Factors contributing to the adoption of circular economy strategies in PV waste management in Australia

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Use of photovoltaic technology as renewable energy has been increasing globally (Masson, Bosh et al. 2022). Benefits of using photovoltaic (PV) panels have caused an exponential demand for PV panels manufacture and deployment. In theory, PV panels are aimed to have a lifespan of 25-30 years. In practice, however, their lifespan can be as short as two years (IRENA and IEA PVPS 2016). Hence, predictions of PV panel waste amount constitute a global concern. Currently, large amounts of PV waste are ending up in landfills. From a material perspective, this represents large amounts of valuable materials being lost. From a social-environmental perspective, this represents potential toxic hazards for the environment and human health.

Global research to date has been focused mainly on innovations in recycling processes. However, there is scarce literature using circular economy principles towards PV waste management. Circular economy principles applied holistically support innovations in technical, social and regulatory fields collaboratively to reduce/eliminate waste, extend materials/products life span and regenerate nature. Therefore, there is a need to explore social research methods and tools to underpin which CE opportunities can enable changes in behaviours in PV waste management. Collaboration amongst different industry stakeholders supported by governmental policies and regulations for PV panels may benefit all stakeholders involved in the PV supply chain, including users.

The aim of this research was to explore, from a social perspective, which circular economy strategies can be adopted in Australia to support circular PV waste management. The study analysed how the 10 R's strategies for circularity (Cramer 2017) and the ReSOLVE (Gentilini and Salt 2019) framework can propose an innovative and holistic system for the PV lifecycle and its waste in Australia.

Qualitative research methods were used, preceeded by literature review. Semi-structured interviews with different stakeholders' groups (academic, government, installers/retailers, PV organisations and recycling organisations) were conducted to obtain social insights about current PV waste/ e-waste management in Australia and identify potential areas of improvement.

The underpinning theoretical framework for the research was structured on a human-centred approach, design thinking. Design thinking is one of the most followed processes in social research as they are known to unveil potential innovations in various social behaviour projects, including policy making. As mentioned in the study by Villa Alvarez, Auricchio et al. (2022) design activities can be used as a tool for implementing policy and can support policy formulation. Using design thinking into policy-making processes is not a new concept. To mention some, UK, New Zealand and Australia have been exploring the benefits of incorporating design activities into policy making realm. As established by Mintrom and Luetjens (2016) design thinking can be used as support in policy making as it helps to understand and present the expectations of stakeholders to unveil potential pathways to achieve the desired goals.

Results

Following design thinking practices and based on interview insights, a "customer journey map" was adapted to a PV journey perspective to understand current and ideal PV waste management practices. "Customer journey map" is a design thinking tool that can provide deeper insights for the

customer experience towards a service or a product. This helps to understand the gaps of barriers or enablers for a circular PV waste management process. Areas of improvement and innovation were determined when the “journey” of a PV panel was analysed. Figure 1 exemplifies the “ideal journey” of a PV as determined by interviewees' insights.

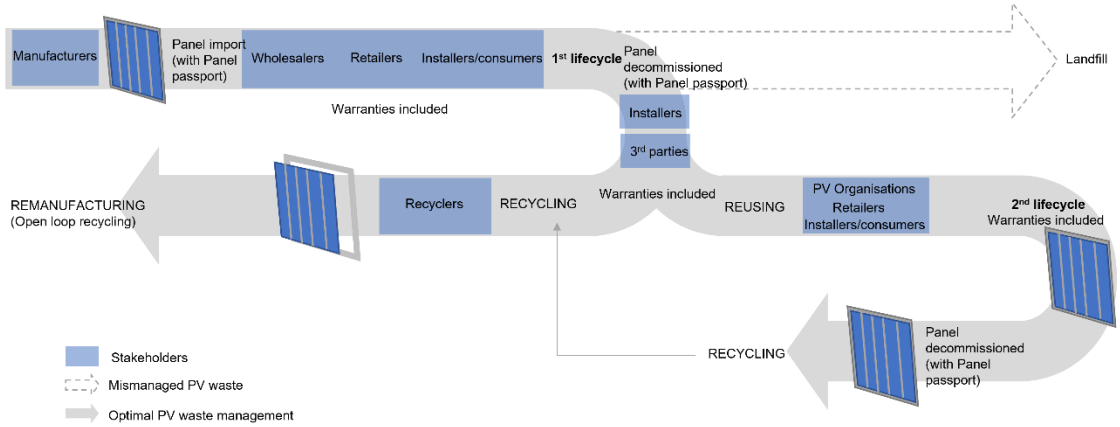

Figure 1. Ideal PV waste management practice. Source: (Nunez Madrigal, Iyer-Raniga et al. 2023)

Figure 1 depicts the general flow of PV waste management chain; however, it is complemented holistically only if early stages of the PV panel (from manufacturing) and more end-of-life options (different than recycling and reusing) are explored. Hence, delving deeper in PV lifecycle stages, a conceptual system diagram was created to understand which of the 10 R’s and which stakeholders need to be engaged in determined PV stage. See Figure 2.

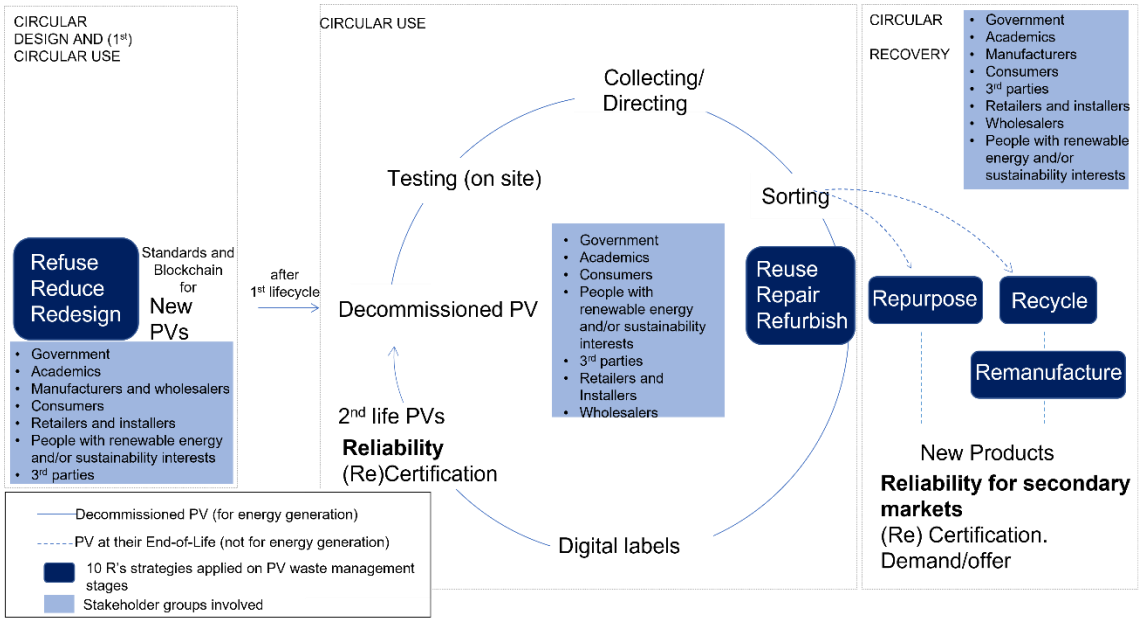

Figure 2. Conceptual system diagram of PV lifecycles. Source: (Nunez Madrigal, Iyer-Raniga et al. 2023)

Figure 1 and Figure 2 are complemented when interactions amongst the stakeholders are clarified. Thus, a conceptual map about future stakeholder actions per PV stage (Figure 3) was developed to inform possible suggestions for actions to happen to improve PV waste management. This map is

the result of overlapping and analysing the gaps between the current PV waste management chain and the ideal process (Figure 1). In this map manufacturers, governments and academics are not mentioned. For the Australian context, PV manufacturing takes place mostly overseas, hence the map starts with PV imports. The role of governments impact the overall actions of all the stakeholders by creating policies and infrastructure which allows ideal PV waste management practices. Academics provide the required R&D input through the entire PV waste management chain.

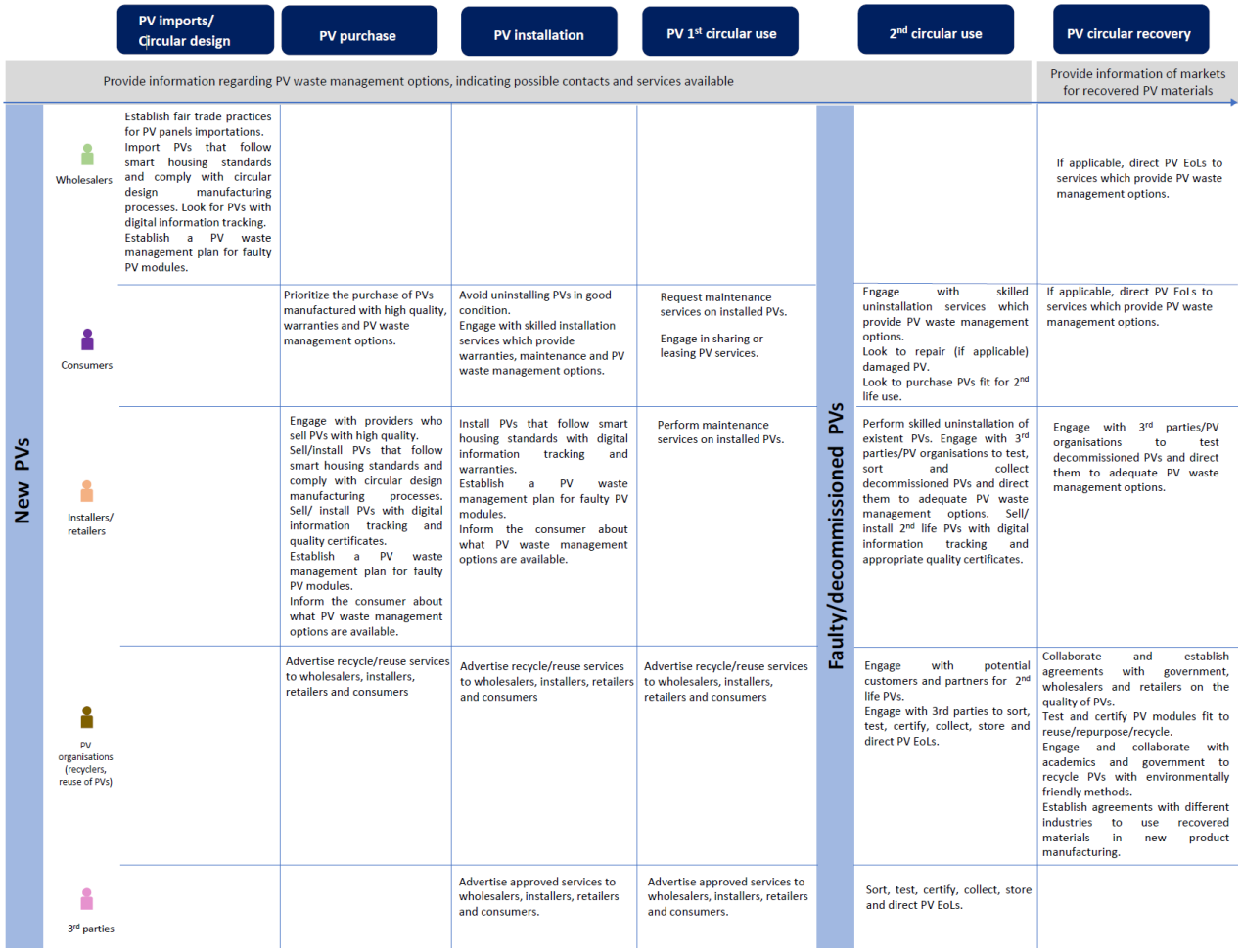

Figure 3. Conceptual map of future stakeholder action per PV stage

Conclusion

To summarise, the results of the study highlight the need for a PV waste management that is based on reliability (trust) and regulations (incentives to enhance willingness to engage in CE practices). These can be nurtured through awareness/education, certification and digital labels (panel passports) which can enable transparency across the different stages of the PV lifecycle. This transparency can potentially improve the collaboration amongst the stakeholders, leading to active engagement towards diverting PVs from landfill.

Consequently, the outputs of this research aims to inform policy makers in the formulation of policies based on stakeholders insights and best practice examples to increase the feasibility of creating a circular PV waste management. Theres a need for PV policies that establish:

- Clear quality standards for PV imports
- PV installation and uninstallation procedures
- PV testing certificates for reuse

- PV certificates for the quality of recovered materials

PV policies that encourage:

- Avoidance of undamaged PV modules to be uninstalled
- Communication/education of PV waste management options since the early stages
- Communication/education of sharing or leasing PV options
- Collaboration amongst PV recycling companies and potential consumers of recovered materials

PV regulations which address:

- Digital information tracking for PV panels through the PV lifecycle
- Safety and energy generation certificates for second life PVs
- Shared responsibility of PV waste management

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