FROM NICHE TO NORM: DEVELOPING AND SCALING REUSE PRACTICES FOR PHOTOVOLTAIC PANELS IN AMSTERDAM

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EXECUTIVE SUMMARY

The growing threat of climate change has made transitioning to renewable energy sources essential, with solar photovoltaic (PV) technology crucial for reducing carbon emissions (NASA, 2020). Cities like Amsterdam are striving to meet ambitious climate goals, aiming to cut greenhouse gas emissions by 49% by 2030 and achieve net-zero by 2050 (Ministerie van Economische Zaken en Klimaat, 2019). A key part of this strategy is expanding solar energy, with the city planning to install over 550 MW of solar capacity by 2030 (Halsema et al., 2023).

However, this growth brings a pressing issue: managing increasing volumes of PV panel waste. Many panels are discarded early due to repowering or perceived inefficiency, contributing to rising electronic waste (Späth et al., 2022). This research addresses the gap in sustainable end-of-life management for PV panels by focusing on scaling reuse practices. The objective is to explore how reuse strategies can reduce waste, extend the useful life of panels, and align with Amsterdam's broader circular economy and climate goals.

This thesis aims to answer: What are the enabling and barrier factors influencing the development and scaling of PV panel reuse practices in Amsterdam, and how can policy mixes address these factors? The study is guided by three sub-questions: (1) How do expectations, network formation, and learning processes influence the initial scaling of PV panel reuse practices in Amsterdam? (2) What barriers and opportunities exist within the recycling regime, and how do landscape factors affect the scalability of reuse practices? (3) What policy mixes can enhance the scaling of reuse practices for PV panels in Amsterdam? These questions offer a comprehensive understanding of the barriers and enablers to scaling PV panel reuse and identify key policy solutions.

The research is grounded in Strategic Niche Management (SNM), Multi-Level Perspective (MLP), and Policy Mix frameworks. SNM explores how PV panel reuse practices grow within protected spaces, focusing on stakeholder engagement and network formation. MLP analyzes how niche innovations interact with the broader socio-technical system, including regime dynamics and external pressures. The Policy Mix approach integrates insights from SNM and MLP, proposing coordinated policy interventions to support reuse practices. These frameworks provide a robust lens to understand and scale PV panel reuse within Amsterdam's sustainability goals and offer insights for policy solutions across the Netherlands.

This research uses a qualitative case study design, suitable for investigating socio-technical complexities. Methods included semi-structured interviews and document analysis, allowing an in-depth exploration of the reuse niche. Purposive sampling selected stakeholders involved in reuse initiatives, ensuring diverse perspectives. Ethical clearance was obtained from the TU Delft Ethics Committee, and all participants provided informed consent. Data analysis involved deductive coding, guided by SNM, MLP, and Policy Mix frameworks. Using Atlas.ti software, interview data were coded to align with predefined indicators. Triangulation of data sources, including interview transcripts and policy documents, enhanced the reliability and validity of findings. This approach captured the nuanced dynamics of network formation, stakeholder engagement, and external influences affecting the reuse niche, providing a foundation for actionable policy recommendations.

The SNM findings reveal a shift in stakeholder expectations within the PV panel reuse niche, moving from small-scale experiments to scaling up operations. Local actors, like Stichting ZonNext, have moved from exploratory projects to building sustainable, local reuse chains due to difficulties with exporting panels. Municipal authorities and housing cooperatives play a crucial role by providing infrastructure and acting as "launching customers." However, external skepticism persists, mainly due to concerns over the safety, cost, and performance of reused panels compared to new ones. Network formation has been central to advancing reuse practices, with core actors such as the Municipality of Amsterdam, Refurn, and WEEE Nederland forging strong partnerships. Nevertheless, the network lacks engagement from Stichting OPEN, which controls Extended Producer Responsibility (EPR) funds critical for systematic scaling. While communication among core stakeholders is strong, broader external involvement and clearer regulatory frameworks are needed to address key barriers and encourage wider adoption.

At the regime level, stability in existing end-of-life (EoL) practices for PV panels remains a challenge. Only around 60-70% of producers meet their EPR obligations, creating financial shortfalls that hinder innovation. Stichting OPEN has been criticized for favoring low-value recycling methods over more sustainable processes. However, organizations like Solar2Cycle are introducing advanced recycling technologies that recover valuable materials, potentially shifting toward more environmentally friendly practices. Collaborative efforts between ZonNext and Solar2Cycle show progress, but entrenched producer interests and cost-focused strategies within Stichting OPEN's governance remain barriers.

At the landscape level, external economic pressures and technological advancements shape the reuse potential for PV panels. The low cost of new panels, driven by subsidies and production in China, undermines the competitiveness of reused panels. Nonetheless, geopolitical factors, such as scrutiny on forced labor practices and potential trade restrictions, may drive up the cost of new panels, making reuse more attractive. Technological innovations like IoT-based monitoring systems and modular panel designs enhance the feasibility of reuse by enabling better tracking of performance and easier disassembly. These developments suggest that, despite current challenges, opportunities for advancing PV panel reuse are growing.

The research applied SNM, MLP, and Policy Mix frameworks to analyze PV panel reuse in Amsterdam, identifying enablers like strong networks and barriers such as skepticism over economic viability. While these frameworks were useful, their selective application limited understanding of niche-regime dynamics, highlighting the need for more focused research. Findings align with literature emphasizing recycling over reuse but add insights into local policy gaps and financial challenges. The study's limitations, including a broad scope and incomplete data from key stakeholders, indicate the need for more targeted analysis. Despite this, the research provides actionable insights for policymakers and industry stakeholders.

To scale PV panel reuse, Amsterdam should implement strategic policies addressing key barriers and opportunities. This includes mandating reuse targets in waste management, promoting public procurement of reused panels, supporting second-life business models, enhancing certification standards, reallocating EPR budgets based on environmental impact, and providing financial support for reused panels in low-income housing. Public awareness campaigns and digital tracking platforms will further boost demand and streamline logistics. Collaboration between local businesses, industry associations, and the Dutch government is crucial. Future research should refine these strategies through pilot studies, quantifying barriers, and establishing clear implementation timelines. Exploring environmental optimization beyond CO_2 emissions will ensure a holistic approach to sustainability. By adopting these cross-sector policies, Amsterdam can lead in circular economy practices while meeting its sustainability goals.

In conclusion, this thesis highlights the critical role of scaling PV panel reuse in achieving Amsterdam's sustainability goals. The research identifies key barriers and enablers to reuse practices, offering actionable policy recommendations aligned with the city's circular economy and climate objectives. Addressing these challenges through strategic policies and cross-sector collaboration will enable Amsterdam to become a leader in sustainable urban development, integrating reuse strategies into broader environmental agendas

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LIST OF ABBREVIATIONS

AEEA	Afgedankte Elektrische en Elektronische Apparaten
AMS	Advanced Metropolitan Solutions
AVV	Algemeen Verbindend Verklaring
CBS	Centraal Bureau Statistiek
CE	Circular Economy
EoL	End-of-Life
EPR	Extended Producer Responsibility
EU	European Union
ILT	Inspectie Leefomgeving en Transport
IPCC	Intergovernmental Panel on Climate Change
MLP	Multi-Level-Perspective
NHZ	Noord-Holland Zuid
NP RES	Nationaal Programma Regionale Energie Strategie
PV	Photovoltaic
R&D	Research & Development
RSC	Recycling Service Centrum
SME	Small and medium enterprises
SNM	Strategic Niche Management
WEEE	Waste Electrical and Electronic Equipment
ZRN	Zonne-Energie Recycling Nederland

1. INTRODUCTION

Climate change presents one of the most pressing challenges of our time, with global warming causing unprecedented changes including rising sea levels, extreme weather events, and biodiversity loss (NASA, 2020). International efforts, spearheaded by the Intergovernmental Panel on Climate Change (IPCC) and the Paris Agreement, aim to mitigate these effects. The Paris Agreement, adopted in 2015, seeks to keep global temperature increases well below 2 degrees Celsius above pre-industrial levels, with an aspirational target of limiting the increase to 1.5 degrees (United Nations, 2015). However, despite these efforts, 2023 was recorded as the warmest year on record, with a 1.35-degree Celsius increase from pre-industrial levels (NOAA, 2024). Human activities—particularly fossil fuel combustion, industrial processes, and agriculture—remain the primary drivers of global temperature increases (Ritchie et al., 2023). To prevent catastrophic climate impacts and protect ecosystems, it is imperative to reduce greenhouse gas emissions. The IPCC has highlighted the necessity of a 45% reduction in emissions by 2030 and achieving net zero by 2050, which requires immediate action in clean energy investment, phasing out fossil fuels, and developing carbon capture solutions (IPCC, 2023; IEA, 2021).

In response to this urgency, the global energy landscape has been undergoing a significant transformation. This shift, driven by both environmental concerns and the need for sustainable development, is marked by the increasing adoption of renewable energy sources (Halady & Rao, 2010). Among these, solar energy—particularly photovoltaic (PV) technology—has emerged as a cornerstone in global efforts to reduce carbon emissions and transition away from fossil fuels. PV systems, which convert sunlight directly into electricity without emitting greenhouse gases, provide a sustainable solution to the energy demands of modern society. In 2023, solar PV accounted for three-quarters of renewable capacity additions globally, a testament to its critical role in reshaping the future of energy systems (Bojek, 2023). Solar deployment is accelerating, with 56 GW installed globally in 2023, exceeding the annual installation of 54 GW needed to meet EU energy targets (McWilliams et al., 2024). The European Commission has called solar energy the ‘kingpin’ in reducing dependence on Russian fossil fuels, advocating for ‘go-to areas’ where renewable projects can receive accelerated permitting to further hasten the deployment of solar energy (European Commission, 2022).

Amsterdam has positioned itself as a frontrunner in integrating sustainability into its urban planning, adopting the innovative Doughnut Model to balance planetary boundaries with social needs. This model shapes the city’s climate strategy by ensuring that development plans respect ecological limits while providing a social foundation for its citizens (Gemeente Amsterdam, 2020). Additionally, Amsterdam’s sustainability initiatives emphasize reducing greenhouse gas emissions, accelerating the adoption of renewable energy, and promoting circular economy principles, demonstrating the city’s commitment to creating a resilient and environmentally responsible urban future.

1.1 PROBLEM STATEMENT

1.1.1 AMSTERDAM'S CLIMATE AND ENERGY GOALS

Aligned with the Dutch Climate Act's ambitious goals, Amsterdam aims to reduce its greenhouse gas emissions by 49% by 2030 and achieve net zero emissions by 2050 compared to 1990 levels (Ministerie van Economische Zaken en Klimaat, 2019). As part of the National Programme Regional Energy Strategy (NP RES), Amsterdam is a sub-region within the Noord-Holland Zuid (NHZ) energy region, contributing to the national target of generating at least 35 TWh of large-scale sustainable electricity on land by 2030 (Dutch National Programme Regional Energy Strategies (NP RES) - Regionale Energiestrategie, n.d.).

A key initiative within Amsterdam's sustainability agenda is to reduce its CO2 emissions by 60% by 2030. This includes ambitious solar energy targets, such as achieving 350 MW of solar energy capacity by the end of the current administration term and aiming for 550 MW by 2030 (Halsema et al., 2023). As outlined in the latest "Herijking RES 2024" published in 2024, the city plans to utilize 50% of all suitable rooftops for solar energy production by 2030, translating to 550 MW of installed capacity, with 400 MW expected from large rooftops. By 2040, the goal is to cover 100% of suitable rooftops with solar installations, reaching a total capacity of 1,100 MW (Stuurgroep Regionale Energiestrategie Noord-Holland Zuid, 2024, pp. 48–55)

To reach these targets, Amsterdam is considering mandatory rooftop solar installations and providing support to small and medium-sized enterprises (SMEs) through subsidies and collective procurement for solar technology and infrastructure (Halsema et al., 2023). These efforts underscore the city's commitment to maximizing the use of its roofs for solar energy generation, significantly contributing to its goal of becoming climate-neutral.

1.1.2 SOLAR PANEL WASTE MANAGEMENT CHALLENGES

Despite Amsterdam's proactive sustainability efforts and rapid adoption of renewable energy, the city faces the emerging challenge of managing solar panel waste. According to a 2022 publication by TNO, 3.5 GW of annually installed PV panels will eventually represent over 200,000 tons of electronic waste each year (Späth et al., 2022). Based on calculations by the Centraal Bureau Statistiek (CBS), the amount of installed solar photovoltaic capacity in the Netherlands in 2023 was 4.344 GW, resulting in an even higher amount of future e-waste (CBS Statline, 2024). End-of-life PV panels are now collected by Stichting OPEN, which is responsible for coordinating their collection and recycling under WEEE regulations. However, less than 50% of these panels are currently collected for recycling, despite producers being legally obligated to collect and process at least 65% of the electronics placed on the market, as per the national Afgedankt Elektrisch en Elektronisch Afval (AEEA) regulation (AEEA – Article 10, 2024; de Vilder et al., 2024). The recycling process remains low-grade due to cost-cutting measures and technical advancements that are yet to be made. As a result, most panels are shredded and mixed with bulk materials such as concrete, or incinerated, with only a fraction of valuable materials like silicon, silver, and aluminum being effectively recovered (Stokvisch, 2022).

PV panels are generally designed to last 25 to 30 years, but they are often replaced much earlier due to economic and efficiency considerations, in a process called repowering

(SolarPower Europe, 2024). In repowering, functional panels are replaced to enhance energy output, even though many still have considerable power generation potential, retaining around 80% efficiency at the end of their typical lifespan (Majewski et al., 2021). Estimates suggest that 45-65% of panels currently entering the waste stream could be reused, provided they meet technical standards and undergo proper testing and refurbishment (Tsanakas et al., 2020). Reusing these functional panels can delay the need for recycling and, in doing so, alleviate the demand for new PV panels. This is especially critical considering the anticipated growth of the PV industry, which is expected to become a major consumer of several critical materials, including flat glass and silver (ETIP & EERA, 2024).

While newer panels offer enhanced energy efficiency, the environmental benefits of repowering must be carefully weighed against the significant resource savings and waste reduction achieved by extending the life of existing panels. Premature replacement not only exacerbates material supply chain pressures—much of which relies on imports from regions with considerable environmental and social challenges, particularly in China—but also increases the strain on recycling systems that are not yet fully capable of recovering valuable materials such as silicon and silver (de Vilder et al., 2024). By delaying the recycling of PV panels until more advanced recovery technologies become available, we can ensure a more efficient and sustainable approach to resource recovery (de Vilder et al., 2024). Embracing the reuse of functional PV panels presents a critical opportunity to address these supply chain challenges, reduce waste, and promote a circular economy. However, realizing this potential requires immediate and coordinated action from policymakers, industry stakeholders, and local authorities to scale reuse practices, optimize resource use, and integrate reuse into broader sustainability goals. Without such measures, the growing volume of PV waste risks undermining the long-term success of the renewable energy transition. These challenges underscore the need for innovative strategies that can scale reuse practices, which will be the focus of this research.

1.2 SHIFT TOWARDS REUSE

1.2.1 EMERGENSE OF THE PV PANEL REUSE NICHE

In response to the challenges of solar panel waste and the inefficiencies in current recycling methods, a reuse niche for PV panels is developing, supported by the City of Amsterdam as part of its broader circular economy goals. This emerging niche involves various key players working together to extend the lifecycle of PV panels through collection, testing, and redistribution, helping to reduce electronic waste and promote a sustainable energy transition.

Central to this niche are organizations like WEEE NL and Stichting ZonNext, which manage the logistics of collecting decommissioned panels and ensuring they are reused when possible. Stichting ZonNext coordinates with PV owners to match suitable panels with new installations, aiming to keep functional panels in circulation. ZonNext has received financial backing from the Rabobank Foundation, which has been instrumental in sustaining these efforts.

Scientific backing for this niche is provided by knowledge institutes such as AMS Institute, TU Delft, and the University of Leiden. These institutes contribute to research on the technical and logistical aspects of PV panel reuse, offering vital insights into the testing, refurbishment, and redistribution of second-hand panels. Their involvement ensures that reuse efforts are grounded in rigorous research, enhancing the credibility and scalability of this approach.

A crucial step in the reuse process is the testing and certification of panels to ensure they meet performance standards. This process is carried out by Refurn in Apeldoorn, where the panels are tested and certified according to European standards, providing assurance to new users regarding their performance and longevity.

Energiecoöperatie Zuiderlicht also plays a key role in this reuse network, actively integrating second-hand panels into local community energy projects. Through their collaboration with ZonNext, Zuiderlicht has made significant strides in promoting circular energy solutions within Amsterdam, further exemplifying the community-driven aspect of the reuse niche.

1.2.2 PILOT PROJECTS

Pilot projects in Amsterdam, such as those at the Marineterrein and the Kazerne, showcase the potential of reused panels. These projects demonstrate how second-hand solar panels can effectively contribute to the city's renewable energy targets while simultaneously promoting circular economy principles.

For example, at the Marineterrein in Amsterdam, Energiecoöperatie Zuiderlicht, in collaboration with ZonNext, successfully repurposed 900 second-hand panels from a commercial rooftop. After certification by Refurn, 800 panels were deemed fit for reuse, with an additional 100 newer panels added to fully utilize available roof space (ZonNext, 2023). Volunteers were heavily involved in the installation, showcasing the community's active role in making the project a reality. This initiative illustrates how community-driven efforts can align with sustainability goals and circular practices to reduce electronic waste (ZonNext, 2023b).

Similarly, the Kazerne project in Amsterdam further highlights the viability of integrating reused solar panels into new energy projects. These Amsterdam-based initiatives underline the potential for reused panels to contribute meaningfully to the city’s renewable energy targets, offering both environmental benefits and a circular approach to energy infrastructure. Beyond Amsterdam, Stichting ZonNext has also been involved in reuse projects in Africa and several local pilots, such as installations at Hockeyclub MHC in Dieren, the Anne Frank School in Leiden, and the Petrakerk in Harderwijk (ZonNext, 2023a). These projects extend the impact of the reuse niche beyond the city, proving the scalability of these practices.

Looking ahead, a new collaborative project is set to launch between WEEE NL, ZonNext, Refurn, and the City of Amsterdam. This initiative will aim to reuse 1,200 solar panels in the Amsterdam region, with logistical support from the Recycling Service Centrum (RSC) for storage and distribution (H. Bos, personal communication, August 2024). This project signifies a step forward in scaling up reuse efforts and highlights the important role of local authorities in supporting these initiatives. While these pilot projects have laid important groundwork, they represent only one part of the reuse niche.

1.2.3 SCALING THE REUSE NICHE

These pilot projects, while crucial, are only a part of the broader reuse niche that is developing in Amsterdam, involving a wider network of stakeholders. While projects at the Marineterrein and the Kazerne provide valuable insights into the practical implementation of reuse strategies, this research goes beyond individual projects to examine the broader development of the reuse niche. The reuse niche consists of a larger network of stakeholders, including local governments, research institutions, and private companies, working together to scale these practices.

In addition to analyzing network dynamics, this research draws on the valuable perspectives and insights of these stakeholders, capturing their experiences with reuse initiatives and their views on the challenges and opportunities in scaling reuse practices. By combining insights from pilot projects and the broader niche, this study identifies enablers and barriers, contributing to Amsterdam's circular economy goals and sustainability agenda.

1.3 RESEARCH GOAL AND RESEARCH QUESTIONS

1.3.1 RESEARCH GOAL

The primary goal of this research is to explore strategies for advancing the reuse niche of photovoltaic (PV) panels, focusing on promoting practices that extend their useful life. This is essential to reducing the environmental impact associated with the production and disposal of these panels. According to the circular economy's R-ladder framework by Potting et al. (2017), reuse (R3) and refurbishing (R5) are ranked higher in effectiveness than recycling (R8). Extending the service life of products like PV panels lowers the demand for new raw materials and energy, supporting sustainability objectives in cities like Amsterdam, where environmental pressures are increasing due to the premature disposal of functional PV panels (De Vilder et al., 2024).

To achieve this, the research employs a combination of Strategic Niche Management (SNM), the Multi-Level Perspective (MLP), and the Policy Mix approach. This integrated framework is designed to identify the barriers and enablers within the reuse niche, assess the socio-technical context influencing these practices, and propose policy pathways to scale them. By leveraging these frameworks, the research provides a comprehensive analysis of how Amsterdam can align its reuse initiatives with broader sustainability goals, tackling both technical and socio-political challenges. Furthermore, this research considers how policy interventions can overcome the dominance of recycling, facilitating a transition toward more sustainable reuse practices.

1.3.2 STRATEGIC NICHE MANAGEMENT, MULTI-LEVEL PERSPECTIVE, AND POLICY MIX

This research integrates Strategic Niche Management (SNM), the Multi-Level Perspective (MLP), and a Policy Mix approach to investigate how PV panel reuse practices can be developed and scaled. Together, these frameworks offer a robust lens for understanding the dynamics of innovation within Amsterdam's energy landscape.

Strategic Niche Management (SNM) focuses on the creation of protected spaces, or niches, where innovations like PV panel reuse can develop. These niches allow for experimentation and learning processes, such as network formation, expectation management, and stakeholder engagement. SNM helps identify the internal factors influencing the growth and scaling of these reuse practices, while also evaluating how these innovations may challenge or integrate into existing regimes, such as the dominant recycling regime that prioritizes cost-efficient material recovery.

The Multi-Level Perspective (MLP) complements SNM by situating niche innovations within a broader socio-technical system. This framework explores the interactions between niche-level innovations, regime dynamics, and landscape-level pressures (such as regulatory changes and market shifts). MLP helps to understand how external pressures and internal regime structures either facilitate or obstruct the scaling of reuse practices. Together, SNM and MLP provide a holistic analysis of the socio-technical barriers and opportunities that affect the development of reuse practices.

The Policy Mix approach builds on the insights of SNM and MLP to propose coordinated policy strategies that align regulatory, economic, and informational tools in support of niche development. It offers policies for addressing the barriers identified through SNM and MLP, ensuring that reuse practices can scale in alignment with Amsterdam's sustainability goals.

These three frameworks work together to develop a set of policy recommendations that support not only the growth of the reuse niche within Amsterdam but also guide national efforts across the Netherlands. Since the challenges and opportunities identified are not unique to Amsterdam, the policy solutions proposed can provide valuable insights for other cities, regions, and the national government in fostering reuse practices and advancing the circular economy.

1.3.3 RESEARCH QUESTIONS

This research integrates the SNM, MLP, and Policy Mix frameworks to address the end-of-life management of PV panels, focusing on the reuse niche in Amsterdam. The key aim is to identify both enablers and barriers to developing and scaling these reuse practices, and to resolve these barriers with policy solutions.

Main Research Question

What are the enabling and barrier factors that influence the development and scaling of reuse practices for extending the useful life of photovoltaic panels in the municipality of Amsterdam, and how can policy mixes address these factors?

Sub-Research Questions

1. How do expectations, network formation, and learning processes initiatives for the reuse of end-of-life photovoltaic panels in Amsterdam influence the development and initial scaling of these practices?
2. What are the barriers and opportunities within the recycling regime, and how do landscape factors affect the scalability of reuse practices for extending the useful life of PV panels in Amsterdam?
3. What policy mixes can enhance the scaling of reuse practices for photovoltaic panels in Amsterdam?

The integration of these frameworks provides a strong foundation for addressing the main research question. The focus will be on identifying barriers and enablers that influence the development and scaling of reuse practices in Amsterdam, while also exploring how policy interventions can support this transition. The outcome of this research will be a set of actionable policy recommendations that facilitate the adoption of reuse practices not only within Amsterdam but also across the broader national context, contributing to the country's sustainability agenda.

1.4 OUTLINE OF REPORT

This report is structured into nine main chapters. **Chapter 2** reviews the literature on circular economy and EoL management for PV panels, identifying key knowledge gaps. **Chapter 3** outlines the theoretical frameworks (STS, SNM, MLP, and Policy Mix) used to analyze the scaling of reuse practices. **Chapter 4** describes the research methodology, including data collection and analysis methods. **Chapter 5** presents the current state of existing EoL practices for PV in the Netherlands. **Chapter 6** presents the results of the niche-level analysis, focusing on expectations, network formation, and learning processes. **Chapter 7** analyzes regime and landscape-level dynamics. **Chapter 8** synthesizes the findings and proposes policy mixes for scaling reuse practices. **Chapter 9** discusses the theoretical implications, research limitations, and practical applications. **Chapter 10** concludes with recommendations for the City of Amsterdam and suggestions for future research.

2. LITERATURE REVIEW AND ACADEMIC KNOWLEDGE GAP

Addressing the challenges of scaling reuse practices for PV panels in Amsterdam requires an understanding of both the technical and socio-economic dimensions involved in end-of-life (EoL) management. This chapter begins with an exploration of circular economy strategies and how they apply to the lifecycle of PV panels, providing a backdrop for the specific case study of Amsterdam. These concepts are critical in framing the potential for reuse, refurbishing, and sustainable EoL practices. The review then delves into the academic literature on circular economy and PV panel management, highlighting innovations, challenges, and knowledge gaps that inform the research questions and theoretical framework.

2.1 CIRCULAR ECONOMY AND PV

Photovoltaic Panels

Photovoltaic (PV) panels are devices that convert sunlight directly into electricity using semiconductor materials, primarily silicon. These panels are widely used across various settings in the Netherlands, including residential rooftops, commercial buildings, industrial facilities, and large-scale solar parks.

This research encompasses all PV panels utilized for electricity generation, whether they are installed on buildings or in solar parks. As the deployment of these panels continues to grow, so does the need for effective lifecycle management to ensure their long-term sustainability.

Understanding the origin and characteristics of decommissioned PV modules is crucial for planning their end-of-life management. *Figure 2.1* illustrates the global cumulative power production by module type from 2000 to 2023 (Phillips & Warmuth, 2024). The majority of installed modules consist of mono- or multicrystalline silicon technology, with thin-film modules accounting for only about 5% of total capacity. Although many panels have not yet reached their full technical lifespan, an increasing number are being removed from service due to system upgrades aimed at boosting efficiency. In Europe, for instance, early PV installations from the feed-in tariff period are now over 10 years old, and many of these panels are being replaced, even though they are still functional (SolarPower Europe, 2024). This trend underscores the need to develop robust strategies for managing the sustainable end of life of panels that are retired prematurely.

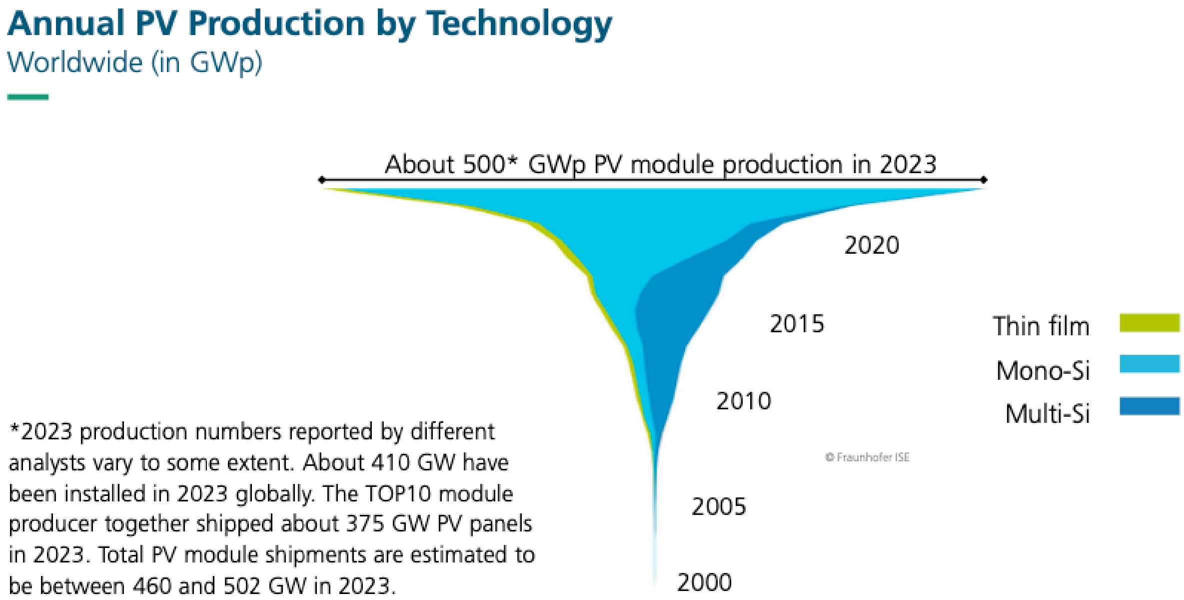

Figure 2.1: Annual PV Production by Technology. Worldwide (in GWP). Source: Philipps & Warmuth,(2024)

Circular Economy

A Circular Economy is an alternative to a traditional linear economy (make, use, dispose) and is designed to be restorative or regenerative. It aims to keep products, equipment, and infrastructure in use for a longer period, thereby improving the productivity of these resources. All waste should be seen as a resource, ideally feeding back into the cycle to create further value. This concept aligns closely with sustainable End-of-Life (EoL) management by emphasizing the importance of recycling and the continual use of materials.

End-of-Life (EoL Management)

End-of-Life Management (EoL Management) refers to the processes involved at the end of a product's useful life, including collection, sorting, refurbishing, recycling, or disposal. For PV panels, EoL management traditionally focuses on recycling, which often results in downcycling where the materials are of lower quality and value than the original. Sustainable EoL management aims to maximize resource recovery and minimize environmental impacts by reintegrating valuable components into new production cycles whenever possible, or safely disposing of non-reusable parts. This approach seeks to improve the current practice of downcycling and promote a more circular economy for PV panels, directly aligning with the strategies outlined in the R-ladder.

R-Strategies in the Circular Economy

The R-ladder, as conceptualized by Potting et al. (2016) and illustrated in *Figure 2.1.1* below, organizes circular economy strategies in a hierarchy that indicates the level of circularity, with higher strategies being preferable due to their greater contribution to resource efficiency and waste reduction. At the top of the ladder, strategies like "Refuse" and "Rethink" aim to minimize resource use and redesign systems to avoid waste altogether, representing the most circular and sustainable practices. Conversely, strategies like "Recover," which focus on energy recovery from waste materials, are at the bottom of the ladder and are considered the least preferable, as they contribute less to overall circularity.

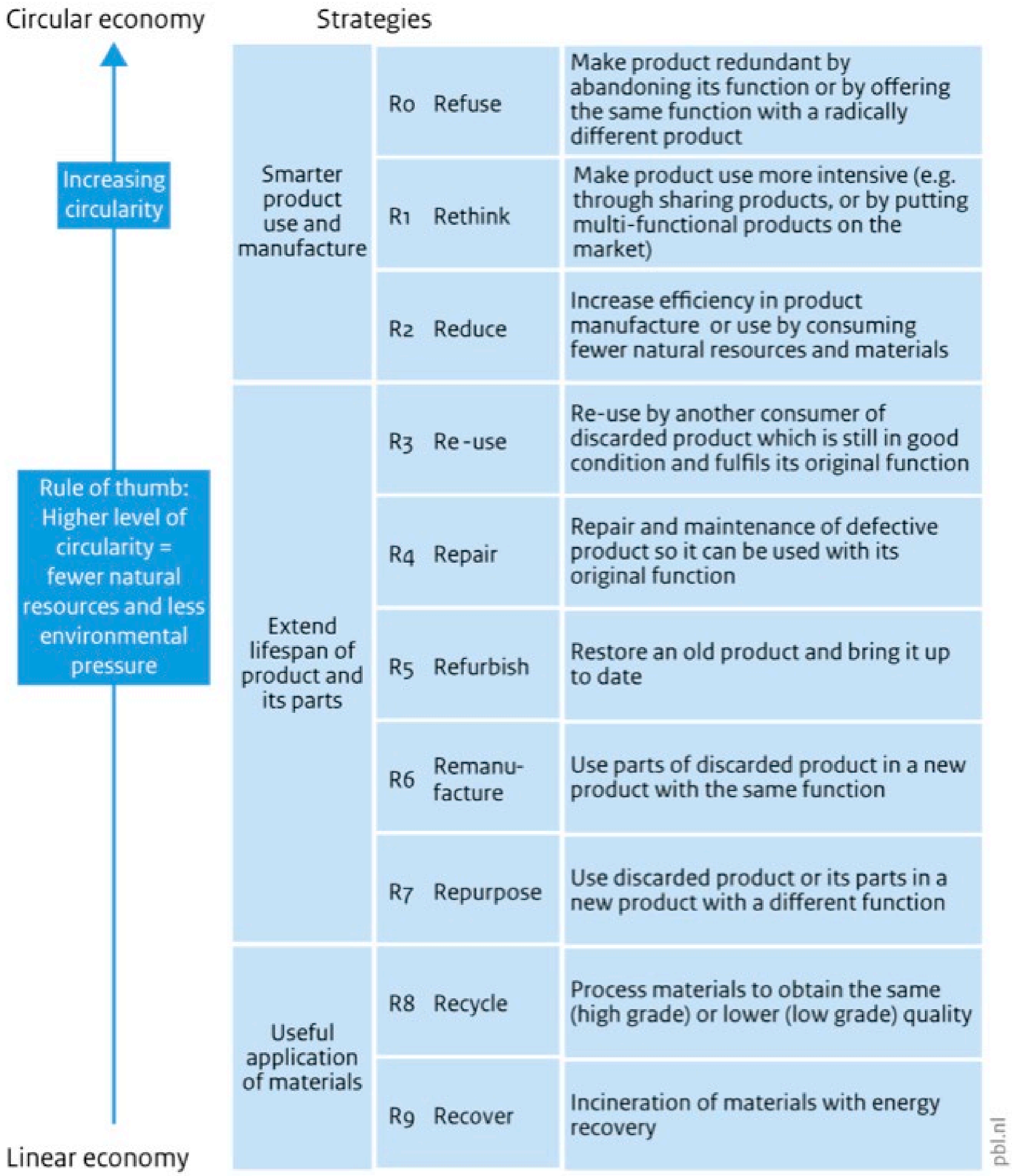

Figure 2.1.1: Circularity strategies in order of priority. Source: Potting et al., (2016).

In this research, the R-ladder is based on Potting et al.'s (2016) framework but has been tailored to include six strategies, aligning with the most recent approach used by PBL and RVO (R-ladder - Strategieën Van Circulariteit, 2020). This adjustment reflects practical considerations, as higher-level strategies like "Refuse" and "Rethink" are rarely implemented in practice, leading to their combination. Additionally, strategies such as "Repair," "Refurbish," "Remanufacture," and "Repurpose" are grouped under "Repair" and "Remanufacture" due to their similar focus on the reuse of product components. This tailored R-ladder is designed for practical application in the Dutch context, following the guidelines outlined by PBL and RVO (Kishna et al., 2019).

Figure 2.1.2: Tailored R-ladder with strategies for circularity. Source: R-ladder – Strategieën Van Circulariteit (2020).

Reuse and Refurbishment

Reuse and refurbishment are key strategies within the circular economy framework, aimed at extending the life of products by maintaining or restoring them to a functional state. Reuse involves the continued use of a product for its original purpose without significant alterations, allowing it to fulfill its intended function for a longer period. Refurbishment refers to the process of repairing and upgrading a product to restore it to a good working condition, often enhancing its performance or extending its lifespan.

In the context of this research, reuse and refurbishment represent the most effective steps in the R-ladder, aside from "Refuse" and "Rethink" (Potting et al., 2016; Kishna et al., 2019; R-ladder – Strategieën van Circulariteit, 2020). While "Refuse" traditionally refers to avoiding resource consumption altogether, in the case of solar PV panels, this is less applicable due to the pressing need for renewable energy. However, extending the lifespan of panels by delaying their replacement aligns with the core principle of "Refuse," as it minimizes unnecessary resource use by avoiding the production of new panels. Therefore, focusing on reuse and refurbishment is crucial, especially since many PV panels are decommissioned early, as discussed in the introduction.

To further illustrate the lifecycle management of PV panels and the potential for their second life, Figure 2.1.3 outlines the decision-making process that occurs after panels are decommissioned. This process involves key stakeholders, such as plant owners and O&M service providers, determining whether panels can be repurposed or need to be recycled. Panels that meet testing criteria for functionality can proceed to repair and reuse, and panels that do not meet the standards are directed to a recycling consortium to recover valuable materials. These steps align with the principles of a circular economy by prioritizing resource recovery, extending product life cycles, and minimizing waste through the reuse and recycling of materials.

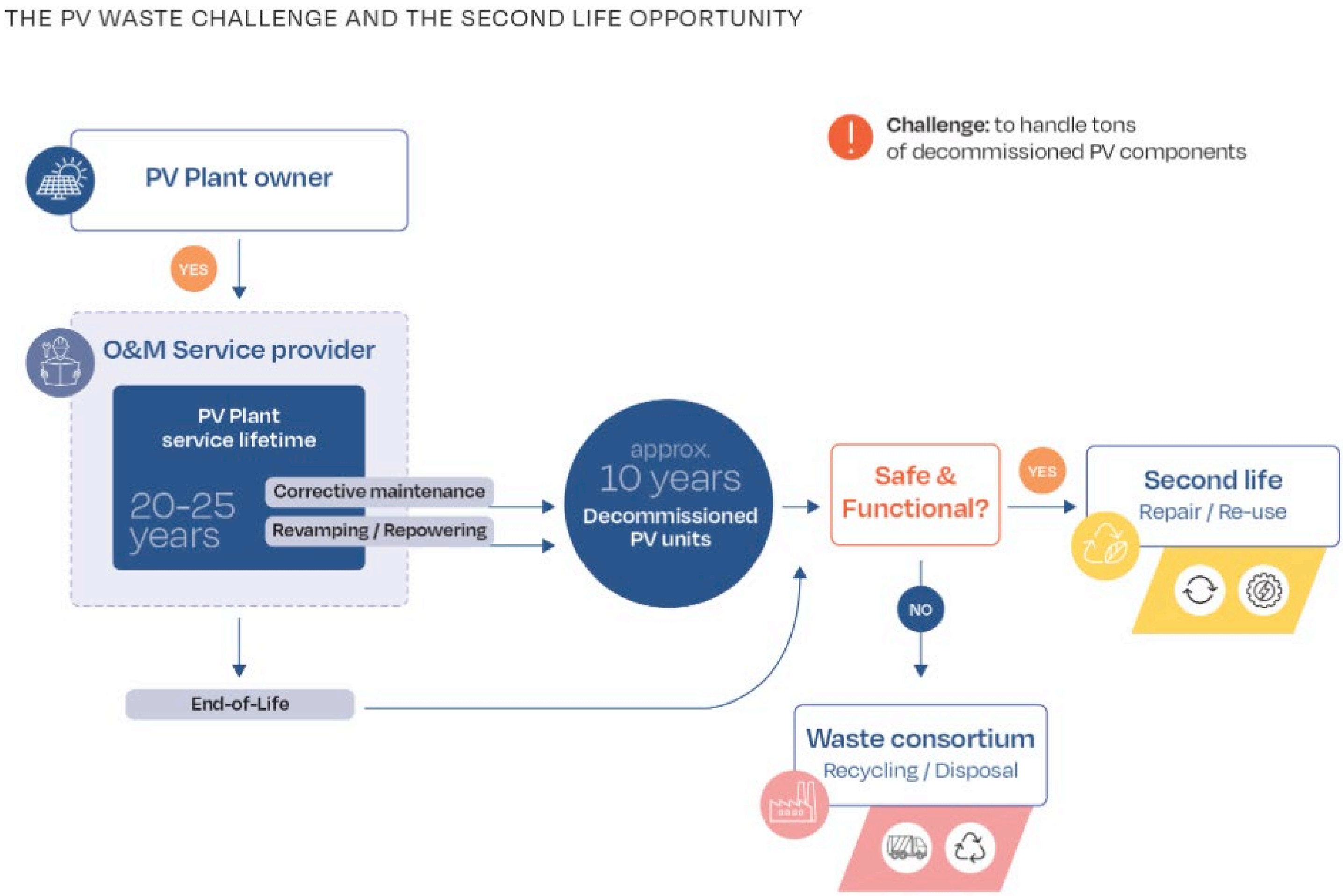

Figure 2.1.3: The PV waste challenge and second life opportunity.
Source: SolarPower Europe (2024)

2.2 LITERATURE REVIEW

Building on the challenges outlined in the introduction, this literature review examines academic research on circular economy strategies and EoL management of photovoltaic panels. The focus is on identifying existing practices, challenges in scaling reuse, and stakeholder collaboration, as well as strategic and policy approaches. This review will highlight the gaps in the literature that inform the specific research questions and theoretical framework outlined earlier.

2.2.1 SEARCH STRATEGY

To capture the latest developments in sustainable end-of-life (EoL) practices for photovoltaic (PV) panels, Scopus was utilized as the primary database for this literature review. The search targeted publications from 2019 to the present, ensuring the inclusion of the most current research and innovations in the field. The term "photovoltaic" was chosen as the primary search term, as it yielded the most comprehensive set of relevant articles compared to synonyms and abbreviations. The search strategy was intentionally broad, covering various aspects of EoL management for PV panels, including sustainable practices such as reuse, refurbishment, policy implications, circular economy approaches, and stakeholder involvement. Duplicate records were identified and removed to ensure that each study represented unique contributions. This approach was designed to help identify potential knowledge gaps, promising innovations, and emerging solutions. From the search results, the most relevant studies were carefully selected for in-depth review. The specific search terms used and the corresponding hits in Scopus are detailed in Table 2.2.

Table 2.2: Search Strategy Literature Review

Category	1st term	2nd term	3rd term	Hits
End-of-Life Management and Sustainability	"end-of-life"	"photovoltaic"	"sustainability"	65
	"end-of-life"	"photovoltaic"	"Netherlands"	0
	"environmental impact"	"photovoltaic"	"disposal"	55
	"stakeholder"	"photovoltaic"	"end-of-life"	35
	"scalability of end-of-life practices"	"photovoltaic"	"economic viability"	2
Recycling and Refurbishment Technologies	"recycling technologies"	"photovoltaic"	"efficiency"	13
	"refurbishment"	"photovoltaic"		81
	"technological innovation"	"photovoltaic"	"end-of-life"	3
Circular Economy and Industrial Approaches	"circular economy"	"photovoltaic"	"end-of-life"	83
	"industrial symbiosis"	"photovoltaic"	"end-of-life"	1
	"industrial ecology"	"photovoltaic"	"end-of-life"	3
Policy and Strategic Management	"policy framework"	"photovoltaic"	"end-of-life"	3
	"strategic niche management"	"photovoltaic"	"end-of-life"	0
	"waste management"	"photovoltaic"	"case studies"	27

2.2.2 SELECTED ARTICLES

After an extensive review of all articles identified using the specified search terms, a selection was made of the most relevant articles for this research. These articles, categorized by main theme and sorted by publication date within each theme, serve as the basis for the subsequent analysis. The complete dataset, including all identified articles and their categorization, is available in Appendix B1. This selection forms the foundation for the analysis presented in section “2.2.3 Literature Review Results” and directly informs the identification of the academic knowledge gap discussed in chapter 2.3 Knowledge Gap”.

2.2.3 LITERATURE REVIEW RESULTS

The literature review conducted for this thesis covers a broad spectrum of topics related to the end-of-life (EoL) management of photovoltaic (PV) panels, with a focus on sustainable practices and innovative approaches. The review is organized into four main themes: Circular Economy Approaches, Challenges and Strategies for EoL Management, Recycling Technologies and Processes, and Environmental Benefits and Challenges. Each theme addresses critical aspects of the current state of EoL practices in the PV industry and highlights key insights and challenges. The findings from these themes provide a comprehensive overview of the existing research landscape and set the stage for identifying the knowledge gaps that this thesis aims to address. The complete dataset, including all identified articles and their categorization, is available in Appendix B for reference.

2.2.3.1 CIRCULAR ECONOMY APPROACHES

The adoption of circular economy approaches in the photovoltaic (PV) industry faces a series of complex challenges, particularly concerning the technical and infrastructural constraints that hinder large-scale implementation. According to Tsanakas et al. (2020), current processes for recycling and refurbishing PV panels are still limited by significant technical difficulties, particularly in separating and recovering high-value materials from the panels. Additionally, there is a lack of standardized protocols for refurbishing and re-certifying panels, which makes it challenging to extend their operational life cycles. This gap reflects the broader limitations in the industry's ability to scale circular economy practices, especially when it comes to maximizing the lifecycle of PV systems through reuse and refurbishment.

Tsanakas et al. (2020) emphasize that the exponential growth in PV waste presents a significant environmental challenge, but also offers opportunities for innovation. However, the lack of research and well-established business models to support these circular strategies has kept the focus largely on recycling, with limited progress in developing the infrastructure for repair and reuse pathways. This is compounded by the limited knowledge around repair and refurbishment processes, as well as the absence of formal systems for re-certification of second-life PV modules. As noted, up to 50% of PV waste could potentially be diverted from the recycling stream through repair and reuse, yet the sector remains underdeveloped (Tsanakas et al., 2020).

In a broader context, circular economy approaches in the PV industry are further constrained by inadequate infrastructure and technological solutions (Farrell et al., 2020). Moreover, the concept of life cycle symbiosis, aimed at integrating the various stages of the PV panel lifecycle to promote circularity, faces considerable challenges due to misalignment of stakeholder interests across the supply chain (Mathur, Singh, & Sutherland, 2020). The lack of established market mechanisms for integrating end-of-life and decommissioned PV panels into the renewable energy market further exacerbates these challenges (Marsillac, 2021).

Additionally, the long operational lifespan of PV panels complicates efforts to create circular models, as design and business innovations must remain relevant over extended periods (Sahajwalla & Hossain, 2023). In Europe, regulatory barriers, insufficient incentives, and a lack of stakeholder engagement are also noted as key obstacles to advancing circular economy practices (Nyffenegger et al., 2024). The alignment of organizational strategies with varying market dynamics further adds to the difficulty of adopting circular economy principles in the industry (Van Opstal & Smeets, 2023).

Tsanakas et al. (2020) conclude that addressing these cumulative challenges requires comprehensive collaboration across the industry and innovative efforts to create viable circular business models. They stress the importance of research, real-world experience, and streamlined decision-making processes to unlock the potential of circular economy practices in the PV sector. This would involve formalizing repair and reuse pathways, supported by technical standards and regulatory frameworks that enable the broader adoption of second-life PV modules.

2.2.3.2 CHALLENGES AND STRATEGIES FOR EOL MANAGEMENT

The literature on end-of-life (EOL) management of solar photovoltaic (PV) systems highlights significant global challenges, including insufficient recycling technologies, fragmented regulatory frameworks, and inadequate stakeholder collaboration. In Australia, Salim et al. (2019, 2020) identify the need for standardized EOL practices and propose a systems approach that integrates technical, regulatory, and economic aspects to improve management strategies. Globally, Tao et al. (2020) emphasize the critical need for enhanced recycling technologies to overcome economic and logistical barriers, which is echoed in Germany by El-Khawad et al. (2022), who advocate for stronger regulatory frameworks to improve sustainability in PV waste management. Jain et al. (2022) underline the urgent need for regulatory development in India to manage its rapidly increasing PV waste, while Ali et al. (2023) stress the importance of cohesive policies in China and the USA to address EOL challenges effectively. In Europe, Bošnjaković et al. (2023) call for unified strategies across the EU to overcome inconsistent regulations and inadequate infrastructure. Souza et al. (2024) identify the lack of a robust regulatory framework and limited stakeholder engagement as key obstacles in Brazil, suggesting the adoption of international best practices. Nain and Anctil (2024) further emphasize the need for harmonized global regulations by comparing the regulatory approaches of the EU and the USA, underscoring the importance of coordinated efforts to improve EOL management worldwide.

2.2.3.3 RECYCLING TECHNOLOGIES AND PROCESSES

The literature on recycling technologies and processes for photovoltaic (PV) panels reveals both promising advancements and significant barriers that must be overcome to achieve a sustainable circular economy. In Australia, recycling can reduce environmental impacts by up to 50%, particularly in greenhouse gas emissions, but the costs, ranging from AUD 25-30 per panel, often outweigh the value of recovered materials, making it financially unfeasible under current market conditions (Mahmoudi et al., 2020). Similarly, the Resielp project in Europe has developed techniques that recover over 90% of valuable materials from silicon PV panels, yet the high costs, approximately EUR 15-20 per panel, and substantial capital investment requirements limit widespread adoption (Cerchier et al., 2021).

Logistical challenges further impede recycling efforts, with only 10-15% of PV waste currently collected for recycling in regions like New South Wales, Australia, though an optimized network could increase this to over 80% (Islam et al., 2021). Globally, less than 20% of decommissioned PV panels are recycled, and with the expected surge in PV waste to 78 million tons annually by 2050, there is an urgent need for standardized processes and international collaboration to scale recycling efforts (Cheema et al., 2024). Additionally, while circular energy material recycling could supply up to 30% of the raw materials needed for new battery production, challenges such as material degradation during recycling must be addressed to ensure the quality and sustainability of these processes (Sultana et al., 2022). In Türkiye, where less than 5% of PV panels are recycled, policy incentives and technological advancements could boost this rate to over 50%, aligning better with circular economy principles (Aşkın et al., 2023). The economic viability of recycling plants, such as those analyzed in Italy, shows that achieving profitability requires large-scale operations and stable material prices, further highlighting the economic challenges in this sector (D’Adamo et al., 2023).

Overall, the findings underscore the need for cost-effective recycling technologies, efficient logistical networks, and coordinated global efforts to manage the growing volume of PV waste sustainably.

2.2.3.4 ENVIRONMENTAL BENEFITS AND CHALLENGES

The literature on the environmental and economic impacts of photovoltaic (PV) systems highlights the challenges of balancing sustainability and cost-effectiveness. Recycling end-of-life (EOL) PV panels in Australia can reduce greenhouse gas emissions by up to 50%, but the process costs around AUD 25-30 per panel, making it economically unfeasible without subsidies or policy support (Mahmoudi et al., 2020). Although advancements in PV technology have reduced life-cycle emissions by 20-30%, the production and disposal stages still pose significant environmental risks, emphasizing the need for cleaner production technologies and more effective recycling processes (Tawalbeh et al., 2021). Dynamic modeling of Australia’s transition to a product stewardship approach for rooftop PV systems suggests that such a program could enhance recycling rates and mitigate environmental impacts, but this requires robust regulatory frameworks and industry collaboration (Salim et al., 2021).

2.3 KNOWLEDGE GAP

The existing literature provides a solid foundation for understanding the end-of-life (EoL) management of photovoltaic (PV) panels, yet several significant gaps remain. These gaps are centered around the dominance of recycling strategies, limitations in current practices, and underexplored areas such as reuse, socio-economic frameworks, and stakeholder engagement.

2.3.1 DOMINANCE OF RECYCLING FOCUS

As detailed in the Literature Review (Chapter 2.2), the existing research overwhelmingly emphasizes recycling over other circular economy strategies, leaving reuse practices underexplored. While Tsanakas et al. (2020) and others highlight potential opportunities for reuse, the literature lacks comprehensive studies on scaling these practices.

Academic Knowledge Gap: The literature demonstrates a clear dominance of recycling research, with insufficient exploration of alternative circular economy practices such as reuse and refurbishment. There is a gap in studies that investigate a broader range of circular solutions to complement recycling efforts.

2.3.2 LIMITATIONS OF CURRENT RECYCLING PRACTICES

Although the literature highlights significant advancements in recycling technologies, large-scale recycling remains difficult to achieve. High recycling costs, logistical challenges, and low collection rates for PV waste pose significant barriers (Mahmoudi et al., 2020; Islam et al., 2021). While certain technologies can recover a high percentage of valuable materials, these efforts are often not economically viable without substantial subsidies or incentives (Cerchier et al., 2021). These challenges reflect the complexity of scaling up recycling operations and indicate that current approaches are not yet optimized for widespread implementation.

Academic Knowledge Gap: The literature lacks comprehensive research on how to address the economic, logistical, and infrastructural barriers to large-scale recycling of PV panels. Further investigation is required to explore ways to enhance the efficiency and cost-effectiveness of recycling efforts.

2.3.3 UNDEREXPLORED POTENTIAL OF REUSE

While the potential for reuse is acknowledged in the literature, it remains significantly underdeveloped. Research suggests that reuse could divert a considerable portion of PV waste from recycling (Tsanakas et al., 2020), but the lack of standardized protocols for refurbishing and re-certifying second-life PV panels restricts its broader application. Additionally, market mechanisms and business models to support reuse remain underdeveloped, further limiting its adoption as a viable EoL strategy.

Academic Knowledge Gap: There is a notable lack of research on how to establish and scale reuse practices for PV panels. Specifically, the absence of technical standards and market mechanisms for second-life applications represents a significant gap in the current literature.

2.3.4 SOCIO-ECONOMIC AND REGULATORY GAPS

The literature predominantly addresses technical challenges in EoL PV management but does not sufficiently explore the socio-economic and regulatory frameworks necessary for effective circular economy options. Fragmented regulatory frameworks, insufficient incentives, and inconsistent policies across regions are cited as key obstacles (Bošnjaković et al., 2023; Nain & Anctil, 2024). The lack of comprehensive socio-economic research and coordinated policy development limits the scalability and effectiveness of circular economy approaches, including both recycling and reuse.

Academic Knowledge Gap: There is a gap in research on the socio-economic and regulatory frameworks required to support circular economy practices for PV panels. Further studies are needed to investigate how cohesive policies, economic incentives, and stakeholder engagement can enable more effective EoL management strategies.

2.4 TRANSITION TO THEORETICAL FRAMEWORKS

The knowledge gaps identified in the literature (Section 2.3) form the foundation for this study's research question, which aims to understand the enablers and barriers to scaling reuse practices for photovoltaic panels in Amsterdam. To systematically address this question, this research applies several theoretical frameworks—Socio-Technical Systems (STS), Strategic Niche Management (SNM), the Multi-Level Perspective (MLP), and the Policy Mix approach. These frameworks provide tools for analyzing the dynamics between technological innovations, socio-economic factors, and regulatory environments, helping to frame the conditions that influence the development and scalability of reuse practices.

3. THEORETICAL BACKGROUND

This section provides the theoretical foundation for analyzing how reuse practices for photovoltaic (PV) panels can be developed and scaled in Amsterdam, while contributing to broader national sustainability efforts. The research draws on four key frameworks: Socio-Technical Systems (STS), Strategic Niche Management (SNM), the Multi-Level Perspective (MLP), and the Policy Mix approach. These frameworks offer a comprehensive lens to understand the dynamics involved in fostering sustainable innovations and integrating them into socio-technical systems.
STS (Section 3.1) serves as the overarching framework, highlighting the interdependencies between technological innovations and the social, regulatory, and institutional contexts in which they operate. This perspective is crucial for understanding how PV panel reuse can be shaped by broader social and institutional structures, especially as Amsterdam and the Netherlands pursue sustainability and circular economy goals.

SNM (Section 3.2) focuses on nurturing niche innovations such as the reuse of PV panels, emphasizing processes like network formation, learning, and expectation management. It provides insights into how to support these innovations within protected spaces.

MLP (Section 3.3) situates niche innovations within a broader socio-technical system, examining how interactions between niche, regime, and landscape levels either facilitate or hinder the scaling of reuse practices. The framework helps assess the pressures and opportunities PV panel reuse faces, both locally and nationally.

The Policy Mix approach (Section 3.4) integrates SNM and MLP to propose coordinated policy pathways that support the scaling of reuse practices by aligning regulatory, economic, and informational policies. This approach addresses barriers identified in SNM and MLP, while also leveraging opportunities for scaling up reuse practices in Amsterdam and beyond.

Together, these frameworks provide a comprehensive structure to address the research questions, guiding the analysis of how PV panel reuse practices can be effectively scaled in Amsterdam and contribute to national sustainability efforts.

3.1 SOCIO-TECHNICAL SYSTEM APPROACH

The research on developing and scaling reuse practices for EoL PV panels in Amsterdam can be viewed through the lens of socio-technical systems. This perspective recognizes that technological innovations, such as PV panel reuse initiatives, are embedded within a broader social context involving various stakeholders, regulations, and infrastructures (Geels, 2019). The socio-technical systems approach highlights the interplay between technical aspects (e.g. PV technology, recycling processes) and social factors (e.g. stakeholder networks, policies, consumer behavior) in shaping successful sustainability transformations (Geels, 2019). Stakeholder engagement and collaboration are crucial in this context, as they facilitate the alignment of diverse actors and are a driver for niche level development.

The socio-technical perspective provides the underlying conceptual foundation for both the SNM and MLP theories by highlighting the co-evolution of technology and society (Loorbach & van Raak, 2006). SNM focuses on nurturing and upscaling niche innovations, such as PV panel reuse initiatives, through network building, learning processes and stakeholder alignment. The MLP framework complements SNM by considering the broader landscape pressures and regime dynamics that influence the adoption and diffusion of niche innovations (Loorbach & Raak, 2006). By adopting a socio-technical systems perspective, this research can provide insights into the complex interplay between technical, social, and institutional factors that shape the development and scaling of PV panel reuse practices in Amsterdam and help answering the research question.

3.2 STRATEGIC NICHE MANAGEMENT

Strategic Niche Management (SNM) is a well-established framework used to analyze the development and scaling of innovative technologies within protected niches, particularly those that aim to contribute to socio-technical transitions toward sustainability. In SNM, a niche is understood as a protected space where new technologies and practices can develop, often aimed at solving problems within the dominant regime (Geels, 2002). These niches are characterized by low stability and high uncertainty, allowing for greater flexibility and experimentation. SNM provides a structured approach to understanding how new technologies can progress from experimental stages to broader market adoption and integration into existing regimes. Initially developed to explore how innovative technologies could be fostered in niches insulated from dominant market forces, SNM has evolved to offer insights into how policy, social, and technological factors interact to influence the trajectory of these technologies (Schot & Geels, 2008; Raven, 2005).

In these niches, innovations are shielded from market pressures, allowing them to develop through experimentation and learning. This process is crucial because these emerging technologies often face stiff competition from established technologies embedded within large social networks, or regimes, which follow specific rules, including regulatory frameworks, market preferences, and technological standards (Geels & Schot, 2007). A niche technology often encounters highly uncertain aspects of design, user preferences, public policies, and social networks (Geels, 2004). In contrast, regimes operate with more stable rules that provide them with technological and economic advantages, especially in the early stages of niche development. Therefore, SNM suggests the concept of a technological niche as a protected space where new and radical technologies can be nurtured and developed despite these uncertainties (Kamp & Vanheule, 2015).

Over time, a niche technology, initially protected within a technological niche, can evolve into a market niche, where users recognize its value, enabling it to compete with established technologies. Eventually, these innovations may either help create a new regime or integrate into existing ones, influencing the broader socio-technical landscape (Schot & Geels, 2008; Smith & Raven, 2012).

While empirical insights from pilot projects like those at Marineterrein and the Kazerne are valuable for understanding the practical applications of PV panel reuse, this research goes beyond these specific cases. It examines the broader development of the reuse niche as a whole in Amsterdam, considering a wide network of actors including local governments, research institutions, and private companies. These pilot projects serve as illustrative examples but are not the sole focus; the study aims to analyze the broader dynamics of the niche, learning from stakeholder perspectives and exploring how the reuse niche can be scaled effectively.

3.2.1 SHIELDING, NURTURING, AND EMPOWERING

According to Smith & Raven (2012), niche development can be understood through three key functions: shielding, nurturing, and empowering. **Shielding** refers to the protection of niche innovations from external pressures, allowing them to develop in a relatively insulated environment. This protection can be passive, through geographical or sectoral isolation, or active, through deliberate policy interventions such as subsidies or regulatory exemptions.

Once a niche is shielded, the focus shifts to nurturing the innovation. Nurturing involves activities that support the growth and stabilization of the niche, including the shaping and managing of expectations, the formation and alignment of networks, and the facilitation of learning processes. These nurturing activities are critical for ensuring that the niche can evolve from a protected technological niche into a market niche where it can begin to stand on its own.

Empowering occurs when the niche innovation has matured to a point where it can compete with or influence the existing regime. This involves strategies that either fit the niche into the existing regime without major disruptions ("fit and conform") or transform the regime to better accommodate the niche innovation ("stretch and transform") (Smith & Raven, 2012). However, given the current developmental stage of the photovoltaic panel reuse niche in Amsterdam, the primary focus remains on nurturing rather than empowering.

3.2.2 NURTURING IN SNM: FOCUS ON EXPECTATIONS, NETWORK FORMATION, AND LEARNING PROCESSES

Given the current status of the niche, where the focus is on nurturing its growth, this research emphasizes three key processes central to SNM: expectations, network formation, and learning processes. These processes are integral to the nurturing phase and are critical for identifying the enablers and barriers that can influence the niche's further development and eventual scaling (Kamp & Bermúdez Forn, 2016).

3.2.2.1 NETWORK FORMATION

Actor networks play a crucial role in niche development, as they sustain progress, attract resources and new participants, enable learning, and carry forward shared expectations. Two key characteristics are essential when analyzing these networks: composition and alignment (van der Laak & Raven, 2007).

First, network composition is vital. A successful network requires a heterogeneous group of actors with diverse interests, roles, and perspectives. This diversity ensures a comprehensive understanding of the innovation's challenges and opportunities, incorporating various viewpoints and expertise (Raven, 2005). Relevant actors may include firms, researchers, policymakers, user groups, and other stakeholders. Initially, these roles might be fluid and undefined, which can introduce instability. However, as the network matures, these roles become clearer and more stabilized, enhancing the network's strength and the clarity of contributions from each actor. This process highlights the dual nature of role diversity as both an enabler and potential barrier within the niche development, underscoring the need for strategic alignment and integration of roles.

Secondly, network alignment is equally important. This characteristic refers to the degree to which the visions, expectations, and strategies of the actors are in line with the niche development. Achieving this alignment necessitates regular interaction and cooperation among the network members. By doing so, actors can develop shared goals, coordinate efforts, resolve conflicts, and maintain momentum towards the successful development and diffusion of the innovation (van der Laak & Raven, 2007). Relevant actors may include firms, researchers, policymakers, user groups, and other stakeholders. Each actor plays a unique role, contributing different skills, knowledge, and resources, which are essential for comprehensive niche development. The diversity of roles can foster comprehensive expertise, resource mobilization, complementary functions, market insights, and access to specialized communities, enabling niche progression. However, it can also introduce challenges, such as potential conflicts, power imbalances, coordination difficulties, cultural differences, or misalignment of goals and expectations among actors, which can act as barriers to effective cooperation.

Network formation, as emphasized in Strategic Niche Management (SNM), involves creating these broad social networks to support and drive niche innovation. Effective network formation sustains niche development by pooling resources and support from various actors, attracting new actors and resources to the niche, enabling learning and knowledge exchange among network members, and reinforcing positive expectations and visions about the niche innovation. This collaborative environment is essential for overcoming challenges and creating a supportive context for niche innovations to thrive and potentially influence broader socio-technical transitions.

3.2.2.2 DYNAMICS OF EXPECTATIONS

Expectations play a crucial role in directing technology development, shaping design decisions, and attracting resources and new participants. Successful niche development requires that these expectations become robust, specific, and validated by ongoing experimental outcomes. Initially, stakeholders invest based on broad and often vague anticipations of future success, embodying diverse and sometimes conflicting visions of the technology's future (Hoogma et al., 2002).

As the niche evolves, expectations can shift due to **endogenous developments** such as experimental results within the niche, and **exogenous factors** such as regulatory changes and market dynamics (Raven, 2005). This dynamic highlights the importance of distinguishing between **internal expectations**—those held by actors within the niche who are directly involved in its development—and **external expectations**, which are held by actors outside the niche, such as potential adopters, policymakers, or the general public (Raven, 2005).

Internal expectations are critical as they drive the niche's immediate developmental strategies and adjustments. These expectations are often influenced by the niche's direct experiences and learning processes. In contrast, **external expectations** reflect the broader societal and market awareness of the technology. These perceptions can significantly influence the niche's long-term viability and acceptance (Kamp & Vanheule, 2015).

The quality of these expectations plays a vital role. More robust and specific expectations, shared widely among internal actors, provide clearer guidance and are more likely to be validated through ongoing experiments within the niche. Additionally, understanding and potentially influencing **external expectations** through targeted awareness campaigns can help in managing the broader perception of the technology, thereby stimulating sector growth and facilitating the niche’s expansion (Kamp & Vanheule, 2015).

The different types of expectations (**internal, external, endogenous, and exogenous)** offer deeper insights into their roles in driving niche development and shaping the broader acceptance and success of emerging technologies.

3.2.2.3 LEARNING PROCESSES

The learning processes in Strategic Niche Management (SNM) theory emphasize the importance of facilitating learning at various levels to support the development and diffusion of sustainable innovations. There are two key types of learning processes to consider (Hoogma et al., 2002):

First-Order Learning within Local Projects/Experiments
This type of learning focuses on the technical design, user preferences, and societal embedding of the innovation through real-world experimentation and feedback loops. It aims

to enhance the innovation and understand its potential value by refining its design and adapting it to user needs and societal contexts.

Second-Order Learning at the Global Niche Level
This learning process involves understanding the broader institutional, economic, and socio-cultural changes necessary for the innovation to become mainstream. It informs strategies to overcome regime barriers and create an enabling environment for the wider diffusion of the innovation.

According to Hoogma et al. (2002), learning can be distinguished into five key aspects: technical development and infrastructure, industrial development, social and environmental impact, development of the user context, and government policy and regulatory framework. These aspects are crucial for shaping and adjusting expectations about the innovation, building broad networks of stakeholders, and facilitating institutional adaptation. Continuous cycles of experimentation, evaluation, and adjustment based on these learning processes are vital for successful niche development and eventual regime shifts towards sustainability. By fostering both first-order and second-order learning across these five aspects, SNM aims to create a robust foundation for sustainable innovations to thrive and influence broader socio-technical transitions.

3.2.4 NICHE INDICATORS

To systematically analyze the development of the niche for the reuse of end-of-life photovoltaic panels, this research uses specific indicators associated with the three key processes of SNM: expectations, network formation, and learning processes. These indicators, summarized in *Table 3.2.4*, are used to identify the barriers and enablers within the niche.

Table 3.2.4: The niche phases and their indicators (Kamp & Vanheule, 2015)

Niche process	Indicator	Analysis of
Expectations	1.1.1 Internal expectations	the quality, robustness and specification of expectations of the current actors in the niche
	1.1.2 External expectations	the awareness and confidence level of actors outside the niche
	1.1.3 Exogenous expectations	expectations originating from developments that are external to the niche expectations: landscape and regime factors, the development and/or rise of other niches
	1.1.4 Endogenous expectations	expectations originating from learning experiences and network composition within the niche
Network formation	1.2.1 Network composition	the desired network composition and network completeness
	1.2.2 Quality of the sub networks	the extent to which the involved actor groups contribute to niche development
	1.2.3 Network interactions	how and to which degree the network actors are interacting
	1.2.4 Network alignment	the degree to which actors' vision, expectations and strategies are in line with the niche development

Learning processes	1.3.1 Technical development and infrastructure	the learning about design specifications, complementary technology and the required infrastructure needed for technology dissemination
	1.3.2 Industrial development	the learning about the production and maintenance network needed to broaden technology dissemination
	1.3.3 Social and environmental impact	the learning about the technology's impact on safety, energy and the environment
	1.3.4 Development of the user context	the learning about the end-user characteristics, their requirements, their barriers for technology adoption and the meanings they attach to a new technology
	1.3.5 Government policy and regulatory framework	the learning about the institutional structures and legislation that are relevant for dissemination, and the incentives they can provide to encourage adoption

These indicators, derived from Kamp & Vanheule (2015), are central to the analysis and will help address the sub-research question: "How do expectations, network formation, and learning processes initiatives for the reuse of end-of-life photovoltaic panels in Amsterdam influence the development and initial scaling of these practices?" By focusing on these three key processes, the research aims to provide a comprehensive understanding of the current state of the niche and the factors that will determine its future trajectory.

3.3. MULTI LEVEL PERSPECTIVE

The Multi-Level Perspective (MLP) is a comprehensive framework used to analyze socio-technical transitions, providing a structured approach to understanding how innovations emerge, develop, and potentially transform existing socio-technical systems. While Strategic Niche Management (SNM) offers insights into the internal dynamics of niches, such as network formation, stakeholder alignment, and learning processes, MLP situates these niches within a broader socio-technical context. MLP emphasizes the significance of external influences on the upscaling of innovations by conceptualizing transitions as the interplay between three analytical levels: niche, regime, and landscape (Geels, 2002). Each level represents a different aspect of the socio-technical system, interacting dynamically to shape the pathways of innovation and change. This framework is essential for comprehending the broader context within which niche innovations operate and evolve. By incorporating major external developments, MLP complements SNM, enabling a more holistic analysis of socio-technical transitions. In the following subchapters, we will explore the distinct roles and characteristics of the landscape, regime, and niche levels within the MLP framework.

3.3.1. NICHE-LEVEL INNOVATIONS

As discussed earlier, niches are protected spaces where new technologies and practices can develop, often aimed at solving problems within the dominant regime (Geels, 2002). Due to their weak structuration, niches display low stability and high uncertainty, making them vulnerable to influence from both the regime and the landscape. However, this lack of stability also allows for greater flexibility and experimentation. Niches typically involve small networks of actors who share a vision for change and work collaboratively to refine and improve the innovation through continuous learning and adaptation.

In Amsterdam, pilot projects for the reuse of end-of-life (EoL) PV panels serve as examples of niches where innovations can be tested and developed. However, these pilot projects, such as those at the Marineterrein and the Kazerne, are just components of the broader reuse niche, which includes a larger network of stakeholders. This network consists of local governments, research institutions, and private companies working together to develop and scale reuse practices. While pilot projects offer valuable insights, the niche encompasses a broader effort to align stakeholder expectations, form effective networks, and mobilize resources to drive innovation.

Effective network formation, resource mobilization, and alignment of stakeholder expectations are crucial for building internal momentum within niches. For example, pilot projects might involve collaborations between these diverse stakeholders to test new methods of refurbishing and reusing PV panels. As niches mature, they can potentially influence the regime, provided they can demonstrate improved performance, garner support from powerful actors, and address existing system inefficiencies (Geels, 2011).

3.3.2. REGIME-LEVEL DYNAMICS

Situated above the niche level, the socio-technical regime encompasses the established technologies, institutions, practices, and networks that maintain the status quo. Regimes are generally stable and resistant to change due to their deeply rooted nature and path dependency (van Eijck & Romijn, 2008). This stability arises from the alignment of various elements, including regulatory frameworks, industry standards, market structures, and cultural norms, which collectively reinforce existing practices and technologies. The regime's resistance to change makes it challenging for new technologies to gain a foothold, as established actors and institutions often oppose innovations that threaten the existing order (Geels & Schot, 2007). Understanding the dynamics within regimes is essential for identifying the challenges and opportunities for niche innovations to integrate into or disrupt the dominant system. For instance, in Amsterdam, the existing waste management and recycling systems for PV panels represent the regime that reuse practices must navigate and potentially disrupt. Regulatory frameworks governing waste management, established business models of recycling companies, and consumer habits all contribute to the stability of this regime.

3.3.3. LANDSCAPE-LEVEL INFLUENCES

The landscape level consists of deep structural trends and factors that, while not part of the regime or niche, significantly influence both (Geels, 2011). Relevant landscape factors for Amsterdam include macro-economic trends such as fluctuations in renewable energy incentives, European Union environmental regulations, and societal shifts towards sustainability. Cultural aspects, such as the increasing public awareness and support for circular economy practices, also play a crucial role. For instance, the European Union's push for stricter environmental regulations and circular economy initiatives creates a favorable context for the adoption of reuse practices for EoL PV panels. Economic factors such as funding programs and subsidies for renewable energy projects also impact the feasibility and attractiveness of niche innovations. Additionally, technological advancements in material recovery and recycling can influence the development and scalability of reuse practices. Understanding these landscape-level influences is crucial for identifying the broader contextual pressures and opportunities that shape the potential for scaling niche innovations like the reuse of EoL PV panels in Amsterdam.

3.3.4. INTERACTIONS BETWEEN LEVELS

The potential for an innovation to scale up is significantly influenced by the interactions between the landscape, regime, and niche levels. The stability of the regime plays a crucial role in determining the space for niche developments; a highly stable regime tends to resist new technologies, whereas a destabilized or weakened regime presents windows of opportunity for niche breakthroughs. Regime destabilization can result from external landscape pressures, such as regulatory changes or economic shifts, and internal regime tensions, such as technological outdatedness or market dynamics. When niches build internal momentum through improved price/performance ratios, support from influential actors, and enhanced functionality, they can apply bottom-up pressures on the regime (Geels & Schot, 2007).

Effective alignment of interactions between these levels is essential for reinforcing each other and creating conditions conducive to radical innovation. The timing and nature of these multi-level interactions are critical; aligned interactions can open windows of opportunity for niche innovations to break through and potentially transform the dominant regime (Geels & Schot, 2007). In the context of Amsterdam, understanding these multi-level dynamics is crucial for developing strategies to scale the reuse of EoL PV panels, ensuring that niche innovations can flourish and contribute to broader socio-technical transitions. For example, a successful pilot project (niche) that demonstrates economic viability and environmental benefits could gain support from policymakers (regime) and be further strengthened by European Union directives promoting circular economy practices (landscape).

3.3.5. SUMMARY OF MLP INDICATORS

To systematically analyze the socio-technical transition of reuse practices for EoL PV panels in Amsterdam, this study employs a set of indicators across the niche, regime, and landscape levels of the Multi-Level Perspective (MLP).

At the niche level, the analysis focuses on the three key processes central to Strategic Niche Management (SNM): expectations, network formation, and learning processes. These indicators are used to identify the barriers and enablers within the niche, helping to answer the first sub-research question. Identifying these barriers and enablers is crucial for understanding what factors facilitate or hinder the development and scaling of niche innovations, allowing for the formulation of strategies to overcome obstacles or capitalize on opportunities.

At the regime and landscape levels, the focus shifts to understanding the broader socio-technical dynamics that influence the niche. Indicators at these levels assess the stability of the current socio-technical system, the suitability of sectoral policies, and the impact of broader economic and technological trends. These indicators are designed to address the second sub-research question: *"What are the barriers and opportunities within the recycling regime, and how do landscape factors affect the scalability of reuse practices for extending the useful life of PV panels in Amsterdam?"* By evaluating these indicators, the research aims to provide a comprehensive understanding of the multi-level dynamics that influence the potential for niche innovations to scale and impact the existing regime.

Table 3.3.5: Indicators for each phase of the MLP framework based on insights by Kamp & Bermúdez Forn (2016).

Socio-technical Level	Indicator	Data Requirements
Niche	SNM indicators, see Chapter 3.2.4	Expectations, network formation, learning processes, see Table 3.2.4
Regime	Stability in regime	Resistance to change, entrenched practices, institutional barriers
	Suitability of sectoral policy	Policy support, regulatory frameworks, incentives and disincentives
	Amount of lock-in in regime	Path dependencies, market dominance of existing technologies, cultural inertia
Landscape	Macro-economic trends	Economic incentives, funding availability, market dynamics
	Policy and legislation trends	Changes in environmental regulations, policy shifts towards sustainability, impact of legislation on niche practices
	Technological advancements	Innovations in recycling and reuse technologies, impact of new technologies on feasibility, adaptation of niche practices

These indicators, derived from Kamp & Bermúdez Forn (2016), provide a structured approach to analyzing the complex interplay of factors across the niche, regime, and landscape levels that affect the development and scalability of reuse practices for EoL PV panels in Amsterdam. By identifying barriers and enablers at each level, the research can offer targeted strategies to enhance the scalability of these practices, contributing to broader socio-technical transitions.

3.4: POLICY MIX FOR SCALING REUSE PRACTICES

To effectively overcome the barriers and leverage the opportunities identified through the Strategic Niche Management (SNM) and Multi-Level Perspective (MLP) frameworks, a well-crafted policy mix is essential. This approach enables the alignment of various policy instruments to create a supportive environment for scaling reuse practices for end-of-life (EoL) photovoltaic (PV) panels in Amsterdam. While SNM focuses on the internal dynamics of niches, such as expectations, network formation, and learning processes, and MLP situates these niches within broader socio-technical systems, the policy mix approach provides a practical tool for aligning and coordinating the necessary policies and stakeholder actions to facilitate the transition.

This chapter directly addresses the third sub-research question: "What policy pathways can be developed to enhance the scaling of reuse practices for photovoltaic panels in Amsterdam?" By focusing on the development of policy pathways, this section aims to identify how different policy instruments can work together to create a conducive environment for scaling these reuse practices.

3.4.1 THE ROLE OF POLICY MIX IN SCALING NICHE INNOVATIONS

The policy mix concept is increasingly recognized in sustainability transitions literature as a crucial framework for fostering niche innovations and enabling their scaling within existing socio-technical regimes (Kivimaa & Kern, 2016). A policy mix consists of a combination of regulatory, economic, and informational policy instruments that are strategically aligned to support the development and expansion of niche practices (Rogge & Reichardt, 2016). This approach complements the SNM and MLP frameworks by providing a structured method to coordinate these policies in a way that addresses the specific needs and challenges of niche innovations, such as PV panel reuse.

Designing Policy Pathways

Designing effective policy pathways involves a comprehensive analysis of the current policy landscape, identifying gaps, and proposing new or adjusted policy instruments that address these gaps. According to Rogge and Reichardt (2016), this process involves considering not only the individual policy instruments but also their interactions and the overall policy mix characteristics, including consistency, coherence, credibility, and comprehensiveness. Insights from SNM and MLP help identify the specific barriers and opportunities within the niche and regime levels. These insights guide the selection and alignment of policy instruments in the policy mix, ensuring that the proposed pathways are tailored to address the unique challenges faced in scaling reuse practices. The design process begins with the identification of specific barriers and opportunities for scaling reuse practices, as highlighted by the SNM and MLP frameworks. From there, a policy mix is constructed that aligns regulatory, economic, and informational instruments in a way that collectively addresses these barriers and leverages the opportunities.

Implementing Policy Pathways

While this thesis focuses on proposing policy pathways for scaling reuse practices, it is important to acknowledge the critical role of effective implementation in achieving these goals. Although the actual implementation of these pathways is outside the scope of this research, it is essential to consider factors such as the credibility of the policy mix, coherence between different policy instruments, and regular monitoring and evaluation.

Establishing the credibility of the policy mix involves gaining stakeholder trust in the commitment of policymakers to long-term goals, which can be achieved through consistent policy signals, clear regulatory frameworks, and stable economic incentives (Rogge & Reichardt, 2016). Ensuring coherence between policy instruments is also crucial, meaning that regulatory, economic, and informational policies should reinforce each other to create a synergistic effect that enhances the scalability of reuse practices.

In the discussion section, the need for ongoing monitoring and evaluation will be emphasized as a recommendation for future research or practical applications. This will ensure that the proposed policy pathways remain effective and adaptable in response to changing conditions.

In the context of PV panel reuse in Amsterdam, a well-designed policy mix can address the specific challenges and opportunities identified through SNM and MLP analysis. Regulatory policies, economic incentives, and informational campaigns are identified as key components of the policy mix because they directly influence the legal framework, economic viability, and public awareness, which are all critical factors for scaling reuse practices.

Regulatory Policies
Regulatory policies are essential for establishing the legal frameworks and standards that mandate or encourage the reuse of PV panels. These might include laws requiring the recycling and reuse of PV panels, or standards that ensure the quality and safety of refurbished panels. Regulatory policies create the necessary conditions for niche innovations to operate within the broader regime and can help reduce resistance from incumbent actors (Kivimaa & Kern, 2016).

Economic Policies
Economic incentives, such as subsidies, tax breaks, or grants, are crucial for reducing the costs associated with refurbishing and reusing PV panels. These policies help make reuse practices more financially viable, thereby encouraging businesses and consumers to adopt them. Economic policies also provide the financial support needed to overcome initial market barriers and to scale operations (Rogge & Reichardt, 2016).

Informational Policies
Informational policies, such as public awareness campaigns and educational initiatives, are vital for building consumer confidence in refurbished PV panels. These policies help change public perceptions and increase demand for sustainable products. Informational policies can also play a key role in aligning stakeholders by fostering a shared understanding of the benefits and importance of reuse practices (Flanagan et al., 2011).

Table 3.4.1: Policy instruments and their purpose (Rogge & Reichardt, 2016)

PRIMARY TYPE	Technology Push	Demand Pull	Systemic
Economic Instruments	RD&D grants and loans, tax incentives, state equity assistance	Subsidies, feed-in tariffs, trading systems, taxes, levies, deposit-refund systems, public	Tax and subsidy reforms, infrastructure provision,

		procurement, export credit guarantees	cooperative RD&D grants
Regulation	Patent law, intellectual property rights	Technology/performance standards, prohibition of products/practices, application constraints	Market design, grid access guarantee, priority feed-in, environmental liability law
Information	Professional training and qualification, entrepreneurship training, scientific workshops	Training on new technologies, rating and labelling programs, public information campaigns	Education system, thematic meetings, public debates, cooperative RD&D programs, clusters

Table 3.4.1 summarizes the three key policy instruments and their primary purposes, illustrating how they collectively contribute to the scaling of reuse practices. When applied in concert, these policy instruments not only address individual challenges but also reinforce each other, creating a robust environment that supports the scaling of reuse practices (Rogge & Reichardt, 2016).

3.5 CONCEPTUAL FRAMEWORK

The conceptual framework for this research integrates **Socio-Technical Systems**, **Strategic Niche Management (SNM)**, and the **Multi-Level Perspective (MLP)**, complemented by the **Policy Mix** approach. Together, these frameworks provide a robust foundation for analyzing how reuse practices for photovoltaic panels can be developed and scaled in Amsterdam, while contributing to broader sustainability efforts in the Netherlands.

Socio-Technical Systems (Section 3.1) provides the foundational understanding of the interplay between technological innovations and the broader social and institutional contexts. While this framework helps establish the broader context, it primarily supports the development of the SNM and MLP frameworks used in this research.

Strategic Niche Management (Section 3.2) focuses on how niche innovations like PV panel reuse can be nurtured through processes such as network formation, learning, and expectation management. This framework directly addresses **Sub-Research Question 1**: *How do expectations, network formation, and learning processes initiatives for the reuse of end-of-life photovoltaic panels in Amsterdam influence the development and initial scaling of these practices?*

The Multi-Level Perspective (Section 3.3) situates niche innovations within the broader socio-technical system, assessing how interactions between the niche, regime, and landscape levels affect the scaling of reuse practices. This is key to understanding the broader socio-technical dynamics and answering **Sub-Research Question 2**: *What are the barriers and opportunities within the recycling regime, and how do landscape factors affect the scalability of reuse practices for extending the useful life of PV panels in Amsterdam?*

The Policy Mix (Section 3.4) synthesizes insights from SNM and MLP to propose policy pathways that address the barriers identified within the niche and regime levels, aiming to create a supportive environment for scaling reuse practices. This directly contributes to **Sub-Research Question 3**: *What policy mixes can enhance the scaling of reuse practices for photovoltaic panels in Amsterdam?*

By integrating these theoretical frameworks, this conceptual framework enables a comprehensive analysis of the factors influencing the development and scaling of reuse practices for PV panels. This approach ensures that the research addresses not only local sustainability challenges in Amsterdam but also broader national goals, contributing to the overarching research question: "*What are the enabling and barrier factors that influence the development and scaling of reuse practices for extending the useful life of photovoltaic panels in the municipality of Amsterdam, and how can policy mixes address these factors?*"

In the next chapter, these theoretical insights will be operationalized into a research design, outlining the methods and strategies for empirical investigation to answer the research questions.

4. RESEARCH APPROACH & METHODOLOGY

This chapter outlines the research approach and methodology employed to investigate the development and scaling of reuse practices for end-of-life (EoL) photovoltaic (PV) panels in Amsterdam. The study adopts a qualitative research design, focusing on in-depth understanding and analysis of the niche within its broader socio-technical context. This approach allows for a detailed exploration of the complex interactions between various stakeholders, technologies, and institutional frameworks.

4.1 RESEARCH APPROACH

Qualitative Research Design

The research is grounded in a qualitative methodology, which is particularly suited to studying the socially embedded phenomena of scaling reuse practices within socio-technical systems. Qualitative methods provide rich, contextualized insights into stakeholder perspectives and processes, capturing the nuanced dynamics of network formation, learning, and external influences on the reuse niche for PV panels (Creswell & Poth, 2018).

Case Study Context

The research focuses on the developing reuse niche for photovoltaic panels in the Netherlands, with a specific emphasis on Amsterdam. As outlined in Section 2.2.5 "Circular Initiatives and Innovations," several initiatives and innovations are emerging across the Netherlands aimed at improving the circularity of PV panel management, particularly focusing on reuse and refurbishment. This niche includes a range of activities, from emerging initiatives to pilot projects that are actively testing reuse practices. In Amsterdam, two prominent pilot projects, the *Marineterrein Project* and the *Kazerne Project*, have successfully installed reused panels and serve as real-world examples of reuse practices. These projects provide invaluable insights into the practical implementation of reuse strategies and are key examples within the niche. However, to fully understand the scaling potential, it is crucial to analyze the broader development of the niche beyond these projects. Together, these projects and the broader reuse initiatives collectively represent the reuse niche and the case study context.

Research Design and Analytical Framework

This research uses a qualitative case study design, which is well-suited for investigating the complex interactions within socio-technical systems (Al-Busaidi, 2008). The case study allows for in-depth analysis of specific initiatives like the *Marineterrein* and *Kazerne* projects, while also considering the broader network of stakeholders involved in reuse practices.

The analysis is guided by Strategic Niche Management (SNM) and Multi-Level Perspective (MLP) frameworks, where indicators from these frameworks are used to analyze the collected data. These indicators focus on key processes such as expectations, network formation, and learning, along with broader regime and landscape influences (as outlined in Sections 3.2.4 and 3.3.5). Additionally, open-ended questions will be used to capture insights for developing policy mixes, complementing the coded analysis.

Research Questions and Theoretical Integration

The research is structured around one main research question and three sub-research questions, each linked to a specific theoretical framework.

Table 4.1: Research questions and corresponding theoretical framework

Research Question	Theoretical Framework
Main Research Question	
How can reuse practices for extending the useful life of photovoltaic panels be developed and scaled in the municipality of Amsterdam, and what are the factors that facilitate these practices?	SNM, MLP, Policy Mix
Sub-Research Questions	
1. How do expectations, network formation, and learning processes initiatives for the reuse of end-of-life photovoltaic panels in Amsterdam influence the development and initial scaling of these practices?	SNM
2. What are the barriers and opportunities within the recycling regime, and how do landscape factors affect the scalability of reuse practices for extending the useful life of PV panels in Amsterdam?	MLP
3. What policy pathways can be developed to enhance the scaling of reuse practices for photovoltaic panels in Amsterdam?	Policy Mix

In this research, the indicators from SNM and MLP are used to analyze the niche, regime, and landscape levels. These insights, combined with open-ended questions, will help inform policy development, providing a comprehensive analysis of the factors influencing the scaling of reuse practices.

4.2 DATA COLLECTION

The data collection for this research comprises both primary and secondary methods. The primary method involved conducting interviews with key stakeholders, while the secondary method focused on document analysis. The following sections describe the approach to selecting participants, the interview process, and the analysis of relevant documents. These methods were employed to ensure a comprehensive understanding of the subject matter.

4.2.1 PRIMARY DATA COLLECTION

Purposive sampling was employed to select participants with specific characteristics and knowledge relevant to the study. This non-random sampling technique ensured a diverse range of perspectives and the acquisition of the necessary information (Tongco, 2007). Key informants included stakeholders directly involved in PV panel reuse initiatives, ranging from project managers to policymakers and industry experts.

Consent and Confidentiality: Prior to conducting the interviews, ethical clearance was obtained from the TU Delft Ethics Committee to ensure compliance with ethical standards for human subject research. This process included a review of the research design, data collection methods, and data usage plans to protect participant rights and confidentiality. Participants were briefed on the study's aims, and their consent was obtained through a signed consent form. All participants provided informed consent for their contributions to be used in both anonymized and attributed formats, with two people requesting to review and approve attributed quotations before publication. Participants had the option to agree or disagree with specific terms, and all ultimately consented to the use of their contributions. For further details on the consent process, see Appendix A1.

Interviewees are referenced using abbreviations corresponding to their affiliated organizations, such as "AMS1" and "AMS2" for different roles within the AMS Institute, and "ZN" for a representative from ZonNext. This method allows for the discussion of general insights while maintaining focus on the range of viewpoints rather than implying organizational positions. Direct quotes with names and roles are included only when unique insights are relevant and after explicit agreement from participants.

Use of Direct Quotes: Direct quotes with names and roles were included only when specific, unique insights were relevant to the research context and added depth to the analysis. These quotes were used in accordance with the consent form and only after explicit agreement from the participants. In some cases, individuals reviewed and approved the specific quotes with their names prior to inclusion, ensuring alignment with their preferences and further safeguarding confidentiality.

Semi-Structured Interviews

Semi-structured interviews form the core of the qualitative data collection, using a flexible interview protocol that includes both general and specific questions tailored to each phase of the research. This method allows for structured yet adaptable conversations, enabling the exploration of complex issues while accommodating the dynamic flow of discussion (Adams, 2015). The interview questions are designed based on the indicators outlined in sections 3.2.4, 3.3.5, and the policy mix theory in 3.4, ensuring comprehensive coverage of the research questions. The interview questions are crafted to be relevant to as many stakeholders as possible, although it is acknowledged that not all questions will be applicable to every interviewee. In such cases, a selection will be made to focus on the most relevant questions for each interview. For example, questions under SRQ1 are likely less relevant for recyclers, whereas questions under SRQ2 and SRQ3 are more applicable. The interview protocol can be found in Appendix A2.

Table 4.2.1: Overview of the interviewed participants

Number	Name	Company	Abbreviation	Description	Pilot
1	Sietse de Vilder	AMS Institute	AMS1	Project manager and living lab coordinator	Marineterrein
2	Niels van Olffen	ZonNext	ZN	Director	Marineterrein
3	Gerard de Leede	Solarge	SOL	Chief Technology Officer & Co-founder	
4	Annoesjka Nienhuis*	Municipality of Amsterdam	AMST	Program Manager Innovation and sustainability	Kazerne/marineterrein
5	Henk Bos	WEEE NL	WNL	Project Director & Board Member ZonNext	Marineterrein
6	Aukje Bezeij	Zuiderlicht	ZL	Co-Founder	Marineterrein
7	Peter de Wit	Groenleven	GL	Business Development Manager Solar	
8	Esther Zumpolle	ZRN	ZRN	Operational Manager	
9	Gijs ten Brinke	Solar2Cycle	S2C	Owner	
10	Jeroen Kruisheer	Wocozon	WCZ	Surveyor, Energy Commissioner	
11	Francesca Alberti*	AMS Institute	AMS2	Project Manager Circularity in Urban Regions	Kazerne

4.2.2 SECONDARY DATA COLLECTION

Document Analysis

A document analysis was conducted to complement the interview data. This included examining relevant reports, policy documents, and regulatory frameworks to provide additional context for the niche, pilot projects, and broader landscape. A detailed list of analyzed documents is included in Appendix B1.

4.3 DATA ANALYSIS METHODS

Coding and Thematic Analysis The data analysis employed a structured coding approach aligned with the indicators identified in sections 3.2.4 and 3.3.5. The qualitative data from the interviews will be analyzed using Atlas.ti, a qualitative data analysis software that facilitates the organization and coding of large amounts of text data. Using Atlas.ti software, qualitative data from the interviews were coded according to the predefined indicators relevant to each sub-research question.

Deductive Coding was utilized as the primary coding technique. Deductive coding is a method where the coding process is guided by pre-existing theories or frameworks (Elo & Kyngäs, 2008). In this research, the codes are derived from the Strategic Niche Management (SNM), Multi-Level Perspective (MLP), and Policy Mix frameworks, ensuring that the analysis is directly aligned with the theoretical constructs and research questions. The specific codes are the same as the indicators in *Table 3.2.4 and Table 3.3.5*. The coding scheme as it is showed in Atlas is outlined in Appendix C.

Triangulation will be employed to enhance the validity and reliability of the research findings. This involves cross-verifying data from multiple sources, including interview transcripts and document analysis. By comparing insights gained from different data sources, the research can identify consistencies and discrepancies, thus providing a more comprehensive and credible understanding of the factors influencing the reuse niche for PV panels in Amsterdam (Thurmond, 2001).

4.4 REPORTING

The findings from each phase of the research will be reported systematically, following the structure of the sub-research questions. Each sub-research question will have its own dedicated section in the report, detailing the methods used, the results obtained, and the subsequent discussion.

- The report is structured as follows:
  Sub-Research Question 1 (Niche Level): Results will be organized around the barriers and drivers identified for *Expectations*, *Network Formation*, and *Learning Processes*.
- **Sub-Research Question 2 (Regime and Landscape Levels)**: Findings will focus on the barriers and drivers within the *Regime* (Stability, Policy Suitability, Lock-in) and *Landscape* (Economic Trends, Policy/Legislation Trends, Technological Advancements).
- **Sub-Research Question 3 (Policy Pathways)**: This section will synthesize insights from the analysis of SRQ1 and SRQ2, along with stakeholder visions gathered through interviews, to propose policy mixes for scaling reuse practices.

The report concludes with actionable recommendations for policymakers and industry stakeholders, based on the synthesis of findings across the different levels of analysis. The research flow diagram in chapter 4.5 visualizes the research flow.

4.5 RESEARCH FLOW DIAGRAM

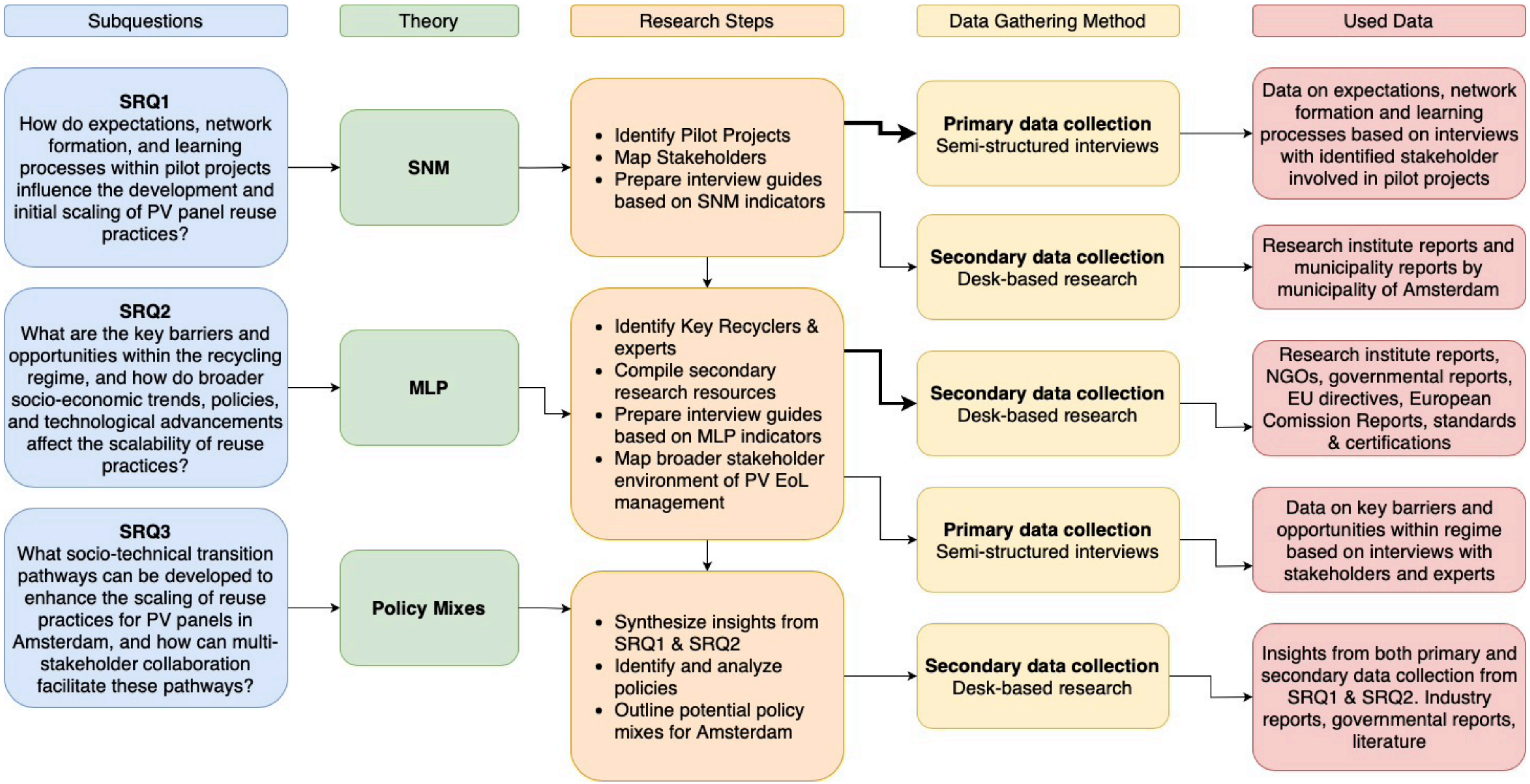

Figure 4.5: Research Flow Diagram

5. RESULTS

This chapter presents the findings of the research, starting with an overview of current practices and the emerging reuse niche for end-of-life (EoL) photovoltaic (PV) panels in Amsterdam. Following this, the results are structured according to the Strategic Niche Management (SNM) framework in Chapter 6 and an examination of regime and landscape-level dynamics through the Multi-Level Perspective (MLP) analysis in Chapter 7. In these sections, the barriers and enablers to developing and scaling reuse practices are identified based on the indicators from the theoretical frameworks outlined in earlier chapters. These findings will support Chapter 8: Policy Mixes, which provides recommendations to enhance reuse practices. Chapter 6 addresses the first sub-question, Chapter 7 focuses on the second sub-question, and Chapter 8 answers the third sub-question by exploring policy pathways.

5.1 OVERVIEW OF CURRENT PRACTICES AND EMERGING REUSE NICHE

This section provides an overview of existing practices in the end-of-life management of photovoltaic (PV) panels, as well as emerging trends in reuse and circularity. While the **Marineterrein** and **Kazerne** pilot projects demonstrate the viability of reuse, broader initiatives across the Netherlands reflect a growing interest in circular strategies. These projects offer valuable insights into the challenges of certification, logistics, and the role of collaboration between public and private stakeholders. It sets the stage for deeper analysis, showing how these pilot projects and the emerging niche are shaping the future of PV panel reuse in the Netherlands.

5.1.1 REMOVAL AND INITIAL HANDLING

When PV panels reach the end of their operational life or are replaced early, certified installers or contractors ensure the safe dismantling of the panels and surrounding structures, such as rooftops and mounting systems. However, despite careful handling of the installation, the panels themselves often sustain significant damage during removal. Improper methods—such as carelessly throwing panels into containers—frequently result in damage that diminishes their potential for reuse (S2C). Additionally, many panels are handled with little regard for their reuse potential, as they are assumed to be destined for recycling. This lack of care, combined with the fragility of the panels, leads to a considerable loss of reusable material (ZN). As a result, many panels are unnecessarily pushed into the waste stream.

5.1.2 COLLECTION AND TRANSPORT

After removal, the panels are transported to designated collection points, such as municipal environmental yards (milieustraten) and authorized e-waste collection entities. WEEE Nederland and WeCycle are the main parties responsible for the operational execution of the collection process, working under the supervision of Stichting OPEN, which has managed this task since it was officially appointed by the government in 2021. Stichting OPEN oversees the organization of the collection, processing, and recycling of PV panels but does not physically receive panels. Instead, it coordinates the financial contributions from producers and ensures compliance with national e-waste regulations (de Vilder et al., 2024).

The current collection system emphasizes cost-efficiency, focusing on minimizing logistics costs and quickly moving panels through the recycling stream. However, this cost-driven approach often undermines the potential for reuse, as many panels are handled with the assumption that they will be recycled rather than reused. As de Vilder et al. (2024*)* notes, much of the logistics is geared towards bulk collection for recycling, limiting the infrastructure needed to support circular reuse strategies.

The collection and recycling structure involves several stakeholders, whose roles and relationships are shown in figure 5.1. This figure provides an overview of the main organizations and regulatory bodies involved in the inzameling en recyclingstructuur in the Netherlands.

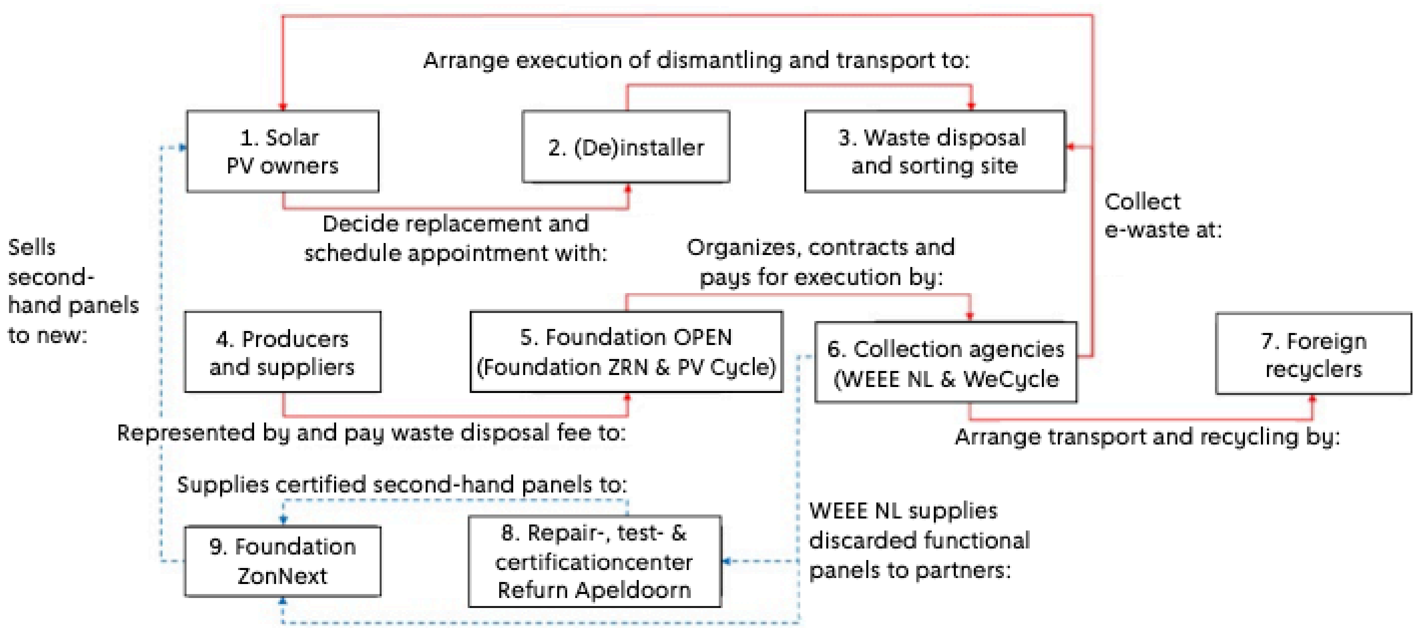

Figure 5.1: Overview of Stakeholder in the Collection and Recycling Structure for PV in the Netherlands. Source: de Vilder et al., (2024)

5.1.3 RECYCLING PROCESS

Stichting OPEN is responsible for overseeing the transport of collected PV panels to specialized recycling facilities, primarily located in Belgium and Germany. In these facilities, the panels undergo several steps (De Koning, 2024; WNL):

- Dismantling: Aluminium frames and copper cables are removed and recycled.
- Material Repurposing: The glass sheets, solar cells, and plastic layers are typically repurposed as fillers in the construction industry, such as in road building. However, these

materials often do not return to the PV supply chain, limiting the circularity of the recycling process.

This cost-driven approach treats the recycling process more as waste management rather than as an opportunity for circularity, which has drawn criticism from various stakeholders (ZN).

5.1.4 EXTENDED PRODUCER RESPONSIBILITY (EPR)

The Extended Producer Responsibility (EPR) framework plays a critical role in the EoL management of PV panels in the Netherlands. Under this system, producers and importers of PV panels are held responsible for the full lifecycle of their products, including take-back and recycling at the end of their use.

In 2021, the Dutch government implemented an Algemeen Verbindend Verklaring (AVV), which granted Stichting OPEN the mandate to manage the EPR framework for PV panels. This mandate requires all producers and importers to contribute to the costs of collection, transportation, and recycling of panels. The waste management fee, which was increased in 2023 from €6.50 per ton to €40 per ton, is designed to help cover the rising costs associated with the increasing volume of discarded PV panels. The fee is paid by all solar panel producers and importers to Stichting OPEN, which oversees the recycling process. The new rate will apply at least until the end of 2025 (Skujins, 2023).

Despite these measures, Stichting OPEN has struggled to meet the statutory collection targets for electrical and electronic equipment (AEEA). In May 2024, the Inspectie Leefomgeving en Transport (ILT) issued a formal warning, citing that Stichting OPEN had missed its collection targets. The ILT requested a remedial plan from Stichting OPEN by October 2024, outlining the reasons behind the shortfall and proposing steps to meet future targets. This information was provided by ILT in response to questions from *AfvalOnline* (Stichting Open op vingers getikt voor missen doelstelling, 2024). If the plan is deemed insufficient, further regulatory interventions could follow, including penalties.

5.1.5 CIRCULAR INITIATIVES AND INNOVATIONS

Despite the challenges in traditional recycling methods, several initiatives and innovations are emerging in the Netherlands aimed at improving the circularity of PV panel management. These efforts focus on extending the life of PV panels through reuse and refurbishment, as well as developing more sustainable recycling processes.

- **Solarge**: This company is at the forefront of producing lightweight, fully recyclable solar panels, designed to reduce environmental impact throughout their lifecycle.
- **Refurn**: Specializing in the reuse and refurbishment of PV panels, Refurn tests, cleans, and refurbishes decommissioned panels with sufficient capacity, thereby extending their operational life.
- **Stichting ZonNext**: In collaboration with **Sungevity**, ZonNext operates a platform that facilitates the reuse of PV panels by connecting suppliers of second-hand panels with potential buyers, both within the Netherlands and internationally.

- **WEEE Nederland's Test Facility**: Located in Apeldoorn and developed in partnership with Refurn, this facility focuses on the recertification of discarded solar panels, promoting reuse over immediate recycling.

5.1.6 PILOT PROJECTS

Several pilot projects have been launched in Amsterdam to explore the potential for reusing decommissioned PV panels, contributing to the city's sustainability goals. Notable examples include:

Marineterrein Project: This project in Amsterdam is a collaborative effort aimed at reusing decommissioned PV panels from a commercial rooftop. A total of 1,100 panels were originally decommissioned, of which 900 were selected for potential reuse. After certification by Refurn, 800 panels were deemed suitable for reuse. To complete the installation, 100 additional panels were sourced from other projects. The Marineterrein project is a partnership involving AMS Institute, ZonNext, Sungevity, WEEE Nederland, Refurn, and the energy cooperative Zuiderlicht. These panels are now being reused in local installations, supported by the local government, showcasing a successful model of circularity in the PV sector.

Kazerne Project: The Kazerne project in Amsterdam-Zuidoost is another significant initiative focusing on the reuse of second-hand PV panels. In September 2023, 20 panels were installed on the roof of the former fire station at Reigerbos as part of a broader living lab in the area. This project was developed with the involvement of a project group from the MADE (Metropolitan Analysis, Design, and Engineering) program at the AMS Institute. The project is part of a broader effort to integrate sustainability into urban infrastructure and has provided valuable insights into the practical challenges and learning experiences associated with scaling up the reuse of PV panels in urban environments.

5.1.7 CONCLUSION

The current state of EoL management for PV panels in the Netherlands reflects a balance between traditional recycling practices and emerging circular initiatives. While most panels are currently processed abroad in a manner that prioritizes cost-efficiency, there is a growing movement toward greater material circularity and sustainability. The ongoing evolution of the EPR framework, coupled with the success of circular initiatives, will be crucial in driving the Netherlands toward a more circular approach to PV panel management.

6. RESULTS: NICHE LEVEL DYNAMICS

This chapter presents the results of the analysis focused on the niche-level dynamics that influence the development and scaling of reuse practices for end-of-life (EoL) photovoltaic (PV) panels in Amsterdam. The results are structured according to the three main areas identified in the Strategic Niche Management (SNM) framework: expectations, network formation, and learning processes. These areas are crucial for understanding how niche innovations, such as the reuse of PV panels, can be nurtured and scaled within a broader socio-technical system. The specific indicators and what they analyze can be found in *Table 3.2.4.*

6.1 EXPECTATIONS

This section examines the expectations of stakeholders within the niche of reuse for end-of-life (EoL) photovoltaic (PV) panels, focusing on four key areas: Internal Expectations, External Expectations, Exogenous Expectations, and Endogenous Expectations. Each area reflects different dimensions of stakeholder expectations and their implications for the development and scaling of reuse practices.

6.1.1 INTERNAL EXPECTATIONS

Internal expectations refer to the initial goals, strategies, and evolving outlooks of stakeholders directly engaged in the reuse niche for PV panels. These expectations shape internal decision-making and influence how organizations actively contribute to the niche's development.

Initial Goals and Strategic Shifts

Stakeholders directly involved in reuse practices have displayed a notable evolution in their goals and strategies over time. Sietse de Vilder (AMS1) initially aimed to export second-hand PV panels to countries with higher solar irradiation, believing this would enhance electricity generation and make the business case more attractive. However, he shifted his focus to establishing a local reuse chain due to logistical challenges, including certification requirements and the complexities of setting up an international reuse network. He now emphasizes local, temporary applications, such as installations on roofs scheduled for renovation or on temporary housing units, viewing these as ideal locations for second-hand panels. This shift reflects an internal expectation that local reuse could offer a more sustainable and manageable solution (AMS1).

Niels van Olffen (ZN) also noted a transition from what he described as "missionary work" to a more structured and scalable model. His organization now experiences "serious stability in supply," with new partners joining weekly. The current focus has shifted towards scaling up projects, indicating a growing confidence in the viability and potential expansion of reuse practices (ZN).

Adapting to Challenges and Building Confidence

Other stakeholders, such as Aukje Bezeij, have adjusted their expectations based on their direct involvement in reuse projects. Initially driven by "naïve enthusiasm," Bezeij's perspective has evolved to "realistic idealism," recognizing the complexities involved in scaling up reuse practices. Despite these challenges, she remains optimistic that with enough concrete projects, many of the hurdles can be overcome, suggesting a continued commitment to advancing reuse efforts (ZL).

Emphasis on Learning and Local Applications
Henk Bos also highlights the adaptability of reuse practices, noting the flexibility in repurposing components from other technologies, such as charging stations, to support the reuse of PV panels. This pragmatic approach, which leverages existing resources and knowledge, underscores an internal expectation that reuse can be effectively scaled if supported by a robust network and infrastructure (WNL).

6.1.2 EXTERNAL EXPECTATIONS

External expectations focus on the awareness and confidence levels of stakeholders outside the immediate network of reuse practices. Understanding these perceptions is crucial for assessing external support and identifying opportunities for broader acceptance and integration of reuse practices.

Awareness Levels Among External Stakeholders
Niels van Olffen from Stichting ZonNext (ZN) observed that reuse practices are gaining traction among external stakeholders, particularly within municipalities like Amsterdam and Rotterdam. He described this shift as "spreading like an oil slick," indicating that awareness and interest in reuse practices are growing among some external actors. Sietse de Vilder from AMS1 also noted a growing momentum for reuse; however, he pointed out that this interest is often overshadowed by a stronger focus on technological development and recycling. According to de Vilder, "the potential of reuse is overshadowed by the focus on technological development and recycling," suggesting that external stakeholders may not yet fully recognize the benefits of reuse compared to other advancements.

Confidence and Skepticism from External Stakeholders
While there are signs of increasing awareness, some external stakeholders express caution regarding reuse practices. Esther Zumpolle from Stichting ZRN, representing producers and importers, voiced skepticism about the engagement with reuse, stating, "My expectations are not very high; I hope to be pleasantly surprised." Similarly, Jeroen Kruisheer from Wocozon (WCZ) highlighted concerns about the safety and insurance implications of second-hand panels, mentioning they are perceived as "more fire-prone than new panels." Gerard de Leede from Solarge (SOL) also pointed out economic concerns, preferring "the reuse of materials and components rather than whole panels," due to cost considerations. These perspectives reflect varying levels of confidence and highlight different priorities among stakeholders outside the immediate reuse network.

Changing Roles and Perceptions

The roles of traditional waste processors are also evolving in response to growing interest in reuse and refurbishment. Henk Bos (WNL) noted that traditional waste processors are beginning to explore new roles within the value chain as awareness of reuse benefits increases. This shift in roles reflects a broader engagement with reuse practices among external stakeholders, indicating potential changes in how these stakeholders perceive and interact with the reuse niche.

6.1.3 EXOGENOUS EXPECTATIONS

Exogenous expectations are shaped by external developments such as market trends, regulatory changes, and broader socio-economic factors that influence the niche indirectly. These expectations are important for understanding how factors outside the niche impact strategies and expectations within it.

Impact of Market Trends and Economic Pressures

Sietse de Vilder (AMS1) highlighted the challenge of competing with new panels, noting, "New panels currently have a historically low price, making it difficult for second-hand panels to compete." This market trend is a significant external factor shaping the organization's strategies and expectations. Similarly, Gerarde de Leede (SOL) noted that shareholder expectations for returns significantly impact strategic decisions, citing examples from large corporations like Shell and Exxon to illustrate how financial considerations often outweigh environmental motivations.

Regulatory and Policy Influences

Aukje Bezeij (ZL) discussed the rising costs of installation and insurance, highlighting that regulations now require "everything to be scope 12 certified," creating uncertainty around how these standards apply to used panels. This regulatory ambiguity presents a significant external barrier to scaling reuse practices. Similarly, Gijs Ten Brinke (S2C) emphasized the volatility in panel availability and the lack of stable input streams, challenges that are further exacerbated by regulatory and policy uncertainties. He expressed hope that "the procurement process with Stichting OPEN will provide more direction," underscoring the sector's reliance on clear external regulatory frameworks.

Opportunities from External Developments

Henk Bos (WNL) identified opportunities for reuse in regions with high solar radiation, such as Africa, noting that there could be substantial environmental benefits even in scenarios with low economic returns. He also highlighted a project in Ukraine with Tesla, involving off-grid installations for field hospitals or regular hospitals, demonstrating the practical applications of reuse in various settings. These examples suggest potential exogenous opportunities for niche expansion.

6.1.4 ENDOGENOUS EXPECTATIONS

Endogenous expectations develop from within the niche, shaped by internal learning experiences, interactions, and adaptations. These expectations reflect how stakeholders refine their strategies and goals based on their direct involvement and experiences within the reuse niche.

Learning from Direct Involvement and Local Experiences
Stakeholders directly involved in reuse practices, such as AMS Institute, ZonNext, and Zuiderlicht, have developed specific expectations based on their practical experiences. Sietse de Vilder (AMS1) emphasized the value of local pilot projects, noting, "If you set something up locally and it proves successful, you can expand that model to other cities." This reflects an endogenous expectation that local successes can be scaled, influencing broader strategic decisions. Similarly, Niels van Olffen (ZN) highlighted that internal learning and reflection have led to a more pragmatic approach where reuse is viewed as a viable strategy not just for cost reduction but also for sustainability. This shift is driving the organization's strategy to integrate more reuse and refurbishment efforts. Aukje Bezeij (ZL) discussed challenges in scaling up reuse, pointing out capacity constraints and the need to adapt to a "mindset focused on money," which requires internal training and organizational change, indicating a continuous adaptation to internal challenges.

Adaptation and Internal Debates Among Non-Directly Involved Stakeholders
On the other hand, stakeholders like Wocozon (WCZ), Solarge (SOL), and ZRN, who have not been directly involved in reuse practices, are also shaping their expectations based on internal discussions and observations. Jeroen Kruisheer (WCZ) emphasized the internal debate about adopting circular panels, with some advocating for a leadership role in sustainability while others are cautious due to perceived risks. This internal discourse illustrates how expectations and strategies are shaped even without direct involvement in reuse activities. Similarly, Gerard de Leede (SOL) and Esther Zumpolle (ZRN) have emphasized the importance of adapting expectations based on niche dynamics, such as the growing recognition of the benefits of high-quality recycling over full-panel reuse. "High-quality recycling is seen as the best solution," noted SOL, reflecting a strategic realignment within the niche based on their observations and accumulated knowledge.

6.1.5 CONCLUSIONS FROM THE EXPECTATIONS ANALYSIS

6.1.1 **Internal Expectations** predominantly act as an enabler for the reuse niche, especially among stakeholders directly engaged in reuse activities. These stakeholders have shifted from initial, exploratory goals, such as international export, to more structured, local strategies that focus on sustainable and manageable reuse practices. This evolution reflects a growing confidence in the feasibility and scalability of reuse, fostering internal alignment and commitment to advancing the niche. While the emphasis on local applications and adaptability indicates a positive outlook, ongoing challenges and a need for continued learning highlight areas where further internal alignment could enhance the niche's development.

6.1.2 **External Expectations** function as both an enabler and a barrier. Increased awareness and interest in reuse among municipalities and certain external stakeholders create a supportive environment for collaboration. However, skepticism from producers, importers, and some market actors about the economic viability and safety of reused panels presents a barrier. This mixed external perception highlights the need for targeted efforts to enhance acceptance and integration of reuse practices.

6.1.3 **Exogenous Expectations** tend to act as a barrier due to economic pressures from low-cost new panels and regulatory uncertainties that challenge the reuse niche's competitiveness. These external factors create significant obstacles to scaling reuse practices. Nonetheless, opportunities in international markets and specific applications present potential for niche expansion if conditions are favorable.

6.1.4 **Endogenous Expectations** generally enable niche development by fostering continuous learning and adaptation among stakeholders directly involved in reuse activities. These expectations are informed by practical experience, encouraging a realistic and flexible approach to challenges. However, cautious attitudes among non-directly involved stakeholders may slow progress, suggesting that while endogenous expectations support niche growth, better internal alignment could enhance their positive impact.

6.2 NETWORK FORMATION

In Strategic Niche Management, network formation refers to the ability of the niche to establish relationships between different actors who contribute to the development and scaling of the innovation. This section evaluates how well the network supporting PV panel reuse is composed, its quality, the frequency and nature of interactions, and the alignment of goals among participants.

6.2.1 NETWORK COMPOSITION

Network composition refers to the range of stakeholders involved in the reuse of PV panels and assesses whether the network is sufficiently comprehensive to support the scaling of reuse practices.

Key Actors and Their Contributions

Municipal Authorities and Housing Corporations
Municipalities like Gemeente Amsterdam and housing corporations are critical for providing infrastructure and creating demand for reused panels. They act as key intermediaries, linking the supply of certified panels to suitable applications, such as temporary roofs or flexible housing solutions. Niels van Olffen (ZN) emphasized the role of these entities: "Municipalities like Amsterdam play a 'launching customer' role, and housing corporations are crucial for filling temporary roofs or flexible housing solutions" (ZN). This demonstrates how these actors help drive demand and facilitate the practical deployment of reused panels. Sietse de Vilder (AMS1) further highlighted the role of municipalities in funding opportunities: "Using social return can create funding opportunities for reuse projects in Amsterdam" (AMS1).

Operational and Recycling Partners:
Refurn and WEEE Nederland are pivotal in the technical assessment and preparation of panels for reuse. These organizations ensure that panels meet quality standards before redeployment. Niels van Olffen (ZN) noted, "Parties like Refurn and WEEE Nederland are essential as they carry out the work necessary for reuse. Without them, the process would not advance" (ZN). This emphasizes their fundamental role in maintaining the quality and effectiveness of the reuse process.

NGOs and Cooperatives:
Stichting ZonNext and Zuiderlicht are instrumental in coordinating reuse initiatives and engaging the community. ZonNext facilitates connections between panel owners and new users, helping maintain a steady flow of panels within the network. Zuiderlicht actively engages with local communities to build support for reuse projects, which is crucial for the successful deployment and acceptance of reused panels.

Academic and Research Institutions:
AMS Institute and TU Delft contribute by conducting research, running pilot projects, and

developing innovations in reuse technologies and strategies. These institutions provide the data and insights needed to support policy development and decision-making.

Private Sector and Financial Institutions:
The private sector and financial institutions, particularly those with a focus on Environmental, Social, and Governance (ESG) goals, could provide substantial financial support for scaling reuse practices. Sietse de Vilder (AMS1) highlighted the potential of engaging these entities more deeply: "Large financiers interested in ESG objectives or social transition indicators could play a crucial role," with the Rabobank Foundation already showing support (AMS1).

Enhancing the Network Composition

Completeness of current network
The current network is complete enough to realize reuse practices for PV. Niels van Olffen (ZN) stated, "At this stage, I don't think any actors are missing. The more, the better, but we now need to scale up" (ZN). This perspective suggests that while the network may not be fully comprehensive, it is adequate for initiating reuse practices. However, scaling up would require additional actors and resources. Similarly, Henk Bos (WNL) noted that despite having a network, it remains limited in scope, emphasizing the need to expand the network of operational partners: "There is a network, but it is a narrow one because we are the only ones doing it" (WNL).

Need for Broader Engagement from Producers and EPR Organizations:
To achieve scale, there are still critical gaps to address, such as the absence of producers and Stichting OPEN, which are essential for a more systematic approach to reuse and recycling. Henk Bos (WNL) pointed out, "Producers and producer responsibility are missing; for example, Stichting OPEN is not yet involved" (WNL). These entities are crucial for ensuring a circular flow of materials, facilitating better management of reusable panels, aligning with circular economy principles, and providing funding for reuse practices. Bos advocated for an integrated system where materials are sorted and assessed for reuse, stating, "We advocate for materials to go to a sorting center where it is assessed what can and cannot be reused" (WNL). Their active participation could strengthen lifecycle management and provide a systematic approach to end-of-life PV panel management.

Inclusion of Smaller Installers and Repair Entities:
There is a recognized need to involve smaller installers and repair entities more effectively. These actors could play a pivotal role in refurbishing and maintaining panels, ensuring their longevity and quality. Aukje Bezeij (ZL) highlighted this gap, suggesting that "Smaller entities and repair cafés could contribute significantly if better integrated into the network" (ZL). Their involvement could enhance grassroots-level engagement, which is vital for the network's robustness and the sustainability of reuse practices.

Engaging Private Sector and Financial Institutions:
Engaging more private sector entities and financial institutions with a focus on ESG goals could

provide the necessary financial support for scaling reuse practices. As Sietse de Vilder (AMS1) noted, "Large financiers interested in ESG objectives or social transition indicators could play a crucial role" (AMS1). Their involvement would not only bring in funding but also add legitimacy to the reuse niche, attracting more stakeholders and increasing the network's overall capacity.

6.2.2 QUALITY OF THE SUB NETWORKS

The quality of the subnetworks refers to the effectiveness with which different stakeholder groups contribute to the development and scaling of the PV panel reuse niche. It evaluates the depth, effectiveness, and impact of their contributions, focusing on collaborative efforts, innovation, and operational excellence.

Evaluating Stakeholder Effectiveness

Municipal and Government Bodies: The municipality of Amsterdam goes beyond acting as a "launching customer"; it proactively simplifies the reuse process and integrates social value into initiatives. Sietse de Vilder (AMS1) highlighted the municipality's initial support, crucial for jumpstarting the reuse chain, and its role in funding reuse projects through social return initiatives. Niels van Olffen (ZN) acknowledged the city's motivation to meet sustainability goals, which sets a strong example for other regions.

Non-Governmental Organizations and Cooperatives: NGOs like Stichting ZonNext (ZN) and cooperatives such as Zuiderlicht (ZL) play a central role in maintaining high standards for reused panels. ZonNext employs rigorous testing and certification processes, ensuring durability and reliability, as noted by Henk Bos (WNL): "We have purchased testing equipment and work with Solar Tester to maintain high standards, ensuring panels can last another 15-20 years" (WNL). Zuiderlicht collaborates with academic institutions like TU Delft and the University of Amsterdam to integrate educational opportunities with practical applications, fostering a learning environment and enhancing social sustainability.

Private Sector and Operational Partners: The private sector contributes to the reuse network's capacity and appeal through significant investments in infrastructure and social initiatives. For example, WEEE Nederland has invested €200,000 in a professional washing facility and integrates social labor, reinforcing its dual focus on environmental and social outcomes.

Collaborative Strengths

Academic and Research Partnerships: Collaborations with institutions such as TU Delft and the University of Amsterdam have been pivotal in advancing technical innovation and educational engagement. These partnerships provide essential R&D support, contributing to the continuous improvement of reuse methodologies and solutions.

Pilot Projects and Knowledge Sharing: Pilot projects are a cornerstone of the network's strategy, offering practical learning experiences and fostering a culture of continuous improvement. Aukje Bezeij (ZL) emphasized the importance of these projects and the cooperative approach to knowledge sharing: "We must continue with these pilot projects and always try to learn from each experience. Sharing knowledge is something cooperatives always do" (ZL).

Challenges and Areas for Improvement

Regulatory and Certification Barriers: A significant challenge is the lack of standardized certification for reused panels, which limits broader adoption. Jeroen Kruisheer (WCZ) pointed out that without recognized certifications, reused panels are often not insurable, which restricts their marketability.

Limited Engagement of Smaller Actors: The network's flexibility and scalability are hindered by the limited integration of smaller entities, such as individual installers and repair shops. Aukje Bezeij (ZL) suggested that enhancing collaboration with smaller local initiatives, like repair cafés, could improve grassroots engagement and operational capacity.

Need for Broader Institutional Support: There is a noticeable gap in the engagement of producers and EPR organizations, which is crucial for establishing a circular economy model. Henk Bos (WNL) highlighted this barrier, noting the lack of proactive participation from producers.

6.2.3 NETWORK INTERACTIONS

Network interactions refer to the effectiveness and frequency of communication between different stakeholders within the PV panel reuse network. This includes examining how well different actors communicate, the methods or platforms they use, and whether these interactions are perceived as effective. Understanding the nature of these interactions is crucial for identifying potential barriers to collaboration and opportunities to enhance cooperation for scaling up reuse practices.

Communication Among Core Stakeholders

Within the PV panel reuse network, core stakeholders, including Stichting ZonNext (ZN), the Municipality of Amsterdam (AMST), and WEEE Nederland (WNL), generally maintain effective communication. Sietse de Vilder (AMS1) describes these stakeholders as forming a "hard core" within the network, working closely together due to their aligned interests and mutual goals. This effective communication is facilitated by a shared understanding of objectives and the mutual benefits of collaboration (AMS1). However, interactions with other entities, such as housing corporations, can be inconsistent. De Vilder (AMS1) notes that while some corporations, like Ymere, are proactive and responsive, others may take weeks to respond, causing delays in project progress. This variability suggests that while core stakeholders have robust communication, effectiveness can vary significantly across different stakeholder types (AMS1).

Frequency and Nature of Interactions
The interactions within the network are often characterized by their informal and opportunistic nature. Niels van Olffen (ZN) mentions that while networking events and European initiatives provide some opportunities for interaction, there is no standardized structure for meetings specifically focused on PV panel reuse in the Netherlands. Similarly, Gerard de Leede (SOL) points out that stakeholders often meet at events, but these encounters are more opportunistic than strategically planned. This indicates a gap in structured, long-term collaboration efforts that could be addressed to enhance network effectiveness.

Challenges in Communication and Coordination in Pilots
Several stakeholders have highlighted challenges related to communication and coordination within pilot projects. Francesca Alberti (AMS2) discusses bureaucratic hurdles and slow response times, which have complicated coordination efforts, especially in multi-stakeholder projects like the Kazerne project. She notes, "Sometimes, you'd email someone and hear back three weeks later," underscoring how these delays can impact project timelines (AMS2). Additionally, Alberti points out that a clearer understanding of responsibilities among stakeholders at the start of projects could prevent some delays (AMS2). Aukje Bezeij (ZL) echoes these sentiments, describing challenges in projects like Marineterrein, where logistical problems and insufficient planning led to delays and frustrations. She describes the process as "incredibly difficult," highlighting the lack of coordination as a critical issue that negatively impacted the project's progress (ZL).

Citizen Engagement and Pressure on Municipalities
Francesca Alberti (AMS2) also identifies a gap in the current network interactions related to citizen involvement. "We might have the technology and ideas and stakeholders, but we still lack a strong citizen voice," she notes (AMS2). To enhance engagement, she suggests providing more practical, accessible formats like a handbook outlining the reuse process step-by-step. This would help citizens better understand the process and actively participate in discussions with experts. She recommends, "Instead of multiple workshops, we could provide a handbook or an overview and engage citizens more actively with experts, giving them a platform to express their thoughts" (AMS2). This approach could also help mobilize citizen support to pressure municipalities to take more decisive actions on reuse initiatives.

6.2.4 NETWORK ALIGNMENT

Network alignment examines how well stakeholders' visions, expectations, and strategies align with the overall goals of the PV panel reuse niche. Alignment is crucial for coherent niche development, as misalignment can fragment efforts, while strong alignment promotes collaboration and efficiency.
Findings:

Diverse Visions and Expectations Among Stakeholders
"Stakeholders within the PV panel reuse network demonstrate varying degrees of commitment and strategic focus, which influences the network's overall alignment. While core stakeholders like Stichting ZonNext, the Municipality of Amsterdam, and WEEE Nederland share a common vision for advancing reuse practices, there are notable differences in how other stakeholders, such as housing corporations, prioritize their involvement. Sietse de Vilder (AMS1) observed that some entities are highly proactive in their approach, aligning closely with the reuse niche's goals, whereas others exhibit less urgency or differing strategic priorities. These disparities in engagement levels and strategic focus highlight challenges in achieving a unified direction, as different stakeholders allocate resources based on their specific agendas and objectives."

Structural and Cultural Barriers to Alignment:
Alignment within the network is also challenged by structural and cultural barriers within organizations. Henk Bos (WNL) highlighted significant internal conflicts, pointing out that different departments within the same organization often have conflicting goals. He noted, "In Amsterdam, one department wants to promote sustainability, but another focuses on procuring as cheaply as possible. If you don't procure sustainably and are only judged on low cost, that conflicts" (WNL). This type of internal misalignment can fragment efforts and prevent the development of a cohesive strategy, as different departments prioritize different outcomes.

Differing Strategic Approaches to Reuse and Recycling:
The network also faces challenges in aligning on strategic approaches to balancing reuse and recycling. Gerard de Leede (SOL) advocated for a balanced strategy, suggesting that "Reuse and recycling should go hand in hand. Reuse is beneficial when items still have value, like for temporary housing, and they can always be recycled later" (SOL). However, not all stakeholders share this sequential strategy. Some focus exclusively on recycling, potentially limiting a cohesive approach to achieving circularity. This divergence in strategy illustrates the need for better alignment on long-term objectives and methodologies to maximize both reuse and recycling efforts.

6.2.5 CONCLUSIONS NETWORK FORMATION

The current **6.2.1 network composition** is an enabler for the PV panel reuse niche. It includes a diverse set of stakeholders, such as municipal authorities, NGOs, academic institutions, and private sector entities, who provide essential infrastructure, technical expertise, and community engagement. The network's foundational composition is strong enough to support initial reuse practices, which is vital for the niche's nurturing phase. However, to scale further, it requires broader engagement from producers, Extended Producer Responsibility (EPR) organizations, and smaller installers. Addressing these gaps would enhance the network's robustness and ability to sustain and expand reuse practices, aligning with the nurturing function of SNM by promoting a stable and supportive environment for niche growth.

The **6.2.2 quality of the subnetworks** is largely an enabler but also presents some barriers to the development of the reuse niche. Effective contributions from key actors, such as municipalities, NGOs, and private sector partners, ensure high standards for reuse practices and foster a collaborative environment. These strengths align with SNM's nurturing function by facilitating learning processes, setting high standards, and promoting innovation within the niche. However, challenges such as regulatory and certification barriers and limited engagement from smaller actors indicate areas where improvements are necessary. Overcoming these barriers is crucial to enhancing the network's effectiveness and supporting the scaling of reuse practices.

6.2.3 Network interactions within the PV panel reuse niche are both an enabler and a barrier. Core stakeholders exhibit effective communication and cooperation, which fosters a cohesive network environment and aligns with the nurturing aspect of SNM by maintaining momentum and facilitating shared learning. However, inconsistencies in communication with peripheral stakeholders and the lack of structured, strategic collaboration hinder broader network alignment and scalability. These gaps represent barriers that need to be addressed to ensure more cohesive interactions, enhance trust, and foster collaboration, ultimately enabling a more effective and integrated network for reuse practices.

6.2.4 Network alignment currently acts more as a barrier to the development of the PV panel reuse niche. While there is a strong alignment among core stakeholders, differences in strategic priorities, internal organizational conflicts, and varying approaches to balancing reuse and recycling create fragmentation within the network. This misalignment challenges the coherent development of the niche, as it prevents unified action and coordinated efforts, crucial for niche progression according to SNM. To convert this barrier into an enabler, stakeholders need to engage in dialogue to align their visions, expectations, and strategies more closely with the niche's overall goals, thereby fostering a more collaborative and efficient network environment.

By drawing these conclusions, each indicator's role as an enabler or barrier is clarified in relation to its impact on the nurturing phase of the PV panel reuse niche's development, as framed by the Strategic Niche Management (SNM) theory.

6.3 LEARNING PROCESSES

Learning is a central element of niche development, providing opportunities for actors to improve both technological and organizational capabilities. This section evaluates how actors within the PV reuse niche have engaged in technical, industrial, social, and environmental learning processes.

6.3.1 TECHNICAL DEVELOPMENT AND INFRASTRUCTURE

Definition and Relevance

Learning in technical development and infrastructure involves understanding the design specifications, complementary technologies, and the required infrastructure necessary for technology dissemination. This process is critical for identifying and overcoming technical barriers, optimizing deployment strategies, and ensuring the necessary support systems are in place for widespread adoption.

Technical Rationale for Testing and Installation

To ensure the safety and effectiveness of reused PV panels, comprehensive testing and certification are crucial. Henk Bos (WNL) emphasizes that reused panels must undergo rigorous testing and inspection to confirm their functionality and safety. He notes, "If you want to give solar panels a second life, you must do it in a high-quality manner, including inspections and tests similar to new solar panels" (WNL). This preparation process includes visual inspections for damage, thorough cleaning, and specific testing for electrical performance and structural integrity. WEEE NL, for instance, has invested in specialized testing equipment to detect cracks and other defects that could affect the panels' longevity (WNL).

Following the initial assessment, comprehensive testing and certification are necessary to ensure the quality and safety of the reused panels. Bos further emphasizes the importance of rigorous testing, noting, "We have invested in high-standard testing equipment and collaborate with Solar Tester, applying stringent standards to reused panels, similar to new ones" (WNL). This thorough testing process aims to confirm that reused panels meet safety and performance standards for an extended lifecycle.

Niels van Olffen (ZN) suggests that testing should begin even before panels reach advanced testing facilities to streamline the process and minimize costs: "Ideally, the assessment should be done on the roof during removal, so it's immediately clear which panels are suitable for reuse and which should go directly to Refurn Apeldoorn for further inspection" (ZN). This proactive testing could help in identifying reusable panels early, reducing unnecessary handling and transport that could degrade their quality.

Storage and Maintenance Requirements

Proper storage facilities are necessary to maintain the quality of the panels before they are reused. Sietse de Vilder (AMS1) highlights the importance of secure storage solutions, stating, "If you have a storage location and more continuity in the chain, this is less of a problem" (AMS1). The absence of adequate storage and handling protocols can lead to significant losses, as evidenced by instances where panels with potential for reuse were discarded due to improper handling or damaged cables during removal.

Complementary Technologies and Process Innovations

Developing complementary technologies and innovative processes is essential for enhancing the reuse of PV panels. Henk Bos (WNL) highlights a proactive approach in this area, mentioning the development of a "washing street" for panels, an investment aimed at professionalizing the cleaning process. "This allows for efficient cleaning, even in winter, which is not feasible manually," states Bos (WNL). Such innovations help maintain the quality of reused panels, making them more viable for extended use.

Continuous Learning from Experimental Projects
Continuous learning through experimental projects and pilot initiatives is crucial for advancing technical development and infrastructure in the reuse of PV panels. Pilot projects provide invaluable insights into real-world challenges and help refine processes. For example, in a pilot project at the Kazerne, Francesca Alberti (AMS2) observed significant difficulties in securing insurance for the overall installation on that specific rooftop. She explains, "Insurance was tricky because, while Sungevity was willing to supply the used panels and conducted the safety checks for them, getting insurance for the actual installation was still challenging" (AMS2). It wasn't clear who oversaw arranging the installation's insurance. At the end, the owner of the building (municipality) set it up. This case illustrates the need for clearer regulatory frameworks and streamlined certification processes to reduce barriers and facilitate market growth for PV panel reuse.

Stakeholders like Henk Bos (WNL) and Aukje Bezeij (ZL) underscore the importance of pilot projects in addressing these barriers and advancing the niche. Bos notes, "We need to bring things into practice to drive the transition, and this involves continuous learning and adaptation" (WNL). Similarly, Bezeij emphasizes that "pilot projects allow for learning from every experience, which is crucial for refining our approach to reusing panels" (ZL). These projects foster a proactive approach to experimentation, evaluation, and adjustment, essential for overcoming technical and logistical challenges and promoting the reuse of PV panels more broadly.

6.3.2 INDUSTRIAL DEVELOPMENT

Definition and Relevance
Learning in industrial development within the PV panel reuse sector focuses on understanding the practical aspects of preparing and maintaining reused panels. This includes the logistical processes involved in their installation, storage, and handling, as well as the role of networks in facilitating these activities. Effective industrial development supports the broadening of technology dissemination through established practices for maintenance, preparation, and collaboration.

Logistics and Handling of Reused Panels:
Efficient logistics and handling are vital for minimizing damage to panels and reducing costs. Gijs ten Brinke (S2C) underscores the importance of safe handling practices during transport and storage, noting that improper methods often result in significant damage: "Panels are often thrown from roofs into containers, causing damage" (S2C). This problem highlights the need for strict guidelines to ensure panels remain intact during these processes, which is essential for preserving their usability and value. For the recycling happening at S2C, it is also a necessity that PV panels arrive without being damaged. To address this, S2C has implemented rigorous standards for panel collection and transport. "We want to know exactly what panels we are receiving," Gijs ten Brinke explains. "We require parties to submit a list detailing the type, quantity, and dimensions of panels. They must be placed on pallets with the glass side facing down and secured with wrap or straps" (S2C). These measures prove that with careful planning

and execution, it is entirely possible to handle panels properly, preserving their condition and value for reuse or recycling.

To reduce transportation costs and improve accessibility, a decentralized approach is suggested. Gijs Ten Brinke (S2C) proposes setting up multiple collection points, saying, "In every province, you could have several points where panels can be handed in. That would significantly save on transport costs" (S2C). This approach would facilitate easier collection and distribution, enhancing the efficiency of panel reuse networks.

Storage Challenges and Solutions:
Effective storage management of PV panels poses several logistical and financial challenges that stakeholders must navigate to facilitate reuse. Sietse de Vilder (AMS1) highlights a fundamental issue in organizing pilot projects: the complex dynamic between supply and demand. He underscores the importance of establishing clear agreements on storage logistics early on, stating, "It is crucial to establish beforehand where panels will be stored, who will be responsible for them, and who bears the financial risks. The longer the panels sit in storage, the higher the costs become" (AMS1). This highlights the need for strategic planning in storage to mitigate rising costs and avoid financial ambiguities that could hinder project feasibility.

To address these challenges, several strategic approaches have been proposed to optimize storage for reused PV panels. Sietse de Vilder (AMS1) mentions a proactive step taken by stakeholders with the establishment of a dedicated storage facility for the reuse chain, which has helped streamline the process and reduce ambiguities. He notes, "Now that we have a storage location for the reuse chain we are setting up, we can put a concrete price tag on a panel, which was harder to do before" (AMS1). This development not only provides clarity in pricing but also offers a controlled environment to manage inventory more effectively, ultimately contributing to cost management.

Esther Zumpolle (ZRN) suggests leveraging existing infrastructures and partnerships to provide flexible storage options, mentioning, "Municipalities could facilitate certain things, such as storage space. Maybe also wholesalers who think, 'You still have some space, why not offer it?'" (ZRN). This collaborative approach could help optimize resource use and reduce storage costs.

Testing and Installation from an Operational Perspective:
Testing and installation are critical from an operational standpoint to ensure panels are fit for reuse. The operational concern is how testing is integrated into the workflow, including cost management and logistical considerations. Niels van Olffen (ZN) suggests that on-site assessments could streamline the process: "Ideally, the assessment should be done on the roof during removal, so it's immediately clear which panels are suitable for reuse and which should go directly to Apeldoorn for further inspection" (ZN).

However, even with thorough testing, concerns about liability and warranties remain significant operational barriers to broader adoption. These issues impact how reused panels are marketed and sold, as installers are wary of the risks involved with second-hand products. Esther Zumpolle

(ZRN) points out, "A regular installer won't guarantee someone else's old stuff…" (ZRN). Gijs Ten Brinke (S2C) further elaborates, "No one dares to offer a warranty on second-hand panels. If they catch fire, who is responsible?" (S2C). He highlights a specific challenge: "The original installer provides a 25-year warranty, but that becomes void when the panels change hands. What if a tested panel still catches fire? Who would be liable? I wouldn't dare install second-hand panels" (S2C).

These warranty and liability issues present operational challenges that need to be addressed through effective management strategies and clearer agreements among stakeholders to foster confidence in the reuse market.

Challenges and Learning in Industrial Processes:
The industrial processes associated with preparing and maintaining reused PV panels come with several challenges that stakeholders have identified through their experiences. Francesca Alberti (AMS2) discusses the complications arising from additional costs and safety concerns when installing second-hand panels. She notes, "There were issues around fire safety, and more insurance requirements, like ensuring the roofs were leak-proof and strong enough, which added more costs" (AMS2). These challenges highlight the need for clearer protocols and better coordination among stakeholders to address technical and safety concerns effectively.

Strategies for Effective Industrial Development:
Learning from these experiences, stakeholders have identified several strategies to enhance the industrial development of reused PV panels. One key strategy is to invest in specialized infrastructure and equipment that supports high-quality preparation and maintenance of panels. For example, Bos (WNL) mentions the installation of a professional washing line for panels, a significant investment aimed at improving the quality of reused panels (WNL).
Another strategy involves expanding collaborative networks to include a broader range of stakeholders, such as educational institutions, community groups, and local governments. This expansion helps build a more robust support system for the reuse of PV panels, facilitating knowledge exchange, and capacity building. As Bezeij (ZL) highlights, "The most beautiful thing would be to also use the reused panels in a way that adds social value" (ZL). This approach not only promotes sustainability but also fosters community engagement and social innovation.

Role of Networks in Supporting Installation and Reuse:
Networks play a crucial role in promoting and supporting the installation of reused PV panels. Niels van Olffen (ZN) points out that networks such as Stichting ZonNext are instrumental in coordinating between suppliers, installers, and testing facilities to streamline the reuse process. He explains, "Stichting ZonNext works to quickly assess whether panels are suitable for reuse before they are removed from roofs, preventing unnecessary damage and ensuring they are handled properly" (ZN). This network coordination helps reduce logistical challenges and ensures that panels are adequately prepared for their new installations.

Collaboration among various stakeholders, including municipalities, recycling organizations, and private companies, has also been key to promoting the reuse of PV panels. Aukje Bezeij (ZL) mentions efforts to involve community organizations and educational institutions in projects that use reused panels. "We are retraining project leaders and focusing on young people," she explains, "It's about changing mindsets and building capacity" (ZL). These collaborative efforts help expand the network of professionals and organizations involved in the reuse niche, promoting broader dissemination and adoption of reused panels.

6.3.3 SOCIAL AND ENVIRONMENTAL IMPACT

Definition and Relevance:
Learning about the social and environmental impacts in the context of reusing PV panels involves understanding the broader effects of this practice on communities, employment, and sustainability goals. This indicator examines how these impacts shape stakeholder engagement and influence project approaches to enhance the acceptance and effectiveness of solar panel reuse.

Social Impact: Employment and Community Engagement
Reusing photovoltaic (PV) panels offers more than just environmental benefits; it presents a powerful opportunity for social change. This approach aligns sustainability with broader social values, demonstrating how renewable energy initiatives can drive positive societal impacts beyond financial returns.

The broader social impact of PV panel reuse lies in its potential to redefine value creation. Henk Bos (WNL) emphasizes this shift, stating, “We want to do something social… Value creation is more than financial gain.” ZonNext repurposes PV panels not for profit but to create social good, highlighting how these initiatives can prioritize societal benefits over economic returns. Bos advocates for deploying reused panels in areas like Africa, where solar yield is high, underscoring a global perspective that combines sustainability with social equity. “We are not going to solve the climate problem with a business model. We will have to spend money to do the right things,” he adds (WNL), challenging traditional business paradigms and urging a focus on holistic value.

Beyond redefining value, PV panel reuse initiatives also offer tangible benefits through job creation and community involvement. Sietse de Vilder (AMS1) points out that reusing solar panels can create employment for people with limited access to the labor market: “The costs for a second-hand solar panel are largely in operational costs, which can be filled by these people” (AMS1). This approach not only lowers deployment costs but also provides meaningful employment opportunities, integrating social labor into sustainable practices. Francesca Alberti’s experience with the Kazerne project highlights the dual potential of reuse initiatives. The project aimed to promote reuse by installing second-hand panels while also planning to train unemployed individuals in installation skills. However, due to several delays, this training goal was not fully realized. Instead, Sungevity organized the installation by providing a team for the task. Alberti reflects, “You get two birds with one stone—reuse panels and provide new skills to people,” pointing to the broader potential of such projects to foster community pride and ownership, even if this goal was not fully achieved in this instance.

Addressing energy poverty is another significant social benefit of PV panel reuse. In the Netherlands, 10 to 15% of people live in energy poverty, as noted by Gerarde de Leede (SOL). He suggests that "lower-performing solar panels" could be deployed to help alleviate this issue, although limited roof space presents a challenge (SOL). This approach offers a creative solution where less efficient panels can still provide valuable energy to those in need.

Changing mindsets and behaviors toward sustainability is also a crucial outcome of reuse initiatives. Aukje van Bezeij (ZL) believes that involving people in these projects can lead to lasting change. “If you’ve contributed to the first project… you will take it with you for the rest of your life,” she states (ZL), suggesting that participation fosters a deeper commitment to sustainable practices.

Meanwhile, Esther Zumpolle (ZRN) points out the challenges faced by developers in balancing social goals with economic realities. She describes the solar market as a "cowboy world" where continuity is often lacking, making it difficult to commit to reuse projects that may not offer immediate financial returns (ZRN). Despite these challenges, she acknowledges the potential for social return on investment, especially when projects are designed to provide broader social benefits, such as employment or education.

Environmental Impact: Sustainability and Resource Efficiency

Following the exploration of social benefits, it is crucial to understand the significant environmental impacts of reusing photovoltaic (PV) panels. Reuse initiatives contribute to sustainability by reducing waste, conserving resources, and lowering carbon footprints. By extending the lifespan of solar panels, these practices help achieve environmental goals while addressing challenges related to energy use and efficiency.

Research by de Vilder et al. (2024) highlights the substantial environmental benefits that can be achieved by extending the lifespan of solar panels in urban areas like Amsterdam. Their study, "De Impact van Gebruiksduurverlenging van Zonnepanelen in Steden," quantifies the potential CO2 reduction when the lifespan of solar panels is extended from the current average of 12 years to 25 years. The findings suggest that such a lifespan extension could avoid up to 125 kilotons of CO2 emissions at the city level by 2040, even under conservative scenarios. This reduction is equivalent to the total annual emissions from energy consumption by approximately 37,800 households, illustrating a significant environmental impact (de Vilder et al., 2024).

The study outlines several scenarios that demonstrate varying degrees of climate benefits based on technological advancements and policy shifts, such as the relocation of PV production to Europe and changes in the electricity mix in the Netherlands. Even in the least optimistic scenario, the environmental gains from extending the operational life of solar panels are substantial. If Amsterdam successfully implements policies to extend the average operational life of solar panels from 12 to 25 years, the city could achieve a CO2 reduction comparable to the emissions saved by converting one to two city districts, like the Kinkerbuurt, from natural gas to alternative energy sources (de Vilder et al., 2024).

These findings underscore the importance of prioritizing reuse over replacement in urban settings, where the cumulative environmental benefits are most pronounced. Henk Bos (WNL) supports this view, noting that reusing panels can significantly reduce the energy and resources required compared to recycling or disposing of old panels. "Reusing panels, if possible, is always better," he asserts, highlighting the need to explore opportunities for reuse before recycling (WNL).

Additionally, reuse initiatives play a crucial role in waste management and resource conservation. Instead of disposing of panels that retain some utility, combining reuse with recycling maximizes their environmental benefits. Gerard de Leede (SOL) points out, “We must ensure that reuse and recycling go hand in hand. It's good to reuse something if it still has value, for example, on temporary housing, and it can always be recycled afterward” (SOL). This approach supports a circular economy by ensuring materials are fully utilized before recycling, reducing waste and conserving resources.

Moreover, Gerard de Leede (SOL) highlights the potential environmental benefits of reusing materials like solar-grade silicon. Producing new solar-grade silicon is an energy-intensive process with a significant carbon footprint. "If you can reuse silicon that has already been used, that's the ideal picture," he explains, underscoring the environmental advantages of reusing existing materials over producing new ones (SOL). Extending the operational life of panels effectively delays the need for new material production and provides time for developing advanced recycling technologies that can reclaim high-value materials more efficiently in the future (de Vilder et al., 2024).

However, the environmental benefits of reuse are not without challenges. The efficiency and performance of older panels must be considered to ensure their deployment is both environmentally and economically viable. Gerarde de Leede (SOL) suggests that while lower-performing panels could be repurposed, practical limitations like limited roof space can affect their effectiveness: “These people often have little roof space, while you want to cover your roof with as high a yield as possible to get the maximum out of it” (SOL). Strategic placement is essential to maximize both environmental benefits and practical utility.

6.3.4 DEVELOPMENT OF THE USER CONTEXT

The adoption of reused photovoltaic (PV) panels is shaped by various user characteristics, barriers, and driving factors. Understanding these elements is crucial for promoting reuse practices. This subchapter examines the end-user profiles that are critical for the acceptance of reused panels, the barriers they face, and strategies to enhance adoption.

User Characteristics

1. **Community-Oriented Organizations**:
   Community-focused entities, such as schools, community centers, and cooperatives, are

often driven by social and educational values, making them more inclined to adopt reused solar panels. Francesca Alberti highlighted the success of community projects, such as the Kazerne project, where "The whole community felt like they owned the project, which was great to see" (AMS2). This sense of ownership and pride can be a powerful motivator, as noted by Aukje Bezeij, who mentioned, "People feel connected to what happens in their community, and it becomes a part of their identity" (ZL). Such organizations are often more open to integrating sustainability initiatives, especially when there is a clear social or educational benefit.

2. **Social Housing and Temporary Structures**:
   Reused panels are particularly suitable for temporary structures or buildings with shorter life spans. Nienhuis noted that "second-hand solar panels are interesting for temporary roofs, like buildings scheduled for demolition in 8 to 10 years" (AMST). Nienhuis pointed out the complexity involved: "Housing corporations are often reluctant to give up their roofs, especially when considering the long-term implications of using second-hand panels" (AMST). Despite these challenges, there remains potential for using reused panels in social housing if administrative processes are simplified and incentives are made clear.
3. **Financially Constrained Consumers**:
   Consumers with limited financial resources may find reused panels appealing if they offer immediate cost savings. However, as Gerarde de Leede observed, "People in energy poverty often have little roof space, while you want to cover your roof with the highest possible yield to get the most out of it" (SOL). This group may face practical limitations, such as insufficient roof space, which can make the case for reused panels less compelling. Further complicating matters is the financial sensitivity of these consumers, which can limit their willingness to invest in solutions perceived as less efficient. However, many energy suppliers in the Netherlands now charge fees for returning excess electricity generated by solar panels to the grid, known as terugleverkosten (Doolaard, 2024). These fees vary depending on the amount of electricity fed back into the grid, making it potentially less financially beneficial for households with high-efficiency panels to maximize their output. In this context, using second-hand, less efficient panels could reduce the financial burden associated with these fees while still contributing to the household's energy needs.
4. **Environmentally Conscious Individuals and Groups**:
   A smaller segment of potential adopters includes environmentally conscious individuals and groups who prioritize sustainability over financial returns. These users may be less concerned with the efficiency losses associated with reused panels and more focused on the environmental benefits of reducing waste and conserving resources. As Aukje Bezeij stated, "You need to think about educational return" (ZL), suggesting that these users may value the broader educational and environmental impacts of using reused panels. This focus on non-financial returns aligns with broader societal goals of reducing carbon footprints and promoting a circular economy. After the Kazerne pilot, there was a surge of interest from private citizens eager to explore similar initiatives. Francesca Alberti shared, “I got a lot of interest from private citizens; how much would it be; could you do it for my house?” (AMS2). However, as the pilot was primarily a proof of concept, it wasn’t feasible to extend the project directly to individual homes at that time. Recognizing the growing interest, Alberti suggested developing a manual that would summarize the lessons learned and

outline the processes. This could empower individuals and communities to more easily undertake similar projects on their own, fostering broader adoption of reused solar panels and furthering environmental and educational objectives (AMS2).

5. **Social Return Initiatives**:
   Another critical factor influencing end-user characteristics is the concept of social return, which is increasingly being integrated into larger projects. Esther Zumpolle noted, "Yes, I see that too. In large projects, social return is often required" (ZRN). This requirement can be leveraged to promote the use of reused panels. Sietse de Vilder elaborated on this point by explaining that contractors are mandated to spend a portion of their tender budget on creating employment, providing opportunities to finance reuse projects in Amsterdam: "Contractors could fulfill their social return obligations by investing in a reuse project, although this is challenging because it requires local operation and project alignment" (AMS1). This presents an opportunity for collaboration with organizations that have a vested interest in social and environmental outcomes, such as the Rabobank Foundation, which already supports initiatives like Stichting ZonNext (AMS1).

Barriers Faced by End-Users

1. **Financial Constraints and Awareness Gaps**:
   Financial limitations and a lack of awareness about the benefits of reusing PV panels are significant barriers. Many residents are hesitant to engage with reused panels if they do not perceive immediate financial benefits or savings on energy costs. Sietse de Vilder articulated, "The biggest barriers are financial resources and the awareness of the importance of reuse" (AMS1). Similarly, Peter de Wit emphasized the economic focus of many decision-makers, stating, "It’s all about money, as harsh as that may sound" (GL). This economic concern is compounded by the complexity surrounding ownership and benefit distribution in multi-tenant buildings, where residents must consent to roof usage and possibly join an energy cooperative to share the benefits. "It’s complex around ownership and who benefits from it," (AMS1).
2. **Technical and Logistical Challenges**:
   Technical considerations, such as the remaining lifespan of reused panels, pose significant challenges. Niels van Olffen noted, "If you place a reused panel on a new roof that needs to last 25 years, it may not be logical, as you might need to work on the roof sooner" (ZN). This mismatch between the expected lifespan of roofs and reused panels necessitates careful planning and consideration, particularly for housing corporations and private homeowners. Niels van Olffen echoed this, explaining that reused panels are often more suited to specific situations, such as buildings with lower power needs or temporary structures (ZN).
3. **Regulatory and Procedural Hurdles**:
   The lack of clear regulatory frameworks and requirements for the use of reused panels creates uncertainty for potential adopters. Niels van Olffen pointed out that "Municipalities and provinces often do not include requirements for reuse in permits, or they do not consider the impact" (ZN). This regulatory gap can deter adoption, as there is uncertainty about maintenance responsibilities and long-term impacts. Moreover, Gerarde de Leede

suggested the need for more robust regulatory support to encourage the adoption of reused panels, proposing that "Reuse and recycling should go hand in hand" (SOL).

4. **Perceptions and Misconceptions about Reused Technology**:
   Perceptions about the safety, efficiency, and reliability of reused panels significantly influence their adoption. Jeroen Kruisheer noted that "The market pushes us to use more efficient panels," reflecting a preference for new, higher-output panels over reused ones (WCZ). Kruisheer also highlighted additional technical concerns, particularly regarding safety and insurance, noting, "Second-hand panels are seen as more fire-prone than new ones, which isn't necessarily true, but it's a point of concern" (WCZ).This perception is often based on concerns about the lower efficiency and potential output of reused panels.

Driving Factors for Adoption

1. **Educational Initiatives and Awareness Campaigns**:
   Increasing awareness about the environmental and social benefits of reused panels can help shift perceptions and encourage adoption. Educational initiatives, especially those integrated into community projects or schools, can foster a culture of sustainability. Aukje Bezeij emphasized the importance of thinking beyond financial gains: "You need to think about educational return" (ZL). She further highlighted the role of education, noting that "creating awareness slowly and positively" is key to creating acceptance (ZL).
2. **Policy and Regulatory Support**:
   Developing clear policies and regulations that support the use of reused panels can provide a more predictable framework for potential adopters. Niels van Olffen proposed that "More focus should come on what happens after the lifespan of an installation and how you handle maintenance environmentally" (ZN). Introducing mandatory requirements for reused panels in certain types of new construction or renovation projects could help normalize their use and reduce market resistance.
3. **Incentives and Financial Models**:
   Financial incentives or subsidies could make reused panels more attractive, particularly to cost-sensitive users. Additionally, creating models where reused panels are part of a larger community or social initiative may offer dual benefits of cost savings and social impact. Francesca Alberti suggested that combining reused panels with training programs could appeal to both financial and social values: "Combining reused panels with training programs for unemployed individuals could provide dual benefits" (AMS2).
4. **Streamlined Processes and Clear Communication**:
   Simplifying the procedural and administrative processes associated with the installation of reused panels can alleviate some logistical barriers. Clear communication about the benefits, potential challenges, and steps involved in adopting reused panels is essential for building trust and encouraging broader participation. Alberti noted that projects often stalled due to unclear logistics and communication: "The decision-making process was too slow… it wasn't necessarily about the reused panels themselves but more about communication issues and slow responses" (AMS2).

5. **Collaboration with Trusted Organizations**:
   Partnering with trusted organizations, such as local cooperatives or well-established NGOs, can help build credibility and trust in reused panel initiatives. Henk Bos suggested, "Municipalities should work more with parties that have proven things can work in practice" (WNL). These organizations can serve as intermediaries, providing knowledge, resources, and support to end-users, thereby reducing the perceived risk associated with adopting reused technology.

6.3.5 GOVERNMENT POLICY AND REGULATORY FRAMEWORK

This subchapter examines how current local policies and regulatory frameworks influence the development of the reuse niche for photovoltaic (PV) panels in Amsterdam. It explores the specific institutional structures, regulations, and incentives that impact niche actors' ability to innovate and scale reuse practices.

Understanding the Regulatory Landscape
The regulatory environment for reused PV panels in the Netherlands is shaped by both national and European policies. One significant policy influencing local markets is the Corporate Sustainability Reporting Directive (CSRD). This directive mandates companies to report on various sustainability aspects, including their carbon footprint, use of toxic substances, water usage, and efforts toward developing a circular business model. Niels van Olffen (ZN) emphasized the significance of these requirements, stating, "Companies are now compelled to seriously consider the sustainability of their activities," driving a shift towards more sustainable business practices. This regulatory push affects niche actors by increasing the demand for sustainable practices and innovations, including the reuse of PV panels.

Despite these regulations, significant challenges persist at the local level. Gerard de Leede (SOL) pointed out, "Government bodies often lack the necessary knowledge to effectively address waste management issues related to PV panels." He suggested that tackling these challenges requires a dedicated team of 10 to 20 civil servants and that there should be interest in learning from initiatives abroad. The current reactive approach, as mentioned by de Leede, "We wait until we hit a wall, and then we make policy", creates an uncertain environment for niche actors, limiting their ability to plan and grow effectively.

Aukje Bezeij (ZL) further emphasized the instability in the Dutch political landscape: "Everything is ultra-variable, making it very challenging in the Netherlands." This inconsistency affects long-term investments and the ability to build a stable niche market for reused PV panels. Annoesjka Nienhuis (AMST) mentioned practical barriers, such as the difficulty in securing rooftops for solar installations, illustrating the operational challenges within the niche. It cost the same or even more money to find, refurbish, transport and install the panels on a roof as new ones, while the new ones deliver more energy.

Challenges in Government Policy and Implementation

Local policies provide some support through initiatives like interest-free loans for homeowners' associations (VVE's) and collective purchasing initiatives, which support both new and reused panels. However, there are also critical barriers to effective implementation. Nienhuis (AMST) noted, "Everyone assumes it's easy, but it's incredibly difficult to secure the right to use a roof," highlighting specific local challenges related to accessing infrastructure for solar installations. This indicates that while financial models exist to support niche development, operational hurdles like securing suitable rooftops remain significant obstacles.

Henk Bos (WNL) suggested the need for more proactive government involvement, stating, "If the ministry decides tomorrow that Stichting OPEN should do things differently and sets a framework, the world changes." This highlights the potential for government-led frameworks to provide clearer guidance and support for niche actors.

Esther Zumpolle (ZRN) argued that Extended Producer Responsibility (EPR) schemes could be more effectively utilized to encourage reuse practices. She stated, "There should be a level playing field where all wholesalers participate in the EPR scheme. If you don't comply, you're essentially defrauding the system." However, she also noted that current financial contributions are insufficient to cover the costs of sustainable end-of-life management, underscoring a gap in necessary financial support.

The Role of Incentives and Financial Models

Financial incentives and models are crucial for supporting niche development in Amsterdam. Nienhuis (AMST) mentioned initiatives such as the creation of a solar atlas to identify suitable rooftops for solar installations, including reused panels. This effort is designed to reduce barriers and streamline adoption processes. Henk Bos (WNL) emphasized the importance of clearer guidelines and government accountability, noting that a more structured approach to financial incentives could greatly impact niche development. He stated, "If the ministry decides tomorrow that Stichting OPEN should do things differently and sets a framework, the world changes," pointing to the need for strategic government interventions.

Zumpolle further elaborated on the role of EPR schemes, suggesting they could be more effectively structured to promote reuse. She remarked, "Current EPR contributions do not fully cover the costs associated with sustainable end-of-life management," highlighting the need for increased financial contributions or more efficient use of funds to support the niche.

6.3.6 CONCLUSIONS LEARNING PROCESSES

The **6.3.1 Technical Development and Infrastructure** indicator acts primarily as an enabler for the reuse niche. The emphasis on rigorous testing, certification processes, and the development of complementary technologies and infrastructure has been pivotal in ensuring the quality and safety of reused PV panels. Continuous learning through pilot projects further enhances technical capabilities and fosters innovation. However, the challenges related to standardization and logistical complexities also highlight areas for improvement to fully support scaling efforts.

6.3.2 Industrial development serves as both an enabler and a barrier. On one hand, it facilitates the reuse niche through investments in specialized infrastructure, streamlined logistics, and improved storage solutions. On the other hand, operational challenges, such as handling and transport, liability concerns, and financial risks associated with storage, present significant barriers that need to be addressed to ensure broader adoption and scalability.

The **6.3.3 Social and Environmental Impact** indicator acts as a strong enabler for the reuse niche. The reuse of PV panels aligns with broader societal values by promoting social equity, creating employment opportunities, and contributing to environmental sustainability goals. However, while these benefits are substantial, challenges such as changing mindsets and addressing the economic realities within the market context still need targeted strategies to fully capitalize on these social and environmental impacts.

6.3.4 Development of the User Context is primarily a barrier for the reuse niche. While there are pockets of potential adopters among community-oriented organizations and environmentally conscious individuals, significant barriers exist. These include financial constraints, lack of awareness, technical mismatches, and regulatory hurdles, which collectively hinder widespread adoption. Addressing these barriers through education, clear regulations, and targeted incentives is essential for enhancing user acceptance and engagement.

6.3.5 Government Policy and Regulatory Framework functions as a barrier with some enabling characteristics. While policies such as the Corporate Sustainability Reporting Directive (CSRD) and local initiatives like interest-free loans and collective purchasing provide support for sustainable practices, significant barriers remain. These barriers include regulatory inconsistencies, knowledge gaps among policymakers, and practical challenges in implementation, such as securing rooftops for installations. A more proactive and consistent regulatory approach, combined with clearer guidelines and better-utilized financial incentives, is needed to enhance the enabling characteristics of this indicator and support the reuse niche more effectively.

6.4 OVERVIEW SNM ANALYSIS

The following table provides an overview of all the identified enabler and barriers in the SNM analysis.

Table 6.4: Overview of all the enablers and barriers identified among the three niche processes.

Niche process	Chapter	Indicator	Enabler	Barrier
Expectations	6.1.1	Internal Expectations	**Stakeholders shift to sustainable, local strategies; growing confidence in reuse fosters alignment and scalability.**	
	6.1.2	External Expectations	**Increased awareness and interest among municipalities and some stakeholders create collaboration opportunities.**	**Skepticism about economic viability and safety of reused panels among producers and market actors.**
	6.1.3	Exogenous Expectations	Positive attitude towards (external) development opportunities	**Economic pressures from low-cost new panels and regulatory uncertainties challenge competitiveness.**
	6.1.4	Endogenous Expectations	**Encourages continuous learning and adaptation; supports realistic and flexible approaches to challenges.**	Cautious attitudes among non-directly involved stakeholders may hinder faster progress.
Network formation	6.2.1	Network Composition	**Strong foundational network; supports initial reuse practices.**	Broader engagement from producers and EPR organizations would help upscaling.
	6.2.2	Quality of the Sub Networks	**Effective contributions from key actors. Promotes collaboration and high standards.**	Regulatory barriers and limited engagement from smaller actors limit effectiveness.
	6.2.3	Network Interactions	**Core stakeholders communicate effectively; fosters collaboration. More structured interactions could further enhance cooperation.**	**Inconsistent communication with peripheral stakeholders poses challenges.**
	6.2.4	Network Alignment	Strong alignment between core stakeholders	**Fragmentation within the network due to differences in priorities, internal conflicts and varying approaches to EoL solutions hinder unified action.**
Learning Processes	6.3.1	Technical Development and Infrastructure	**Strong focus on rigorous testing and infrastructure development supports quality and scalability.**	Challenges related to standardization and logistical complexities also highlight areas for improvement to fully support scaling efforts.
	6.3.2	Industrial Development	**Investments in infrastructure and streamlined logistics support reuse.**	**Operational challenges and liability concerns hinder broader adoption.**
	6.3.3	Social and Environmental Impact	**Promotes social equity, job creation, and sustainability, aligning with broader societal goals.**	
	6.3.4	Development of the User Context	Potential adopters among community-oriented organizations and	**Financial constraints, awareness gaps, and regulatory hurdles limit user adoption.**

			environmentally conscious individuals	
	6.3.5	Government Policy and Regulatory Framework	Policies like CSRD and local financial incentives support sustainable practices	**Inconsistent policies, slow government response, regulatory knowledge gaps and practical barriers hinder effective reuse practices.**

7. RESULTS: REGIME AND LANDSCAPE LEVEL

7.1 REGIME LEVEL

The regime level focuses on the existing structures, policies, and practices governing the end-of-life management of PV panels. This chapter examines how stability within the regime, sectoral policies, and entrenched interests either support or hinder the development and scaling of reuse practices. By understanding these dynamics, we can assess the opportunities and barriers to advancing sustainable end-of-life solutions for PV panels in Amsterdam.

7.1.1 STABILITY IN REGIME

End-of-life (EoL) management practices for solar panels have evolved over time, but resistance to change and entrenched practices continue to hinder progress toward more sustainable solutions. This chapter examines the current state of EoL practices, focusing on the roles of key stakeholders such as Stichting OPEN, ZonNext, Solar2Cycle, and ZRN, and explores the challenges and potential for innovation in recycling and reuse.

Current Practices and Challenges

The existing practices for managing the EoL of solar panels are largely shaped by financial considerations rather than environmental or sustainable reuse goals. Stichting OPEN, the organization responsible for managing the Extended Producer Responsibility (EPR) funds in the Netherlands, has often been criticized for its conservative approach to change.

Niels van Olffen from ZonNext, an organization advocating for more sustainable reuse practices, argues that "Stichting OPEN primarily thinks in terms of waste streams rather than opportunities," highlighting a bureaucratic approach that stifles innovative reuse or recycling practices (ZN). This viewpoint is echoed by several stakeholders who have engaged with Stichting OPEN in the past. Van Olffen notes that their failure to fully utilize EPR funds for recycling and reuse initiatives is compounded by a reluctance to adopt more flexible and collaborative approaches, as evidenced by multiple unproductive discussions with the organization (ZN).

Adding to this, **Henk Bos** points out that much of the recycling managed by Stichting OPEN involves low-value shredding processes conducted abroad. This practice undermines the potential for higher-value recycling or reuse within the local market, effectively exporting waste instead of leveraging it as a resource for domestic industry (WNL).

Producer-Centric Mindset
The governance and operational strategies of Stichting OPEN have been criticized for being overly focused on minimizing costs rather than maximizing environmental benefits. **Niels van Olffen** explains, "The premise was that if you place everything with one party, they can do it more efficiently than the competition. This could theoretically be correct, but not if the producers are at the helm. They are in the board, and their interest in reuse is very limited. The board should be more diverse, including representatives from the government or municipalities to establish reuse objectives" (ZN).

Stichting OPEN manages the contributions from producers to cover the costs of the e-waste collection and processing system. Producers have a vested interest in keeping these costs as low as possible. They have asked municipalities to help make the collection of e-waste more efficient, as municipalities are an integral part of the collection structure according to the Waste Electrical and Electronic Equipment (WEEE) Directive (WEEE - Article 3, 2024).
This focus on cost efficiency often conflicts with national and municipal circular economy goals. The resulting collection practices aim to minimize collection costs and expedite the flow of e-waste. For photovoltaic (PV) systems, this means quickly removing discarded components from rooftops and transporting them to recycling facilities (downcycling) across borders. This pursuit of efficiency, measured in terms of labor costs and speed, stands in stark contrast to goals of extending product life and promoting reuse (de Vilder, 2024).

Conflicts of Interest and Emerging Opportunities
There are complex dynamics at play within Stichting OPEN's leadership. Steven van Eijck, the chairman of Stichting OPEN, also serves as a special envoy for the government to promote the circular economy. However, he is also a lobbyist for producers, creating a potential conflict of interest. This dual role presents both challenges and opportunities.

Despite the previous mentioned challenges, there are signs of a shift toward more sustainable practices. Stichting OPEN is currently seeking partners to achieve future-proof, improved recycling of solar panels. This involves close collaboration with Holland Solar and Stichting ZRN and requires partners to offer sufficient qualitative and quantitative recycling capacity (Gorny, 2024). In early June, Stichting OPEN published a call for parties to express their interest in processing EoL solar panels. The call focuses on two lots:

1. Processing of solar panels with techniques that have high technical reliability (high Technology Readiness Level, or TRL). The majority of the available volume is reserved for this category.
2. High-quality processing of solar panels with innovative techniques that need further development, possibly through a pilot installation.

Gijs ten Brinke (S2C) explains that the two lots are tailored to different levels of technological readiness. The first lot requires a Technology Readiness Level (TRL) of 7 or higher, indicating that the technology is already operational. "For this lot, the technology must be proven and operational, which means having an established pilot line where feasibility has been demonstrated," Ten Brinke notes. The second lot is intended for technologies at TRL 5 or below, which are still in the research and development phase. "This lot is more suited for knowledge institutions that are still testing their theories in practical settings," he explains. Solar2Cycle, which already has an operational pilot line, is well-positioned to participate in the first lot. "We believe we have a good chance, especially given the limited number of competitors in the Netherlands who meet these criteria." (S2C). This strategic positioning reflects a shift towards higher-value recycling processes and greater local involvement.

Collaborative Efforts and the Future of Recycling
The efforts to change entrenched practices in solar panel recycling are gaining momentum. Solar2Cycle, potentially one of the TRL 7 recyclers for Stichting OPEN, indicates a willingness to collaborate with ZonNext to enhance reuse opportunities: "Yes, I think we can create a closed loop with ZonNext, where ZonNext supplies the panels, and we recycle them," states Ten Brinke. He further notes that while this would be great to have on paper, they do not want to create a monopoly in the Netherlands: "Collaboration is important" (S2C).

Henk Bos confirms the importance of collaboration, emphasizing that while past cooperation with Stichting OPEN may not have yielded significant results, it is crucial to constructively but critically discuss these matters to achieve successful partnerships in the future (WNL). Moreover, there are indications of a broader willingness to change among other stakeholders. Esther Zumpolle from ZRN, the interest group representing PV producers in the Netherlands, expresses frustration with the current recycling approach, particularly with "repowering" (replacing older panels with newer, more efficient ones without considering reuse options). Zumpolle indicates that ZRN is open to discussing reuse possibilities with producers, signaling a potential shift towards more sustainable practices within the industry.

7.1.2 SUITABILITY OF SECTORAL POLICY

This chapter assesses the effectiveness of current sectoral policies and regulatory frameworks in promoting the recycling and reuse of PV panels in Amsterdam. It focuses on identifying gaps and barriers within these policies that affect the integration of niche practices into the broader market.

Policy Gaps and Legislative Challenges
The current legal framework lacks explicit directives supporting PV panel reuse, allowing companies to fulfill minimum recycling compliance without adopting reuse practices. Niels van Olffen highlighted this gap: "Current policies do not enforce reuse strategies or clearly define the roles of entities like Stichting OPEN." This lack of clear legislative guidance hampers the establishment of a market specifically for the preparation of PV panels for reuse.

Furthermore, the interconnection between the Waste Framework Directive 2008/98/EC, the WEEE Directive 2012/19/EU, and the Waste Shipment Regulation 1013/2006/EC complicates efforts to establish a reuse market for PV panels. Preparation for reuse is recognized as a critical step within the waste hierarchy of managing waste electrical and electronic equipment (WEEE). The WEEE Directive sets a target of 80% preparation for reuse and recycling for all products under Category 4, "Large equipment" (WEEE Directive 2012/19/EU, Article 11). However, many operators dealing with second-hand PV panels are not familiar with these three pieces of waste legislation. The complexity of these regulations creates a "grey area" in the market, explaining why the second-hand PV panel market is not yet widely developed and continues to face significant growth challenges (Tsanakas et al., 2020).

Certification Challenges and Market Acceptance
The perceived lack of standardized certification for reused PV panels presents a substantial barrier to market acceptance. Concerns over safety and reliability deter insurers and project developers. Jeroen Kruisheer (WCZ) noted, "Without proper certification, the panels won't be insured, which is a major barrier for their reuse." This lack of certification standards creates uncertainty, making reused panels less appealing compared to new ones and complicating broader adoption efforts.

Francesca Alberti (AMS2) reflected on the insurance challenges encountered during the project, clarifying that the difficulties were not solely due to the second-hand nature of the panels. "The insurance requirements made the business case for second-hand panels very challenging, but these kinds of risk assessments would likely be necessary for any solar panel installation, new or used." The insurer's questions included details on ownership, roof insulation material, potential inflammable materials, installation value, and adherence to Dutch Building Regulations. This underscores the broader need for comprehensive risk assessments and certification frameworks to ensure the safety and reliability of all solar panel installations.

To address these regulatory and market challenges, the H2020 European-funded project CIRCUSOL published guidelines in 2022 for preparing PV panels for reuse (Oviedo Hernandez et al., 2022, van Der Heide et al., 2022). These guidelines are an update to an initial proposal described in the PV CYCLE Study from 2020, outlining steps for applying various testing methods aimed at determining what constitutes a functional PV panel while ensuring sufficient quality and safety standards cost-effectively. This document now serves as a baseline for the IEC Technical Committee (TC) 82, which is currently drafting a Technical Report. The outcome of this report could potentially evolve into a new Standard or Technical Specification, further promoting standardized reuse practices for PV panels (Van der Heide et al., 2022). Additionally, there is an ongoing effort by Soren and a working group to develop a set of technical criteria specifically for PV panel reuse, further contributing to a more structured and regulated second-hand market.

Economic Misalignment and Lack of Market Incentives
The current Extended Producer Responsibility (EPR) system does not sufficiently incentivize sustainable practices. Gijs Ten Brinke (S2C) explained that "Stichting OPEN accepts panels for free and picks them up for free, making it difficult for us to compete" (S2C). This model discourages investment in innovative recycling and reuse solutions. Furthermore, the existing

EPR fees are too low to encourage companies to prioritize sustainability. Esther Zumpolle highlighted that "the current EPR of €40 per ton does not cover the costs of processing" (ZRN). Gijs added, "The costs associated with high-quality recycling, including transport and disposal of certain materials, exceed the available EPR budget, leading to financial shortfalls" (S2C).

A significant proportion of producers and importers are not complying with their EPR obligations, exacerbating the financial strain on those who do. Gijs Ten Brinke (S2C) reported that "between 60% and 70% of producers are not registered or paying the required EPR fees," creating a substantial gap in funding for recycling efforts. This lack of compliance results in a financial imbalance, where compliant companies are unfairly burdened while non-compliant ones avoid their responsibilities. Esther Zumpolle added that "there is insufficient enforcement from Stichting OPEN and the government to ensure all producers and importers meet their EPR obligations," further undermining the effectiveness of the policy (ZRN).

Enforcement and Compliance Efforts

Recognizing the challenges in achieving compliance, Stichting OPEN has undertaken several initiatives to enforce EPR regulations and create a fair market. According to their website, they commissioned DNE Research, a specialized research agency, to map the market for solar panels and identify companies that are not yet registered (Stichting Open, 2023). Additionally, they have contracted an advisory firm to actively track down freeriders. If companies remain non-compliant after being notified, Stichting OPEN is prepared to involve inspection authorities to enforce compliance. These efforts aim to ensure that all importers and producers contribute fairly to recycling costs, maintaining a level playing field (Stichting Open, 2023).

Despite these initiatives, there are still significant issues in meeting recycling targets. Stichting OPEN has failed to meet its recycling targets, complicating efforts to promote sustainability in electronic waste management. According to the national Waste Electrical and Electronic Equipment (WEEE) regulation (Article 10, 2024), producers of electronic equipment, including solar panels, are legally required to collect 65% of the products placed on the market for recycling. However, this regulation is not effectively enforced. Henk Bos (WNL) noted, "If the producer collects less, it will incur lower costs and will not achieve the legal target. At the moment, the government cannot impose a real sanction to this." This lack of enforcement, coupled with an inadequate registration system, results in many panels being unaccounted for, often ending up in landfills or processed incorrectly by uncertified metal recyclers, which further undermines the goals of the WEEE regulation.

Recent research by the Human Environment and Transport Inspectorate (ILT) has highlighted a significant gap in meeting these recycling targets. Stichting OPEN has been warned by the ILT for collecting only 43% of the required 65% collection rate and must develop new strategies to increase this value by the end of 2024 (WNL).

Need for Policy Reforms and Strategic Incentives

The current EPR framework is inadequate for driving a circular economy. It needs restructuring to cover both recycling and reuse comprehensively. Gijs Ten Brinke suggested that "increasing the EPR fees and ensuring that they support both recycling and reuse initiatives could incentivize more sustainable practices" (S2C). This reform would involve revisiting EPR rates and reallocating funds to support a broader range of sustainable activities, including high-quality recycling and reuse.

To foster a market for reused PV panels, positive incentives are crucial. This could include tax breaks, subsidies, or grants for companies adopting reuse projects. Additionally, penalties for non-compliance with reuse targets or early disposal of panels could discourage wasteful practices. Implementing a CO2 tax or other economic mechanisms that increase the cost of virgin materials while lowering the cost of secondary materials could further promote the shift toward a circular economy.

7.1.3 AMOUNT OF LOCK-IN IN REGIME

Financial Lock-In
According to Niels van Olffen (ZN), financial barriers are not the primary obstacle to advancing reuse and recycling initiatives. He notes that Stichting OPEN, as stated in their annual report, has "tens of millions over," yet these funds are not being utilized effectively for sustainable practices. Van Olffen suggests there is a lack of accountability, stating that producers and importers contributing to Stichting OPEN may not fully understand what their payments are supporting: "I don't think they realize what exactly they are paying for because they do not hold Stichting OPEN accountable for its responsibilities". This points to a disconnect between the available financial resources and their deployment, with a tendency to allocate funds towards established recycling methods rather than exploring new, innovative solutions.

Despite being the sole initiative focused on reuse in the Netherlands, ZonNext faces challenges in securing funding. Van Olffen highlights this struggle: "We struggle every year to get some money" (46:20). Despite being the only initiative focused on reuse in the Netherlands, they find it difficult to access funds from Stichting OPEN, which continues to prioritize existing recycling practices.

Institutional and Organizational Lock-In
The governance structure of Stichting OPEN also contributes to the persistence of existing practices. Niels van Olffen (ZN) critiques the current arrangement, where producers hold significant influence over the board. He comments, "The premise was that if you place everything with one party, they can do it more efficiently. But producers being in charge limits their interest in reuse". This governance model, which emphasizes cost efficiency, may not align with broader objectives for reuse and high-quality recycling. Producers' focus tends to be on minimizing costs rather than promoting sustainable practices. To address this, Van Olffen suggests that a more diverse board, including representatives from the government or municipalities, could help establish clearer objectives for reuse. However, the current governance framework shows resistance to such changes, reflecting an organizational lock-in that favors maintaining the status quo.

Inefficiency and Lack of Sustainability in Current Practices
In the Netherlands, many end-of-life solar panels are not recycled through high-quality processes. Instead, they are sent to Belgium for low-grade processing. Gijs ten Brinke (S2C) describes the current recycling method used by Stichting OPEN, where collected solar panels are shipped to Belgium for "low-quality" recycling. He explains, "The aluminum frame is dismantled, the cables are cut, and then the panel goes into the shredder. After shredding, the materials are sifted, but because everything is mixed together, you get a blend with a silicon purity of only 60%". This resulting material has "almost no value, comparable to a cubic meter of sand."

Alternatively, Solar2Cycle advocates for a high-quality recycling approach within the Netherlands, aiming to recover pure raw materials such as solar cells and metals. Ten Brinke notes that while this method incurs higher initial costs, it "yields pure raw materials, which makes it worthwhile." He challenges the perception that high-quality recycling is necessarily more expensive than the current practices in Belgium, pointing out additional costs involved in Belgium, such as "€270 per 1000 kg to transport EVA and the backsheet to the incinerator," along with costs for disposal, electricity, and labor. Despite the higher initial investment, he suggests that the value of the recovered materials could offset these costs.

Path Dependency
While financial, institutional, and organizational factors suggest a degree of lock-in to current recycling practices, the inefficiencies and lack of sustainability in these practices may indicate an absence of a strong path dependency. The current system of recycling end-of-life (EoL) solar panels in the Netherlands relies heavily on low-quality processing abroad, revealing a gap in meeting high sustainability standards and efficient resource use. This may suggest that the existing practices are not sustainable in the long term and might not align with evolving international agreements and environmental regulations.

As global attention increasingly focuses on circular economy principles and sustainable development, the Netherlands could experience growing pressure to move away from inefficient and low-quality recycling practices. Since much of the EoL recycling occurs outside the country, there appears to be less entrenched infrastructure or economic dependence on these practices domestically. This could represent an opportunity for implementing more sustainable and innovative recycling solutions, such as those proposed by Solar2Cycle.

However, the extent to which this opens up space for promoting reuse remains uncertain. Challenges for reuse initiatives include securing funding and overcoming entrenched interests favoring traditional recycling methods. Whether this space will ultimately support reuse initiatives is contingent on future policy directions, market incentives, and shifts in stakeholder priorities.

7.1.4 CONCLUSION REGIME INDICATORS

The **7.1.1 Stability in Regime** indicator, characterized by entrenched practices and resistance to change, primarily acts as a **barrier** to the scalability of reuse practices for extending the useful life of solar panels in Amsterdam. This is due to the focus on minimizing costs and the producer-centric approach, which undermines more sustainable recycling and reuse practices. However, recent collaborative efforts and a shift toward exploring more innovative practices indicate a potential for change, making it a **potential enabler** if these efforts gain enough support and influence.

The **7.1.2 Suitability of Sectoral Policy** are primarily perceived as a **barrier** to the scalability of reuse practices. This is due to the lack of explicit directives for reuse, perceived certification challenges, economic misalignments, and insufficient enforcement of existing regulations. These gaps hinder the development and market acceptance of reused PV panels. Without significant policy reforms and strategic incentives, these barriers are likely to persist.

The **7.1.3 Amount of Lock-In in Regime** indicator is perceived as both a enabler and a **potential barrier**. Financial, institutional, and organizational lock-ins favor existing low-quality recycling practices, posing significant barriers to more innovative reuse initiatives. However, the lack of strong path dependency and the inefficiencies in current practices suggest that there is room for new, more sustainable solutions. This makes the lock-in a **potential enabler** if strategic interventions can overcome the entrenched interests and promote more sustainable practices.

Table 7.1.4: Overview of regime enablers and barriers identified through the SNM analysis

Indicator	Enabler	Barrier
7.1.1 Stability in Regime	**Emerging collaboration and shifts towards innovation could support change.**	**Entrenched practices and resistance to change hinder sustainable reuse.**
7.1.2 Suitability of Sectoral Policy		**Lack of clear directives, perceived certification challenges, and insufficient policy support for reuse.**
7.1.3 Amount of Lock-In in Regime	**Low path dependency and potential for more sustainable practices.**	Financial, institutional, and organizational lock-ins favor existing low-quality recycling.

7.2 LANDSCAPE

The landscape level explores the broader external factors that influence the reuse of PV panels in Amsterdam. This chapter examines macro-economic trends, policy and legislative shifts, and technological advancements that either enable or hinder the scalability of reuse practices. By understanding these broader forces, we can better assess how external pressures shape the development of reuse strategies in a rapidly changing market and regulatory environment.

7.2.1: MACRO-ECONOMIC TRENDS

This indicator captures the broader economic context that affects reuse initiatives of PV panels in Amsterdam. It includes the availability of funding for reuse initiatives, economic incentives for extending the life of PV panels, and the overall market conditions influencing the scalability of reuse practices.

Economic Barriers to Scalability
One significant barrier to scaling reuse practices in Amsterdam is the low cost of new PV panels, which makes it challenging for reused panels to compete. As Sietse de Vilder explained, "New panels currently have historically low prices, partly due to subsidies in China and unethical production practices such as labor camps. As a result, the costs are artificially kept low, making it difficult for reuse to compete". Additionally, installation costs play a role in economic decision-making. Sietse de Vilder noted that for the installation of reused panels, "One-third of the costs are in material costs, but a significant part is also in installation costs". This price dynamic discourages the reuse of panels because many consumers and businesses prefer newer, cheaper options that offer higher efficiency and longer warranties.

Economic Opportunities for Reuse
Despite existing barriers, there are significant opportunities to promote reuse practices for PV panels in Amsterdam, especially if market conditions change due to geopolitical tensions and regulatory shifts. One opportunity lies in reducing installation costs by involving external financiers through Environmental, Social, and Governance (ESG) objectives, which could enhance financial continuity and lower overall costs in the supply chain. As Sietse de Vilder suggests: “Additionally, you could involve external financiers through ESG objectives. If continuity in the chain is achieved, costs can decrease” (AMS1).

Currently, the European Union relies heavily on Chinese-manufactured solar panels, with over 95 percent of solar panels in the EU being imported from China due to their low cost (see Figure 7.2.1). In 2022, Chinese panels were priced at approximately $0.26 per watt, making them the cheapest globally, while European-produced panels, such as those from Germany, were around 40 percent more expensive at $0.38 per watt (McWilliams et al., 2024). This price difference is driven by higher input costs in Europe, such as energy and labor, as well as limited access to critical raw materials. Moreover, recent decreases in polysilicon prices have further lowered the cost of Chinese solar panels to as low as $0.15 per watt by September 2023, widening the price gap between Chinese and European panels even more.

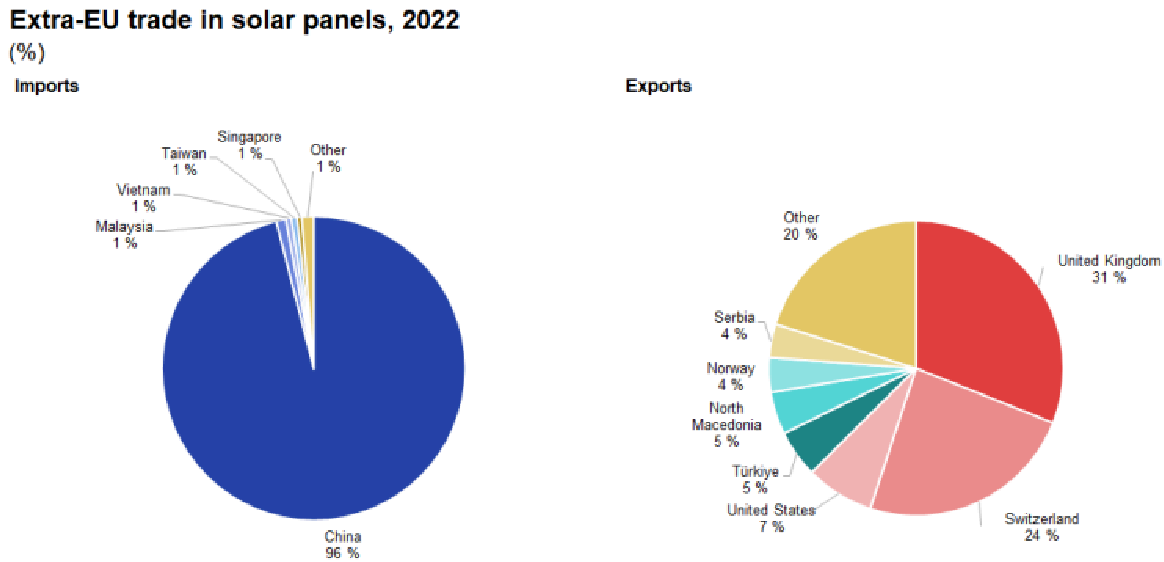

Figure 7.2.1: Extra-EU imports and exports in PV in 2022. Source: Eurostat (2023).

This heavy reliance on low-cost Chinese imports poses significant economic and geopolitical risks. If geopolitical tensions escalate, this could include increased scrutiny over forced labor practices in Xinjiang (OHCHR, 2022). These actions could significantly raise the cost of new panels. The EU has already proposed a market ban on products made with forced labor, reflecting growing concerns about dependency on China and the ethical implications of its supply chains (European commission, 2022).

In such a scenario, where the price of new panels increases due to geopolitical or regulatory pressures, reuse of existing panels becomes a more attractive option. As Sietse de Vilder noted, "If prices for new panels increase due to, for example, regulations or geopolitical tensions, reuse suddenly becomes a much more attractive alternative" (AMS1).

Additionally, the European Union's initiative under the Net-Zero Industry Act (NZIA) aims to achieve 40 percent self-sufficiency in solar panel manufacturing by 2030, which could significantly affect market dynamics (European council, 2024). This act, agreed upon in February 2024, is part of a broader effort to support domestic production of clean technologies, including solar PV, in response to growing concerns about economic security and geopolitical resilience (European Comission, 2023). These concerns have been fueled by recent disruptions in global supply chains, the energy crisis, and China's increased control over critical raw materials, prompting European policymakers to reconsider their reliance on imports. By setting a target for increased local manufacturing, the EU hopes to reduce its dependency on Chinese solar panels.

Conclusion

The macro-economic landscape presents both barriers and opportunities for the scalability of PV panel reuse practices in Amsterdam. The low cost of new panels, primarily driven by cheap imports from China, poses a significant challenge for reuse initiatives, as it makes reused panels less competitive. However, changing geopolitical dynamics and regulatory pressures could shift these economic conditions. Increasing scrutiny over forced labor practices in China's supply chain and potential trade restrictions may raise the cost of new panels, thereby making reuse a more viable alternative. Furthermore, the European Union's push toward self-sufficiency in solar panel manufacturing, while aimed at reducing dependency on imports, could also lead to higher production costs and further bolster the case for reuse.

Additionally, the broader trend toward increasing solar power use across Europe is favorable for reuse practices, as it ensures a growing market for PV panels. With the EU planning to nearly double its solar capacity by 2030, there is an expanding sector that could benefit from integrating reused panels. This growing demand for solar power, coupled with potential economic shifts, suggests that reuse practices could play a crucial role in meeting sustainability goals while offering cost-effective solutions in a changing market landscape.

7.2.2 POLICY AND LEGISLATION TRENDS

This chapter examines broader policy and legislative trends at the landscape level that impact the reuse of PV panels, focusing on both European Union and local strategies.

Developing Universal Guidelines for Reuse

To create clarity in the market, it is crucial that universal guidelines and standards for PV panel reuse are developed. Initial suggestions for these requirements have been proposed by the H2020 project CIRCUSOL, which prompted a team of experts from the IEC Technical Committee 82 WG2 to begin preparing a Technical Report entitled "PV module re-use and circular economy." This report aims to provide clear recommendations for PV module reuse and could serve as a foundation for future IEC Technical Specifications and Standards. Recent progress on this report has been complemented with real field data from a case study where reuse preparation procedures were tested and validated. The study discusses adapted and optimized on-site functionality test procedures and provides practical insights from the operation and maintenance (O&M) perspective (Van Der Heide et al., 2023).

Furthermore, the BEC National Committee launched a New Work Item (NWI) initiative within IEC TC82 WG2 to oversee the creation of IEC Technical Report TR 63525, sponsored by PVCycle, a non-profit organization specializing in waste management and legal compliance services for the solar industry. The involvement of PVCycle highlights the importance of industry collaboration in addressing complex environmental challenges. The planned release of the TR 63525 report in Q1 2025 marks a significant step towards establishing sustainable solutions for PV module end-of-life management (CEB BEC, 2024).

Local Policy Framework: Amsterdam Circular Strategy 2020-2025

Amsterdam's Circular Strategy 2020-2025 lays a foundational framework that indirectly supports PV panel reuse through its broader circular economy goals. The strategy aims to reduce overall consumption by 20% by 2030 and commit to 100% circular procurement for the City's premises (Gemeente Amsterdam, 2020). Moreover, the strategy includes developing infrastructure for sharing platforms, second-hand shops, and repair services. This infrastructure could potentially facilitate the reuse of PV panels, providing venues and systems for their refurbishment and redistribution.

European Union Policy Framework

EU Ecodesign Directive (2009/125/EC)

The EU Ecodesign Directive (2009/125/EC) traditionally targets the energy efficiency and environmental impact of energy-related products. While PV panels are not currently included under this directive, the European Commission is actively evaluating the feasibility of their inclusion. The Ecodesign and Energy Labelling Working Plan 2022-2024 outlines efforts to introduce ecodesign requirements for solar photovoltaic modules, inverters, and systems. These evaluations focus on improving not only energy efficiency but also material efficiency, including aspects such as durability, reparability, upgradability, recycling, and potential carbon footprint requirements for these products (European Commission, 2022b).

The inclusion of PV panels under the Ecodesign Directive could have substantial implications for their design and end-of-life management. If adopted, manufacturers would need to adhere to stricter guidelines that enhance the recyclability, durability, and repairability of PV panels. This shift would align with circular economy principles and potentially make PV panels more suitable for reuse. The ongoing efforts suggest that regulations for PV panels could be adopted soon, reflecting a broader commitment to ensuring that solar PV technologies contribute to sustainability goals throughout their entire lifecycle.

Extended Producer Responsibility (EPR) The principle of Extended Producer Responsibility (EPR) is central to supporting the EU's circular economy strategy. EPR mandates that producers are responsible for the entire lifecycle of their products, including end-of-life management. This responsibility extends to PV panels, inverters, storage systems, and packaging materials. The EPR policies require producers to establish collection networks and ensure proper waste management, which can indirectly support reuse initiatives by providing the necessary infrastructure and logistics

European Green Deal and Circular Economy Action Plan

The European Green Deal, launched in 2019, sets the overarching goal of making the EU climate-neutral by 2050. As part of this initiative, the Circular Economy Action Plan (CEAP) promotes the durability, reusability, and recyclability of products across various sectors, with a focus on high circularity potential areas like electronics (European Commission, 2020a). Although PV panels are not explicitly mentioned, the principles outlined in the CEAP support the broader adoption of circular economy practices, which could lead to the development of policies encouraging PV panel reuse. This may include higher recovery targets and subsidies for refurbishment activities (European Commission, 2020b).

Corporate Sustainability Reporting Directive (CSRD)

Recent directives, such as the Corporate Sustainability Reporting Directive (CSRD) mandates large companies to report on environmental impacts and sustainability practices. Niels van Olffen (ZN) highlighted that this directive pushes companies to consider circular business models, such as PV panel reuse, as part of their sustainability strategies. While not directly mandating PV panel reuse, the directive promotes transparency and accountability in corporate sustainability efforts, indirectly supporting circular economy practices.

Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU)

The Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU) significantly impacts the management of PV panels by categorizing them under "consumer equipment and photovoltaic panels." This inclusion brings PV panels under the directive's regulatory scope, which mandates high targets for collection (85% of WEEE generated) and recovery (85% recovery and 80% preparation for reuse and recycling) (European Parliament & European Council, 2012). While these targets support both recycling and preparation for reuse, in practice, they may inadvertently encourage entities to prioritize recycling over reuse. This is because recycled panels contribute more directly and measurably to meeting the directive’s targets, whereas reused panels might not always be accounted for in the same way. As a result, this dynamic could hinder efforts to promote reuse practices, as entities might focus more on recycling to comply with the directive’s requirements.

Waste Framework Directive (WFD)

The Waste Framework Directive (WFD) 2008/98/EC, which provides overarching guidelines for waste management in the EU, is another key legislative instrument impacting the PV panel sector. The WFD establishes fundamental principles for waste management, such as the waste hierarchy, which prioritizes waste management practices from most to least desirable: prevention, preparing for reuse, recycling, recovery, and disposal (SolarPower Europe, 2024). This hierarchy places "preparing for reuse" above recycling, emphasizing the importance of extending the life of products before considering recycling or disposal. For the PV panel reuse niche, this directive serves as a critical regulatory foundation that promotes sustainable practices and encourages the reuse of materials. This hierarchy is visualized in figure 7.2.2.

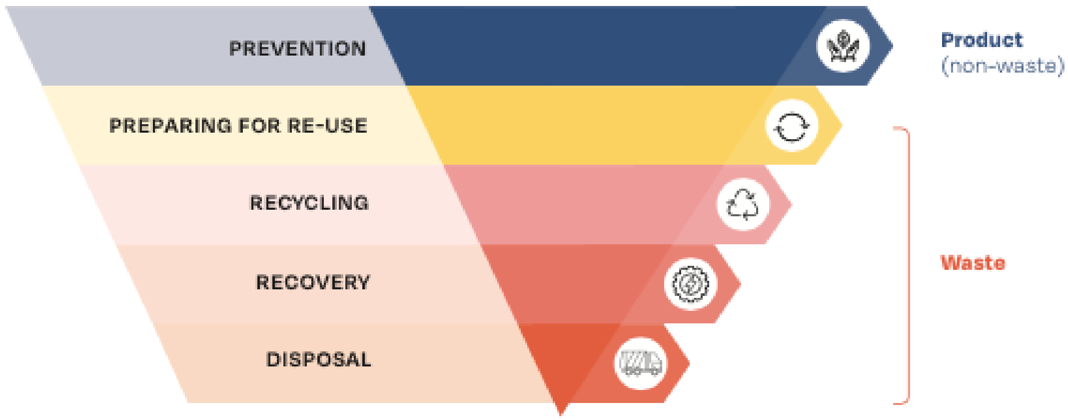

Figure 7.2.2: Waste hierarchy as defined in the Waste Framework Directive 2008/98/EC (SolarPower Europe, 2024)

Challenges and Opportunities in Policy Implementation

Despite these supportive frameworks, the practical implementation of these policies remains challenging. As noted by Gerard de Leede (SOL), there is a lack of comprehensive governmental readiness and expertise in handling PV panel waste, and a more robust approach is needed to effectively manage the end-of-life of these panels. Furthermore, there is a perception that policymakers often wait until issues become critical before acting, which can slow down the progress needed for fostering reuse practices.

Moreover, compliance schemes under the EPR framework, which manage waste obligations for producers, could be more effectively aligned with circular economy principles to promote reuse. While these schemes generate cost efficiencies by collectively managing waste, there is potential to better support reuse practices through enhanced coordination and targeted incentives.

On a more positive note, shifts in policy are creating a growing awareness among companies about their environmental responsibilities. New guidelines and regulations are prompting companies to think more critically about their sustainability strategies, moving beyond mere sales targets to considering the long-term impacts of their products. As Niels van Olffen (ZN) observed, companies are increasingly engaging sustainability managers and researchers to address these concerns, which could support more innovative approaches to PV panel reuse.

Conclusion

Current environmental policies and legislation at both local and EU levels provide a foundation for PV panel end-of-life management, yet they are not fully optimized to support reuse initiatives. The Amsterdam Circular Strategy offers a supportive local framework that could facilitate PV panel reuse through its circular economy goals and improved infrastructure. However, EU-level policies like the WEEE Directive may unintentionally discourage reuse by favoring recycling to meet regulatory targets.

Looking ahead, the evolving regulatory landscape, with potential amendments to the WEEE Directive and Waste Framework Directive (WFD), and the possible inclusion of PV panels in the Ecodesign Directive, could better align with circular economy principles. These changes may foster more favorable conditions for PV panel reuse, promoting sustainable waste management practices that extend the useful life of PV panels and align with the broader objectives of the European Green Deal and Circular Economy Action Plan.

7.2.3 TECHNOLOGICAL ADVANCEMENTS

This indicator examines the role of technological innovation in enhancing the feasibility and scalability of reuse practices for photovoltaic (PV) panels. It focuses on new technologies supporting the recycling and reuse of PV panels and their impact on the potential for reuse.

Advancements in Recycling
Recent technological advancements in recycling have significantly impacted the reuse potential of PV panels in the Netherlands. Companies like Solar2Cycle are leading these innovations by developing advanced recycling methods that recover a substantial portion of valuable materials, such as silicon and silver, with minimal energy input. As Gijs Ten Brinke highlighted, their techniques allow for high-purity material recovery, reducing the need for energy-intensive processes like the Siemens method traditionally used for solar-grade silicon purification (S2C).

These advancements mean that the energy and cost savings associated with high-efficiency recycling could outweigh the benefits of reusing older panels. As noted by Niels van Olffen, "If you can recover pure materials with low energy, it doesn't make sense to reuse solar panels with lower efficiency," suggesting that advanced recycling could become a more logical choice over reuse in certain contexts (ZN).

Innovative PV Panel Designs
Technological innovations in PV panel design are increasingly supporting the reuse of panels by making them easier to disassemble and redeploy, aligning with circular economy goals. Companies like Solarge are pioneering these developments with modular panel designs that allow for easier separation of components, which significantly enhances the potential for reuse. As Gerard de Leede highlighted, these panels are made from materials that facilitate disassembly, enabling the recovery of valuable materials like silicon and silver with high purity (SOL). This modularity not only simplifies the reuse process of components, but also reduces the energy and resources needed to prepare panels for their second life, making reuse a more attractive option.

Beyond modularity, innovations such as reversible materials and self-healing coatings further boost the reuse potential by extending the lifespan of panels through multiple cycles of use (ETIP-PV, 2023). These advancements reduce the need for energy-intensive recycling processes and support the sustainability of PV systems by maximizing the value extracted from each panel over its lifecycle. By improving the ease and efficiency of reuse, these designs provide economic benefits and help reduce the overall carbon footprint associated with PV panels.

While some of these advancements could also make recycling more efficient, the improvements in panel design are increasingly tipping the balance in favor of reuse, especially in scenarios where panels are still functional and can be redeployed with minimal refurbishment. The focus on designing panels for easier disassembly and extended use is a clear step towards making reuse a more economically viable and environmentally friendly option. As these technologies continue to evolve, they are likely to enhance the scalability and attractiveness of reuse practices, contributing to a more sustainable and circular approach to PV panel lifecycle management.

Increasing Efficiency of Solar Panels

Another technological advancement impacting the reuse niche is the increasing efficiency of new solar panels. Modern panels, such as those mentioned by various interviewees, have significantly higher power output and efficiency compared to older models. For instance, newer panels can produce 400-450 watt-peak power, nearly double that of panels from a decade ago (ZRN). This significant increase in efficiency means that replacing old panels with new ones can generate much more energy within the same space, making the economic case for reuse less compelling. As panels become more powerful and less costly, the incentive to invest in reusing less efficient, older panels diminishes, further shifting the focus towards upgrading to more efficient models.

Repowering and Its Impact on Reuse Opportunities

Repowering—replacing older solar panels with newer, more efficient ones—presents both a challenge and an opportunity for the reuse of PV panels. As Esther Zumpolle explained, large developers often decide to "repower" solar parks after only a few years to take advantage of advancements in panel technology and maximize energy output. "Developers think, 'I'm going to repower. I'll take these panels off, put modern panels on, and increase my capacity by 50%, because I can generate much more energy,'" Zumpolle noted (ZRN).

While this approach is economically advantageous for developers, it has implications for the reuse market. Panels removed during repowering are often still relatively new and in good condition, making them ideal candidates for reuse. Furthermore, these panels typically come from large solar parks, meaning they are uniform in size and specifications, which simplifies the reuse process (ZNR). However, repowering also means that panels are being replaced sooner than their expected lifespan, potentially increasing waste and environmental impact. Nonetheless, for the reuse niche, repowering presents an opportunity to obtain high-quality, standardized panels that can be redeployed in new settings, such as smaller installations or residential systems, thereby extending their useful life and contributing to circular economy goals.

Monitoring and Data Technologies

Recent advancements in monitoring and data processing technologies are promising for enhancing the reuse potential of PV panels by enabling more effective tracking of their condition and availability. Integrating IoT-based wireless solar PV monitoring systems, equipped with advanced sensors and data processing boards, allows for real-time monitoring of panels' operational metrics, such as power output, efficiency, and degradation (Ansari et al., 2021). This granular data enables precise assessments of which panels remain viable for reuse without necessitating their removal or manual inspection.

Digital Twin Technology complements these systems by creating virtual replicas of installed panels, allowing stakeholders to remotely monitor and simulate performance over time. This technology supports predictive maintenance and helps identify panels that retain sufficient efficiency and durability for redeployment, potentially maximizing their remaining useful life (ETIP-PV, 2023).

Further enhancing these capabilities, **AI-driven software solutions** are being developed to analyze operational data and forecast maintenance needs. These AI algorithms can detect potential issues before significant performance losses occur, reducing the frequency of manual inspections and minimizing downtime for panels already in use (ETIP-PV, 2023). This approach extends the usable life of existing installations, supporting circular economy principles by reducing the need for new materials.

Improved Data and Tracking Systems also show potential in facilitating the reuse of rooftop panels. As Annoesjka Nienhuis (AMST) pointed out, robust data management platforms could create comprehensive inventories of installed panels, documenting their age, condition, and expected availability. These platforms can inform strategic planning and decision-making for panel redeployment, especially for panels that remain efficient and suitable for secondary uses, such as in smaller residential setups or community solar projects.

Additionally, adopting identification and tracking technologies, like RFID tagging or QR codes on individual panels, could streamline their integration into a secondary market (ETIP-PV, 2023). These technologies make it easier to track the origin, usage history, and condition of panels, simplifying the process of matching them with potential new users. This approach aligns with successful strategies in other industries, such as automotive parts reuse, where effective tracking ensures components are repurposed sustainably.

7.2.4 CONCLUSION LANDSCAPE INDICATORS

The **7.2.1 Macro-Economic Trends** indicator for the reuse of PV panels in Amsterdam presents a complex mix of barriers and potential enablers. The current low cost of new PV panels, driven by cheap imports from China, represents a significant **barrier** as it makes reused panels less competitive. However, there are economic opportunities that could act as **enablers**. Shifting geopolitical dynamics and regulatory changes, such as increasing scrutiny over forced labor practices and the EU's push for self-sufficiency in solar manufacturing, could raise the cost of new panels, making reuse a more viable alternative. Additionally, the growing demand for solar power in Europe provides a favorable context for scaling reuse practices.

7.2.2 Policy and Legislative Trends at both the European Union and local levels are primarily perceived as **enablers** for the reuse niche of PV panels. Amsterdam's Circular Strategy and broader EU initiatives, such as the Circular Economy Action Plan, offer supportive frameworks for circular practices, including reuse. However, some existing regulations, like the WEEE Directive, could pose a **barrier** by inadvertently prioritizing recycling over reuse due to their specific targets. Future regulatory amendments and evolving policies could further enhance conditions for reuse, aligning better with circular economy principles.

7.2.3 Technological Advancements are a significant **enabler** for the development and scalability of reuse practices for PV panels. Innovations in panel design, such as modularity and advancements in recycling techniques, improve the feasibility and attractiveness of reuse by making panels easier to disassemble, repair, and redeploy. Improved monitoring and data technologies also enhance the ability to assess the condition and reuse potential of existing panels. While some advancements in recycling could detract from reuse incentives, the overall technological trend strongly favors expanding reuse opportunities within a sustainable PV lifecycle framework.

7.3 OVERVIEW MLP ANALYSIS

The following tables provides an overview of the identified enablers and barriers based on the MLP analysis.

Table 7.3: Overview of identified enablers and barriers based on the MLP analysis

Socio - Technical Level	Chapter	Indicator	Enabler	Barrier
Regime	7.1.1	Stability in Regime	**Emerging collaboration and shifts towards innovation could support change.**	**Entrenched practices and resistance to change hinder sustainable reuse.**
	7.1.2	Suitability of Sectoral Policy		**Lack of clear directives, perceived certification challenges, and insufficient policy support for reuse.**
	7.1.3	Amount of Lock-In in Regime	**Low path dependency and potential for more sustainable practices.**	Financial, institutional, and organizational lock-ins favor existing low-quality recycling.
Landscape	7.2.1	Macro-Economic Trends	Potential increase in new panel costs due to geopolitical tensions and regulatory shifts could make reuse more attractive.	**Low cost of new panels driven by cheap imports makes reused panels less competitive.**
	7.2.2	Policy and Legislation Trends	**Supportive local and EU frameworks for circular economy practices and potential regulatory amendments promote reuse.**	Existing regulations (e.g., WEEE Directive) might prioritize recycling over reuse.
	7.2.3	Technological Advancements	**Innovations in panel design, modularity, and monitoring technologies enhance the feasibility and attractiveness of reuse.**	Advanced recycling techniques could reduce incentives for reuse in favor of efficient recycling.

8. RESULTS: POLICY MIXES

This chapter aims to propose a set of policy mixes to enhance the scaling of reuse practices for photovoltaic (PV) panels in Amsterdam. Building on insights from the Strategic Niche Management (SNM) analysis (Chapter 6), the Multi-Level Perspective (MLP) analysis (Chapter 7), stakeholder interviews, and grey literature, the chapter synthesizes these findings to identify targeted policies that address key barriers and leverage existing opportunities.
The chapter is organized as follows:

- **8.1 Synthesis of Findings**: Provides a summary of the barriers and enablers identified in earlier analyses, serving as a basis for the development of policy recommendations.
- **8.2 Policy Mixes**: Presents proposed policies categorized into Regulatory, Economic, and Informational types. Each policy recommendation is linked to the specific barriers and enablers it addresses, along with the expected outcomes of each policy pathway.
- **8.3 Evaluation of Policy Mix**: Evaluates the coherence and synergy of the proposed policies, highlighting potential challenges and opportunities for effective implementation.

The proposed policy mixes aim to create a supportive environment that fosters the adoption and scaling of reuse practices, aligning with Amsterdam's broader sustainability and circular economy objectives.

8.1 SYNTHESIS OF FINDINGS

This section summarizes the barriers and enablers identified in previous analyses of the reuse of PV panels in Amsterdam. Drawing from the Strategic Niche Management (SNM) and Multi-Level Perspective (MLP) frameworks, as well as insights from stakeholder interviews, the synthesis provides a foundation for developing targeted policy recommendations. Understanding these factors is crucial for designing a coherent policy mix that effectively addresses challenges and leverages opportunities.

Table 8.1: Synthesis of key enablers and barriers identified in previous sections.

Niche process	Chapter	Indicator	Enabler	Barrier
Expectations	6.1.1	Internal Expectations	**Stakeholders shift to sustainable, local strategies; growing confidence in reuse fosters alignment and scalability.**	
	6.1.2	External Expectations	**Increased awareness and interest among municipalities and some stakeholders create collaboration opportunities.**	**Skepticism about economic viability and safety of reused panels among producers and market actors.**
	6.1.3	Exogenous Expectations	Positive attitude towards (external) development opportunities	**Economic pressures from low-cost new panels and regulatory uncertainties challenge competitiveness.**

	6.1.4	Endogenous Expectations	**Encourages continuous learning and adaptation; supports realistic and flexible approaches to challenges.**	Cautious attitudes among non-directly involved stakeholders may hinder faster progress.
Network formation	6.2.1	Network Composition	**Strong foundational network; supports initial reuse practices.**	Broader engagement from producers and EPR organizations would help upscaling.
	6.2.2	Quality of the Sub Networks	**Effective contributions from key actors. Promotes collaboration and high standards.**	Regulatory barriers and limited engagement from smaller actors limit effectiveness.
	6.2.3	Network Interactions	**Core stakeholders communicate effectively; fosters collaboration. More structured interactions could further enhance cooperation.**	**Inconsistent communication with peripheral stakeholders poses challenges.**
	6.2.4	Network Alignment	Strong alignment between core stakeholders	**Fragmentation within the network due to differences in priorities, internal conflicts and varying approaches to EoL solutions hinder unified action.**
Learning Processes	6.3.1	Technical Development and Infrastructure	**Strong focus on rigorous testing and infrastructure development supports quality and scalability.**	Challenges related to standardization and logistical complexities also highlight areas for improvement to fully support scaling efforts.
	6.3.2	Industrial Development	**Investments in infrastructure and streamlined logistics support reuse.**	**Operational challenges and liability concerns hinder broader adoption.**
	6.3.3	Social and Environmental Impact	**Promotes social equity, job creation, and sustainability, aligning with broader societal goals.**	
	6.3.4	Development of the User Context	Potential adopters among community-oriented organizations and environmentally conscious individuals	**Financial constraints, awareness gaps, and regulatory hurdles limit user adoption.**
	6.3.5	Government Policy and Regulatory Framework	Policies like CSRD and local financial incentives support sustainable practices	**Inconsistent policies, slow government response, regulatory knowledge gaps and practical barriers hinder effective reuse practices.**

Socio - Technical Level	Chapter	Indicator	Enabler	Barrier
Regime	7.1.1	Stability in Regime	**Emerging collaboration and shifts towards innovation could support change.**	**Entrenched practices and resistance to change hinder sustainable reuse.**
	7.1.2	Suitability of Sectoral Policy		**Lack of clear directives, perceived certification challenges, and insufficient policy support for reuse.**
	7.1.3	Amount of Lock-In in Regime	**Low path dependency and potential for more sustainable practices.**	Financial, institutional, and organizational lock-ins favor existing low-quality recycling.

Landscape	7.2.1	Macro-Economic Trends	Potential increase in new panel costs due to geopolitical tensions and regulatory shifts could make reuse more attractive.	**Low cost of new panels driven by cheap imports makes reused panels less competitive.**
	7.2.2	Policy and Legislation Trends	**Emerging supportive local and EU frameworks for circular economy practices and potential regulatory amendments promote reuse.**	Existing regulations (e.g., WEEE Directive) might prioritize recycling over reuse.
	7.2.3	Technological Advancements	**Innovations in panel design, modularity, and monitoring technologies enhance the feasibility and attractiveness of reuse.**	Advanced recycling techniques could reduce incentives for reuse in favor of efficient recycling.

8.2 PROPOSED POLICIES

This section outlines proposed policies designed to facilitate the scaling of reuse practices for photovoltaic (PV) panels in Amsterdam. These suggestions are intended to serve as a guide for various stakeholders, including the municipality, industry partners, and policy experts, to collaboratively develop actionable strategies. The policies are organized into Regulatory, Economic, and Informational categories, with each one aligned to the specific barriers and enablers identified in the research.

8.2.1 REGULATORY POLICIES

Policy 1: Enhancing Flexibility and Responsiveness in Certification and Quality Standards for Reused PV Panels

Objective: To ensure the market can quickly adapt to emerging certification and quality standards for reused PV panels, enhancing clarity and compliance within the industry. To address skepticism about the economic viability and safety of reused panels and to reduce regulatory barriers related to quality and certification.

- **Policy Action:** The development of universal guidelines and standards for PV module reuse is already underway, with the H2020 project CIRCUSOL leading efforts that have prompted the IEC Technical Committee 82 WG2 to prepare a Technical Report titled "PV Module Re-use and Circular Economy." This report, which is expected to provide comprehensive recommendations for PV module reuse, could form the basis for future IEC Technical Specifications and Standards. The latest progress on this report, including real-world testing and validation of reuse procedures, highlights the need for adapted on-site functionality tests and provides practical insights from an operations and maintenance (O&M) perspective (Van Der Heide et al., 2023).

- Further supporting these efforts, the BEC National Committee has initiated a New Work Item (NWI) with the IEC TC82 WG2 to create the IEC Technical Report TR 63525, a project managed by PVCycle, a non-profit specializing in waste management and legal compliance for the solar industry. The planned launch of the TR 63525 report in Q1 2025 represents a significant step forward (CEB BEC, 2024). In light of these developments, it is recommended that stakeholders such as the municipality and industry players work together to establish a task force or rapid response team to monitor and swiftly implement these emerging standards. This team would provide guidance to local businesses and ensure compliance, fostering a proactive approach to regulatory changes.

Expected Outcomes: Enhanced market readiness and compliance with global standards, reduced uncertainty, and increased market confidence in reused PV panels. By ensuring rapid adaptation to emerging standards, this policy will help address skepticism about the safety and viability of reused panels and align local practices with international benchmarks.

Policy 2: Mandating Reuse Targets in Amsterdam's Waste Management Policies

Objective: To prioritize reuse over recycling in line with Amsterdam's Circular Strategy 2020 – 2025 and the broader circular economy goals of the European Union

- **Policy Action: Policy Action and Supporting Information:** The municipality could consider adopting reuse targets, in consultation with relevant stakeholders, as part of its waste management policies. Building on the existing Amsterdam Circular Strategy 2020-2025, which commits to reducing overall consumption by 20% by 2030 and achieving 100% circular procurement for city premises, this policy would mandate that a certain percentage of end-of-life PV panels collected must be refurbished and reused, rather than recycled. Latest research by CIRCUSOL indicates that 45% - 65% of decommissioned PV panels with occurred failures can be repaired/refurbished and reused (ETIP PV & EERA PV, 2024). This could involve setting a minimum threshold, trying to get as close as possible to these indicated percentages while staying economically feasible. This also stimulates the infrastructure already being developed for second-hand shops, sharing platforms, and repair services. This would help further develop the circular economy in the region.
- This policy aligns with the Waste Framework Directive (WFD) 2008/98/EC, which places "preparing for reuse" above recycling in the waste hierarchy, and could be integrated with existing Extended Producer Responsibility (EPR) schemes to ensure producers and waste managers are incentivized to prioritize reuse over recycling.

Expected Outcomes: Increased prioritization of reuse over recycling, alignment with circular economy objectives, enhanced local reuse infrastructure, and stronger market demand for reused PV panels. This policy would address barriers related to the existing regulatory focus on recycling and foster a shift towards more sustainable practices in line with both local and EU-level goals.

Policy 3: Public Procurement Policies Favoring Reused Panels

Objective: To create demand-pull for reused panels by prioritizing their use in public sector projects.

Policy Action: The Municipalit, in collaboration with public procurement officers, could explore revising its public procurement guidelines to require that all new publicly funded solar energy projects include a specified percentage of reused or repairable PV panels. This requirement will apply to all tenders and contracts for PV installations on public buildings, infrastructure, and lands.

- **Circular Economy Performance Scoring**: Develop a detailed scoring system within the procurement process to assess suppliers based on their commitment to circular economy practices. Criteria will include the use of reused or repairable PV panels, sustainability of supply chains, and innovative end-of-life management solutions. Suppliers demonstrating robust circular practices will receive higher scores, enhancing their competitiveness in public tenders.
- **Mandatory Reporting and Transparency**: All suppliers participating in public procurement must provide comprehensive documentation of their reuse and repair practices, including data on panel lifespan extension, waste reduction, and carbon footprint. This documentation will be publicly accessible to ensure transparency and accountability.
- **Capacity Building for Procurement Officers**: Implement a training program for procurement officers to ensure they are well-versed in circular economy principles, the specific requirements of the revised procurement guidelines, and the benefits of integrating reused and repairable PV panels into projects. This program will also provide them with tools to effectively assess supplier compliance and performance.

Expected Outcomes: Increased market demand for reused and repairable PV panels, driving innovation and sustainability in the local PV industry. Enhanced public sector leadership in circular economy practices, influencing broader market dynamics. Improved transparency and accountability in public procurement, aligning with Amsterdam's and the EU's circular economy objectives.

8.2.2 ECONOMIC POLICIES

Policy 4: Redefining EPR Budget Allocation Criteria Based on Environmental Impact

Objective: To incentivize Stichting OPEN to allocate Extended Producer Responsibility (EPR) funds towards higher R-strategies like reuse, refurbishment, and repair of PV panels, and to improve compliance among PV panel producers with EPR obligations, based on lifecycle assessment (LCA).

Policy Action:
In collaboration with national authorities and industry bodies, stakeholders could advocate for an LCA-based approach to EPR fund distribution. A portion of EPR budgets could be allocated specifically for reuse and refurbishment initiatives, encouraging investment in these higher R-strategies.

- **LCA-Based Allocation:** Require Stichting OPEN to allocate a defined portion (e.g., 30%) of the EPR budget specifically for initiatives supporting reuse, refurbishment, and repair of PV panels. Funding should be tied to lifecycle assessments (LCAs) that demonstrate significant environmental benefits from extending the lifespan of PV panels.
- **Environmental Impact Benchmarks:** Establish LCA-based benchmarks to guide EPR fund allocation. Projects that achieve lower environmental footprints through reuse or refurbishment should be prioritized for funding, promoting sustainable practices and innovation in the PV sector.
- **Transparency and Reporting:** Implement a robust reporting framework that requires Stichting OPEN to provide annual reports on EPR fund distribution across different end-of-life strategies (reuse, recycling, refurbishment) and the associated environmental outcomes. This will enhance transparency and accountability.
- **Enhanced Compliance Mechanisms:** Strengthen EPR compliance by introducing regular audits of PV panel producers and importers to verify fee payments. Develop a centralized digital platform to facilitate registration, fee payment, and compliance tracking, reducing administrative burdens and increasing transparency.
- **Incentives for Compliance:** Introduce financial incentives, such as tax discounts on sustainable investments, for companies that consistently comply with the EPR requirements. Additionally, introduce public recognition programs to enhance brand reputation among environmentally conscious consumers, creating a competitive advantage for compliant companies.

Expected Outcomes:
This policy would help direct more financial support toward reuse and refurbishment, promoting sustainable practices and innovation in the PV industry. Greater transparency and stronger compliance would ensure fair contributions from all market participants, reducing environmental impacts.

Policy 5: Supporting Second Life Business Models and the Growth of Second-Hand Traders

Objective: To promote the development of second-life business models and second-hand traders in the PV sector, enhancing market visibility, financial viability, and consumer confidence in reused, repaired, and refurbished PV panels.

Policy Action: Collaborative efforts between the municipality, financial institutions, and industry stakeholders could focus on providing startup grants, low-interest loans, and tax incentives for businesses engaging in circular economy activities. Offering subsidies for certification would help ensure that second-life panels meet regulatory standards, boosting market confidence. This framework could include the following components:

- **Startup Grants and Low-Interest Loans:** Provide financial support to new and existing businesses specializing in second-life PV activities. This would help cover initial costs such as setting up infrastructure for storage, repair, refurbishment, and resale of decommissioned PV panels, thus lowering the financial barriers to market entry.
- **Subsidies for Quality Assurance and Certification:** Offer subsidies for obtaining necessary certifications and adhering to quality standards. This would ensure that reused and refurbished PV panels meet market and regulatory expectations for safety and performance, thereby enhancing market confidence.
- **Tax Incentives for Circular Business Models:** Introduce tax credits for businesses engaged in circular economy activities, such as B2B models (turnkey solutions for commercial and industrial rooftops) and B2C models (e-commerce platforms trading decommissioned PV components). Additionally, provide financial incentives for donation-based models, encouraging companies to donate decommissioned PV panels to charitable organizations for off-grid applications.

Expected Outcomes: Growth in the number of second-hand traders and businesses adopting circular models, increased visibility and consumer confidence in second-life PV products, greater market adoption of reused and refurbished PV panels, and reduced PV waste entering the waste stream. *Figure 8.2.2* illustrates a second-life business model for a second-hand PV trader, demonstrating the economic flow and activities involved in the reuse, repair, and refurbishment of decommissioned PV panels. This model highlights the central role that second-hand traders can play in extending the lifecycle of PV panels, thereby contributing to circular economy objectives and sustainability goals.

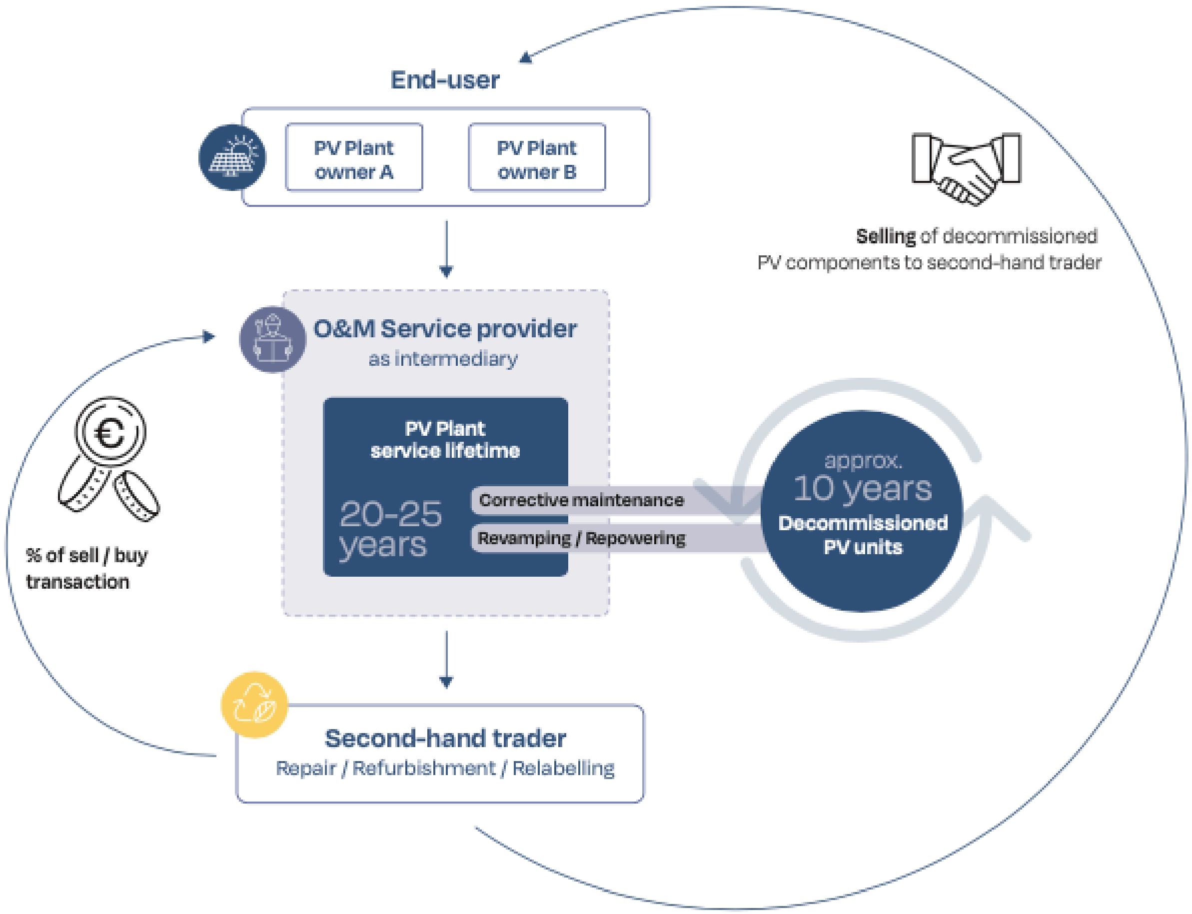

Figure 8.2.2: Second Life Business Model for a Second-Hand Trader (SolarPower Europe, 2024)

Policy 6: Financial Support and Social Return Program for Reused PV Panels in Low-Income and Social Housing

Objective: To promote the adoption of reused PV panels in low-income households and social housing while fostering social inclusion by creating job opportunities for individuals with limited access to the labor market. This policy aims to address energy poverty, improve social equity, and advance Amsterdam's sustainability objectives.

Policy Action:

The Municipality of Amsterdam, in collaboration with housing associations, social welfare organizations, and local businesses, could implement a comprehensive support program designed to make reused PV panels more accessible to low-income households and social housing projects, while promoting social return and job creation. The program will include:

- **Financial Support Linked to Social Return Initiatives:**
  Provide grants or low-interest loans for the installation of reused PV panels in social housing and low-income households. The financial support would be contingent upon the engagement of individuals from vulnerable labor market groups, such as those who are long-term unemployed, people with disabilities, or individuals lacking formal qualifications. This linkage ensures that financial assistance promotes both environmental and social benefits, supporting job creation and community development.
- **Training and Skill Development Subsidies:**
  Offer subsidies for vocational training and skill development programs tailored for individuals hired under the social return component. Training programs will cover PV panel installation, maintenance, and recycling processes, equipping participants with marketable skills and increasing their employability. These programs can be coordinated with local educational institutions, vocational schools, and industry professionals to provide comprehensive, hands-on training.
- **Support for Housing Associations and Social Enterprises:**
  Provide targeted financial incentives to housing associations and social enterprises that actively participate in the program. These incentives could include reduced rates for permits, access to municipal grants, or direct subsidies to offset the costs associated with integrating reused PV panels and hiring individuals from the target groups. By offering these benefits, the program aligns economic incentives with social and environmental objectives.
- **Community Engagement and Awareness Campaigns:**
  Launch targeted outreach initiatives to raise awareness about the benefits of reused PV panels and the available financial support among low-income households, social housing tenants, and community organizations. The campaign would focus on the dual benefits of reducing energy costs and creating local employment opportunities, encouraging broad community support and participation.

The program is expected to boost the adoption of reused PV panels in low-income households and social housing, lowering energy costs and combating energy poverty. By linking financial support to social return, it promotes job creation and skills development for underrepresented groups, aligning with the city's sustainability and social equity objectives.

8.2.3 INFORMATIONAL POLICIES

Policy 7: Marketing Campaigns and Eco-Labeling to Boost Demand for Reused PV Panels

Objective: To increase the demand for reused PV panels by targeting environmentally conscious customers, including both consumers and businesses, through effective marketing strategies and eco-labeling initiatives.

Policy Action: Collaboration between the municipality, industry stakeholders, and sustainability organizations could focus on launching marketing campaigns that highlight the environmental benefits of reused panels. Developing an eco-label specific to reused PV panels would provide clear, trustworthy information to consumers and businesses. This campaign would include several key components:

- **Eco-Labeling for Reused PV Panels**: Develop an eco-label specific to reused PV panels that highlights their environmental benefits, such as reduced carbon footprint and waste minimization. This label would serve as a recognizable symbol for consumers and businesses, indicating that the panels meet certain sustainability criteria and contribute to circular economy goals. The Municipality could work with certification bodies and industry experts to establish the standards and criteria for this eco-label.
- **Targeted Marketing and Awareness Campaigns**: Implement targeted marketing campaigns to raise awareness about the benefits of reused PV panels among different customer segments, including residential consumers, businesses, and public institutions. These campaigns could leverage various media channels, including social media, online advertising, and public events, to reach a broad audience and educate them on the advantages of choosing reused panels over new ones.
- **Partnerships with Green Building and Sustainability Organizations**: Form partnerships with organizations that promote green building and sustainability practices, such as LEED and BREEAM. These partnerships would help incorporate reused PV panels into green building certification systems, thereby increasing their appeal to environmentally conscious property developers and businesses.
- **Highlighting Success Stories and Case Studies**: Showcase successful projects and case studies where reused PV panels have been effectively integrated into new installations. Highlighting these examples in marketing materials, public presentations, and media stories would help build consumer confidence in the reliability and performance of reused panels.
- **Incentivizing Retailers and Installers**: Provide incentives for retailers and installers to promote reused PV panels to their customers. This could include financial rewards or recognition programs for businesses that achieve high sales volumes of reused panels, encouraging them to actively market these sustainable options.

Expected Outcomes:
The implementation of these marketing and eco-labeling strategies is expected to increase awareness and demand for reused PV panels among environmentally conscious consumers and businesses. By promoting the benefits of reused panels and providing clear, trustworthy

information through eco-labels, the policy will help shift consumer preferences towards more sustainable choices. This increased demand will support the growth of the reuse market, reduce PV waste, and align with Amsterdam's broader circular economy objectives.

Policy 8: Digital Tracking and Coordination Platform for PV Panels

Objective: To enhance the management of the inflow and outflow of reused PV panels by improving visibility of installed panels nearing decommissioning and coordinating their potential reuse. The policy aims to establish a digital tracking system to provide a better overview of panel availability and facilitate planning for their redeployment.

Policy Action: A digital platform could be developed in collaboration with industry stakeholders and technology providers to track installed panels nearing decommissioning and match them with reuse opportunities.

- **Inventory of Installed Panels:** Create a comprehensive inventory of existing PV panel installations across Amsterdam, including key data such as installation dates, expected end-of-life, condition, and ownership. This inventory would be maintained in a digital platform accessible to relevant stakeholders to provide real-time information on panels likely to be decommissioned soon.
- **Digital Tagging and Tracking of Panels:** Implement a tagging system, such as QR codes or RFID tags, for newly installed panels to collect data on their usage and maintenance history. This would allow for easy tracking of panels throughout their lifecycle and ensure that data is readily available when panels approach the end of their service life.
- **Coordination with Decommissioning and Reuse Activities:** Establish coordination mechanisms within the digital platform to align panel decommissioning with reuse opportunities. This would involve notifying stakeholders, such as second-hand traders and installation companies, of panels scheduled for removal and ready for reuse, facilitating better planning and logistics.
- **Planning and Forecasting Tools:** Integrate basic planning and forecasting tools to predict the availability of panels for reuse based on the age and expected end-of-life of current installations. This would help balance supply and demand more effectively, ensuring panels are reallocated swiftly to new projects.
- **Outreach and Collaboration with Stakeholders:** Work with PV panel owners, recycling firms, and installation companies to encourage participation in the digital tracking system. Provide guidelines and support on how to tag and track panels effectively, fostering collaboration and ensuring broad adoption of the system.
- **Pilot Programs and Data Sharing Initiatives:** Launch pilot programs with selected stakeholders to test the digital tracking system, collect initial data, and refine the platform based on feedback. Encourage data sharing among participants to enhance the quality and accuracy of the inventory and tracking data.

Expected Outcomes:
The implementation of a digital tracking system for installed and decommissioned PV panels is expected to provide better visibility of panel availability and facilitate the coordination of reuse

activities. By creating an inventory of installed panels and tracking those nearing decommissioning, the policy will help balance supply and demand, reduce delays in redeployment, and minimize waste. This will support Amsterdam's circular economy goals by promoting the efficient reuse of PV panels and ensuring a more sustainable end-of-life management process.

Policy 9: Knowledge-Sharing and Best Practices Platform for PV Panel Reuse

Objective: To enhance the capacity and knowledge of stakeholders involved in PV panel reuse by providing a centralized platform for sharing best practices, technical guidance, and lessons learned. This policy aims to support continuous improvement and innovation in PV panel reuse strategies by fostering collaboration and information exchange among stakeholders.

Policy Action: The Municipality, in collaboration with academic institutions, industry experts, and sustainability organizations, could develop a Knowledge-Sharing and Best Practices Platform specifically focused on PV panel reuse. This platform would serve as a hub for disseminating valuable information and fostering collaboration through the following actions:

- **Centralized Online Repository:** Create an online repository of resources, including technical manuals, case studies, white papers, and guidelines on PV panel reuse. This repository would provide stakeholders, such as installers, recyclers, second-hand traders, and policymakers, with easy access to up-to-date information and best practices in the field.
- **Webinars and Workshops:** Organize regular webinars and workshops featuring industry experts, researchers, and practitioners to discuss emerging trends, innovative techniques, and challenges in PV panel reuse. These events would facilitate knowledge exchange and provide opportunities for stakeholders to learn from each other's experiences.
- **Interactive Forums and Peer Learning Networks:** Establish interactive forums and peer learning networks within the platform where stakeholders can share their experiences, ask questions, and collaborate on common challenges. These forums would encourage a community-driven approach to problem-solving and innovation in the reuse of PV panels.
- **Partnerships with Educational Institutions:** Partner with universities and research centers to develop specialized training modules and courses on PV panel reuse. These partnerships would help integrate the latest research findings into practice and build a pipeline of skilled professionals in the reuse sector.
- **Monitoring and Evaluation of Reuse Practices:** Include tools for monitoring and evaluating reuse practices, allowing stakeholders to benchmark their performance against industry standards and identify areas for improvement. This feature would help drive continuous improvement and innovation in PV panel reuse.
- **Promoting Success Stories and Innovation:** Highlight and promote successful reuse projects and innovative approaches on the platform. Showcasing these examples would inspire other stakeholders to adopt best practices and drive further innovation in the sector.

Expected Outcomes:
The establishment of a Knowledge-Sharing and Best Practices Platform is expected to enhance the capacity and knowledge of stakeholders involved in PV panel reuse. By providing a centralized resource for information exchange and collaboration, the policy will support continuous improvement and innovation in reuse practices. This will help overcome technical and operational barriers, foster a culture of learning and innovation, and ultimately contribute to the growth and sustainability of the PV panel reuse market in Amsterdam.

8.2.4 POLICIES AND SPECIFIC INDICATORS ADDRESSED

The table below visualizes all the policies and include which exact indicator they address and which specific enablers and or barriers are addressed by this policy measure.

Table 8.2.4: Overview Policies & addressed enablers & barriers

Policy	Indicator & Chapter Addressed	Enabler Addressed	Barrier Addressed
Policy 1: Enhancing Flexibility and Responsiveness in Certification and Quality Standards	6.1.2 External Expectations, 6.2.2 Quality of the Sub Networks, 6.2.4 Network Alignment, 7.1.2 Suitability of Sectoral Policy	Effective contributions from key actors, strong alignment between core stakeholders, increased awareness among stakeholders	Skepticism about economic viability and safety of reused panels, regulatory barriers, fragmentation in the network
Policy 2: Mandating Reuse Targets in Amsterdam's Waste Management Policies	6.2.4 Network Alignment, 6.3.5 Government Policy and Regulatory Framework, 7.1.1 Stability in Regime, 7.1.2 Suitability of Sectoral Policy, 7.2.2 Policy and Legislation Trends	Strong alignment between core stakeholders, emerging supportive local and EU frameworks	Inconsistent policies, slow government response, regulatory knowledge gaps, entrenched practices and resistance to change
Policy 3: Public Procurement Policies Favoring Reused Panels	6.1.1 Internal Expectations, 6.3.4 Development of the User Context, 7.1.1 Stability in Regime, 7.2.2 Policy and Legislation Trends	Stakeholders shift to sustainable strategies, potential adopters among community organizations	Lack of clear directives and policy support for reuse, low market demand due to entrenched practices
Policy 4: Redefining EPR Budget Allocation Criteria Based on Environmental Impact	6.3.2 Industrial Development, 7.1.3 Amount of Lock-In in Regime, 6.3.5 Government Policy and Regulatory Framework	Investments in infrastructure, low path dependency and potential for sustainable practices	Financial, institutional, and organizational lock-ins favor existing low-quality recycling, inconsistent policies

Policy 5: Supporting Second Life Business Models and the Growth of Second-Hand Traders	6.2.1 Network Composition, 6.3.2 Industrial Development, 7.2.1 Macro-Economic Trends	Strong foundational network, investments in infrastructure, increased new panel costs could make reuse more attractive	Broader engagement needed from producers and EPR organizations, operational challenges, and liability concerns
Policy 6: Financial Support and Social Return Program for Reused PV Panels in Low-Income and Social Housing	6.1.3 Exogenous Expectations, 6.3.3 Social and Environmental Impact, 7.2.1 Macro-Economic Trends	Positive attitude towards external development opportunities, promotes social equity and job creation	Economic pressures from low-cost new panels, financial constraints, awareness gaps
Policy 7: Marketing Campaigns and Eco-Labeling to Boost Demand for Reused PV Panels	6.1.2 External Expectations, 6.3.4 Development of the User Context	Increased awareness and interest among municipalities and stakeholders	Skepticism about economic viability and safety of reused panels, financial constraints, and awareness gaps
Policy 8: Digital Tracking and Coordination Platform for PV Panels	6.3.1 Technical Development and Infrastructure, 6.2.3 Network Interactions, 6.3.4 Development of the User Context	Strong focus on rigorous testing and infrastructure development, effective communication among core stakeholders	Challenges related to standardization, logistical complexities, inconsistent communication with peripheral stakeholders
Policy 9: Knowledge-Sharing and Best Practices Platform for PV Panel Reuse	6.1.4 Endogenous Expectations, 6.2.3 Network Interactions, 6.3.1 Technical Development and Infrastructure	Encourages continuous learning and adaptation, promotes collaboration and high standards	Cautious attitudes among non-directly involved stakeholders, standardization challenges, operational barriers

8.3 PROPOSED POLICY MIXES & EVALUATION

This section proposes policy mixes, focusing on their coherence, synergy, and potential effectiveness. It assesses how well the policies work together to address identified challenges and opportunities and identifies any potential conflicts or gaps. This evaluation aims to ensure that the policy mix is both comprehensive and strategically aligned to promote the scaling of reuse practices for PV panels in Amsterdam.

8.3.1 POLICY MIX 1: TAILORED FOR THE CITY OF AMSTERDAM

This mix focuses on policies that Amsterdam can directly implement and that align with the city's regulatory and economic capabilities. It creates both supply and demand for reused PV panels by leveraging public procurement, financial support for local businesses, and marketing strategies.

Table 8.3.1: Policy Mix for the City of Amsterdam

Policy	Description	Barriers/Enablers Addressed
Policy 2	Mandating Reuse Targets in Amsterdam's Waste Management Policies	Inconsistent policies (Barrier 7.1.2); strong alignment between stakeholders (Enabler 6.2.4)
Policy 3	Public Procurement Policies Favoring Reused Panels	Lack of clear directives (Barrier 7.2.2); entrenched practices (Barrier 6.3.4); potential adopters in the public sector (Enabler 6.1.1)
Policy 5	Supporting Second Life Business Models and the Growth of Local Traders	Financial constraints (Barrier 6.3.2); operational challenges for small actors (Barrier 6.2.2); growing local market for reuse (Enabler 6.2.1)
Policy 7	Marketing Campaigns and Eco-Labeling to Boost Demand for Reused PV Panels	Awareness gaps (Barrier 6.3.4); skepticism about safety (Barrier 6.1.2)

Expected Outcomes and Synergy Rationale:

- Regulatory and Demand Creation (Policy 2 & 3): Mandating reuse targets (Policy 2) ensures clear directives that prioritize reuse, while public procurement policies (Policy 3) create strong demand from the public sector. These policies signal the market that reuse is both viable and required. Public procurement acts as a guaranteed market, further enhancing demand.
- Supporting Local Supply (Policy 5): Financial support for second-life business models (Policy 5) addresses supply-side constraints by helping local businesses expand their reuse operations. Grants and loans reduce financial barriers, ensuring that businesses can scale to meet growing demand from public procurement and broader market needs.
- Driving Consumer Confidence and Awareness (Policy 7): Marketing campaigns and eco-labeling (Policy 7) help address skepticism and raise consumer awareness. This demand-pull strategy ensures that consumers trust reused PV panels and are more likely to adopt them, complementing the supply-side growth supported by Policy 5.

This policy mix creates a balanced ecosystem for PV panel reuse in Amsterdam by addressing both supply and demand. Public procurement provides initial demand, financial support strengthens local supply, and awareness campaigns ensure sustained market interest. Together, they create a self-sustaining circular economy for PV panels.

8.3.2 POLICY MIX 2: TAILORED FOR THE DUTCH NATIONAL GOVERNMENT

This policy mix focuses on broad national strategies that can address systemic barriers and enablers at the national level. It combines regulatory reforms, economic incentives, and information-sharing platforms to drive reuse across the country.

Table 8.3.2: Policy Mix for the Dutch National Government

Policy	Description	Barriers/Enablers Addressed
Policy 1	Enhancing Flexibility and Responsiveness in Certification and Quality Standards for Reused PV Panels	Regulatory barriers (Barrier 7.1.2); skepticism about viability (Barrier 6.1.2); alignment of standards (Enabler 6.2.4)
Policy 4	Redefining EPR Budget Allocation Criteria Based on Environmental Impact	Institutional lock-ins favoring recycling (Barrier 7.1.3); financial constraints (Barrier 6.1.3); strong potential for reuse (Enabler 6.3.2)
Policy 9	Knowledge-Sharing and Best Practices Platform for PV Panel Reuse	Lack of collaborative networks (Barrier 6.2.4); standardization challenges (Barrier 6.3.1); promotes learning and collaboration (Enabler 6.2.3)

Expected Outcomes and Synergy Rationale

- Building National Standards and Trust (Policy 1): Enhancing certification and quality standards (Policy 1) builds market confidence and addresses skepticism about reused panels. This supply-side push enables businesses to meet quality expectations and fosters trust among consumers and producers.
- Economic Incentives for Reuse (Policy 4): Redefining EPR budget allocations (Policy 4) shifts financial incentives toward reuse, encouraging producers to prioritize repair and refurbishment over recycling. This systemic economic reform aligns investments with sustainability goals, creating a financial foundation for the reuse market.
- Knowledge Sharing and Collaboration (Policy 9): The knowledge-sharing platform (Policy 9) ensures that best practices are disseminated across the industry. It fosters collaboration, promoting innovation and improving operational efficiencies. This systemic support helps stakeholders navigate both technical and regulatory challenges.

This policy mix addresses national-level challenges by building trust through standardization, offering financial incentives for reuse, and fostering a collaborative environment. Together, these policies create a cohesive framework that supports the scaling of PV panel reuse across the country.

8.3.3 POLICY MIX 3: COMBINED NATIONAL AND AMSTERDAM STRATEGY

This policy mix combines local and national strategies to ensure consistency across governance levels. It aligns Amsterdam's local efforts with national policies, creating a unified framework that leverages both regional and national strengths.

Table 8.3.3: Combined National and Regional Policy Mix

Policy	Description	Barriers/Enablers Addressed
Policy 1	Enhancing Flexibility and Responsiveness in Certification and Quality Standards for Reused PV Panels	Regulatory barriers (Barrier 7.1.2); skepticism (Barrier 6.1.2); alignment with national standards (Enabler 6.2.4)
Policy 2	Mandating Reuse Targets in Amsterdam's Waste Management Policies	Inconsistent policies (Barrier 7.1.2); entrenched practices (Barrier 6.3.4); alignment between stakeholders (Enabler 6.2.4)
Policy 4	Redefining EPR Budget Allocation Criteria Based on Environmental Impact	Institutional lock-ins favoring recycling (Barrier 7.1.3); financial constraints (Barrier 6.1.3); alignment of environmental goals (Enabler 6.3.2)
Policy 6	Financial Support and Social Return Program for Reused PV Panels in Low-Income and Social Housing	Social equity gaps (Barrier 6.3.3); economic pressures from low-cost panels (Barrier 7.2.1); promoting job creation (Enabler 6.1.3)
Policy 8	Digital Tracking and Coordination Platform for PV Panels	Logistical complexities (Barrier 6.3.1); inconsistent data sharing (Barrier 6.2.3); strong infrastructure focus (Enabler 6.3.1)

Expected Outcomes and Synergy Rationale

- Alignment between National Standards and Local Implementation (Policy 1 & Policy 2): National certification and quality standards (Policy 1) provide the supply-side foundation by ensuring that reused PV panels meet safety and quality benchmarks, building trust in the market. Local reuse targets (Policy 2) create demand-pull by requiring public projects to prioritize reuse. This alignment between supply and demand fosters consistent implementation across Amsterdam, reducing confusion and enhancing collaboration between national and local stakeholders.
- Economic Support for Social Inclusion and Environmental Goals (Policy 4 & Policy 6): EPR budget reallocation (Policy 4) serves as a systemic economic instrument that supports supply-side activities by encouraging reuse initiatives through financial incentives. Policy 6 drives demand-pull by linking reuse with social housing projects, making reused PV panels accessible to low-income households while addressing both environmental and social equity goals.
- Efficient Panel Management (Policy 8): The digital tracking platform (Policy 8) acts as a systemic tool, enhancing the supply chain by improving logistical coordination for PV panels nearing decommissioning. This supports both the national and local efforts to efficiently manage and redistribute panels, minimizing waste and optimizing reuse processes.

This integrated policy mix aligns supply-side enhancements (quality standards, financial incentives) with demand-pullmechanisms (reuse targets, social inclusion programs), ensuring consistent reuse practices across governance levels. It promotes a balanced approach, supporting both the scaling of PV panel reuse and ensuring resource efficiency through systemic coordination and economic inclusion.

8.4 POTENTIAL CONFLICTS AND GAPS

While each policy mix offers a well-structured approach to scaling PV panel reuse, potential conflicts and gaps may arise due to differing goals, regulatory complexities, and resource allocation. This section identifies these potential issues for each policy mix.

8.4.1 POTENTIAL CONFLICTS AND GAPS IN POLICY MIX 1: CITY OF AMSTERDAM FOCUS

1. **Resource and Capacity Constraints**:
    - Policies supporting local traders (Policy 5) may face capacity challenges as small businesses struggle to meet increased demand created by public procurement (Policy 3) and reuse mandates (Policy 2). Without sufficient financial and operational support, local actors may find it difficult to scale effectively, limiting supply.
2. **Demand Imbalance**:
    - Public procurement (Policy 3) and reuse mandates (Policy 2) create strong demand-pull forces, but if supply-side policies like financial support (Policy 5) are not scaled appropriately, there could be an imbalance. Demand may outpace the supply of reused PV panels, slowing the adoption process.
3. **Public Awareness Gaps**:
    - Although Policy 7 addresses consumer confidence through marketing and eco-labeling, there may still be gaps in consumer education. If the awareness campaigns are not extensive or persuasive enough, the uptake of reused PV panels could remain low, despite strong institutional demand.

8.4.2 POTENTIAL CONFLICTS AND GAPS IN POLICY MIX 2: DUTCH NATIONAL GOVERNMENT FOCUS

1. **Regulatory Lag**:
    - Certification standards (Policy 1) and changes to EPR budget allocation (Policy 4) may face delays due to the complex regulatory environment at the national level. If standards are not established quickly, reuse projects may stall, limiting supply-side growth.
2. **Misalignment of Financial Incentives**:
    - The redefined EPR framework (Policy 4) encourages systemic financial support, but if not aligned with market realities, it may lead to unintended consequences. For instance, financial incentives might disproportionately favor recycling over reuse, limiting the effectiveness of the policy to shift behavior toward reuse.
3. **Collaboration Challenges**:
    - The knowledge-sharing platform (Policy 9) aims to foster collaboration, but without strong engagement from all stakeholders, particularly smaller and local actors, it may not generate the necessary momentum for systemic change. This could lead to fragmented progress in scaling reuse practices.

8.4.3 POTENTIAL CONFLICTS AND GAPS IN POLICY MIX 3: COMBINED NATIONAL AND AMSTERDAM STRATEGY

1. **Coordination Between National and Local Levels**:
    - While this policy mix seeks alignment, discrepancies in implementation between national standards (Policy 1) and local targets (Policy 2) may arise. For example, national regulations may not fully accommodate the specific needs of local markets, leading to slower adoption of reuse practices in Amsterdam.
2. **Funding and Resource Allocation**:
    - Financial incentives (Policy 4) at the national level may not always align with the specific economic conditions in Amsterdam. Local programs, such as social return initiatives (Policy 6), could face funding shortages if national priorities shift away from reuse. This could create gaps in supply and affect equitable access to reused PV panels.
3. **Logistical and Data Coordination**:
    - While the digital tracking platform (Policy 8) aims to streamline supply chains, integration between national and local data systems may prove challenging. Inconsistent data sharing and logistical complexities could limit the ability to efficiently manage panel flows and coordinate reuse efforts across governance levels.

Conclusion

In each policy mix, the key conflicts revolve around **capacity constraints**, **misaligned incentives**, and **coordination challenges** between national and local stakeholders. While the mixes are designed to balance supply and demand, addressing these potential conflicts will require careful resource allocation, regulatory alignment, and stronger stakeholder engagement to ensure the successful scaling of PV panel reuse practices.

9. DISCUSSION

9.1 REFLECTION ON THE APPLIATION OF THEORY

In this section, we critically reflect on the application of the Strategic Niche Management (SNM), Multi-Level Perspective (MLP), and Policy Mix frameworks within this research on scaling reuse practices for photovoltaic (PV) panels in Amsterdam. The chosen theoretical frameworks were intended to provide a comprehensive understanding of the socio-technical dynamics influencing the development of reuse practices. While these frameworks were valuable for identifying barriers and enablers, several challenges were encountered in their application, particularly in capturing the full complexity of the socio-technical transitions required for such innovations.

Application of Strategic Niche Management (SNM)
Utility of SNM in Identifying Barriers and Enablers: SNM was particularly effective in analyzing the development of reuse practices as niche innovations. It facilitated the identification of enablers and barriers across three main processes: expectations, network formation, and learning (Geels, 2002; Schot & Geels, 2008). For instance, the analysis revealed that stakeholders' growing confidence in reuse and the strong foundational network were critical enablers (*see Table 10.1*). Conversely, skepticism about the economic viability and safety of reused panels emerged as significant barriers, pointing to areas where policy interventions could help build market confidence.

Focused but Limited Application: Although SNM provided a useful framework for identifying indicators of niche development, its application in this research was limited to basic elements. The study emphasized nurturing processes, such as building networks and fostering learning, over more advanced SNM elements like shielding and empowering niche innovations. This selective application allowed for a targeted analysis of the current developmental stage of PV panel reuse in Amsterdam, where nurturing remains a priority. However, it also limited the study's ability to explore the full theoretical depth of SNM, particularly in terms of how to protect niches from market pressures (shielding) or how to empower them to challenge existing regimes.

Challenges in Applying SNM Indicators: The broad scope of the research and the diversity of stakeholders involved meant that not all SNM indicators were relevant to every stakeholder. This challenge resulted in incomplete data collection and constrained the ability to comprehensively apply SNM across all relevant dimensions. Additionally, the reliance on qualitative data from interviews introduced subjectivity, as the insights primarily reflected the perspectives of those interviewed, limiting the ability to generalize findings across all potential stakeholders.

Application of the Multi-Level Perspective (MLP)

MLP's Contribution to Understanding Regime and Landscape Dynamics: The MLP framework was valuable for situating the reuse niche within the broader socio-technical context, examining how interactions between the niche, regime, and landscape levels could either facilitate or hinder scaling (Geels, 2002; Geels & Schot, 2007). This multi-layered analysis identified entrenched practices within the recycling regime and highlighted the role of external pressures, such as regulatory changes and market dynamics, in creating opportunities for reuse (see *Table 10.2*). The MLP framework helped show the barriers posed by financial, institutional, and organizational lock-ins that favor existing recycling methods over innovative reuse strategies.

Basic Application of MLP: The application of MLP in this research was similarly basic, focusing primarily on identifying barriers and enablers rather than conducting a detailed analysis of regime dynamics or the pathways through which niche innovations could disrupt or transform existing regimes. While this approach was useful for policy development, it did not capture the full complexity of multi-level interactions or the nuanced ways in which niche, regime, and landscape dynamics interact over time.

Limitations in Exploring Multi-Level Interactions: The study provided a broad overview of socio-technical transitions but did not delve deeply into the specific interactions between niche, regime, and landscape levels due to the broad research focus. For example, while the analysis identified external pressures that could create windows of opportunity for reuse practices, it did not fully explore the interplay between these pressures and the specific actions needed to capitalize on them. This limitation suggests a need for more detailed, context-specific analyses to fully understand the pathways for niche scaling.

Integration of SNM and MLP for Policy Development

Policy Mix Approach as a Synthesis of SNM and MLP Insights: The Policy Mix approach was employed to translate the theoretical insights from SNM and MLP into actionable policy strategies (Rogge & Reichardt, 2016). This approach effectively integrated the barriers and enablers identified through SNM and MLP into a coherent set of policy recommendations designed to support niche development and scaling. The proposed policy mixes, detailed in *chapter 8.3*, combine regulatory, economic, and informational strategies to address key challenges and leverage opportunities.

Challenges in Translating Theory into Practice: While the Policy Mix approach provided a practical tool for policy development, it also revealed the challenges of translating theoretical insights into actionable strategies. The proposed policies were based on identified barriers and enablers but lacked specificity in their implementation steps. As a researcher without formal training in policy-making, there were constraints in understanding how different stakeholders could contribute to policy processes or how to operationalize these policies effectively.

Importance of Policy Processes: The effectiveness of the proposed policy pathways heavily depends on the intricacies of the policy-making and implementation processes (Sabatier & Weible, 2014; Rogge & Reichardt, 2016). Continuous monitoring, adaptation, and learning are necessary to refine the policy mix over time, particularly given the dynamic nature of socio-technical transitions and the evolving political landscape (Kern & Howlett, 2009). Future research should focus on these processes, emphasizing the importance of stakeholder engagement, adaptive policy design, and ongoing evaluation to ensure policies remain relevant and effective.

Conclusion
The application of SNM, MLP, and the Policy Mix frameworks in this research provided valuable insights into the development and scaling of reuse practices for PV panels in Amsterdam. However, the selective application of these frameworks, combined with data collection constraints, suggests a need for more focused, context-specific research. Future studies should aim to deepen the analysis of niche and regime dynamics, enhance stakeholder engagement, and develop more detailed and practical policy recommendations to support sustainable transitions. Integrating theoretical insights with empirical findings more closely would enhance the robustness of future research and contribute to more effective strategies for fostering sustainability transitions.

9.2 REFLECTION OF FINDINGS IN RELATION TO EXISTING LITERATURE

9.2.1 REFLECTION OF FINDINGS IN RELATION TO THE LITERATURE REVIEW

This research confirms several key insights from the literature on End-of-Life (EoL) management of photovoltaic (PV) panels, particularly the dominance of recycling over reuse as the default strategy. The literature frequently emphasizes that recycling is more developed due to better-established infrastructure and market mechanisms (Tsanakas et al., 2020). Similarly, this study found that reuse practices in Amsterdam face significant logistical, financial, and regulatory challenges, which impede their adoption. The findings underscore the need for specific policy interventions, such as standardization and financial incentives, to make reuse practices viable—a gap previously noted but underexplored in the literature.

A central theme in both the literature and this research is the economic and technological barriers to reuse. High costsand the lack of financial incentives have been cited in numerous studies as key obstacles (Mahmoudi et al., 2020). This study corroborates that these barriers are also prevalent in Amsterdam, particularly due to the low cost of new panels and insufficient market support for reused products. However, the study adds to the discussion by highlighting how local factors, such as fragmented policies and limited engagement from key stakeholders, exacerbate these challenges.

The regulatory frameworks supporting reuse, or lack thereof, are also a critical barrier highlighted in the literature. While fragmented policies have been cited as a European-wide issue (Bošnjaković et al., 2023), this study provides a more localized perspective, revealing how Amsterdam's policies are insufficiently aligned with broader EU directives. The literature has called for stronger regulatory frameworks to prioritize reuse (Nain and Anctil, 2024), and this study reflects those concerns, proposing specific reuse mandates and policy adjustments to better support the scaling of reuse practices in Amsterdam.

Finally, the literature often lacks in-depth exploration of scaling reuse practices, focusing instead on recycling. This research fills that gap by not only identifying financial and infrastructural enablers needed for scaling reuse but also proposing detailed policy interventions, such as public procurement policies favoring reused panels and financial incentives for second-life businesses. This approach adds practical, actionable insights that complement the existing body of knowledge.

9.2.2 REFLECTION OF FINDINGS IN RELATION TO EXISTING LITERATURE

The findings of this study reflect and expand upon several key insights from existing literature, offering new perspectives on how Amsterdam's reuse practices fit into broader European trends.

Both this research and the literature highlight the economic viability of reused PV panels as a major barrier. The low cost of new panels (Van der Heide et al., 2023) and the lack of extended warranties and standardized testing make it difficult for reused panels to compete. This study confirms that in Amsterdam, skepticism around economic feasibility and quality control further hinders the market for reused panels. However, the CIRCUSOL guidelines mentioned in the literature (Van der Heide et al., 2023) offer a first attempt at addressing these issues through standardized testing and cost-effective quality assurance, which could be a crucial step for local adoption.

In both Amsterdam and broader European contexts, stakeholder networks are essential for fostering reuse practices. While the literature (SolarPower Europe, 2024) points to a fragmented second-hand PV market across Europe, this study shows that Amsterdam benefits from a strong foundational network but still requires broader engagement, particularly from producers and EPR organizations. The proposed policy mixes in this research, including mandating reuse targets and enhancing public procurement strategies, align well with broader European recommendations for strengthening collaboration among key stakeholders.

The regulatory environment is another shared challenge. Van der Heide et al. (2023) highlight the WEEE Directive's limitations in promoting reuse, noting the lack of specific targets for PV modules. This study confirms that Amsterdam faces similar issues, with fragmented policies and regulatory inconsistencies preventing the full adoption of reuse practices. However, this research adds a local dimension by proposing reuse targets in Amsterdam's waste management policies, which could serve as a model for aligning local and national efforts to promote reuse over recycling.

Despite these barriers, both the literature and this research highlight significant opportunities for scaling reuse. SolarPower Europe (2024) discusses how the repowering wave in Europe is creating a surplus of decommissioned yet functional panels, offering a potential supply for reuse. My findings reflect this trend in Amsterdam, where the city's strong technical infrastructure and local policies could help capitalize on this opportunity. Additionally, advancements in modular panel designs and monitoring systems (ETIP & EERA PV, 2024) provide a technical foundation for reuse, although local investments in logistics and infrastructure are still needed to fully realize this potential.

9.2.3 CONCLUSION

The combined reflections of my findings and existing literature reveal both alignment and divergence in the challenges and opportunities for scaling reuse practices for PV panels. While Amsterdam shares many of the economic, regulatory, and technological barriers identified in broader European contexts, this research provides a more localized view of how these challenges play out on the ground. The proposed policy interventions in this study—focused on standardization, financial incentives, and stakeholder collaboration—offer actionable solutions that complement the broader European policy frameworks. By bridging the regulatory gaps and fostering a stronger circular economy, Amsterdam has the potential to lead in the adoption of reuse practices, contributing to a more sustainable management of PV panels.

9.3 RESEARCH LIMITATIONS

This chapter discusses the limitations of the research conducted on the development and scaling of reuse practices for photovoltaic (PV) panels in Amsterdam. The study employed multiple theoretical frameworks—Socio-Technical Systems (STS), Strategic Niche Management (SNM), the Multi-Level Perspective (MLP), and the Policy Mix approach—to identify barriers and enablers for niche development. While these frameworks provided valuable insights, the research faced several constraints related to scope, data collection, framework application, and policy recommendations.

9.3.1 SCOPE OF THE RESEARCH

Broad Scope of Frameworks: A significant limitation was the broad scope of the research, which integrated multiple theoretical frameworks to explore the socio-technical dynamics influencing PV panel reuse. While this comprehensive approach aimed to cover various dimensions, it limited the depth of analysis for each framework. The research primarily applied basic elements of SNM and MLP to develop indicators for identifying barriers and enablers, rather than conducting a thorough theoretical analysis. This broad focus provided a general understanding but lacked specificity in capturing the detailed dynamics of the reuse niche in Amsterdam.

Stakeholder Engagement Challenges: Due to the broad scope, engaging a wide range of stakeholders was necessary, each with different perspectives and expertise. However, not all questions linked to the SNM and MLP indicators were relevant to every stakeholder. This resulted in incomplete data collection, as not every question could be asked of all participants. The broad stakeholder range also meant that some key voices, particularly those from Stichting OPEN, were not included. Their absence was notable, as they play a crucial role in Extended Producer Responsibility (EPR) for PV panels in the Netherlands, and their insights could have provided a more balanced perspective, especially in addressing criticisms raised by other interviewees.

9.3.2 DATA COLLECTION AND METHODOLOGICAL CONSTRAINTS

Time Constraints: The research was conducted within a limited timeframe as part of a master's program, which restricted the opportunity for more extensive data collection and in-depth analysis. More time would have allowed for engaging additional stakeholders and conducting a more comprehensive exploration of the socio-technical landscape, potentially providing a richer understanding of the reuse niche.

Reliance on Qualitative Data: The study relied on qualitative data from interviews, which, while providing valuable insights, were inherently subjective and limited in scope. This reliance made it difficult to triangulate findings with other data sources, such as quantitative measures or secondary data. The absence of diverse data sources constrained the ability to validate the findings and ensured that the results were indicative rather than comprehensive.

Subjectivity and Potential Bias: The interview-based data collection introduced a risk of bias, reflecting primarily the perspectives of those interviewed. The exclusion of key stakeholders, like Stichting Open, meant that some critical views were underrepresented. Although efforts were made to minimize bias, the lack of engagement with certain stakeholders limited the ability to provide a fully balanced analysis, particularly regarding the criticisms raised by other interviewees.

9.3.3 LIMITATIONS IN FRAMEWORK APPLICATION

Selective Application of SNM and MLP: The research applied SNM and MLP primarily to identify indicators of barriers and enablers, rather than fully utilizing the theoretical depth of these frameworks. This basic application was useful for developing policy recommendations but did not capture the full complexity of niche dynamics or the detailed processes of socio-technical transitions. For example, while SNM highlighted network formation, expectation management, and learning processes, it did not fully explore the intricate processes of shielding, nurturing, and empowering niche innovations.

Challenges in Analyzing Niche Dynamics: The limited use of SNM and MLP meant that the specific dynamics within the reuse niche were not thoroughly explored. While the frameworks provided a broad overview of the socio-technical environment, they lacked the granularity needed to understand the nuanced interactions among stakeholders or the detailed processes driving niche development. This limitation reduced the ability to formulate targeted interventions specific to the Amsterdam context.

Prioritization of Barriers: Another challenge was determining which barriers identified through SNM and MLP should be prioritized for policy intervention. Not all barriers require immediate action, and the frameworks did not provide clear guidance on how to prioritize these barriers or balance short-term and long-term strategic goals. This suggests a need for more refined analysis to identify which barriers are most critical to address to support effective niche development and scaling.

9.3.4 PRACTICAL LIMITATIONS IN POLICY RECOMMENDATIONS

Translating Theory into Practice: The Policy Mix approach aimed to convert theoretical insights from SNM and MLP into actionable policy strategies. However, as a researcher without formal training in policy-making, there were challenges in providing detailed implementation steps or understanding how different stakeholders could contribute. The proposed policies were based on identified barriers and enablers, but lacked specificity in how to operationalize them effectively. Further expertise in policy development would enhance these recommendations, ensuring they are practical and feasible.

Implementation Complexities: The Policy Mix approach did not fully account for the complexities involved in policy implementation, especially in a local context like Amsterdam. The research highlighted political, economic, and institutional barriers that could impede policy changes. Additionally, the approach did not sufficiently consider informal networks or grassroots initiatives, which are often crucial for driving niche development. This oversight limits the applicability of the Policy Mix approach in contexts where informal mechanisms are significant.

Context-Specific Nature of Recommendations: The policy recommendations developed are specific to Amsterdam and may not be directly applicable to other settings. The unique socio-technical environment and policy landscape mean that strategies proposed here might require adaptation for use in different contexts. This underscores the need for context-sensitive policy development and further exploration of the generalizability of these findings.

9.3.5 CONCLUSION

While the research provided valuable insights into the development and scaling of reuse practices for PV panels in Amsterdam, several limitations impacted the study's scope, data collection, framework application, and policy recommendations. These limitations highlight the need for more focused research, greater stakeholder engagement, diverse data sources, and collaboration with policy experts to refine and implement effective strategies. Future research should address these limitations, aiming for a more in-depth and context-specific understanding of socio-technical transitions to support sustainable innovations effectively.

9.4 IMPLICATION FOR KNOWLEDGE USERS

This section provides practical guidance for knowledge users—including policymakers, industry stakeholders, community organizations, and Stichting OPEN—on advancing reuse initiatives for photovoltaic (PV) panels in Amsterdam. Drawing from the research insights on stakeholder expectations, network dynamics, and identified barriers, this chapter outlines actionable steps to enhance reuse practices.

9.4.1 POLICYMAKERS

Strengthening Policy Support for Reuse
Policymakers play a crucial role in creating a regulatory environment conducive to PV panel reuse. This research highlights the need for robust certification standards as this is often perceived as a barrier to broader adoption (Kruisheer, WCZ). To support the scaling of reuse practices, policymakers should collaborate with key stakeholders, including Stichting OPEN, to set specific reuse targets within Extended Producer Responsibility (EPR) frameworks and offer incentives to achieve these goals.

Emphasizing Dynamic Policy Processes
For knowledge users, including policymakers and practitioners, it is crucial to recognize that the success of policy mixes is not solely dependent on their design but also on the ongoing policy processes that involve adaptation, stakeholder engagement, and overcoming implementation barriers (Sabatier & Weible, 2014; Rogge & Reichardt, 2016). Effective application of these findings requires continuous monitoring, iterative learning, and flexible governance practices to ensure that policy pathways can be adjusted and optimized in response to real-world challenges (Kern & Howlett, 2009). This dynamic approach ensures that policies remain relevant and effective over time.

Aligning Financial Incentives
Adjusting financial incentives is essential to promote reuse. The current focus on recycling over reuse, managed under existing EPR schemes, often stems from cost considerations (Zumpolle, ZRN). Policymakers should reform these schemes to include financial rewards for reuse efforts, such as reduced fees or subsidies for testing and certification and incorporate social return mandates into public projects to fund reuse initiatives (de Vilder, AMS1).

9.4.2 INDUSTRY STAKEHOLDERS AND PRACTITIONERS

Optimizing Supply Chains and Logistics
Industry stakeholders, including manufacturers, installers, and waste managers, are crucial in developing sustainable supply chains for reused panels. This research identifies logistical challenges, such as panel collection, testing, and storage, as significant barriers (ten Brinke,

S2C). Addressing these issues requires establishing decentralized collection points, improving storage solutions, and fostering partnerships with municipalities and housing corporations to stabilize supply and demand (van Olffen, ZN).

Leveraging Technological Innovations
Technological advancements, such as modular panel designs and advanced testing tools, can enhance reuse efficiency (de Leede, SOL). Investing in technologies that facilitate disassembly, testing, and repurposing can reduce costs and improve scalability. Tools like IoT-based monitoring and RFID tagging can optimize panel tracking and redeployment, aligning with circular economy principles (ETIP-PV, 2023).

9.4.3 COMMUNITY ORGANIZATIONS AND NGOS

Fostering Community Engagement and Awareness
Community organizations and NGOs are instrumental in raising awareness and fostering local support for PV panel reuse. This research emphasizes the importance of grassroots engagement through educational programs and workshops to shift perceptions and build community buy-in (Alberti, AMS2). Replicating successful pilot projects can demonstrate reuse viability and benefits, encouraging broader adoption and knowledge sharing.

Advocating for Equitable Reuse Practices
Community organizations should advocate for reuse practices that address social needs, such as energy poverty. Reuse initiatives can provide affordable energy solutions to low-income households (de Leede, SOL). By working with local governments, industry stakeholders, and Stichting OPEN, community organizations can ensure that reuse efforts contribute to social equity.

9.4.4 STICHTING OPEN

Adapting EPR Strategies to Support Reuse
Stichting OPEN, as the manager of EPR for PV panels, should expand its focus to promote reuse alongside recycling. This research suggests setting specific reuse targets and forming partnerships with testing and certification agencies to streamline processes. By incorporating differential fees or subsidies for reuse, Stichting OPEN can better support sustainable practices and circular economy goals.
Enhancing Collaboration Across Stakeholders
To foster a supportive network for reuse, Stichting OPEN should improve its collaboration with various stakeholders. This research identifies a lack of coordinated efforts as a barrier to advancing reuse initiatives. Regular stakeholder meetings and transparent decision-making processes can help align diverse interests and promote a more unified approach.

9.4.5 FINANCIAL INSTITUTIONS

Supporting Investments in Reuse
Financial institutions focused on sustainability have an opportunity to support reuse initiatives through targeted funding. This research indicates a growing interest in ESG objectives among financiers. Offering financial products like green loans or impact investments can facilitate the growth of the reuse market, aligning with ESG goals and supporting a sustainable solar energy sector (de Vilder, AMS1).

Conclusion
Scaling PV panel reuse in Amsterdam requires coordinated action among all knowledge users. By aligning policy frameworks, leveraging technological innovations, fostering community engagement, and encouraging financial investments, stakeholders can overcome existing barriers and foster a more sustainable, circular solar energy system.

10. CONCLUSION & RECOMMENDATIONS

10.1 CONCLUSION

SRQ1: How do expectations, network formation, and learning processes initiatives for the reuse of end-of-life photovoltaic panels in Amsterdam influence the development and initial scaling of these practices?

The expectations, network formation, and learning processes for the reuse of end-of-life (EoL) photovoltaic panels in Amsterdam have been analyzed using Strategic Niche Management (SNM) indicators. This analysis identifies specific enablers and barriers across these three niche processes that influence the development and initial scaling of reuse practices, as summarized in *Table 10.1.*

Table 10.1: Overview of enablers and barriers identified in the SNM analysis

Niche process	Chapter	Indicator	Enabler	Barrier
Expectations	6.1.1	Internal Expectations	**Stakeholders shift to sustainable, local strategies; growing confidence in reuse fosters alignment and scalability.**	
	6.1.2	External Expectations	**Increased awareness and interest among municipalities and some stakeholders create collaboration opportunities.**	**Skepticism about economic viability and safety of reused panels among producers and market actors.**
	6.1.3	Exogenous Expectations	Positive attitude towards (external) development opportunities	**Economic pressures from low-cost new panels and regulatory uncertainties challenge competitiveness.**

	6.1.4	Endogenous Expectations	**Encourages continuous learning and adaptation; supports realistic and flexible approaches to challenges.**	Cautious attitudes among non-directly involved stakeholders may hinder faster progress.
Network formation	6.2.1	Network Composition	**Strong foundational network; supports initial reuse practices.**	Broader engagement from producers and EPR organizations would help upscaling.
	6.2.2	Quality of the Sub Networks	**Effective contributions from key actors. Promotes collaboration and high standards.**	Regulatory barriers and limited engagement from smaller actors limit effectiveness.
	6.2.3	Network Interactions	**Core stakeholders communicate effectively; fosters collaboration. More structured interactions could further enhance cooperation.**	**Inconsistent communication with peripheral stakeholders poses challenges.**
	6.2.4	Network Alignment	Strong alignment between core stakeholders	**Fragmentation within the network due to differences in priorities, internal conflicts and varying approaches to EoL solutions hinder unified action.**
Learning Processes	6.3.1	Technical Development and Infrastructure	**Strong focus on rigorous testing and infrastructure development supports quality and scalability.**	Challenges related to standardization and logistical complexities also highlight areas for improvement to fully support scaling efforts.
	6.3.2	Industrial Development	**Investments in infrastructure and streamlined logistics support reuse.**	**Operational challenges and liability concerns hinder broader adoption.**
	6.3.3	Social and Environmental Impact	**Promotes social equity, job creation, and sustainability, aligning with broader societal goals.**	
	6.3.4	Development of the User Context	Potential adopters among community-oriented organizations and environmentally conscious individuals	**Financial constraints, awareness gaps, and regulatory hurdles limit user adoption.**
	6.3.5	Government Policy and Regulatory Framework	Policies like CSRD and local financial incentives support sustainable practices	**Inconsistent policies, slow government response, regulatory knowledge gaps and practical barriers hinder effective reuse practices.**

Answer to SRQ1:

The analysis shows that expectations, network formation, and learning processes are critical factors shaping the initial development and scaling of reuse practices for EoL photovoltaic panels in Amsterdam. Enablers include a shift toward sustainable, local strategies, increasing awareness among stakeholders, strong foundational networks, and investments in technical development and infrastructure. These factors create a conducive environment for scaling reuse practices by fostering innovation, building stakeholder confidence, and encouraging collaboration.

However, barriers such as skepticism about the economic viability and safety of reused panels, regulatory uncertainties, and limited stakeholder engagement need to be addressed. Improving communication, regulatory clarity, and fostering a culture of learning and collaboration among a broader range of actors will help overcome these barriers, enabling reuse practices to scale more effectively. Ultimately, these processes need to be aligned with the city's sustainability goals for maximum impact.

SRQ2: What are the barriers and opportunities within the recycling regime, and how do landscape factors affect the scalability of reuse practices for extending the useful life of PV panels in Amsterdam?

The socio-technical levels of the regime and landscape were analyzed to identify barriers and opportunities affecting the scalability of reuse practices for PV panels in Amsterdam. These factors are summarized in *Table 10.2.*

Table 10.2: Overview of enablers and barriers identified in the MLP analysis

Socio - Technical Level	Chapter	Indicator	Enabler	Barrier
Regime	7.1.1	Stability in Regime	**Emerging collaboration and shifts towards innovation could support change.**	**Entrenched practices and resistance to change hinder sustainable reuse.**
	7.1.2	Suitability of Sectoral Policy		**Lack of clear directives, perceived certification challenges, and insufficient policy support for reuse.**
	7.1.3	Amount of Lock-In in Regime	**Low path dependency and potential for more sustainable practices.**	Financial, institutional, and organizational lock-ins favor existing low-quality recycling.
Landscape	7.2.1	Macro-Economic Trends	Potential increase in new panel costs due to geopolitical tensions and regulatory shifts could make reuse more attractive.	**Low cost of new panels driven by cheap imports makes reused panels less competitive.**
	7.2.2	Policy and Legislation Trends	**Emerging supportive local and EU frameworks for circular economy practices and potential regulatory amendments promote reuse.**	Existing regulations (e.g., WEEE Directive) might prioritize recycling over reuse.
	7.2.3	Technological Advancements	**Innovations in panel design, modularity, and monitoring technologies enhance the feasibility and attractiveness of reuse.**	Advanced recycling techniques could reduce incentives for reuse in favor of efficient recycling.

Answer to SRQ2:
The analysis highlights significant barriers and opportunities within both the recycling regime and broader landscape factors. Within the regime, entrenched practices and resistance to change pose substantial barriers, as the current system favors low-quality recycling over innovative reuse strategies. Financial and institutional lock-ins reinforce this status quo, limiting the potential for reuse. Additionally, the lack of clear policy directives and certification challenges make it difficult to scale reuse practices.

On the landscape level, macro-economic factors like the low cost of new panels due to cheap imports make reused panels less competitive. However, there are notable opportunities: potential increases in new panel costs due to geopolitical tensions and supply chain disruptions could make reuse more attractive. Furthermore, emerging supportive EU and local policies promoting circular economy practices provide a favorable policy environment. Technological advancements in panel design and modularity offer additional opportunities by making reused panels more feasible and attractive. However, improvements in recycling efficiency may reduce the focus on reuse.

Overall, while barriers exist within the regime, opportunities at the landscape level—particularly in policy and technology—present a pathway for scaling reuse practices. Addressing regime lock-ins and aligning new technological advancements with reuse goals will be critical to capitalizing on these opportunities.

SRQ3: What policy mixes can enhance the scaling of reuse practices for photovoltaic panels in Amsterdam?

To enhance the scaling of reuse practices for photovoltaic (PV) panels in Amsterdam, a strategic combination of policies, referred to as policy mixes, has been proposed. These policy mixes integrate regulatory, economic, and informational strategies to address the barriers and leverage the opportunities identified in the analysis. The goal is to create a supportive environment for the growth and scalability of reuse practices. Below is an overview of the proposed policy mixes, grouped by their application at the city, national, and combined levels.

Policy Mix 1: Tailored for the City of Amsterdam

This policy mix focuses on the policies that the City of Amsterdam can directly implement. It aims to address both supply- and demand-side challenges by using public procurement to drive demand for reused PV panels while providing financial and informational support to local businesses.

Table 10.3.1: Policy Mix 1: Tailored for the City of Amsterdam

Policy	Description	Expected Outcomes
Policy 2	Mandate reuse targets in Amsterdam's waste management policies to prioritize reuse over recycling.	Greater prioritization of reuse, alignment with circular economy objectives, and a stronger regulatory framework.

Policy 3	Favor reused panels in public procurement to create demand-pull from the public sector.	Increased public sector demand, market transformation towards reuse, and stronger policy alignment.
Policy 5	Support second-life business models and local traders to foster market development and sustainability.	Growth of the second-life market, enhanced economic viability of reuse practices, and innovation in reuse strategies.
Policy 7	Implement marketing campaigns and eco-labeling to boost consumer demand for reused PV panels.	Increased awareness and demand, better consumer understanding, and market pull for reused PV panels.

Synergies and Expected Outcomes:
By combining regulatory mandates with public procurement strategies, Policy Mix 1 creates immediate demand for reused PV panels, providing a foundation for market transformation. The economic policies supporting second-life businesses (Policy 5) help local businesses scale, while informational campaigns (Policy 7) increase consumer awareness and confidence. Together, these policies reinforce each other to build both the supply and demand sides of the market for reused PV panels in Amsterdam.

Policy Mix 2: Tailored for the Dutch National Government

This policy mix addresses the national-level systemic barriers to scaling reuse practices. It focuses on improving certification standards, reallocating financial resources toward reuse, and promoting knowledge-sharing platforms across stakeholders to foster collaboration and innovation.

Table 10.3.2: Policy Mix 2: Tailored for the Dutch National Government

Policy	Description	Expected Outcomes
Policy 1	Enhance flexibility and responsiveness in certification and quality standards for reused PV panels.	Increased market confidence, reduced regulatory uncertainty, and stronger alignment with national and international standards.
Policy 4	Redefine EPR budget allocation criteria based on environmental impact to incentivize sustainable practices.	Increased investment in reuse strategies, alignment with environmental goals, and reduced reliance on low-quality recycling.
Policy 9	Establish a knowledge-sharing and best practices platform for PV panel reuse.	Enhanced stakeholder capacity, continuous learning, and innovation in reuse practices, leading to broader market adoption.

Synergies and Expected Outcomes:
Policy Mix 2 focuses on systemic reform at the national level. Improving certification standards (Policy 1) and financial incentives (Policy 4) address regulatory and economic barriers, making reuse more attractive for businesses and consumers. The knowledge-sharing platform (Policy 9) promotes innovation and collaboration, enhancing the capacity of stakeholders to scale reuse practices. Together, these policies create a more favorable national landscape for scaling reuse practices, reducing the barriers posed by regulatory and financial uncertainties.

Policy Mix 3: Combined National and Amsterdam Strategy

This policy mix aligns Amsterdam's local efforts with national policies to ensure consistency across governance levels. It integrates local reuse targets with national-level regulatory and financial support, creating a unified framework to enhance both supply and demand for reused PV panels.

Table 10.3.3: Policy Mix 3: Combined National and Amsterdam Strategy

Policy	Description	Expected Outcomes
Policy 1	Enhance flexibility and responsiveness in certification and quality standards for reused PV panels.	Increased market confidence, regulatory consistency, and alignment with national standards.
Policy 2	Mandate reuse targets in Amsterdam's waste management policies.	Increased reuse of PV panels in public and private projects, aligning local reuse strategies with national goals.
Policy 4	Redefine EPR budget allocation based on environmental impact to incentivize reuse practices.	Reduced reliance on low-quality recycling, increased financial support for reuse, and alignment with environmental goals.
Policy 6	Provide financial support and social return programs for reused PV panels in low-income housing.	Increased adoption of reused panels in low-income areas, job creation, and enhanced social inclusion.
Policy 8	Develop a digital tracking and coordination platform to improve visibility and coordination for PV panel reuse.	Improved logistics and coordination, reduced waste through efficient reuse, and better alignment between national and local reuse efforts.

Synergies and Expected Outcomes:
By integrating local and national efforts, Policy Mix 3 ensures consistency in regulatory and financial support across different levels of governance. Local reuse targets (Policy 2) are reinforced by national standards (Policy 1) and financial incentives (Policy 4 and 6). The digital tracking platform (Policy 8) ensures efficient coordination of reuse efforts across Amsterdam and the country, reducing logistical bottlenecks. This integrated approach maximizes the impact of both local and national policies.

Conclusion and Synthesis
The three proposed policy mixes provide a comprehensive and strategic framework for scaling the reuse of PV panels in Amsterdam and beyond. Policy Mix 1 is tailored to Amsterdam's local context, driving demand for reused PV panels while supporting local businesses. Policy Mix 2 addresses national-level barriers, ensuring that certification standards and financial incentives align with the goals of reuse. Policy Mix 3 combines local and national strategies to create a consistent, scalable framework for reuse across multiple governance levels.
Together, these policy mixes address the key barriers identified in the analysis—regulatory uncertainty, economic viability, and coordination challenges—while leveraging opportunities such as increased consumer awareness and growing market demand. By implementing these policy mixes, Amsterdam and the Netherlands can foster the widespread adoption of reuse practices, contributing to a more sustainable and circular management of photovoltaic panels.

Main research question: "What are the enabling and barrier factors that influence the development and scaling of reuse practices for extending the useful life of photovoltaic panels in the municipality of Amsterdam, and how can policy mixes address these factors?"

Answer to Main Research Question:
The development and scaling of reuse practices for photovoltaic (PV) panels in Amsterdam are shaped by both enabling and barrier factors. Enablers include the shift toward sustainable strategies, strong stakeholder networks, technological advancements, and supportive regulatory frameworks at the local and EU levels. However, barriers such as skepticism about economic viability, regulatory uncertainty, entrenched recycling practices, and financial lock-ins hinder broader adoption.

The proposed policy mixes address these barriers and enhance the identified enablers by integrating regulatory, economic, and informational strategies that foster stakeholder collaboration, boost market confidence, and provide financial and logistical support for reuse practices. By aligning both local and national policies, these mixes create a consistent and supportive environment for scaling reuse practices, contributing to a more circular and sustainable management of PV panels in Amsterdam.

10.2 RECOMMENDATIONS FOR THE CITY OF AMSTERDAM

To effectively scale reuse practices for photovoltaic (PV) panels, the City of Amsterdam should consider implementing a strategic combination of policies that address barriers and leverage opportunities identified in the study. These recommendations provide a framework for action, and suggest potential policy mixes that can help achieve the city's sustainability goals.

Proposed Policies:

Policy 1: Enhancing Flexibility and Responsiveness in Certification and Quality Standards
Policy 2: Mandating Reuse Targets in Amsterdam's Waste Management Policies
Policy 3: Public Procurement Policies Favoring Reused Panels
Policy 4: Redefining EPR Budget Allocation Criteria Based on Environmental Impact
Policy 5: Supporting Second Life Business Models and the Growth of Second-Hand Traders
Policy 6: Financial Support and Social Return Program for Reused PV Panels in Low-Income and Social Housing
Policy 7: Marketing Campaigns and Eco-Labeling to Boost Demand for Reused PV Panels
Policy 8: Digital Tracking and Coordination Platform for PV Panels
Policy 9: Knowledge-Sharing and Best Practices Platform for PV Panel Reuse

Proposed Policy Mixes:
The three proposed policy mixes (*detailed in chapter 8.3*) provide different combinations of these policies to address specific barriers and leverage opportunities.

- Policy Mix 1: Tailored for the City of Amsterdam

This mix includes Policies 2, 3, 5, and 7, aiming to stimulate demand for reused PV panels through public procurement while supporting local businesses with financial and technical assistance. Marketing campaigns and eco-labeling initiatives will further increase consumer awareness. By prioritizing these policies, Amsterdam can address both supply- and demand-side challenges.

- Policy Mix 2: Tailored for the Dutch National Government

This mix focuses on Policies 1, 4, and 9, targeting national-level barriers to scaling reuse practices. Enhancing certification standards and reallocating financial resources toward reuse will create a more supportive regulatory environment. The knowledge-sharing platform will further encourage collaboration and innovation.

- Policy Mix 3: Combined National and Amsterdam Strategy

This strategy integrates Policies 1, 2, 4, 6, and 8 to align local reuse targets with national regulatory and financial frameworks. Financial support for reused PV panels in low-income housing, combined with the digital tracking platform, will streamline logistics and ensure consistency across governance levels.

These policy recommendations are intended not only for the municipality of Amsterdam but require collaboration among various stakeholders, including local businesses, industry associations, the Dutch government, academic institutions, and community organizations. The city is encouraged to use these proposals as a flexible guideline, adapting and combining them based on local needs, resources, and evolving circumstances. Each policy addresses specific indicators (*Table 8.2.4),* providing a foundation for designing a tailored policy mix that aligns with both local priorities and broader sustainability objectives.

By adopting a flexible and adaptive approach to implementing these policies and fostering cross-sector collaboration, Amsterdam can effectively scale reuse practices for PV panels. This strategic effort will contribute to a more sustainable, circular economy, positioning Amsterdam as a leader in innovative and sustainable urban development.

10.3 FUTURE RESEARCH – RECOMMENDATIONS TO OTHER STAKEHOLDERS

While the Policy Mix approach provided a valuable framework for developing strategies, the research exposed significant challenges in translating these strategies into actionable steps. A key recommendation for knowledge users and policymakers is to engage with policy experts and practitioners to refine the details of these policy mixes, making them more practical for implementation. This includes clearly defining the roles and responsibilities of various stakeholders to bridge the gap between theoretical policy development and practical execution. Additionally, attention should be given to the differences between national and local governments in policy execution, ensuring coordination across different governance levels.

More In-Depth Pilot Studies
Further pilot projects should be conducted to test the practicality of the proposed policy mixes, particularly in real-world scenarios. This will allow for adjustments based on actual outcomes and the specific challenges that arise during implementation. More extensive pilot programs can provide detailed insights into how these policies can be operationalized effectively and scaled to larger regions.

Quantification of Barriers
Future research should aim to quantify the main priorities in addressing reuse barriers by conducting more extensive interviews and surveys with a broader range of stakeholders. By capturing diverse perspectives, it will be possible to better understand the perceived barriers, assess their relative importance, and refine policies accordingly. This would help policymakers prioritize the most impactful areas for intervention.

Timeframes for Policy Implementation
A critical component that requires further investigation is the timeframe within which proposed policies should be implemented. Clear timelines will provide structure for achieving the objectives of reuse practices and help monitor progress. Further research could focus on

developing feasible timelines for different stakeholders, ensuring that implementation efforts are both timely and coordinated.

Environmental Optimization Beyond CO2

Additionally, future research should delve into understanding the environmental optimum lifespan of a PV panel, focusing not only on CO2 reduction but also on the impact of other materials and substances. This will help identify the optimal point for replacing or reusing PV panels from an environmental perspective, ensuring that sustainability remains a top priority. Such an approach could also provide clear incentives for reuse, grounded in environmental benefits rather than solely economic ones.

By addressing these research gaps, stakeholders can help create a more robust and sustainable framework for scaling the reuse of photovoltaic panels.

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APPENDIX A. SEMI STRUCTURED INTERVIEW DOCUMENTS

A.1 EXAMPLE CONSENT FORM

TU Delft
HUMAN RESEARCH ETHICS, INFORMED CONSENT FORMULIER

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd "From niche to norm, developing and scaling reuse practices for photovoltaic panels in Amsterdam". Dit onderzoek wordt uitgevoerd door Ivo van Bruinessen, een student aan de TU Delft en Universiteit Leiden, in samenwerking met het AMS Institute.

Het doel van dit onderzoek is om te begrijpen hoe hergebruikpraktijken kunnen bijdragen aan het verlengen van de levensduur van fotovoltaïsche (PV) panelen en welke rol stakeholderbetrokkenheid en samenwerking spelen bij het faciliteren en opschalen van deze praktijken. Het interview zal ongeveer 45-60 minuten in beslag nemen. De data zal gebruikt worden voor publicatie in mijn masterscriptie, en zal mogelijk ook worden toegepast in academisch onderwijs en toekomstige onderzoeken.

U wordt gevraagd om deel te nemen aan een interview waarin we uw inzichten en ervaringen bespreken met betrekking tot de huidige stand van zaken en de toekomstige mogelijkheden voor het hergebruik van PV-panelen. We zullen ingaan op onderwerpen zoals verwachtingen en doelen binnen uw organisatie, samenwerking en interacties binnen uw netwerk, en technologische, sociale en beleidsmatige factoren die van invloed zijn op het hergebruik van PV-panelen.

Zoals bij elke online activiteit is het risico van een databreuk aanwezig. Ik doe mijn best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico's door de data anoniem te verzamelen en geen IP-adressen of andere persoonlijke data te bewaren. De data wordt veilig bewaard en geanonimiseerd om uw vertrouwelijkheid te waarborgen.

Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden. Indien u na het interview besluit dat uw data niet gebruikt mag worden, kunt u dit binnen twee weken na het interview aangeven, waarna uw data verwijderd zal worden.

Als u vragen heeft of meer informatie wenst, kunt u contact opnemen met mij via I.H.P.vanBruinessen@student.tudelft.nl of telefonisch op +31 620870918. Voor algemene vragen over het onderzoek kunt u ook contact opnemen met de verantwoordelijke onderzoeker, Jaco Quist, via J.N.Quist@tudelft.nl.

Door deel te nemen aan het interview stemt u in met deze voorwaarden.

Met vriendelijke groet,

Ivo van Bruinessen
I.H.P.vanBruinessen@student.tudelft.nl
+31 620870918
Technische Universiteit Delft & Universiteit Leiden
Joint Degree Industrial Ecology

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. Ik heb de informatie over het onderzoek gedateerd [05/07/2024] gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek de volgende punten betekent: het maken van een audio opgenomen interview van 45-60 minuten, het maken van een transcript en samenvatting van het gesprek, dat de opnames vernietigd worden bij afronding van het project, dat datalek risico's zo klein mogelijk gemaakt worden, en dat zo weinig mogelijk persoonlijke data verzameld worden.	☐	☐
4. Ik begrijp dat het scriptie onderzoek eindigt in september 2024	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. Ik begrijp dat mijn deelname het risico met zich meebrengt dat een datalek kan optreden waardoor persoonlijke gegevens verspreid kunnen raken. Ik begrijp dat deze risico's worden geminimaliseerd door het treffen van voorzorgmaatregelen zoals (i) anonimiseren van transcripten, (ii) het vernietigen van opnames bij afronding van het project, (ii) het gescheiden bewaren van persoonlijke gegevens en (iv) het bewaren van verzamelde data en gegevens in beveiligde omgeving bij TU Delft, alleen toegankelijk voor het onderzoeksteam.	☐	☐
6. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoeksdata worden verzameld, maar dat deze data niet buiten het onderzoeksteam gedeeld worden.	☐	☐
7. Ik begrijp dat binnen de Algemene verordening gegevensbescherming (AVG) een deel van deze persoonlijk identificeerbare onderzoekdata als gevoelig wordt beschouwd, namelijk naam, organisatie, email, telefoonnummer, functie, opvattingen	☐	☐
8. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een datalek te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een datalek: (i) anonimiseren van transcripten, (ii) het vernietigen van opnames bij afronding van het project, (ii) het gescheiden bewaren van persoonlijke gegevens en (iv) het bewaren van verzamelde data en gegevens in beveiligde omgeving bij TU Delft, alleen toegankelijk voor het onderzoeksteam.	☐	☐
9. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals naam, organisatie, functie, emailadres, telefoonnummer niet gedeeld worden buiten het onderzoeksteam.	☐	☐
10. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt bij afronding van het project	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
11. Ik begrijp dat na het onderzoek de geanonimiseerde informatie gebruikt zal worden voor het maken van 2 rapporten voor de gemeente Amsterdam, informatie over project en resultaten op websites van de gemeente Amsterdam, AMS en de TU Delft en mogelijk voor het maken van wetenschappelijke teksten en artikelen op basis van de verzamelde gegevens en analyse. Ik begrijp ook dat mogelijk de informatie gebruikt zal worden door de gemeente en andere partijen om hergebruik van PV te stimuleren.	☐	☐
12. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdrages anoniem te quoten in resulterende teksten.	☐	☐
13. Ik geef toestemming om mijn naam en functie te gebruiken voor quotes in resulterende producten	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
14. I permit the anonymized transcripts that I provide to be archived on the personal hard drive of the researcher for 5 years.	☐	☐
15. I understand that access to these transcripts is private. Transcripts are not placed in an open repository and can only be accessed by the research team.	☐	☐

Signatures

____________________________ ___________________________ _________

Naam deelnemer Handtekening Datum

[Add legal representative, and/or amend text for assent where participants cannot give consent as applicable]

Ik, **de wettelijke vertegenwoordiger**, verklaar dat de informatie en het instemmingsformulier aan de potentiële deelnemer correct zijn voorgelezen, en dat hij/zij de kans heeft gekregen om vragen te stellen. Ik verklaar dat de potentiële deelnemer zijn/haar instemming vrijwillig heeft gegeven.

____________________________ _________________________ __________

Naam wettelijke vertegenwoordiger Handtekening Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

Ivo van Bruinessen

__________________________ ____________________ _26/8/2024_

Naam onderzoeker Handtekening Datum

Ivo van Bruinessen I.H.P.vanBruinessen@student.tudelft.nl , 0620870918

A.2 INTERVIEW QUESTIONS

Table A.2: Interview Questions

Category	#	Questions
Introductie vragen	1	Kunt u uzelf voorstellen en uw professionele achtergrond beschrijven?
	2	Wat is uw ervaring met het hergebruik van zonnepanelen? Waarom bent u betrokken geraakt bij deze sector/niche?
	3	Wat zijn in uw ogen de belangrijkste ontwikkelingen rondom het onderwerp PV, en valt hergebruik daar ook onder?
SRQ1: Stakeholder en Strategieën	4	Kunt u iets vertellen over de oorspronkelijke doelen en verwachtingen voor het hergebruik van PV-panelen binnen uw organisatie? Zijn deze doelen in de loop van tijd veranderd?
	5	Hoe bewust zijn stakeholders buiten uw directe netwerk van de initiatieven voor het hergebruik van PV-panelen, en hoe groot is hun vertrouwen in het succes hiervan?
	6	Zijn er externe factoren zoals nieuwe regelgeving of veranderingen in de markt die uw verwachtingen en strategieën hebben beïnvloed?
	7	Welke nieuwe verwachtingen of doelen zijn ontstaan uit uw ervaringen en interacties binnen de hergebruik niche? Hoe hebben deze nieuwe inzichten uw strategieën beïnvloed?
	8	Kunt u beschrijven wie de belangrijkste stakeholders zijn bij het hergebruik van PV-panelen en welke rollen zij vervullen?
	9	Hoe dragen verschillende groepen of individuen in uw netwerk bij aan de ontwikkeling van de hergebruik niche? Kunt u enkele belangrijke bijdragen noemen?
	10	In hoeverre stemmen de visies, verwachtingen en strategieën van verschillende actoren overeen met de doelen voor hergebruik? Hoe gaat u om met conflicten binnen het netwerk?
	11	Wat heeft u geleerd over de technologieën, infrastructuur en voorbereiding die nodig zijn voor het hergebruik van zonnepanelen?
	12	Wat heeft u geleerd over de sociale en milieu-impact van het hergebruik van PV-panelen? Hoe beïnvloeden deze inzichten uw benadering van het project?
	13	Welke kenmerken en behoeften van eindgebruikers zijn cruciaal voor de acceptatie van hergebruikpraktijken? Welke barrières ondervinden eindgebruikers?
	14	Welke institutionele structuren en wetgevende factoren zijn relevant voor de hergebruik niche? Hoe kunnen overheidsbeleid en stimulansen de acceptatie ondersteunen?
SRQ2	15	Hoe staat het huidige recyclingregime tegenover hergebruik van PV-panelen en welke barrières zijn er?
	16	Wat zijn de belangrijkste belemmeringen in de bestaande recyclingtechnologieën? Hoe beïnvloeden bestaande gewoonten en structuren de acceptatie van nieuwe praktijken?
	17	Hoe beïnvloeden de huidige economische stimulansen, financieringsmogelijkheden en markttrends recycling- en hergebruikspraktijken?
	18	Hoe hebben recente veranderingen in milieuregels en beleidsverschuivingen uw operaties beïnvloed? Hoe beïnvloedt de huidige wetgeving nichepraktijken?
	19	Welke recente innovaties in recycling- en hergebruikstechnologieën heeft u waargenomen? Hoe beïnvloeden deze technologische vooruitgangen de nichepraktijken?

SRQ3	20	Welke kleine veranderingen zouden het hergebruik van PV-panelen binnen het huidige systeem kunnen verbeteren?
	21	Welke methoden voor het opknappen en herbestemmen van PV-panelen zouden de huidige methoden kunnen vervangen?
	22	Hoe kunnen nieuwe ideeën worden geïntegreerd met bestaande systemen om het hergebruik van PV-panelen te veranderen?
	23	Welke grote veranderingen zouden de huidige benadering van hergebruik fundamenteel kunnen veranderen, en welke strategieën zouden kunnen worden geïmplementeerd?
	24	Wat zijn volgens u de meest veelbelovende wegen voor verdere ontwikkeling van de niche voor hergebruik van PV-panelen in Amsterdam?
	25	Hoe kan samenwerking tussen stakeholders (bijv. overheid, industrie, gemeenschap) worden verbeterd om de opschaling van hergebruikpraktijken te ondersteunen?
	26	Kunt u voorbeelden geven van succesvolle multi-stakeholder samenwerkingen in vergelijkbare projecten of initiatieven?
	27	Welke beleidswijzigingen zouden de opschaling van hergebruikpraktijken voor PV-panelen ondersteunen?
	28	Welke technologische vooruitgangen of innovaties hebben impact op het toekomstige succes van het hergebruik van PV-panelen?
Conclusie vragen	29	Zijn er nog andere aspecten of ideeën met betrekking tot het hergebruik van PV-panelen die we niet hebben besproken, maar die belangrijk zijn om te overwegen?
	30	Wat zou u als de belangrijkste uitdaging beschouwen voor de toekomst van het hergebruik van PV-panelen in Amsterdam, en hoe denkt u dat deze uitdaging kan worden aangepakt?

APPENDIX B. LITERATURE REVIEW SCOPUS

APPENDIX B1: SELECTED ARTICLES SCOPUS

1. Circular Economy Approaches

This category includes articles that discuss the broader circular economy principles and their application to the PV industry, including reuse, refurbishment, and integration into circular supply chains.

Table B: Selected articles based on literature review on scopus

Article Title	Author(s)	Year	Journal	Cited
"Towards a circular supply chain for PV modules: Review of today's challenges in PV recycling, refurbishment and re-certification"	Tsanakas, J.A., van der Heide, A., Radavičius, T., (...), Poortmans, J., Voroshazi, E.	2020	Progress in Photovoltaics: Research and Applications	87
"Technical challenges and opportunities in realising a circular economy for waste photovoltaic modules"	Farrell, C.C., Osman, A.I., Doherty, R., (...), Al-Muhtaseb, A.H., Rooney, D.W.	2020	Renewable and Sustainable Energy Reviews	131

“Promoting a circular economy in the solar photovoltaic industry using life cycle symbiosis”	Mathur, N., Singh, S., Sutherland, J.W.	2020	Resources, Conservation and Recycling	52
“Supporting renewable energy market growth through the circular integration of end-of-use and end-of-life photovoltaics”	Marsillac, E.	2021	Sustainability (Switzerland)	2
“Rethinking circular economy for electronics, energy storage, and solar photovoltaics with long product life cycles”	Sahajwalla, V., Hossain, R.	2023	MRS Bulletin	5
“Circular economy strategies as enablers for solar PV adoption in organizational market segments”	Van Opstal, W., Smeets, A.	2023	Sustainable Production and Consumption	22
“How circular is the European photovoltaic industry? Practical insights on current circular economy barriers, enablers, and goals”	Nyffenegger, R., Boukhatmi, Ä., Radavičius, T., Tvaronavičienė, M.	2024	Journal of Cleaner Production	0

2. Challenges and Strategies for End-of-Life Management

This category includes articles that discuss the various challenges and strategies associated with managing end-of-life PV panels, including international experiences and specific country case studies.

Article Title	Author(s)	Year	Journal	Cited
“End-of-life management of solar photovoltaic and battery energy storage systems: A stakeholder survey in Australia”	Salim, H.K., Stewart, R.A., Sahin, O., Dudley, M.	2019	Resources, Conservation and Recycling	41
“Systems approach to end-of-life management of residential photovoltaic panels and battery energy storage system in Australia”	Salim, H.K., Stewart, R.A., Sahin, O., Dudley, M.	2020	Renewable and Sustainable Energy Reviews	16
"Major challenges and opportunities in silicon solar module recycling"	Tao M, Fthenakis V, Ebin B, Steenari B, Butler E, Sinha P, Corkish R, Wambach K, Simon E	2020	Progress in Photovoltaics: Research and Applications	79
“Improving the end-of-life management of solar panels in Germany”	El-Khawad, L., Bartkowiak, D., Kümmerer, K.	2022	Renewable and Sustainable Energy Reviews	15
“End-of-life management of solar PV waste in India: Situation analysis and proposed policy framework”	Jain, S., Sharma, T., Gupta, A.K.	2022	Renewable and Sustainable Energy Reviews	46
“Policies and regulations for solar photovoltaic end-of-life waste management: Insights from China and the USA”	Ali, A., Malik, S.A., Shafiullah, M., Malik, M.Z., Zahir, M.H.	2023	Chemosphere	8
"The End of Life of PV Systems: Is Europe Ready for it?"	Bošnjaković, M., Galović, M., Kuprešak, J., Bošnjaković, T.	2023	Sustainability (Switzerland)	0

“Challenges and strategies for managing end-of-life photovoltaic equipment in Brazil: Learning from international experience”	Souza, V., Rodrigues Figueiredo, A.M., Santos Bortolocci Espejo, M.M.D.	2024	Energy Policy	0
“End-of-life solar photovoltaic waste management: A comparison as per European Union and United States regulatory approaches”	Nain, P., Anctil, A.	2024	Resources, Conservation and Recycling Advances	0

3. Recycling Technologies and Processes

This category focuses on the technological aspects of recycling PV panels, including innovative methods, efficiency improvements, and economic evaluations.

Article Title	Author(s)	Year	Journal	Cited
“Environmental impacts and economic feasibility of end of life photovoltaic panels in Australia: A comprehensive assessment”	Mahmoudi, S., Huda, N., Behnia, M.	2020	Journal of Cleaner Production	48
“Innovative recycling of end of life silicon pv panels: Resielp”	Cerchier, P., Brunelli, K., Pezzato, L., (...), Suitner, H., Dabalà, M.	2021	Detritus	11
“Reverse logistics network design for waste solar photovoltaic panels: A case study of New South Wales councils in Australia”	Islam, M.T., Nizami, M.S.H., Mahmoudi, S., Huda, N.	2021	Waste Management and Research	10
“Recycled value-added circular energy materials for new battery application: Recycling strategies, challenges, and sustainability-a comprehensive review”	Sultana, I., Chen, Y., Huang, S., Rahman, M.M.	2022	Journal of Environmental Chemical Engineering	19
“Circular solar: Evaluating the profitability of a photovoltaic panel recycling plant”	D’Adamo, I., Ferella, F., Gastaldi, M., Ippolito, N.M., Rosa, P.	2023	Waste Management and Research	17
“Recycling photovoltaic modules within a circular economy approach and a snapshot for Türkiye”	Aşkın, A., Kılkış, S., Akınoğlu, B.G.	2023	Renewable Energy	0
“Comprehensive review of the global trends and future perspectives for recycling of decommissioned photovoltaic panels”	Akram Cheema, H., Ilyas, S., Kang, H., Kim, H.	2024	Waste Management	2

4. Environmental and Economic Impacts

This category includes articles that assess the environmental and economic impacts of PV end-of-life management, including life cycle assessments and feasibility studies.

Article Title	Author(s)	Year	Journal	Cited

“Environmental impacts and economic feasibility of end of life photovoltaic panels in Australia: A comprehensive assessment”	Mahmoudi, S., Huda, N., Behnia, M.	2020	Journal of Cleaner Production	48
“Environmental impacts of solar photovoltaic systems: A critical review of recent progress and future outlook”	Tawalbeh, M., Al-Othman, A., Kafiah, F., ...Almomani, F., Alkasrawi, M.	2021	Science of the Total Environment	254
“Dynamic modelling of Australian rooftop solar photovoltaic product stewardship transition”	Salim, H.K., Stewart, R.A., Sahin, O., Dudley, M.	2021	Waste Management	10

APPENDIX B2: SEARCH TERMS LITERATURE REVIEW

End-of-life management

TITLE-ABS-KEY ("end-of-life" "photovoltaic" "sustainability") AND PUBYEAR > 2018

“Challenges and strategies for managing end-of-life photovoltaic equipment in Brazil: Learning from international experience”

“Comprehensive review of the global trends and future perspectives for recycling of decommissioned photovoltaic panels”

“Circular solar: Evaluating the profitability of a photovoltaic panel recycling plant”

TITLE-ABS-KEY ("recycling technologies" "photovoltaic" "efficiency") AND PUBYEAR > 2018

“Innovative recycling of end of life silicon pv panels: Resielp”

TITLE-ABS-KEY ("refurbishment" "photovoltaic") AND PUBYEAR > 2018

“Towards a circular supply chain for PV modules: Review of today's challenges in PV recycling, refurbishment and re-certification”

“Improving the end-of-life management of solar panels in Germany”

Circular economy

TITLE-ABS-KEY ("circular economy" "photovoltaic" "end-of-life") AND PUBYEAR > 2018

“Technical challenges and opportunities in realising a circular economy for waste photovoltaic modules”

“Circular economy strategies as enablers for solar PV adoption in organizational market segments”

“How circular is the European photovoltaic industry? Practical insights on current circular economy barriers, enablers, and goals”

“The End of Life of PV Systems: Is Europe Ready for It?”

“Recycling photovoltaic modules within a circular economy approach and a snapshot for Türkiye”

“Rethinking circular economy for electronics, energy storage, and solar photovoltaics with long product life cycles”

“Recycled value-added circular energy materials for new battery application: Recycling strategies, challenges, and sustainability-a comprehensive review”

TITLE-ABS-KEY ("industrial symbiosis" "photovoltaic" "end-of-life") AND PUBYEAR > 2018

“Promoting a circular economy in the solar photovoltaic industry using life cycle symbiosis”

TITLE-ABS-KEY ("environmental impact" "photovoltaic" "disposal") AND PUBYEAR > 2018

“Environmental impacts of solar photovoltaic systems: A critical review of recent progress and future outlook”
“Environmental impacts and economic feasibility of end of life photovoltaic panels in Australia: A comprehensive assessment”
TITLE-ABS-KEY ("industrial ecology" "photovoltaic" "end-of-life") AND PUBYEAR > 2018
“Supporting renewable energy market growth through the circular integration of end-of-use and end-of-life photovoltaics”
TITLE-ABS-KEY ("stakeholder" "photovoltaic" "end-of-life") AND PUBYEAR > 2018
“Dynamic modelling of Australian rooftop solar photovoltaic product stewardship transition”
“End-of-life solar photovoltaic waste management: A comparison as per European Union and United States regulatory approaches”
“End-of-life management of solar photovoltaic and battery energy storage systems: A stakeholder survey in Australia”
“Systems approach to end-of-life management of residential photovoltaic panels and battery energy storage system in Australia”
“Policies and regulations for solar photovoltaic end-of-life waste management: Insights from China and the USA”

TITLE-ABS-KEY ("policy framework" "photovoltaic" "end-of-life") AND PUBYEAR > 2018
“End-of-life management of solar PV waste in India: Situation analysis and proposed policy framework”
TITLE-ABS-KEY ("waste management" "photovoltaic" "case-studies") AND PUBYEAR > 2018
“Integration of photovoltaic panels and solar collectors into a plant producing biomethane for the transport sector: Dynamic simulation and case study”
“Reverse logistics network design for waste solar photovoltaic panels: A case study of New South Wales councils in Australia”

APPENDIX B3: DOCUMENT ANALYSIS

Table C: Documents for document analysis

Year	Report Name	Organisation	Referred to as
2021	Circular Economy Lab 24: circulaire zonnepanelen – verslag	AMS, USI, Amsterdam Economic Board, Gemeente Amsterdam, Alliantie Cirkelregio Utrecht	AMS institute et al., 2021
2021	RE-USE of PV modules, challenges and opportunities of the circular economy	PVCYCLE & IMEC	Lempkowicz et al., 2021

2022	Balancing costs and revenues for recycling end-of-life PV panels in the Netherlands	TNO	Späth et al., 2022
2022	D3.2 Labelling and certification protocols for second life PV modules	Imec/Circusol	Van Der Heide et al., 2022
2022	Strategies for circular end-of-life management of photovoltaic panels on Amsterdam rooftops	TU Delft	Stokvisch, 2022
2023	Circular Business Models for the Solar Power Industry – Guide for Policy Makers V2.0	Lund University / Circusol	Strupeit & Tojo, 2023
2023	Circular economy strategies as enablers for solar PV adoption in organizational market segments		Opstal & Smeets, 2023
2023	Onze stad van morgen – Duurzame toekomst gemeente Amsterdam	Gemeente Amsterdam	Halsema et al., 2023
2023	Re-use of PV Modules: Progress in Standardisation and Learnings from a Real Case Study	Trust-PV	Van der Heide et al., 2023
2024	Circulaire zonnepanelen: Ontwikkelingen en kansen voor hergebruik zonnepanelen in Amsterdam	TU Delft	Quist & Heidary, 2024
2024	De Impact van Gebruiksduurverlenging van Zonnepanelen in Steden	AMS Institute	De Vilder et al., 2024
2024	End-of-Life Management Best Practice Guidelines V1.0	SolarPower Europe	SolarPower Europe, 2024
2024	Photovoltaics Report 2024	Fraunhofer ISE	Phillips & Warmuth, 2024

2024	Stategic Research and Innovation Agenda on Photovoltaics	ETIP PV, EERA PV	ETIP PV & EERA PV, 2024

APPENDIX C. CODES IN ATLAS

Name		Color	Groups	Quotations
1.1.1 Internal Expectations	Details		Expectations	14
1.1.2 External Expectations			Expectations	13
1.1.3 Exogenous Expectations			Expectations	9
1.1.4 Endogenous Expectations			Expectations	19
1.2.1 Network Composition			Network Formation	40
1.2.2 Quality of the Sub Networks			Network Formation	17
1.2.3 Network Interactions			Network Formation	33
1.2.4 Network Alignment			Network Formation	29
1.3.1 Technical Development and Infrastructure			Learning Processes	38
1.3.2 Industrial Development			Learning Processes	14
1.3.3 Social and Environmental Impact			Learning Processes	31
1.3.4 Development of the User context			Learning Processes	50

1.3.5 Government Policy and Regulatory Framework	Learning Processes	57
2.1.1 Stability in Regime	Regime	31
2.1.2 Suitability of Sectoral Policy	Regime	28
2.1.3 Amount of Lock-In in Regime	Regime	15
2.2.1 Macro-economic Trends	Landscape	15
2.2.2 Policy and Legislation Trends	Landscape	20
2.2.3 Technological Advancements	Landscape	18
3.1.1 Incremental System Optimization	Pathways	6
3.1.2 Transformative System Innovation Details	Pathways	12
3.1.3 Strategic Implementation and Scaling	Pathways	13
3.1.4 Innovative Refurbishment Techniques	Pathways	5
3.1.5 System integration of Novel Ideas	Pathways	9
3.1.6 Promising Development Pathways	Pathways	33

3.1.7 Stakeholder Collaboration Enhancement	Pathways	21
3.1.8 Multi-Stakeholder Collaboration Suc Details	Pathways Pathways	3
3.1.9 Policy Support for Scaling Reuse	Pathways	17
3.2 Key Technological Innovations	Pathways	1
3.2.1 Additional Considerations for Reuse	Pathways	8
3.2.2 Primary Challenge and Solution Approaches	Pathways	8