Sustainability Expert, 2022; Professor within Geography, 2022) or for long term but more seldom (Professor within Geography, 2022). The technology is seen as the aspect setting the limit for how long people can stay (Postdoc within Geography and Tourism, 2022; Sustainability Expert, 2022).

Themes for Potential Adoption

De-urbanization and Remote Working

A Telecommunications Strategist (2022) mentioned that even though they had not specifically examined where people choose to settle, they had seen increased emigration from Stockholm i.e., more people moving out than in from the city. This was described as a temporary trend break, likely prompted by the pandemic:

> *It [the de-urbanization trend in Stockholm] has probably been prompted by working from home during the pandemic. According to the recommendations, you had to work from home, which may have meant that more people worked from the country house or alternative workplaces. So, if you have such a job, then the working method itself could be tested; people saw that it worked and could then move. Either to their holiday accommodation, or new accommodation (Telecommunications Strategist, 2022)*

The work from home trend was further supported by a Senior Analyst (2022) working at a consulting and research company in Sweden. Since the pandemic started, they had been sending surveys asking people to assess whether they believed they would continue to work from home. The survey was sent once per month and the most common answer is that the respondents believed they would continue working from home 1-3 days per week, 2 days on average (Senior Analyst, 2022). Moreover, a Sustainability Leader (2022) mentioned that there is a trend of living in a small environment. There are also individuals that want to live away from the city and to be independent from traditional energy sources (Sustainability Leader, 2022). Place independence and having the freedom to work from different places is also expected to continue evolving in the future (Sustainability Leader, 2022).

Growing Interest and Prices for Second Homes

Continuing from this trend, there also seems to be an increased demand for second homes in Sweden and the prices of second homes, i.e., holiday homes, are similar to the prices of primary homes today in Sweden (Postdoc within Geography and Tourism, 2022). If it is difficult to access holiday homes near cities or popular destinations due to their high price, the demand for off-grid houses could increase (Postdoc within Geography and Tourism, 2022). People have started to consider these types of houses to make themselves less affected by the price war on the real estate market (Strategy Director, 2022). The growing interest in second homes has also created a need for the municipalities to handle the increased population living in their second home for longer time periods than before the pandemic (Senior Analyst, 2022). A Postdoc within Geography and Tourism (2022) also mentioned that from a municipality's perspective it could be interesting with tiny houses. The strategist working at a telecom company highlighted that the municipalities could also try to adapt to the trend of remote working to make the municipality more interesting for people (Telecommunications Strategist, 2022). The cost of this lifestyle must of course still be considered (Strategy Director, 2022) as money tends to be a driving force for decision making (R&D Manager, 2022). Swedes are now used to having a high living and interior standard of their second home (Postdoc within Geography and Tourism, 2022) which was also mentioned as an important aspect by the founder of the off-grid living service (Off-grid Living Expert, 2022). This upgrade of the standard of holiday homes might not be compatible with living off-grid in a tiny house (Postdoc within Geography and Tourism, 2022).

Proximity to Nature, Relaxation and Independence

When interviewing a founder of a company offering stays in their off-grid tiny houses in Sweden, they had seen three main motivations among their customer groups. The main motivation for booking a stay in their cabins was to relax and get a break from everyday life (Off-grid Living Expert, 2022). The contrast to people's normal living habits was seen as the main priority. Secondly, their customers valued the proximity to nature, and to be able to enjoy the forest. Lastly, many customers were also interested in purchasing their own off-grid tiny house, and hence wanted to start by trying out the experience for a shorter period through their service (Off-grid Living Expert, 2022). One interviewee mentioned seeing the trend of downshifting at their institution, meaning the desire to work less, decrease costs, increase amount of free time, and have less consumption, and off-grid living was mentioned as the extreme version of downshifting (Professor within Geography, 2022). Moreover, in time of crisis, the V2X technology and off-grid living becomes more relevant and it appeals to individuals that want to be independent of the grid (R&D Portfolio Manager, 2022). Moreover, these individuals might find the V2X technology interesting and especially the use case of having it as backup power during power outages and other emergencies (Researcher E-Mobility, 2022; R&D Portfolio Manager, 2022).

Environmental Trends

Off-grid V2X could speak to individuals that want to go out in nature (Asset Manager, 2022). Furthermore, one of the interviewees, which offers stays in off-grid tiny houses, observed that the customers decreased their water consumption when a water meter was installed in the cabins. This was seen as possibly related to the increased awareness and desire to be mindful of resources (Off-grid Living Expert, 2022). Another interviewee mentioned that the target group for off-grid living powered through V2X likely are younger, purpose driven, and sustainability mindful individuals that are making active choices of their lifestyle and consumption (Insight Manager, 2022). These individuals are often high-income earners and thus have the opportunity to go off-grid with an EV (Insight Manager, 2022). One interviewee mentioned having the off-grid cabin as a resort solution to get away from everyday life (Telecommunications Strategist, 2022). Furthermore, when the PV panels produce an excess amount of solar electricity, it can be used to charge the EV (Tiny House Manufacturer, 2022) which can be considered a sustainable option for EV charging.

5.2 Analysis of Results

5.2.1 Innovation Readiness Level

Applying the TRL Scale on Empirical Findings

The first level on the TRL scale is when there has been a specific technological idea formulated, and for TRL 2 the idea is explicitly described (Vik, et al., 2021). During the interviews, an EV with bidirectional functionality was seen to possibly be useful and have great potential to prolong the accessibility of off-grid living (Off-grid Living Expert, 2022). Another interviewee mentioned that since an EV is mobile, it can be transported to be charged in a different location and transported back to power the off-grid cabin (Charging Expert, 2022). Hence, TRL 1 and TRL 2 of having a technological idea formulated as well as an idea being explicitly described can be considered fulfilled (Vik, et al., 2021). In the survey, three people assessed the TRL to be at a level 2 or 3, and TRL 3 is when there has been an experimental proof of concepts (Vik, et al., 2021). The survey assessment is supported by previous studies presented in the literature review, where Tuttle et al. simulated that a V2H capable vehicle connected to a PV equipped home could enable fully off-grid operation (Tuttle, et al., 2013). The concept is further described by another experimental study which aimed to prolong the duration the EV could help cope with grid failure, i.e., a temporary off-grid mode (Shin & Baldick, 2017). These experiments qualify the innovation to have reached an TRL 3, as experimental proof of concept is demonstrated.

TRL 4 is when the technological elements have been tested separately in a lab or simulated environment (Vik, et al., 2021). During the survey one interviewee highlighted, as presented under empirical findings, that the V2G technology and off-grid power supply has been validated separately (Mobility Expert, 2022). This qualifies the innovation to be at an TRL 4. This is further supported by the interviews, where the off-grid housing technologies were seen as feasible during late spring, summer, and early fall (R&D Portfolio Manager, 2022; Researcher E-Mobility, 2022; Off-grid Living Expert, 2022). This can be interpreted as that the housing side of the V2X off-grid living system has been validated separately for these seasons.

The remaining survey respondents assessed TRL to be at level 6 or 7. For TRL 5 to have been achieved, the elements are tested together as an integrated solution (Vik, et al., 2021). This is supported by literature as Tostado-Veliz et al. (2021) conducted a study investigating the optimal electrification of off-grid smart homes considering flexible demand and V2H and found that the EV can effectively play the role of a storage facility. It was stated that EVs may bring benefits to off-grid homes (Tostado-Veliz, et al., 2021). Hence, TRL 5 can be considered achieved as that study tested the full system i.e., powering an off-grid home with V2H. Similarly, Gong and Ionel (2021) found that an energy system with a PV, a battery energy storage system and an EV with an 80-kWh battery could manage off-grid operation for at least 72 hours. For TRL 6 to have been achieved, the technology needs to be demonstrated in its natural environment (Vik, et al., 2021). As presented under empirical findings, the survey results estimated the off-grid V2X system to be at a median TRL 6 and this was the most common response and estimation made. This assessment is also supported by the industry context chapter as the Hyundai Ioniq 5 with V2L functionality has been used to power an off-grid cabin in Sweden outside the city of Stockholm in a project called "Today's office" (Hyundai, n.d.b). This can be considered a prototype tested and validated in a relevant environment qualifying for a TRL 6 (Vik, et al., 2021).

One survey respondent assessed the readiness for the off-grid V2X system to have reached TRL 7, and the distinction between TRL 6 and TRL 7 is what type of environment the innovation has been tested; TRL 6 is demonstrated in a relevant environment, and TRL 7 is demonstrated in a natural environment (Vik, et al., 2021). This is a fine distinction, and as "Today's office" did not include the full energy system with residential PV panels, it is considered by the authors of this study to be a relevant but not natural environment. To have an energy system with residential PV panels on an off-grid home and an EV, the system will require a lot from the house infrastructure as highlighted during interviews (Battery Expert, 2022). A switch is needed on the smart inverter that can decide what to reload (Off-grid Living Expert, 2022). The off-grid V2X system is also expected to need a smart discharge with an energy management system with a boundary condition so that the EV does not discharge after a certain battery limit based on the state of charge (Strategy Director, 2022). These PV panels and user interface were not, according to the available material, there in the "Today's office" trial. This hence also supports why the Hyundai trial was relevant but not the full, natural system that this thesis investigates.

TRL 8 is when the product has been tested, validated, and optimized (Vik, et al., 2021) and the innovation is not assessed to have reached this level in the survey nor the interviews or in literature. This assessment is made because the innovation has not been tested and validated in broad scale, nor are all home and charging components to our knowledge fully developed and ready to use in the off-grid setting. The V2X technology as such is validated in broad scale since it is available by some OEMs (Nissan Global, n.d.; Mitsubishi Motors, n.d.) but not tested in broad scale to power off-grid homes which is the scope of this thesis. The V2L technology has been presented in the off-grid setting with "Today's office" i.e., the off-grid scenario, but this was not broad scale and solely a trial (Hyundai, n.d.b). Moreover, the Ioniq 5 is ready to use for V2L to power specific loads and appliances when going camping (Hyundai Motor Group, 2021a) which could be considered off-grid, however, this is only for V2L, and a tent is not an off-grid tiny house in the sense that it has its own PV panels. Concludingly, the survey responses and interview findings seem to be aligned with the available literature presented in the review and industry context. The final assessment leaves the off-grid V2X system technology readiness level to be at level 6.

Applying the MRL Scale on Empirical Findings

The first level on the MRL scale is when there is a hunch of a market need, and the MRL 2 is when market and products have been described (Vik, et al., 2021). Some interviewees agree that powering an off-grid tiny house through V2X is an interesting use case (Energy Policy Advisor, 2022; R&D Manager, 2022; R&D Portfolio Manager, 2022). An EV with V2X functionality could possibly make off-grid living easier (R&D Portfolio Manager, 2022) and off-grid living is today problematized by not having enough energy storage (Zheng & Wu, 2022; Svarc, 2022a). An increased energy storage system is needed to increase the independence level living off-grid to store the solar energy (Khalilpour & Vassallo, 2015) and this problem could be solved by connecting an EV with bidirectional functionality (Off-grid Living Expert, 2022). Based on this, MRL 1 and 2 is assessed to be reached, as a hunch of a market need and a technological solution been formulated (Vik, et al., 2021).

MRL 3 is when the market need and market supply has been explicated (Vik, et al., 2021). During the interviews, the demand for off-grid V2X technology was described as very niche (Charging Expert, 2022; Off-grid Living Expert, 2022; Professor within Geography, 2022), but a market that might grow (R&D Portfolio Manager, 2022). The bidirectional feature itself, is considered to be a "nice-to-have" feature and not a necessity (Charging Expert, 2022; Sustainability Expert, 2022). Moreover, another reason for the slow adoption of the V2X was explained by the EV market supply being in an early stage and is now starting to catch up and offer bidirectional functionality (Asset Manager, 2022), and in the near future most of the cars on the market will be EVs (Strategy Director, 2022). Several car manufacturers have stated that they will offer EVs with V2X functionality, if they do not already offer that today (Volkswagen Newsroom, 2021; Hager Group, n.d.; Press BMW Group, 2021; Tesla, n.d.; Polestar, 2021; Renault Group, 2019; Volvo Cars, 2021) and there are companies developing bidirectional EV chargers that also claim to work during a power outage (Wallbox, n.d.b; Sandberg, 2020). As for some of the OEMs that today offer V2X, they advertise their EVs in an off-grid setting, e.g. Hyundai Ioniq 5 is marketed in camping environment and Tesla Cybertruck is displayed by cooking food on a kitchen stove in the forest powered through the vehicle (Hyundai Motor Group, 2021a; Tesla, n.d.). Based on these findings, MRL 3 "market need and market supply are explicated" is assessed to be achieved as both the market need and supply have been formulated (Vik, et al., 2021). This is further supported by the survey, where the median readiness level was assessed to be at MRL 3.

For MRL 4 to be reached, the idea of using V2X in an off-grid setting needs to be confirmed by both customers and market actors (Vik, et al., 2021). One issue mentioned during the interviews is that the customers might not understand the value of an off-grid V2X system (Sustainability Expert, 2022; Technical Expert, 2022). The V2X technology can provide cost reductions to the user, as it is expensive to connect an off-grid house to the grid (Strategy Director, 2022; R&D Portfolio Manager, 2022) and the cost of installing a large home battery is deemed as high (Off-grid Living Expert, 2022).

Money and cost savings is a common incentive for individuals to test new innovations (R&D Portfolio Manager, 2022) but these must be explicated. One survey respondent commented that this system certainly could be an option among many options in the market for leisure dwellings but deem it to be a fringe phenomenon reserved for enthusiasts today as it must compete with more traditional second home options (Tourism Expert, 2022).

From the market actor perspective, the idea of off-grid V2X technologies has been confirmed by some market actors, for example Hyundai with the Ioniq 5 equipped with V2L (Hyundai, n.d.a). As highlighted in TRL, Hyundai has launched "Today's Office" where their EV model Ioniq 5 powers an off-grid cabin in Stockholm through V2L (Hyundai, n.d.b). This concept gained media coverage and is highlighted as an idea to connect the demand for remote working, creative workspaces and being close to nature (Rådlund, 2021; Todd, 2022; Karlberg, 2021). Today's Office can be viewed as a "small pilot campaign" since it was only created for one place, and one time. However, the Hyundai Ioniq is only V2L compatible and not V2H.

Moreover, the technology of adding bidirectional converters has not been difficult in the past 20 years, but the cost side and understanding why OEMs should carry these costs has been the restraining issue (R&D Manager, 2022), which could be a reason why not all OEMs offer this functionality and have tested it for off-grid living. In addition to this, a technical aspect that limits the market supply is battery degradation, which V2X contributes to and the battery warranty which is affected by this (Battery Expert, 2022; Energy Policy Advisor, 2022; Energy Management Expert, 2022). Today many OEMs provide a battery warranty that might need to be re-formulated when introducing bidirectional capabilities (R&D Portfolio Manager, 2022; Energy Management Expert, 2022). Based on these findings MRL 4: Is the market demand and the idea confirmed by customers and market actors, is partly fulfilled (Vik, et al., 2021). The innovation could enable cost savings, but interviewees believe customers today might not understand the value of off-grid V2X systems. Moreover, the innovation is confirmed by some car manufacturers, like Hyundai testing it in an off-grid setting. Several OEMs state that they will soon offer bidirectional functionality but have not confirmed an idea to use the EVs in an off-grid setting. Concludingly, MRL 3 is assessed to be fulfilled, which is aligned with the survey respondent's assessment.

Applying the RRL Scale on Empirical Findings

RRL 1 regards if the legal and/or regulatory aspects of the technology is unpredictable or unknown and RRL 2 regards if the use of production will require changes of law (Vik, et al., 2021). During the interviews, many experts highlighted that powering an off-grid tiny house with an EV does not require any additional legal requirements (Sustainability Expert, 2022; R&D Manager, 2022; R&D Portfolio Manager, 2022; Energy Expert, 2022). However, there are still many existing electrical safety requirements that need to be fulfilled (Researcher E-Mobility, 2022; Technical Expert, 2022; Energy

Expert, 2022; Regulatory Advisor, 2022). Hence RRL 1 and RRL 2 can be considered achieved as the regulatory aspects are not unknown and legal changes are not estimated to be needed (Vik, et al., 2021) to set up the off-grid V2X system.

Similarly, RRL 3 investigates if the technology requires regulatory change, and as presented during interviews the difficult aspect is getting the home disconnected from the grid, but with a home already disconnected there are no regulatory constraints (Energy Management Expert, 2022). An Energy Policy Advisor (2022) also expected the system to be doable, as it is off-grid. Hence RRL 3 is also considered achieved. This is also supported by literature as it is feasible to disconnect from the grid and set up an off-grid energy system for your own home (Energimarknadsinspektionen, 2017), and there are no regulatory barriers to transport the electricity by charging the EV in one place, and then discharge the electricity to another property or location (Power Circle, 2020). Many interviewees commented on the safety regulations still needing to be fulfilled and a fire fighter needs to understand how to turn off the power (Energy Expert, 2022; Regulatory Advisor, 2022). For the system to be safe, the generator needs a capacity as high as the demand from the loads, or a control system that can connect and disconnect the loads (Researcher E-Mobility, 2022). The electrical installation still needs to fulfil the electricity safety regulations which could be complex to understand as it is unclear which rules are required for it to be safe (Regulatory Advisor, 2022; Researcher E-Mobility, 2022). This is however mentioned as a barrier that likely could be solved by hiring an electrician to do the installation (Regulatory Advisor, 2022).

RRL 4 assess if the innovation needs demanding permissions or approvals to be performed and RRL 5 assess if the use or production will presuppose accessible permission or approvals (Vik, et al., 2021). During the interviews it was highlighted that many car manufacturers are awaiting the approval and release of ISO 15118-20 (Energy Expert, 2022). This standard ISO 15118-20 is under development as a European standard (Charging Expert, 2022; Technical Expert, 2022; Strategy Director, 2022). ISO 15118 is a part of the CCS system, and ISO are developing this updated communications protocol to support bidirectional energy transfer (Mültin, 2021). This is supported by the survey which assessed the RRL to be at a median level 5. One respondent assessed RRL to be at a 4, and one person assessed the RRL to be at level 6. For an innovation to be at RRL 6, these approvals need to be likely, and for RRL 7 the approval should be close to being given (Vik, et al., 2021). This standard was considered soon to be published (Energy Expert, 2022) at the time when interviews were held, and in April 2022 the standard was published (ISO, 2022). Hence, this level can be considered achieved. This ISO approval is not relevant for Asian OEMs following the CHAdeMO standard already offering the bidirectional functionality (Battery Expert, 2022; Researcher E-Mobility, 2022) which also can be seen in the EV models with bidirectional functionality being available on the market today (Hyundai, n.d.a; Kia, n.d.; Mitsubishi Motors, 2021b). There are several different standards on the market today and the market is expected to move towards increased standardization and for V2X to reach mass scale, standardization is needed (Battery Expert, 2022).

Continuing to RRL 8 and RRL 9, the innovation needs to fulfil general conditions and the use and production should be regulatory unproblematic (Vik, et al., 2021). Many interviewees mentioned that to power an off-grid home with V2X is unproblematic and no permissions are needed to set up the system (Sustainability Expert, 2022; Regulatory Advisor, 2022). Hence, RRL 9 can be considered achieved. This is also supported by the "Today's office" project, as Hyundai already has been able to conduct a trial with an off-grid office being powered by V2L as presented in the technology and market readiness assessment above. The two respondents who assessed RRL estimated the innovation to be at a RRL 4 and RRL 6 is lower than the interviewees claiming that the innovation is regulatory unproblematic. This could likely be due to the then waiting process for the ISO standard mentioned above, as the standards are different depending on OEM and country. However, given the large number of interviewees who said that the innovation is doable and unproblematic (Sustainability Expert, 2022; Energy Policy Advisor, 2022; Energy Expert, 2022; Energy Management Expert, 2022) from a regulatory point of view and the fact that Hyundai has tried it in Sweden leads to the conclusion that the innovation has reached RRL 9. Concludingly, it is regulatory unproblematic as long as safety regulations are followed.

Summary of Innovation Readiness Assessment

Concludingly, the off-grid V2X innovation is assessed to have reached TRL 6, MRL 3 and RRL 9. This means that the market is the biggest laggard for deployment of the innovation followed by the technical aspect. From a regulatory perspective, it is regulatory unproblematic to connect the EV to the off-grid home to supply power, as long as safety regulations are followed. For the market to reach a higher level, customers, and market actors both need to confirm the innovation's benefits and opportunities and a business model needs to be described in the off-grid setting. This cannot be done until TRL 9 has been reached, i.e., the technology is fully developed and ready to use in the off-grid setting and the home technology readiness is tested. Both the mobility side of the system and the house infrastructure, need to be ready and have compatible communication and charging standards tested in an off-grid setting. If there is a strong customer demand for the off-grid V2X solution, the development process might accelerate and gain momentum. As one interviewee neatly highlighted:

The market is less ready than technology and the key is standardization of equipment -
(Regulatory Advisor, 2022)

5.2.2 Diffusion of Innovation

In this chapter, attributes of the innovation are analyzed based on the Diffusion of Innovation theory. The analysis is made based on findings from interviews to understand the what the potential adoption for the off-grid V2X system could be.

Attributes of Innovation

Relative advantage

To understand the potential future rate of adoption for an off-grid home powered by an EV, the relative advantage attribute of the innovation is examined. Relative advantage is the degree to which the innovation is perceived as better compared to previous ideas and options (Rogers, 1983). Firstly, the EV with bidirectional functionality is seen to possibly make off-grid living easier compared to owning a traditional fossil-fuel car (R&D Portfolio Manager, 2022). One advantage with the EV, compared to home station batteries, is that the EV is mobile, and can be charged in one place and discharged in another place i.e., the off-grid home (Charging Expert, 2022). This is also supported by Al-Muhaini (2020) who found that one of the main benefits of using an EV as an energy storage is the mobility aspect of the car. The EV can also increase the value of off-grid living to make the homeowners less dependent on their self-produced electricity, but the energy storage needs to correspond to what the PVs are incapable of producing during nighttime for it to be valuable (Sustainability Expert, 2022). However, this depends upon how willing the EV owner is to use, or lend out, the energy stored in the EV to provide electricity at the cost of shortening the battery life (Energy Policy Advisor, 2022). Hence, the EVs relative advantage compared to only having home batteries is that the EV is mobile.

Moreover, as highlighted by an Off-grid Living Expert (2022), tiny homes with a base consumption of 100 W per hour can have home batteries in the range of 2.4-3 kWh to suffice off-grid living from early spring to mid fall. As EV's have an average capacity of 60 kWh (Electric Vehicle Database, n.d.), these batteries have a much higher battery capacity compared to the home batteries which also could be considered a relative advantage.

Another relative advantage is that using the EV to power an off-grid home is likely to be cheaper than connecting the off-grid home to the main grid. In Sweden, it could be expensive to connect an off-grid home to the main grid as it depends to the proximity to the connection point (Strategy Director, 2022; R&D Portfolio Manager, 2022). Another possible relative advantage is that the EV can be charged with green electricity compared to the backup generators driven by liquefied petroleum gas or gasoline which are often used today when the PVs do not generate enough electricity and the battery has run out (Off-grid Living Expert, 2022; Elazab, et al., 2021). A study showed potential for using the EV as an electricity storage solution for households equipped with PV panels (Gudmunds, et al., 2020). Utilizing the already existing EV battery for multiple use cases i.e., transportation and energy storage for the home, can also be seen as more energy efficient and environmentally friendly.

Compatibility

The compatibility factor is another attribute of innovation and explores how aligned the innovation is perceived to be compared to previous values, past experiences, and needs. An innovation that is not aligned with previous norms and values will not be adopted as quickly (Rogers, 1983). As one of the interviewees mentioned, there has been an upgrade of the standard of holiday homes and now there is value in having the same amenities in the holiday home as in the primary home. This might not be compatible with living off-grid in a tiny house (Postdoc within Geography and Tourism, 2022). An EV could provide a large energy capacity, on average 60 kWh to as much as 108 kWh depending on model (Electric Vehicle Database, n.d.) and hence more amenities could technically be possible to run if the house is coupled with a V2X EV compared to a house without the EV. In other words, the norm of having a high standard of living even in second homes could be compatible with off-grid V2X living. The expectation of cabins to have high standard requirements coming from the residents is also aligned with the comment from the Off-grid Living Expert (2022); as their cabins also aim to supply all amenities and comfort needed.

The growing number of EVs and the increasing rate of EV adoption (COP26, n.d.; IEA, 2021) as well as the increasing number of EVs with bidirectional functionality (Ford, n.d.b; Hyundai Motor Group, 2021a; Nissan Motor Corporation, n.d.) could possibly increase the compatibility with previous norms and past experiences. The slow adoption of V2X is seen to be due to the EV market still being in an early stage (Asset Manager, 2022). The market is now starting to catch up and offer the bidirectional charging functionality (Asset Manager, 2022). In the future, EVs are expected to be the most common type of car on the market (Strategy Director, 2022) and when EVs become the norm, using the EV to power the off-grid home could likely be perceived as less revolutionary if people have seen the V2X technology being used to power other loads and homes earlier.

Another aspect of the off-grid V2X system is the needed change in human behavior. To power the home with an EV, the users need to always connect the EV through the charging port when arriving to the house or cabin which might not be compatible with their current behavior today (Strategy Director, 2022). Today people only plugin the EV to the charger port when needing to charge the EV, but for V2X it needs to be plugged in constantly (Strategy Director, 2022).

Another factor affecting the compatibility to previous values relates to the range anxiety. Today many EV drivers struggle with the fear of running out of electricity (Battery Expert, 2022). There could be a fear of not being able to reach the intended target due to lack of charging infrastructure (Insight Manager, 2022). Hence, the perceived value of having electricity in the EV could be higher than its value in the home (R&D Manager, 2022); which makes the concept of using the EV to power off-grid homes less compatible with these previous values. Mehrjerdi (2021) made a model aiming to avoid the fear of running out of energy where the solution was V2H with battery swapping. On the other hand, the EV can be charged for free during summer when there is excess electricity being generated from the PV panels (Tiny House Manufacturer, 2022) which also decreases the risk of running out of energy.

Complexity

The complexity aspect describes how difficult the innovation is to grasp and use. If the innovation can be easily understood by the users, it is then expected to be adopted faster (Rogers, 1983). To set up the off-grid system with connection to the EV can be complex as the power sources must create frequency and voltage itself with required power quality, and the power source must be strong enough to deliver to all loads and for safety systems to function (Researcher E-Mobility, 2022). There are, as well, some complexities regarding all the components to be used in the off-grid system. There are probably some suppliers that can supply all relevant components, but they might not be compatible with all the EVs (Regulatory Advisor, 2022). Furthermore, the EV battery is not optimal to power a home, and much will be required from the house infrastructure (Battery Expert, 2022).

One interviewee also highlighted that one of the reasons as to why the off-grid V2X solution would be considered most applicable for individual usage is because a community solution would be too complicated (Energy Policy Advisor, 2022). Hence, complexity is an important factor for the adoption applicability. Moreover, when using the bidirectional functionality of the EV it becomes even more important for the user to understand the battery health, or state of health, which can increase the complexity of using the V2X functionality (Charging Expert, 2022). However, if the user is knowledgeable of how the battery works, it can be cycled it in a gentle way (Energy Management Expert, 2022). This type of complexity and technical parameters must hence be understood by the user.

Moreover, what decreases the complexity of the innovation is that it seems regulatory unproblematic, and no permissions are needed to set up the system (Regulatory Advisor, 2022; Sustainability Expert, 2022; Wahlström, n.d.). However, the electrical installation still needs to fulfil the electricity safety regulations, which might be complex to understand as it is unclear which rules are required for it to be safe (Regulatory Advisor, 2022; Researcher E-Mobility, 2022). This can, however, likely be solved by hiring an electrician to do the installation (Regulatory Advisor, 2022). A professional installer needs to do the installation even if the house is off-grid to be able to take safety regulations into consideration (Elsäkerhetsverket, 2021)

Trialability

Trialability refers to the degree to which the innovation can be tried on a limited basis, e.g., if the user is given a trial before committing fully it could increase the adoption rate of the innovation (Rogers, 1983). For the innovation of using the EV to power an off-grid home, the trialability is seemingly low as the solution also will require a lot from the home infrastructure (Battery Expert, 2022). To purchase an EV with bidirectional capabilities, the EV charger, a home battery, a HEMS, and smart inverter are hence many investments, which lowers the ease of trialability. Moreover, one interviewee mentioned that it needs to be easy to go off-grid and all prerequisites for a comfortable life and EV charging needs to be in place for it to be interesting for people, which today is not the case (Senior Analyst, 2022).

What could ease the trialability of the system is the increase in adoption of EVs (Strategy Director, 2022; Sustainability Expert, 2022) and that more EV manufactures are exploring V2X or will offer the bidirectional functionality in the future (Volkswagen Newsroom, 2021; Hager Group, n.d.; Press BMW Group, 2021; Tesla, n.d.; Polestar, 2021; Renault Group, 2019; Volvo Cars, 2021) in addition to the car manufactures that already offer that functionality today (Hyundai, n.d.a; MG Motor, n.d.; Kia, n.d.; Genesis, n.d.). If the user is equipped with a car with bidirectional functionality, the only aspect missing to try the innovation is an off-grid house equipped with a HEMS system and/or smart inverter.

Trialability is perceived as more important to early adopters than late adopters as the more innovative individual have no precedent to follow when they adapt the innovation (Rogers, 1983). Given the novelty of the innovation the adopters will be in the early adoption span, from innovators to early majority. This means that the trialability of the off-grid V2X technology will be of importance before an individual adopts the innovation. Therefore, this poses as a barrier for adoption since the trialability is deemed to be quite low due to the high investments cost, unless the individual is already equipped with an EV with bidirectional functionality.

Observability

Observability is the last attribute of innovation. Observability describes how visible the result of an innovation is to be observed by others. If people can see that the innovation creates value for others, it is more likely to be adopted (Rogers, 1983). The EV is expected to be capable of also drawing energy from the home when the PV has generated excess electricity (Tiny House Manufacturer, 2022). Money and cost savings is also a common incentive for people to try new innovations (R&D Portfolio Manager, 2022) and the solution could be more interesting if the user could get lower energy costs (Strategy Director, 2022). Hence, hearing about a neighbor charging their EV for free using their solar panels could possibly increase observability of the value of this solution. However, as highlighted under "complexity", the system itself is quite complex which lowers the observability of the results.

Understanding the value of the V2X system could hence be a pedagogical challenge (Sustainability Expert, 2022).

A factor decreasing the observability is also that the off-grid V2X solution is expected to be most applicable in an individual setting, i.e., each resident has their own EV, see figure 16. Interviewees expected people to want a convenient lifestyle and tend to use more individual solutions (Postdoc within Geography and Tourism, 2022). Moreover, if people are part of a community, they might lose the feeling of being alone and having their private space in nature (Insight Manager, 2022) and Sweden is seen as an individualistic country (Battery Expert, 2022). Hence, the off-grid V2X solution might be most relevant for a remote place in nature, making it more difficult to observe what neighbors are doing.

Summary of Diffusion of Innovation Analysis

To summarize, the V2X off-grid solution offers relative advantages as it is mobile compared to a home battery allowing it to be charged in one place and discharged at the home. Thereto, the EV battery offers a larger storing capacity compared to traditional home batteries which increase the flexibility as the household becomes less dependent on the self-produced renewable energy. The household could also avoid the cost of connecting the home to the main grid which makes the V2X solution a cheaper option. However, the innovation also poses a risk of battery degradation. Thereto, the EV can be charged with green electricity making it more environmentally friendly compared to fossil fuel driven generators. Compatibility wise, the innovation can allow for an increased standard of off-grid living compatible with the demand from Swedish second home buyers as more energy storage and supply is available for use. However, the innovation might not be compatible with previous norms as the user always needs to connect the EV to the home, to ensure it is available for charging and discharging; today EV owners normally only plugin the EV when they need to charge it. Range anxiety might also lower the adoption rate as people could be worried that there will not be enough energy left to leave the tiny house.

From a complexity perspective, the innovation could be considered complex as several system components are needed and the safety regulations need to be followed. The trialability is seemingly low as many investments need to be made before the solution can be tried. Observability wise, the user is likely to be able to observe the value that the solution could offer as it allows for cheap charging by charging the EV with excess solar energy. Overall, the attributes of innovation that likely would increase adoption rate are its many relative advantages and ease of observability, and the attributes that would likely lower the adoption rate are the low compatibility with previous norms, high complexity and low trialability.

6. Case Study

This chapter presents the second part of this thesis, the case study, which aims to assess the second layer of the problem represented by RQ2 "Can V2X help prolong the season for tiny house off-grid living by reducing the energy imbalance?". In this chapter, firstly, the model and the results from the is presented. Secondly, the model results are analyzed in relation to RQ2.

6.1 Results from Model

6.1.1 The Model of an Off-grid V2X System

The case study resulted in the Stella model below and is based on the principles of system dynamics to understand the feasibility of off-grid housing powered by PV panels, a home battery, and an EV. The model has five main sections color-coded below: orange is sun energy input, green is the home station-based battery, red is the powering of home loads, purple is the EV charging and discharging and lastly pink is the charging of the EV made at an external charging point. In addition to these five parts, the grey part represents the excess energy i.e., the energy that cannot fit in the battery or the EV.

The model aims to illustrate the energy balance of the off-grid system. Hence, only energy flow is modeled. The energy flows through the tubes per hour over a full year. The squares represent stocks that can accumulate and save energy until needed. The circular icons are converters with data inputs as well as equations and conditional functions. The arrows are connectors with information communicating with the converters and stocks. The model logic and model building are explained in the "Method" chapter. The solar energy is added as an input in the orange part of the model, this then flows into the excess energy control which checks if there is available storage in the home battery based on the battery threshold represented in green. The energy then flows to supply the red component being the home loads. The purple flows represent the energy provided by the EV if needed as presented in the conceptual model, the EV is only used for discharging if the solar energy and home battery storage is not enough to supply the home loads. The pink part represents the energy coming from the external charging point. If the orange excess energy control saw that the home battery is full, the excess energy flows to charge the EV. When the EV is fully charged, the excess energy leaves the system in the grey part being the energy that cannot fit in the EV nor the battery.

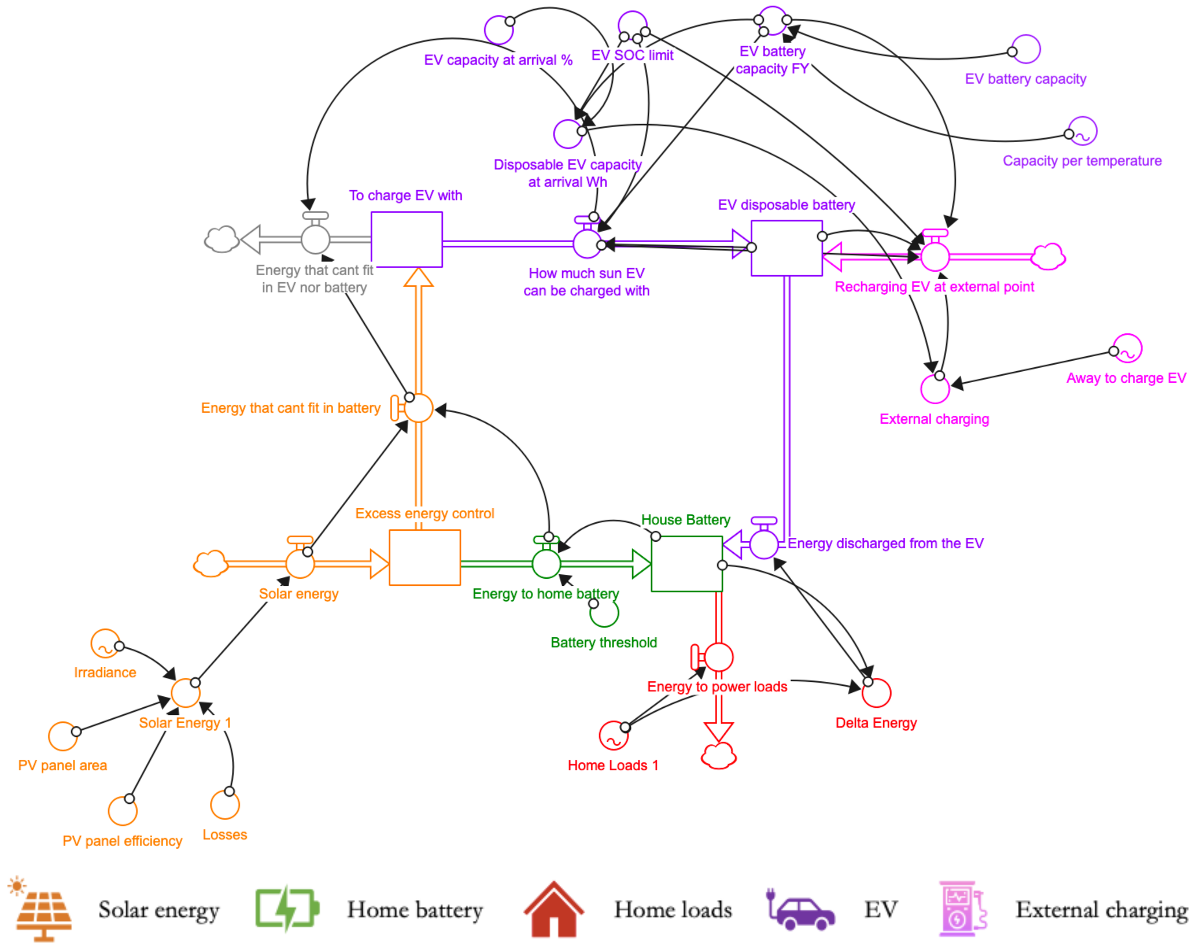

Figure 17 Final model built in Stella for case study

The model was further altered depending on the scenario analyzed. Scenario 0, baseline scenario, has no EV, and this scenario aims to replicate the reality of the case study partner today with an off-grid tiny house powered by PV panels and the excess energy is stored in a home battery i.e., orange, green and red module. Scenario 1 is the same as scenario 0, but also has an EV with V2X functionality, as represented in purple module. In scenario 1, the EV is never charged at an external charging point and is instead only charged by the PV panels after arriving at the tiny house. Scenario 2 is the same as scenario 1 but with the possibility to charge the EV at an external charging point, as represented in pink module. In this scenario, the EV is charged at an external charging point every other week during spring, fall and winter. Similarly, scenario 3 has an EV that is charged at an external charging point but more frequently: once per week during spring, fall and winter. Below is a table summarizing the scenarios and a figure with pictures of all four scenarios in the model.

Table 11 Overview of all scenarios tested

Scenario	Definition
Scenario 0	System has no EV - trying to simulate baseline today
Scenario 1	System has EV but is never recharged at an external charging point
Scenario 2	System has EV and bi-weekly charging at external charging point
Scenario 3	System has EV and weekly charging at external charging point

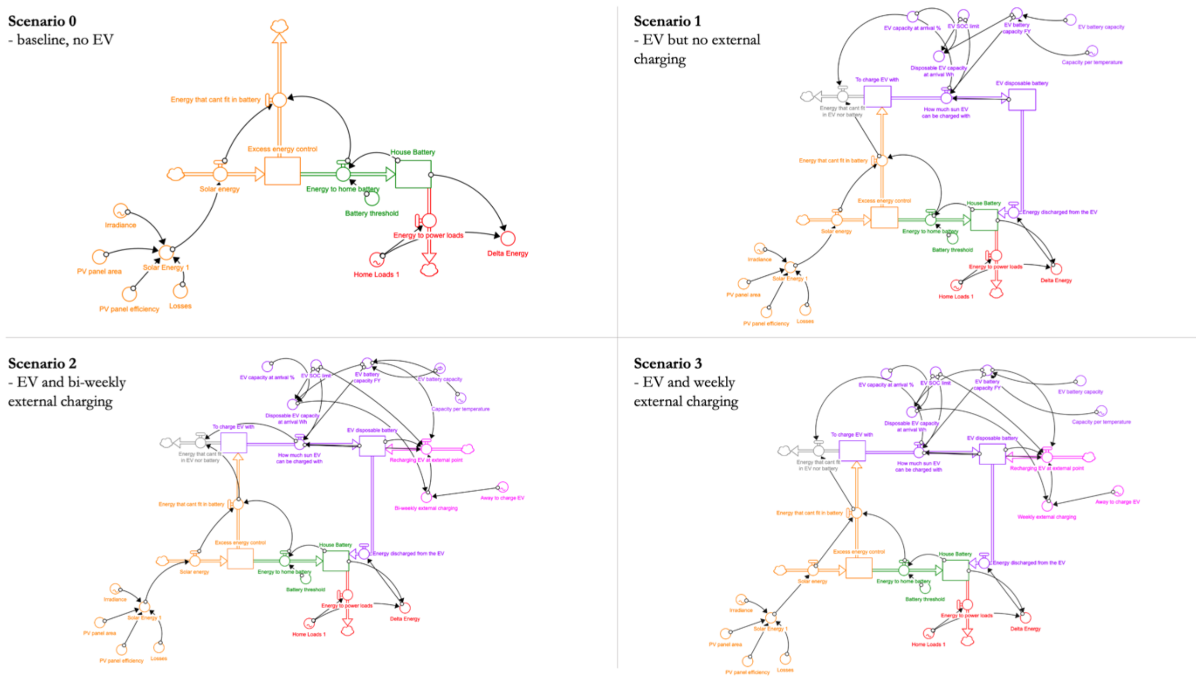

Figure 18 Visualization of all four scenarios

6.1.2 Model Output

Part 1 – Energy Shortage

The figures below illustrate how the energy balance changes in the four scenarios and are further quantified in the following table. The energy balance test is the difference between the home loads and the energy from PV panels, home battery, and EV battery. When the energy balance test is negative, there is an energy shortage. The colored vertical lines in the graph hence illustrate when there is an energy imbalance. When there is no energy shortage, the energy system is considered at balance and self-sufficient.

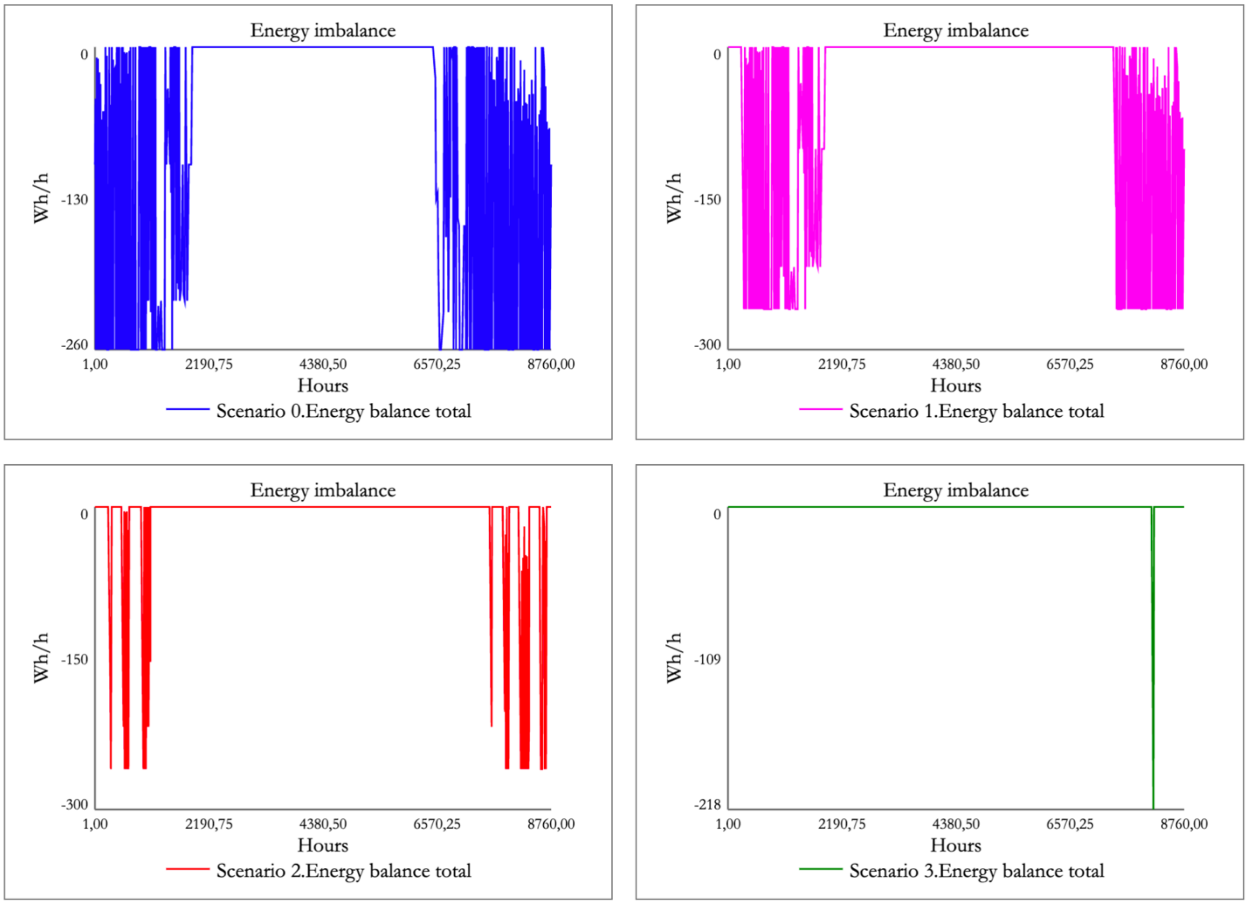

Figure 19 Energy imbalance for the four scenarios

Table 12 Overview of energy balance for the four scenarios

	Scenario 0	**Scenario 1**	**Scenario 2**	**Scenario 3**
Hours with balance	5598	6437	8156	8751
Days with balance	233	268	340	365*
Extra days with balance compared to scenario 0	N/A	35	107	131
Balance from	19-Mar	19-Mar	14-Feb	01-Jan
Balance to	02-Oct	07-Nov	14-Nov	31-Dec*

** There are nine hours with energy imbalance during 7 of Dec*

Part 2 – Excess Energy

Moreover, the excess energy that goes to waste is examined for all scenarios. Figure 20 below illustrates energy stored in the home battery and how it is charged and discharged. During spring, summer and fall the home battery reaches its full capacity, 3 kWh, but is discharged during the night which is illustrated in the graph by the energy level varies from 3 kWh down to approximately 1.5 kWh. When the home battery is full, the energy goes to charge the EV in the scenarios where an EV is included i.e., scenario 1-3. However, in scenario 0 there is no EV meaning that when the home battery is full, the excess energy that has been generated by the PV panels goes to waste. The energy stored in the EV is illustrated in figure 21. In scenario 2 and 3 the EV is charged at an external charging station, and this can be seen in the graph by the spike turns in the beginning and at the end of the year. Further, it can be seen that the EV is fully charged after the home battery has been fully charged, this can be seen by the horizontal line in figure 21. In scenario 1-3 the excess energy is the energy that cannot be stored in the home battery nor the EV at the hours when both batteries are full.

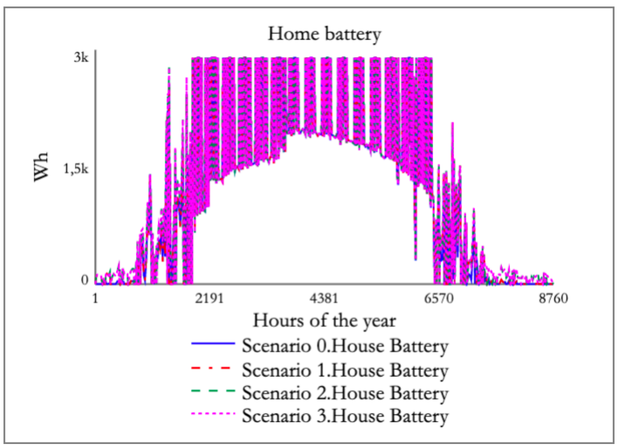

Figure 20 Energy in home battery

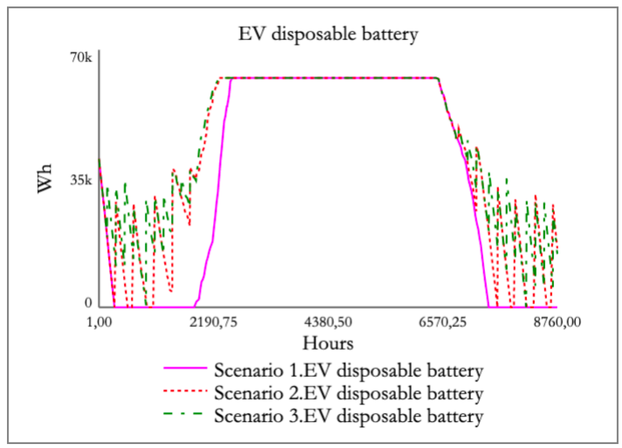

Figure 21 Energy that can be discharged from the EV

How much energy that is discharged from the EV to help power the loads is visualized in figure 22. As it can be seen, the EV is needed during the winter, early spring, and late fall, when the generated solar energy is not sufficient to supply all the home loads. Moreover, the excess energy that cannot be stored in either the EV or the home battery is visualized below in figure 23. Results show that the excess energy decreases in scenarios 1-3 with an EV since the EV can be charged with the energy that does not fit in the battery.

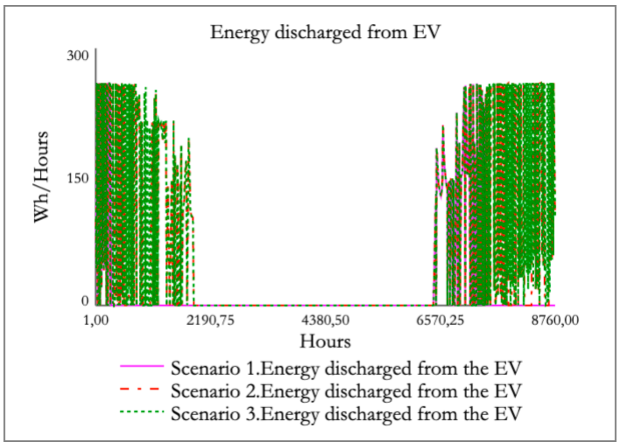

Figure 23 Energy discharged from the EV

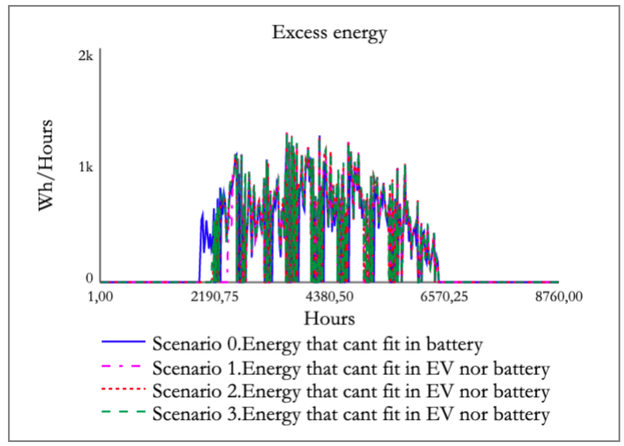

Figure 22 Excess energy

Below is a table summarizing the excess energy over the full year. The results show that there is less energy going to waste if there is an EV also part of the system, i.e., in scenario 1-3.

Table 13 Overview of energy to charge EV with and excess energy

	Scenario 0	**Scenario 1**	**Scenario 2**	**Scenario 3**
Energy to charge EV with [kWh over 1 year]	N/A	63	25	23
Excess energy that cannot fit in EV nor home battery [kWh over 1 year]	805	742	780	782

6.2 Analysis of Model Results

6.2.1 Prolonging the Season by Discharging the EV

When analyzing the results, it can be seen in figure 19 that there is an energy shortage in the beginning of the year and at the end of the year in the baseline scenario, scenario 0. The total number of days with energy balance in this scenario is 233 days, and the dates when it is possible to live off-grid for consecutive days is from the 19th of March to the 2nd of October. In scenario 1, the energy imbalance occurs less frequently which is illustrated in figure 19 as there are fewer hours with a negative value.

Furthermore, in scenario 1 there is energy balance in the beginning of the year, compared to scenario 0, and this is because the energy in the EV battery helps to achieve energy balance corresponding to 12 days. After 12 days, the EV battery is emptied and energy imbalance occurs again, until solar energy produces sufficient energy. In this scenario, the season is also prolonged since the EV battery can store the excess produced energy, and the imbalance occurs later in the year compared to scenario 0. Energy balance is achieved for a total of 268 days. The season where consecutive off-grid living is feasible starts at the same day as scenario 0; 19th of Mars, if not taking into consideration the extra 12 days that EV contributes with at the beginning of the season, and the season ends 7th of November. In other words, the season is prolonged by more than one month.

In scenario 2, it can be seen in figure 19 that the energy imbalance is less than in scenario 0 and 1. This is because the EV is being recharged every other week. In scenario 2, energy balance is achieved for 340 days in a year, and the consecutive off-grid living season is from 14th of February to 14th of November, two months longer than scenario 0. Lastly, in scenario 3, energy balance is almost achieved throughout the year. There are only nine hours of energy imbalance on the 7th of December occurring during the night and early morning. If these nine hours are excluded, the season for off-grid living is applicable from 1st of January to 31st of December.

Overall, the results show that an EV can successfully prolong the season for living off-grid. Even if all three scenarios can prolong the season, scenario 3 is the only scenario that can enable year-around off-grid living, with an exemption for nine hours. However, this is at the cost of charging the car once every week at a charging station during winter, spring, and fall. With bi-weekly charging, off-grid living is accessible between 14th of February to 14th of November for consecutive days. It is possible to stay off-grid before the 14th of February, but not for several days in a row.

Furthermore, scenario 1 prolongs the season without the need to recharge the EV during the stay. As the results presented above, the season is prolonged by two months and when arriving at the cabin during the winter, the EV can supply the cabin with energy for up to 12 days. Combining these two, and if the user is to arrive in spring, instead of 1st of January, the season could probably be prolonged even more as the temperature is not as cold and hence does not negatively affect the battery capacity as much. Winter is the most challenging period since the temperature is low and hence affects how much the EV can store and discharge from the battery.

6.2.2 Utilizing Excess Energy by Charging the EV

Moreover, when analyzing the results from an energy excess perspective results show that the home battery is filled equally fast in all four scenarios, visualized in figure 20. This can be explained by the home load demand being the same in all four scenarios, and the home battery is always filled before the EV is charged with the excess solar. Therefore, the home battery is filled in the same way and time in all scenarios. Hence, the graph displaying the home battery looks the same for all scenarios and the home battery reaches its maximum capacity in all scenarios. In the period where the battery reaches its full capacity, it is still being discharged during the night when there is no solar energy to supply the loads. Which is why the battery varies between 1.5 kWh to 3 kWh during the months with excess solar energy.

Furthermore, results show that the EV disposable battery, shown in figure 21, is the highest in scenario 3 since it is charged at an external charging point once per week during spring, fall and winter, meaning that its state of charge is often higher than in scenario 1 and 2. The reoccurring charging schedule in scenario 2 and 3 explains the quick turns in EV disposable energy for these scenarios. In scenario 1, the EV disposable battery is equal to the state of charge when arriving to the cabin day 1 and then reaches 0 as the EV disposable battery share has been used to supply the loads on day 12. Thereafter, the EV reaches its maximum disposable capacity when spring arrives, and the sun irradiance increases. This graph shows that the EV disposable energy is the highest in scenario 3, which is reasonable as it is charged most frequently in this scenario leaving more energy to be available in the system and can be used to supply the home loads.

Moreover, the excess energy that cannot fit in the home battery is used to charge the EV. Results show that less energy can be used to charge the EV in scenario 2 and 3 compared to scenario 1. This is because the EV is charged at an external charging point, hence have a higher EV disposable battery level in these scenarios.

The excess energy is less in the scenarios with an EV, since in these scenarios, the EV can capture the excess solar energy, shown in figure 23. This can be seen as an answer to the research question RQ2, where the EV can be used to reduce energy imbalance. During summer months, the EV can be charged to its maximum capacity, shown in figure 21. As early as April, there is excess energy available in the residential energy system allowing the EV to be charged. The EV can be charged with 63 kWh in total over the year in scenario 1, and 25 kWh versus 23 kWh in total in scenario 2 and 3. This can be considered as quite low, but what explains the results is that the maximum capacity the EV can be charged with is 62.4 kWh, taking into consideration the 20 % that is never recharged from the vehicle. In scenario 2 and 3 the vehicle is recharged at an external charging station, and the battery is hence not emptied as in scenario 1 and can thus be charged with less energy. Moreover, in the model the EV is never used in the sense of transportation and if the vehicle were used more frequently to travel during the months with excess energy, a higher share of the excess energy could be utilized. However, this can be considered valuable for the household as it otherwise would have gone to waste, and now can be used for charging the EV.

When comparing the excess energy to the energy that can be used to charge the EV visualized in table 13, the EV charging might be interpreted as a small amount of energy. The results are however reasonable as during summertime the load consumption is lower, meaning that the EV is not needed for discharging which in turn means that it does not need to be charged by the EV as frequently. The amount that can be used to charge the EV is dependent on the maximum battery capacity of the EV, as it cannot be charged once the battery is full.

7. Discussion

In this chapter the results and analysis from the general study and case study are discussed. Initially, the results are discussed separately to then be discussed collectively to understand the implications. Further, this chapter discusses the thesis' sustainability and SDG alignment. Lastly, the limitations of this study are discussed.

The aim of this thesis was to explore the innovation of using an EV to power an off-grid home. The first layer of the problem was that there is not much academic research on using the vehicle to anything (V2X) technology in an off-grid setting. The second layer of the problem is that there is an energy imbalance when living off-grid today. The hypothesis was that an EV could reduce the energy imbalance by discharging energy to the home when there is an energy shortage and by charging the EV when there is an energy surplus. Hence, the main research question was "Can off-grid living in a tiny house supported by Vehicle to Anything (V2X) become self-sufficient on energy and what are the prerequisites for usage?". The thesis was divided into two main studies; firstly, a general study based on interviews with experts and a complementing survey, and secondly a case study with an off-grid stay provider.

7.1 General Study

Starting at the general study, which relates to the first layer of the problem represented by research question *RQ1: How ready is the V2X technology to power an off-grid home and what could affect potential adoption?*. This question was analyzed by applying the Innovation Readiness Framework (IRF), and part of the Diffusion of Innovation theory (DOI). As presented under the analysis section, the V2X technology in an off-grid cabin is regulatory unproblematic and the technology is more ready than the market summarized as TRL 6, MRL 3 and RRL 9. For the innovation to reach a higher readiness level the technology needs to be tested, validated, and optimized in its natural environment. Furthermore, for the market to reach a higher readiness level the customer and market actors need to confirm the innovation's benefits and opportunities and a business model needs to be described.

Moreover, the MRL is dependent on the TRL, as market level 6 "Products are being launched in limited scope" or higher likely cannot be reached until the technology has been proven functional, i.e., TRL 9 "Actual system proven functional in natural environment" is achieved. This means that the market readiness will be lower than the technology readiness until TRL 9 has been reached allowing for the innovation to reach the market. However, market demand for this technology could increase the speed at which the technology is developed and deployed. Moreover, "the market is less ready than technology and the key is a standardization of equipment" highlighted by a Regulatory Advisor, could imply that when the new ISO is adapted, both the technology readiness and the market readiness will increase.

Compared with other studies' assessments made, the *on-grid* scenario for V2X is considered to be at the highest TRL range already (Mazur, et al., 2019). Similarly, Meyers et al. (2022) found that V2H for the on-grid scenario providing backup power during a power outage is commercially ready to reach a TRL 9. However, for the fully off-grid scenario, the testing of the technology and the housing infrastructure needed has to our knowledge not been tested outside of Hyundai's trial earlier mentioned but for V2L and without PV panels (Hyundai, n.d.a). Hence, the results of assessing the readiness for the off-grid scenario at TRL 6, slightly lower than the commercial on-grid scenario, is considered reasonable.

Furthermore, as part of the general study, factors affecting potential adoption were examined. Most interviewees believed that the solution would be most applicable for short-term stays, i.e., a few days up to a week, and for individual usage. Attributes likely increasing adoption rate is the relative advantage of the EV being mobile and has larger storage compared to a home battery and increases flexibility. Hence making the home less dependent on self-produced electricity. Moreover, the homeowner could avoid the costs of connecting to the main grid. The homeowner could also observe the benefits of charging the EV with free excess electricity. However, there is a risk for increased battery degradation, and always plugging in the EV to the charger might not be compatible with previous norms and behaviors. Range anxiety might also lower the adoption rate and setting up the off-grid V2X system might be considered complex. There is also low trialability as several home and EV components need to be purchased. In other words, the attributes of innovation that likely would increase the adoption rate are the relative advantages an EV brings and the possibility to observe the value offering. Barriers for adoption are the low trialability, high complexity and low compatibility to previous norms.

Moreover, derived from the analysis chapter, potential adopters can be discussed. Four themes were identified as (1) de-urbanization and remote working, (2) growing interest and prices for second homes, (3) proximity to nature, relaxation and independence and (4) environmental trends. Important to mention is that the innovation is novel and has not entered the market. This implies that the first adopters would be the innovators, characterized by people actively seeking out new information (Rogers, 1983). Further, Noel et al. (2019) found that the adoption attributes for V2G are multidimensional and span over several characteristics and lifestyles. This could mean that there is more than one potential adopter category for the off-grid V2X use case as well, which makes it interesting to discuss several potential adopter categories.

During the interviews it was seen that off-grid V2X systems might be interesting and relevant in time of crisis and appeal to individuals that want to be independent of the grid. This is further supported by literature that found that the motivation for individuals to live off-grid is the value of self-sufficiency, adaptability, resilience, desire for freedom and safety in case of long-term grid outage

Vannini & Taggart, 2013; Bergkvist & Hermansson, 2019; Yttergren, 2021). Hence, these drivers could be argued to lay basis for a one potential adopter group to be "independence seekers".

Another perspective for potential adopters is individuals with demanding jobs that need a break from their everyday life. It was mentioned during interviews that the target group for off-grid living powered through V2X likely would be younger, purpose driven, and sustainability mindful individuals that are making active choices of their lifestyle and consumption. These individuals are often high-income earners and can thus go off-grid with an EV. One motivation for wanting to live off-grid, mentioned during interviews, is to get a break from everyday life. Relaxation is seen as an important reason for traveling to experience nature (Visit Sweden, 2021). Moreover, the trend of workcations has also been growing (Visit Sweden, 2021) as well as deurbanization trend catalyzed by the work from home trend mentioned during interviews. Hence, this type of early adopter could be summarized as "urban people" who want a break from everyday life and also a place to work undisturbed.

Moreover, another group of potential adopters could be environmentally aware people. In the thesis, the trend of downshifting has been mentioned which is supported by literature as well, where individuals that live off-grid were found to value sustainability and ethical consumption (Vannini & Taggart, 2013), and tiny house owners also tend to advocate for minimizing possessions (Wilson & Boehland, 2008; Carlin, 2014). Furthermore, a trend for Swedish domestic tourism is taking environmental considerations into account when choosing holiday destinations (Visit Sweden, 2021). Moreover, using the EV for not only transportation, but also for providing and storing energy could be seen as resource efficient. This, in combination with off-grid tiny houses being powered by renewable energy sources is a motivation for another group of potential adopters could be the "environmentally aware".

Lastly, another target group derived from the themes identified during the interviews was "new holiday home buyers". In Sweden there has been an increased growth in prices for second homes, and the prices for second homes has grown more rapidly than for regular residences (SCB Statistics Sweden, 2021b). It has been highlighted that the demand for off-grid houses could increase due to it being difficult to access holiday homes near cities or popular destinations due to their high price. Similarly, financial motivations were seen as the most common motivation for choosing to live in a tiny house (Olsson, 2020). With this as background it could be argued that potential adopters of off-grid living powered by V2X are new second home buyers that choose this type of living due to financial concerns. However, important to acknowledge is that an EV is a relatively expensive investment, but if the adopter would already have an EV with bidirectional functionality the investment and adoption barrier would decrease.

7.2 Case study

Continuing on to the case study, the aim of the case study was to examine RQ2 "Can V2X help prolong the season for tiny house off-grid living in Sweden by reducing the energy imbalance?" The results show that without an EV, there is an energy balance between the 19th of March, to the 2nd of October when it once again is an energy shortage. Hence, this was the baseline to examine if the EV could prolong this season. In scenario 1, the season was prolonged by more than one month. In scenario 2, when the EV is charged bi-weekly, the season is prolonged by approximately two months compared to the baseline. In scenario 2, the season is between the 14th of February and the 14th of November. Lastly, in scenario 3, when the EV is being charged every week, the season for off-grid living is the full year from the 1st of January to the 31st of December, except for nine hours on the 7th of December. Hence, in scenario 3 off-grid living supported by V2X is seen to be self-sufficient all year round, except for nine hours.

Comparing the results with other studies estimating the power supply an EV could provide with, Tuttle et al. (2013) found that a PHEV in combination with PV panels could enable backup power for 1- 25 days. Another study illustrated that a home in the US with a solar PV system of 7.2 kW, a battery and an EV with an 80-kWh battery could sustain off-grid full operation for at least 72 hours (Gong & Ionel, 2021). Ford claims that their F-150 Lightning with extended range of 131 kWh will be capable of powering a home during a power outage for three days for a household that consumes 30 kWh per day, and ten days if the household has PV panels and are mindful with their energy consumption (Ford Media Center, 2022). Our results analyze a tiny house with an average consumption of 3.2 kWh per day and with a smaller EV capacity of 78 kWh, where the disposable share is approximately 50 kWh when arriving to the home in January. Without sun, the EV can provide the tiny home with enough energy to meet demand for eleven days, and twelve days including the little sun energy available in the beginning of January in Sweden. With PV panels recharging the EV, the EV can suffice off-grid living for 233 days over the full year in the baseline scenario 0.

Hence, as the previous studies and Ford are analyzing normal sized homes, the results in this master thesis for tiny house off-grid living are not directly comparable. However, with regards to the difference in available load a comparison can be assessed: The homes in Ford's example have a ten times higher energy consumption than in the case study of this thesis, which makes it is reasonable that the result of this thesis shows a longer time-period where off-grid living is feasible even without sun. Three days is Ford estimation without sun, compared to the eleven days in our study which is approximately four times longer. The reason the result in this study is not also ten times longer than with Ford is likely due to their EV having 131 kWh maximum capacity and we have used 50 kWh as the disposable capacity of the EV combined with 3 kWh capacity of the home battery, which in total is 60 % lower. Hence, 40 % of 30 days is twelve days which is close to the results of the model in this thesis. Hence, the results of the model are considered reasonable.

However, the case example from Ford in the scenario with PV panels is however more difficult to compare with this thesis's results as the details on their size of PV panels in relation to their home size is not available online. The tiny house in our study can very early during the year be supplied by solar energy, which makes the demand from the EV very low during early spring, summer and early fall. Hence, this could explain why it is possible for off-grid living 233 days in our model with an EV, home battery and PV panels and only ten days with an EV and PV panels in their example. The sun might not contribute with an as large share of the home's total demand in the normal sized house example compared to a tiny house with a much lower energy demand. Hence, the results are considered reasonable for this scenario as well.

Continuing to analyze how realistic the results in scenario 3 are when the EV is set to be charged at an external charging point once per week. This charging pattern could be seen as an obstacle depending on where the off-grid cabin is located and the nearest charging point, and what the motivation behind living off-grid is. This can however be seen as reasonable as the user might need to go grocery shopping once every week to fill up on necessities and food. Moreover, weekly recharging of the EV can also support the idea of short-term stays in off-grid tiny houses. If the user stays one week or less, there is no need to recharge the EV during the stay. This also supports the hospitality side of off-grid living which, based on the findings, now theoretically could accommodate weeklong stays, year-round for their customers as long as they have the V2X compatible EV and the home infrastructure. However, weekly charging is quite frequent, and it might be more reasonable to assume that the individual is more willing to charge the car every other week if the main goal of the stay is to relax and get away from everyday life. Scenario 2, which assesses bi-weekly charging, shows that the season can be prolonged by the EV, but does not allow for full-year access. Overall, all scenarios prolong the season compared to scenario 0 being the baseline.

The other side of the energy imbalance is during the summer months, when there is too much energy available generated by the PV panels than needed to supply the home loads. The results show that the excess energy can be used to charge the EV with as much as 63 kWh over a year in scenario 1, and 25 kWh in scenario 2 and 23 kWh in scenario 3. Derived from this, the excess energy that goes to waste in scenario 0 being the baseline is 805 kWh over a year, i.e., the accumulated amount of energy that cannot fit in the battery. Hence, the EV can help decrease this amount with the share that is being used to charge the EV. If the excess energy in scenario 0 were fully utilized, an EV could theoretically be recharged 13 times. This implies that there is a great potential to use the cars during the months with excess energy and to recharge the EV with solar energy free of charge.

Moreover, discussing possible use cases for the amount of excess energy, it could also allow the people living in the tiny house to increase their electricity consumption during these hours. The excess energy is only present during late spring and during summer months when demand is at the lowest and the sun irradiance is at its highest. This excess energy could hence theoretically be used to power loads which would increase the quality of living for the household, and supply e.g., a fan or air conditioner when the summer is at its warmest temperatures.

Concludingly, the EV is proven successful in theoretically prolonging the stay in an off-grid tiny house and increasing self-sufficiency. How long the season can be prolonged is dependent on the individual and how often they are willing to recharge the EV. However, since the focus of this thesis is to understand short-term stays in an off-grid cabin, it can be proven that short term stays are feasible since the EV can supply the tiny house with energy up to twelve days upon arrival in January, as illustrated in scenario 1.

7.3 Combining Findings from General Study and Case Study

To summarize and compare the findings from both the general study and the case study, it can be seen that the EV prolongs the season for all scenarios and provides benefits for the user. In the scenario with the longest season where off-grid living is feasible, the EV needs to be recharged once per week. This is also aligned with the interview results from the general study, where it can be seen that the interviewees found that the solution for powering an off-grid cabin would be most applicable for short-term stays being a few days up to a week. The synergies of these results are promising, in the sense that it seems possible that the potential adoption would be suitable for the limits of the energy balance as such; being able to stay for seven days in a row or less, or to recharge the EV at external charging point when going e.g., grocery shopping.

Moreover, the interviews mentioned that a lot will be needed from the house infrastructure in the sense that it will need to have a smart discharge enabling the EV to never discharge below a certain limit to avoid range anxiety. This is applied in the model, as there is a SOC limit of 20 % ensuring that there is always energy left in the EV to reach the home. Thereto, the order of prioritization is that the EV is only used when the solar energy is not enough, lowering the risk for battery degradation and that it can be charged by the solar panels when there is excess energy available. This is something that also affects the technology readiness level (TRL) as highlighted earlier, as there needs to be a smart inverter and energy management system that can be installed with the similar charging prioritization order as used in the model. In other words, the energy system needs to be smart in the sense that it can understand when to use the energy available in the home battery from the solar energy or the EV, as well as when to charge the EV with the available solar energy as presented in the case study.

Moreover, the case study and the general study are also aligned in the sense that the model showed possibilities of charging the EV with excess electricity. This is mentioned as a relative advantage in the general study, where the EV owner can have their EV charged with free solar energy. The case study also takes a stance on the interviewee's statements about the importance of mobility, as the EV is charged at an external charging point in scenarios 2 and 3 to further prolong the season for off-grid tiny house living. The system could however be interpreted as complex by a regular Swede owning an EV with bidirectional features and as a tourism expert mentioned the off-grid V2X solution could be most applicable for enthusiasts at this stage. But the niche demand is also seen as a niche that might grow and create value for the potential adopters discussed above; the independence seeker wanting to have energy security, urban people who want relaxation and workcations, environmentally aware who are energy conservative or new holiday home buyers who cannot afford a plot in the location they want and hence can use their EV to reach a remotely placed tiny house.

7.4 Sustainability and SDG Alignment

Moreover, the core of this thesis was created and initiated based on the need for sustainable development and increasing resource efficiency as highlighted in the introduction. Innovation that also serves to contribute with environmental or social benefits can be defined as sustainability-oriented innovations (Klewitz & Hansen, 2014). A common definition for sustainable development is development that meet the needs of the present without compromising the ability of future generations to meet their needs (Brundtland, 1987). The innovation of using the V2X technology in an off-grid setting is aligned and could likely help achieve certain Sustainable Development Goals (SDGs) set out by United Nations (United Nations, n.d.a). The innovation of scope in this thesis is aligned with SDG 7, Clean and Affordable Energy (Unitied Nations, n.d.b); by connecting the EV to an off-grid cabin, you can increase the energy storage capacity and hence more clean energy generated from the solar panels on the cabin can be utilized and stored (Dargahi, et al., 2014; Svarc, 2022b; Corchero & Sanmarti, 2018).

Additionally, as the thesis is focused on the innovation of using an EV to power an off-grid home, it helps foster various new technologies which aligns to SDG 9 Industry, Innovation and Infrastructure (United Nations, n.d.c); both the bidirectional functionality as well as other off-grid technologies which will enable the coordination between the EV, the cabin and solar panels. Furthermore, the off-grid V2X technology is also dependent upon the charging infrastructure, and the adoption of V2X compatible EVs can further contribute to development of the V2X compatible charging infrastructure.

Lastly, SDG 11, Sustainable Cities and Communities focuses on making cities and human settlements inclusive, safe, resilient and sustainable (United Nations, n.d.d). Off-grid tiny houses could make cities more sustainable as they offer housing alternatives that are more surface efficient and energy conservative as well as more economically beneficial and sustainable (Ford & Gomez-Lanier, 2017). An off-grid cabin is also a safe housing alternative in case of emergency and grid outage since they are equipped with its own energy system through the PVs, the battery in the cabin, and also the EV for extra backup energy (Al Muhaini, 2017; Tuttle, et al., 2013). Concludingly, the purpose of this thesis was aligned with the SDG 7, 9 and 11 and aims to contribute to sustainable development in Sweden.

7.5 Limitations

There are some limitations to this thesis work. Firstly, the interviews conducted were with interviewees who had a variety of expertise, ranging from housing, mobility, tourism, and charging. However, 14 of 22 interviewees had expertise within the mobility and charging sector, which increases the risk of the findings being more centered around the mobility part of the off-grid V2X system. This was, however, clearly stated in the list of interviewees to make the reader aware of the division. Moreover, this was taken into consideration when sending out the survey, where it was actively sent to equally many in the "housing & tourism" and the "mobility & charging" segment. Hence, this was made to make the data collection for the general study more balanced.

Secondly, the "Diffusion of Innovation" framework presented was not applied to actual adoption and customer data. It would have been more interesting to apply the analysis to real data, but this limitation was due to the novelty of the innovation and that the customers who have lived off-grid and connected their EV to the home do, to our understanding, not exist in Sweden today. Hence, the assessment of potential adoption was made based on data from interviews with industry experts supported by available literature. This was considered reasonable due to the aim of the thesis and chosen research question.

Another limitation is the calculation of the solar energy generated by the PV panels is estimated based on the solar irradiance during the three last years in Skövde. The PV panel efficiency is estimated based on the angle, position, and shade caused by the forest close to the cabins. For increased accuracy, it would have been beneficial to measure the actual solar energy generated by the PV panels at the case study location. However, as the case study was only conducted for two days in April, this was not possible as full-year data was needed. Therefore, pre-collected solar irradiance for the last three years and the efficiency coefficient were considered accurate enough to be used in the model, but real data would have improved the quality of the model.

Moreover, the model output is linked to the data input defined. In other words, if the loads in the home would differ from the behavior defined, the results and feasibility would be affected. Today the model has been adapted to off-grid living in the sense that residents are expected to be knowledgeable and charge their phones and computers during the day as presented in the method chapter. If they were to increase their household loads during nighttime when there is no sun, the energy balance would be impacted. The estimation for load data used in the model could however be considered cautious as many people who live off-grid tend to not use as many electronic devices as listed in this case study. The demand used in the model is seen as reasonable as it aims to represent typical days and habits when living off-grid today.

Another limitation is also with regards to the performance of the EV in the model. The battery capacity decreases with temperature which the model does take into consideration, but this assumption is made based on how EVs' actual range in relation to its expected range changes with temperature. This is a simplification of reality but serves the purpose of taking the temperature's impact on battery capacity into consideration.

Lastly, there is also a limitation in the model building with regards to the fact that the EV is not being used for other purposes than powering the home during the stay in the off-grid tiny house. The model would have been more nuanced if it was possible to e.g., add the capability of going on a road trip and seeing how this would affect the available battery capacity. This simplification was however considered reasonable as most customers coming to stay in the off-grid tiny houses tend to not use their car when being there. Hence, it is reasonable that the EV is expected to be parked by the cabin during the entire trip.

8. Conclusion

This chapter presents the conclusion to the main research question as well as supporting RQ1 and RQ2. Thereafter, theoretical contributions and practical implications of this thesis are presented. Finally, future studies are suggested.

The purpose of this study was to understand "Can off-grid living in a tiny house supported by Vehicle to Anything (V2X) become self-sufficient on energy and what are the prerequisites for usage?". This was supported by RQ1 as "How ready is the V2X technology to power an off-grid home and what could affect the potential adoption?" and RQ2 being "Can V2X help prolong the season for tiny house off-grid living by reducing the energy imbalance?".

To first answer RQ1, the research concluded that from a technology point of view the innovation is more ready than from the market perspective, and from a regulatory perspective the innovation is regulatory unproblematic. More specifically, the off-grid V2X innovation is assessed to have reached TRL 6, MRL 3, and RRL 9. For the market to reach a higher readiness level, customers, and market actors both need to confirm the innovation's benefits and opportunities and a business model needs to be described in the off-grid setting. This cannot be done until the technology is ready to use in the off-grid setting and the home technology readiness is tested. Both the mobility side of the system and the house infrastructure, need to be ready and have compatible communication and charging standards tested in an off-grid setting.

The attributes of the innovation that supports adoption are that the EV is mobile and can decrease dependency on renewable energy generation by serving as a large battery capacity. However, attributes that likely limit the diffusion of the innovation is the complexity of setting up the off-grid system and following the required safety regulations. Moreover, range anxiety and the fact that it is hard to try the innovation without making larger investments in the system components lowers the likely adoption rate. Thereto, the innovation is seen as most applicable for short-term stays and individual usage.

To answer RQ2, it is seen that by using V2X the season can be prolonged by reducing the seasonal energy imbalance and thus increasing the energy self-sufficiency. The season is prolonged with one to four months enabling full-year access to off-grid tiny house living depending on the charging schedule. The EV can also be charged with excess solar energy, and if the EV has a disposable EV battery capacity of 62 kWh it could theoretically be fully recharged. Concludingly, powering an off-grid tiny house with V2X brings two main value offerings; it can prolong the season by charging the home, and when there is excess sun, the home can charge the EV.

On a final note, to answer the main RQ if off-grid living supported by V2X can become self-sufficient on energy and what the prerequisites are for usage, the study concludes that it is theoretically possible, but the innovation is dependent on all technology components being tested and validated together in an off-grid environment. The EV needs to have bidirectional capabilities and the home needs to be equipped with smart software and an inverter to control the charging and discharging. Thereto, there needs to be a business model that creates value confirmed by the market, both customers and industry actors. Lastly, from a regulatory point of view, the concept is feasible as long as the installation of the energy system follows Swedish safety regulations. The EV can then, according to the model, theoretically help to prolong the season by reducing the energy balance making the energy system self-sufficient on energy. The EV can be discharged as well as charged by the excess solar, and hence the smart bidirectional charging of the EV and the home can increase the share of renewable energy available for use and reduce the energy imbalance.

8.1 Research Contribution and Implications

The theoretical contribution of this thesis is to reduce the knowledge gap on using an EV to power off-grid living. The thoughts and knowledge of industry experts have been consolidated to assess the innovation from a technology, market, and regulatory perspective allowing for a holistic view of the concept as such. Thereto, the study presents drivers for potential adoption and sees how the innovation could create benefits for possible adopters in the future. Moreover, this thesis has contributed with insights on the feasibility of powering an off-grid tiny house in Sweden, showing that this would be theoretically feasible. This thesis has also contributed with a model than can be replicated and used by other scholars to model different energy systems and understand energy flows. This model is universal and can be updated with new data input to represent other energy systems than the one used in this case study, which allows for an easy guide to adapt to other scholars need and research aim by replicating the functions and layout as described.

The practical implication of this thesis illustrates that it is theoretically possible to prolong the season and reduce the energy imbalance. Hence, the findings imply that the innovation is feasible in Sweden and could lay the basis for a practical experiment testing the concept once the innovation readiness level has increased. Using the set logic presented in the model and the general study as a foundation for the prerequisites needed to set up the system could allow for an exploration of this innovation. By testing the innovation and getting real end-user feedback, the system could be further refined and optimized to eventually become commercially viable. Thereto, practical implications suggest full-year access to off-grid cabins is possible which can make the season for off-grid businesses in the hospitality industry longer once all system components are available on the market. This is an exciting practical implication as it would allow for increased business value and opportunities within this housing and tourism industry.

8.2 Future Studies

One proposed future study is to assess the business model potential for an off-grid V2X system. What could be interesting to examine is which market actor would benefit from creating a business in this market. Moreover, future studies could also add value to the research field by assessing the market size for off-grid V2X systems and analyzing if there is a market fit for this within Sweden. This thesis has added a foundation for this future study as the market readiness today as well as adoption attributes are assessed, but it would be interesting with future studies focusing on the market potential and size. This could help lay the foundation for potential business models that could be built within this segment. Further, from a consumer perspective, a proposed future study is to conduct a cost analysis of the proposed off-grid V2X system and understand if it is economically defendable and what the potential return on investment could be. This is interesting to gain knowledge about in order to further understand what the potential market and adoption could be. Moreover, a study to understand the scalability of the proposed solution is suggested. This is to initially understand if it is possible to expand the off-grid V2X system for a community solution and later to assess if there is an interest in the community solution where energy could be shared among neighbors and if this would be regulatory feasible.

Moreover, it would be interesting for future studies to evaluate the feasibility of powering an off-grid tiny house in another climate, e.g., a skiing cabin as this is a popular destination for Swedes (Cederblad, 2021). In this setting, the battery capacity of the EV would be lower due to the colder climate and the behavior of the people living in the cabin would likely be affected as people could use their car to go to the mountain for skiing. This relates to another interesting future study based on the limitations of this study; to build a model where the EV can be used for other purposes than solely getting to and from the cabin and then being parked by the tiny house. This could further help to understand how much of the excess energy is to be captured through regular EV usage. Lastly, future studies could examine the lowest battery capacity that is needed to still suffice off-grid living with different load consumption profiles, weather, and size of the tiny house. This would provide insights on what the boundaries are for off-grid living powered by an EV.

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Insight Manager, 2022. *Tourism and Marketing Company* [Interview] (03 03 2022).

Off-grid Living Expert, 2022. *Off-Grid Cabin Rental Stay* [Interview] (19 01 2022).

Postdoc within Geography and Tourism, 2022. *Academia* [Interview] (20 01 2022).

Professor within Geography, 2022. *Academia* [Interview] (20 01 2022).

R&D Manager, 2022. *Energy Company* [Interview] (27 01 2022).

R&D Portfolio Manager, 2022. *Energy Company* [Interview] (14 03 2022).

Regulatory Advisor, 2022. *Energy Agency* [Interview] (24 03 2022).

Researcher E-Mobility, 2022. *Energy Company* [Interview] (17 03 2022).

Senior Analyst, 2022. *Consulting and Research Company* [Interview] (25 02 2022).

Strategy Director, 2022. *Automotive Company* [Interview] (18 01 2022).

Sustainability Expert, 2022. *Automotive Company* [Interview] (20 01 2022).

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Technical Expert, 2022. *Automotive Company* [Interview] (18 01 2022).

Telecommunications Strategist, 2022. *Telecom Company* [Interview] (22 02 2022).

Tiny House Manufacturer, 2022. *Tiny House Manufacturing Company* [Interview] (19 01 2022).

10. Appendix

Appendix 1: Interview Guide Used

Interview 2022-0X-XX at kl XX.XX– Name – Company – Role

[The questions were translated to Swedish if the interviewee understood Swedish]

Part 1: 5 min intro

Thank you for making the time for an interview. We are Emma and Hanna finalizing our master studies in Industrial Engineering and Management at KTH with a specialization track of Sustainable Power Generation.

A brief introduction of our thesis work is that we are exploring the potential for connecting an EV to an off-grid home in Sweden. This energy system would allow for the EV to charge the off-grid home when the PV panels are not enough to supply the home loads. Then, when there is an excess amount of solar energy available, the EV can be charged. This technology is referred to as Vehicle to Home and Vehicle to Load, jointly referred to as Vehicle to Anything (V2X).

To get started,

- Can you shortly introduce yourself and the work you do?
- How familiar are you with V2H/V2L technology?
- How familiar are you with smart sustainable houses and off-grid housing?

Part A: 20 min open questions

[We did not ask all interviewees all the below question, as this was an unstructured explorative interview taking place based on their familiarity of V2H/V2L versus off-grid housing. Individual questions were formed based on the interviewee's responses]

Starting with technology,

- From a technology perspective, what do you think are possible opportunities and barriers for adoption?
- What technical components are required for the EV to connect to the home and are these available today?
- How ready do you think the technology is to power an off-grid home today?

From the market point of view,

- What are your thoughts on this innovation, is this something you think could create value for people? Does it have market potential?
- Can V2X make living off-grid more interesting for people?
- Which customer groups do you think would have been interested in living off-grid as a holiday home?
- How ready do you think the market is today?

Lastly, from a regulatory point of view,

- Do you see any regulatory opportunities and barriers for using your EV to power your off-grid home?
- Is it problematic or not to connect your EV to the home?
- How ready do you think the regulatory landscape is today?

Part B: 5 min closed-ended question

Now we will share our screen and ask you to assess where you believe this off-grid V2X solution would be most applicable in Sweden. Either for individual usage or community usage (y-axis) and for short term stays or long-term stays (x-axis).

On the y-axis, community usage is defined as the EV is being shared among multiple off-grid households, and it can be driven to multiple houses to power it when needed. Individual usage is defined as each household having their own EV.

On the x-axis, short term usage means staying at the off-grid home for a few days up to a week and long-term usage which would be for multiple weeks to a full season.

Appendix 2: Survey

Innovation Readiness Level: Off-grid V2X System

[Copy of survey sent via Google Forms]

This survey is part of our master thesis in Industrial Engineering and Management at KTH. We sincerely appreciate your response. Thank you!

Vehicle to Anything (V2X) is an umbrella term for various techniques where the electric vehicle (EV) is used as an energy storage solution, a mobile battery bank. Vehicle to Home (V2H) is when the EV is connected to the house and the vehicle can both be charged and discharge the stored energy in the battery to the home. Similarly, Vehicle to Load (V2L) is the technology where the EV battery can power a load.

Off-grid living has experience grow in popularity and is characterized by housing being completely off the grid. The houses are often powered by solar panels, a battery and in some cases combined with a diesel generator. We are exploring the potential and feasibility of an off-grid V2X system in Sweden. More specifically, if an EV can prolong the stay in an off-grid house through the V2H/V2L technology. Meaning that the EV can, in combination with the solar panels, power the house.

This survey aims to understand both the technology, market, and regulatory readiness to use the V2H/V2L technology in an off-grid setting.

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1. Which area of expertise do you have? Please pick the alternative closest to your domain:

- Housing (residential electricity / off-grid cabins / tiny houses)
- Mobility (charging / batteries / EVs)
- Tourism (moving patterns / behaviour / people)

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2. Within which area are you comfortable estimating the readiness of an off-grid V2X system? (If more than one area, please select one here and you will be asked to assess from another perspective on the next page)

- Technological perspective
- Market perspective
- Regulatory perspective

Kindly estimate how ready the V2X off-grid system is by reviewing the questions below. Start with the question for "Level 1", if the answer is "yes" - then move on to the next level. Continue this process for as long as you consider the answer to the question to be "yes" and check this box only.

Innovation definition: Off-grid V2X system, i.e. connecting an EV that has bidirectional capabilities to power an off-grid tiny house

[Survey respondents could choose to answer from 1, 2 or all perspectives and based on their choice the below categories of questions appeared]

Level	TRL	MRL	RRL
1	Is a specific technological idea formulated?	Does an idea regarding a market need exist?	Are the legal and regulatory aspects of the technology unpredictable/unknown?
2	Is the idea explicitly described?	Has an idea regarding a need and a technological solution been formulated?	Will use of the technology demand legal changes?
3	Is a concept clearly demonstrated and described?	Has a market demand and a product been explicated?	Will use of the technology require regulatory changes?
4	Are the core technological elements tested and validated one by one?	Is the market demand and the idea confirmed by customers and market actors?	Will use of the technology require demanding permissions/approvals?
5	Are core components tested together and validated in lab/simulated environment?	Is there a described business model?	Will use of the technology require easily accessible permissions?
6	Is a prototype tested and validated in a relevant environment?	Has the product been sold in small amounts?	Are needed approvals/permissions likely?
7	Is the technology tested and validated in natural environment?	Has there been demand for the product in the market?	Are the necessary approvals/permissions close to be given?
8	Is the technology tested and validated in a broad scale?	Is product demand stable or growing?	Does use and production of the technology fulfill general requirements?
9	Is the technology fully developed and ready to use?	Is the product available in a market through a defined business model?	Is use and production of the technology regulatory unproblematic?

Would you like to add any additional comments to this?

Thank you! We appreciate you taking the time to answer this survey.

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