D1.2

CIRCUSOL description of a vision

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AC	Alternating Current
BOS	Balance Of Systems
Cd	Cadmium
Cr	Chromium
cPSS	circular Product Service System
DC	Direct Current
DfD	Design for Disassembly
DfR	Design for Robustness
EV	Electric Vehicle
LIB	Lithium-Ion Battery
Pb	lead
PV	Photovoltaic
PSS	Product Service System
pPSS	product-oriented Product Service System
rPSS	result-oriented Product Service System
uPSS	user-oriented Product Service System
WEEE	Waste Electrical and Electronic Equipment

EXECUTIVE SUMMARY

Photovoltaic (PV) deployment has grown at unprecedented rates since the early 2000s (IRENA and IEA-PVPS, 2016). As the solar power market booms, so will the volume of discarded products entering the waste stream. Simultaneously, recent advancements in energy storage solutions have fuelled the growth of PV-connected battery system installations. When no longer suitable for automotive purposes, lithium-ion batteries from electric vehicles can be repurposed as stationary energy storage units for renewable energy sources, such as solar PV. The explosive growth in EV sales also poses the question of how decommissioned batteries will be handled after they have reached the end of their automotive life. With this context in mind, this report describes **key elements of a vision**, co-developed by the CIRCUSOL consortium, in which a circular solar power system provides added value for the future *and* the current natural & human environment.

A first part of the vision is a **shared mental compass**, describing a set of guiding principles of a **future circular solar system. This is shown in Box 1**. A second part of the vision describes **three systemic changes** required to support the transition towards the envisioned situation(s). An overview is given in **Box 2**. Based on these required systemic changes, finally some **short and long-term actions** have been co-defined by the CIRCUSOL consortium.

The **CIRCUSOL project already addresses partly this transition**, by developing a circular service design support toolbox for service providers, creating awareness and intense collaboration with stakeholders by initiating and monitoring real-life demonstration projects, developing an asset data platform prototype to share useful information between key stakeholders, developing labelling and (re-)certification protocols for second-life PV modules and batteries, and the dissemination of technological innovations to enhance circularity of solar power solutions.

The content presented in this report will be further refined during the course of the project, primarily by **interacting with stakeholders following the CIRCUSOL project** and by **reflexive monitoring** of real-life activities related to the demonstrators (cf. Task 1.5).

Box 1: the CIRCUSOL shared compass

AN ENVISIONED CIRCULAR SOLAR POWER SYSTEM …

… EMBRACES THE BIGGER PICTURE

- **BY** balancing economic, environmental, health, social and individual value(s) within decision-making or more specific within business definition and creation
- **BY** creating long-term as well as short-term benefits through circular solar power services, without any (major) trade-offs.
- **BY** aligning the (renewable) energy transition with the circular economy transition: this involves balancing operational energy benefits (for end users) of solar power solutions with embodied energy/resources benefits (for product/service providers).
- **BY** taking into account the entire life span of renewable energy solutions (such as PV and battery systems), beyond their intended application and their initial service period. This includes key life cycle stages, such as manufacturing, installation, operation, monitoring, replacement, logistics, remanufacturing, reuse and recycling.

… IS RESOURCE RESPONSIBLE

- **BY** taking care – in an effective[1] *and* efficient[2] way – of natural, human and financial resources required for (solar) energy services.
- **BY** avoiding the use of scarce primary resources and creating zero waste within the production, remanufacturing of renewable energy product systems, including photovoltaics and (stationary) batteries.
- **BY** aiming for net carbon (or greenhouse gas) negative services, by using renewable energy sources in the operational phase as well as in the (re)manufacturing and logistic stages.
- **BY** including the entire life cycle environmental impact of energy solutions in decision-making; integrating a comprehensive set of environmental indicators, instead of only looking at climate change.

… EMBRACES RESILIENCE TOWARDS FUTURE MICRO-ECONOMIC SHOCKS & POLICY SHIFTS.

- **BY** adapting easily to social and technological evolutions, such as 'self-sufficiency', 'digitalization' and 'smart cities'.
- **BY** developing robust businesses which are less or not sensitive to (modifications in) financial stimuli created by public authorities.

… IS ACCESSIBLE AND DESIRABLE FOR ALL

- **BY** providing affordable solar power solutions for end-users, business stakeholders and society.
- **BY** making circular solar power 'sexy' for end-users, business stakeholders and society, by being service-oriented and providing short-term as well as long-term benefits
- **BY** deploying services that fit the needs of different types of users and operating at various scales.

… EMBRACES TRANSPARENCY OVER THE ENTIRE VALUE NETWORK

- **BY** fostering the access to (non-confidential) data and useful information.
- **BY** sharing a diversity of knowledge within the value network (of PV and battery systems).
- **BY** monitoring good and bad practices, in order to share valuable lessons

[1] **'Effective'** focusses on whether or not the purpose(s) is/are accomplished – with the intended or expected result, e.g. creating no waste and using renewable energy instead of fossil fuels and nuclear power. It doesn't focus on *how* the purpose(s) is/are accomplished. Being 'effective' is about *doing the right things.*

[2] **'Efficient'** focusses on how the purpose(s) is/are performed, i.e. in the best possible manner with the least amount of use of resources (materials, energy, time, effort and/or currency). It doesn't focus on the *adequacy* to accomplish the purpose(s). Being efficient is *about doing things right*.

Box 2: required systemic changes

AN ENVISIONED CIRCULAR SOLAR POWER SYSTEM REQUIRES …

… A REDESIGN OF THE INTERNAL RELATIONSHIPS WITHIN THE VALUE NETWORK OF PV AND BATTERY SYSTEMS IN ORDER TO IMPROVE COLLABORATION

- **FROM** individual concerns **TOWARDS** a constructive cooperation and mutual concerns
- **FROM** punctual communication between privileged partners **TOWARDS** sharing of useful information along the value network
- **FROM** pre-consumption-oriented businesses (with a restricted relationship between provider and end-user(s) after purchase) **TOWARDS** life-cycle oriented businesses, through which responsibilities and rights are shared between (service) provider, client/end-user and post-consumption stakeholders.

… A MIND SHIFT OF DIFFERENT STAKEHOLDERS, IN ORDER TO CREATE ADDED VALUE

- As service provider and producer: **FROM** (initial) financial cost-benefit driven **TOWARDS** creation of societal added value
- As end-user: **FROM** ownership **TOWARDS** usership
- As end-user and service provider: **FROM** (planned or unintended) obsolescence **TOWARDS** reuse, repair/remanufacturing and repurposing
- As policy maker: **FROM** regulation **TOWARDS** stimulation and facilitation
- As manufacturer/industry sector: **FROM** a dependency of a few global big producers of electronic devices (e.g. Asian PV panels) and cross-continental suppliers of primary resources **TOWARDS** a thriving local competition in supply of reclaimed and remanufactured components

… A REDESIGN OF SOLAR POWER PRODUCTS & SOLUTIONS, IN ORDER TO EFFECTIVELY DISASSEMBLE, REUSE, RECYCLE AND INTERCHANGE COMPONENTS/PARTS

- **FROM** a static design for single-use **TOWARDS** an adaptable or versatile design to support changing needs and standards (cf. reusability)
- **FROM** composite electronic devices using irreversible connections **TOWARDS** a kit of detachable single-material parts/components (cf. recyclability and reusability)
- **FROM** different PV cell and battery types using different shapes and dimensions **TOWARDS** interchangeable components (cf. compatibility)

INTRODUCTION

CONTEXT

Solar power currently generates nearly 4% of Europe's electricity demand (SolarPower Europe, 2017). The strong growth of the solar photovoltaic (PV) market in Europe is expected to continue, forecasted to result in a total installed solar power generation capacity of 200 GW by 2021 (SolarPower Europe, 2017). As long as the solar power market keeps on booming, so will the volume of discarded PV modules and inverters entering the waste stream. The International Renewable Energy Agency (IRENA) estimates 1.7-8 million tons of PV Panel waste by 2030 and 60-78 million tons by 2050 cumulatively (Figure 1) (IRENA, 2016). IRENA's figures include only post-market waste and will significantly increase if production scrap (estimated to be about 1% of total production volume) is added.

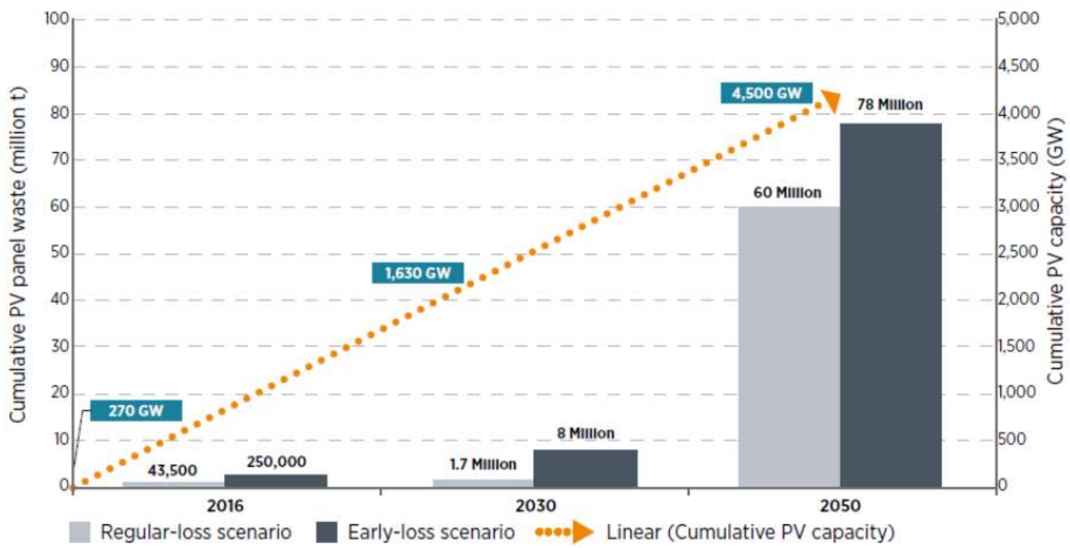


Figure 1: overview of global PV panel waste projections from 2016 to 2050, based on IRENA/IEA-PVPS (2016)

Simultaneously, recent advancements in energy storage solutions have fuelled the growth of PV-connected battery system services. When no longer suitable for automotive purposes, lithium-ion batteries from electric vehicles (EV) can be repurposed as stationary energy storage units for renewable energy sources, such as solar PV. By the end of 2015, 70% of new PV systems in Germany were installed with a local battery (SolarPower Europe, 2017). The momentum is expected to continue, guided by the EU targets to achieve 20% renewables by 2020 and 27% by 2030. It is expected that by 2040, one in every three cars on the road will be an EV. (Bloomberg New Energy Finance, 2016). Similar to PV solutions, the explosive growth in EV sales poses the question of how decommissioned batteries will be handled after their service life, as automobile and stationary battery.

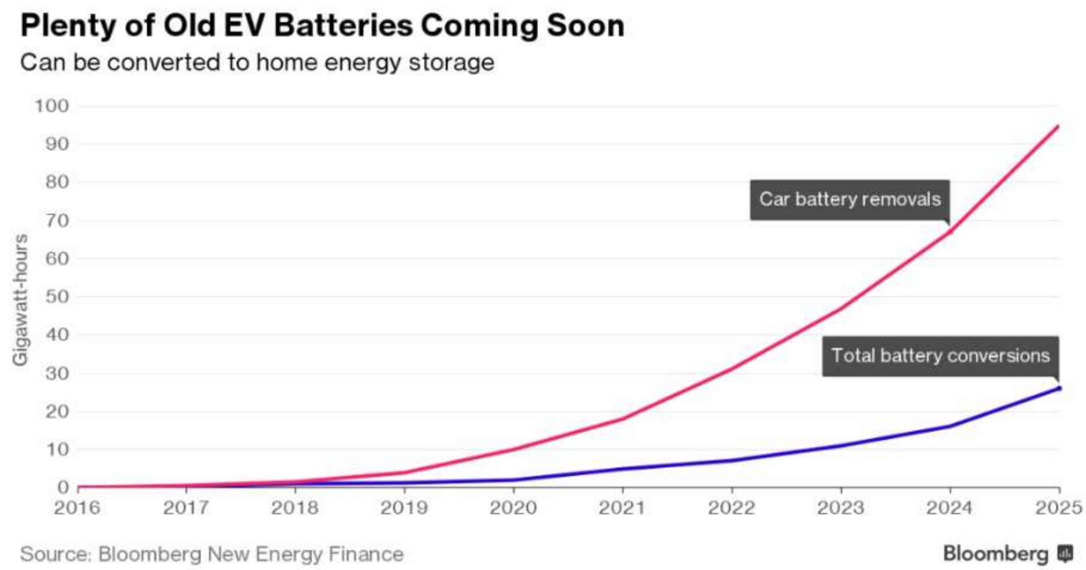


Figure 2: projections on EV battery removal and their conversion for other applications from 2016 to 2025, based on Bloomberg New Energy Finance (2016)

The main objective of the CIRCUSOL project is to provide systemic circular business solutions to the solar power industry to achieve higher resource efficiency, therefore supporting a truly sustainable transition towards a low-carbon renewable energy future. As illustrated in Figure 3, the solar power industry will be faced in 2030 with some major waste obstacles, unless there is a clear shift towards a circular economy. But 2030 is not so far away! With this in mind, a shared understanding of the current status and desired future situation(s) of a circular solar power system is of vital importance for the sector.

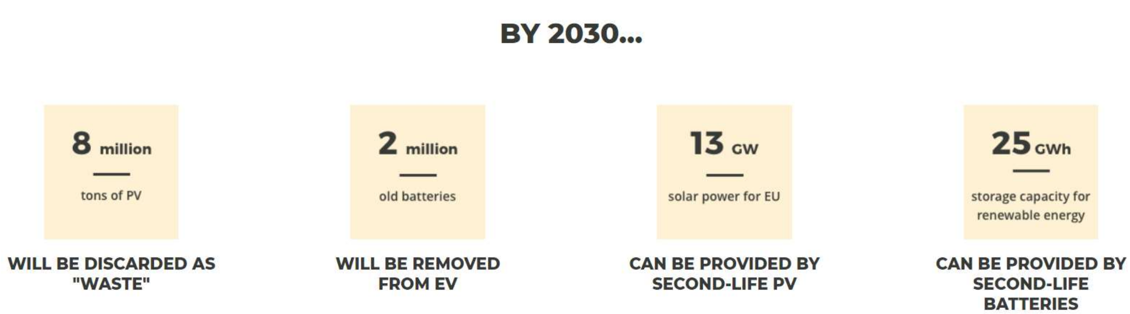


Figure 3: 2030, a tipping point for the solar power industry?

READING GUIDE

This report builds further on deliverable D1.1, *"A systematic literature review of the photovoltaic and EV battery value chains for the development of a circular economy in the solar industry"* (Franco & Grösser, 2018) and describes the major outcomes of Task 1.2 within Work Package 1 of the CIRCUSOL project, through which key elements of a shared vision on the future of circular solar power services is co-created within the CIRCUSOL consortium. This D1.2 report is structured in the following way:

- **Chapter 1** provides an overview of key terminology as part of a common language used within the CIRCUSOL consortium. Guidelines on how to use these key terms are provided in **Annex 1**.
- **Chapter 2** describes the underlying transition framework used to carry out the activities within Task 1.2.
- **Chapter 3** provides a first glimpse of what (a) future situation(s) could be, by providing a shared compass or guiding principles of a desired circular solar power system. The underlying elements of such (an) envisioned situation(s) are provided in **Annex 2**.
- **Chapter 4** describes three major systemic changes and related long-term and short-term actions in order to support the transition towards the envisioned situation(s)
- **Acknowledgements** and **references** are provided at the end of this report.

WHAT'S NEXT?

This report (D1.2) is only a snapshot of what a future circular solar power system could look like, co-created within the CIRCUSOL consortium. This vision will be refined along the course of the project, primarily by interacting with the outside world. First, a synthesis of the content of this report will be used to communicate it through CIRCUSOL's media channels and feedback can be provided on it accordingly. Second, reflexive monitoring (cf. Task 1.5) of experiences throughout the project - especially related to the real-life activities within the demonstrators - will be used to update this report and identify key success factors for the implementation of circular business models within the solar power sector.

1 A COMMON LANGUAGE

Within an interdisciplinary grouping, wherein experts are accustomed to using their own terminology, there is a risk of misunderstanding key concepts - hence, misleading communication and confusion. A common language is a starting point that can be used to structure existing or future terms.

Box 3: a common language: What? Why? and How?

1.1 WHAT?

A common language is not the same as a glossary or a lexicon. Because there are many potentially confusing or conflicting terms between numerous stakeholders within and outside the CIRCUSOL community, the aim of a common language is to reduce the number of terms that are used. This is done by carefully choosing and defining terms that all stakeholders can adopt, and by providing rational arguments therefore.

The language is by no means an exhaustive list or a selection of all interesting, relevant or preferred concepts or approaches. Terms that are adequately defined elsewhere are therefore not included with a separate definition.

1.2 WHY?

The development of a CIRCUSOL common language has different objectives:

- ***Structuring concepts**: link each of the CIRCUSOL key concepts in a way that explains the overall rationale behind the approach presented by CIRCUSOL to move towards a circular solar power system.*
- ***Bringing people together**: create a shared understanding among CIRCUSOL partners and other interested parties about the project's content.*
- ***aligning the project deliverables** in terms of the language used to report about different kinds of activities.*

1.3 HOW?

*The first step in developing a common language is screening communication within and from the CIRCUSOL community, such as the project proposal, related scientific articles, consortium minutes, the project website and other social media. Secondly, terms often used during the different co-creation sessions have been carefully written down (whether or not there was a consensus regarding the meaning of the words). The selection of key terms has been finalised by asking different ambassadors within the consortium to identify key concepts describing the main objectives of the project and activities within it. Once selected and clustered, definitions and guidelines how to use the terms have been drafted in short communication with some 'concept owners'. Finally, a draft version of the language was sent to the consortium for feedback. The output of this process is detailed in **Annex 1**.*

1.4 OVERVIEW OF KEY TERMINOLOGY

1.4.1 OBJECTS OF STUDY

A **solar power (technical) solution** is a physical assembly of multiple photovoltaic (PV) modules, a balance of systems (BOS), a rack system that holds the PV modules in place and optionally an electricity storage device, such a stationary lithium-ion battery LIB).

Related terms: **PV module, Balance of System, Lithium-Ion Battery**

A **second-life product (or components)** is a product (or components) that is/are used again directly or indirectly after some refurbishing, remanufacturing, reconditioning or repairing processes, without any changes in physical *and* chemical composition compared to the previous application of the product (or parts).

Related terms: **Recycling, Repairing, Reconditioning, Refurbishing, Remanufacturing, Reusing, Single-life warranty**

1.4.2 APPROACHES

Circular Business Model Innovation (CBMI) is the process of innovating business modelling - by updating the elements of an existing business model or establishing a new organisation and associated business model - to embed, implement and capitalise on circular economy practices. Such practices may focus on different aspects of circular economy, such as product durability and design for product life extension to slow resource loops, and recycling approaches to close the loop

Related terms: **Business model, Business plan, Circular business experimentation**

Product service system (PSS) is the result of an innovative strategy that shifts the centre of **business** from the design and sale of (physical) products alone, to the offer of product and service systems that are together able to satisfy a particular demand. A **Circular PSS (or cPSS)** is a PSS model that delivers sustainable value by slowing, closing or narrowing resource loops.

Related terms: **Product-oriented PSS, Use-oriented PSS, Result-oriented PSS, Design for Robustness, Design for Disassembly**

1.4.3 INSTRUMENTS

The **Circular Service Design Support Toolbox** (CSDST) is a framework in which tools and processes are grouped in a coherent way in order to guide and support companies in designing and experimenting with circular product service systems (cPPS) in practice

Related terms: **Life cycle thinking, Co-creation**

An **asset database** is a central digital repository to record manufacturing, installation and usage data of each product, to allow for easier repair, reuse, refurbishment and recycling at the end of first life.

Related terms: **asset monitoring, asset history of use**

2 AN UNDERLYING TRANSITION FRAMEWORK

2.1 THREE HORIZONS

The Three Horizons method was used to put the existing barriers, the envisioned future system(s) and the way(s) to get there into perspective. It helps groups to identify which of the dominant patterns are no longer fit for purpose, how the emerging trends can shape the future, and what visionary action is needed to collectively move us towards a viable future. (H3uni)

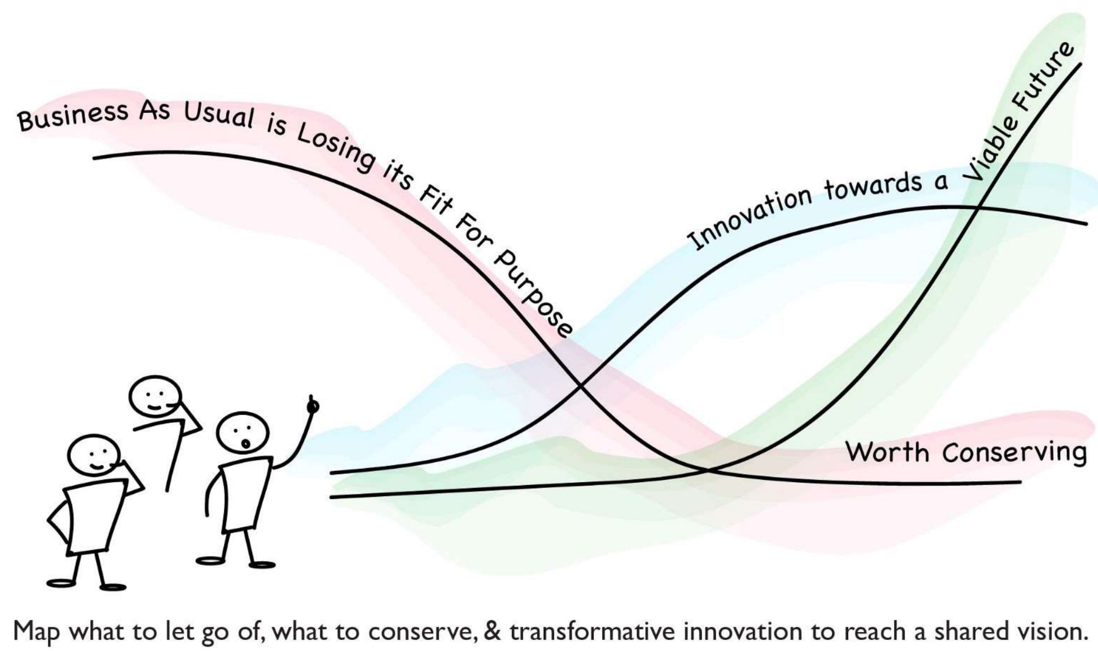
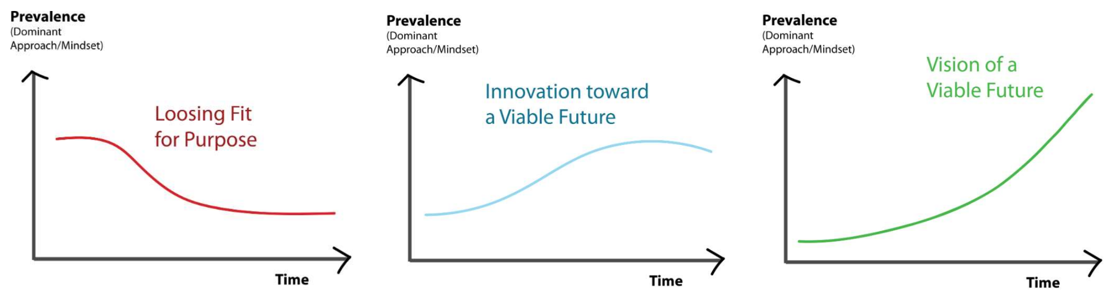


Figure 4: representation of the Three Horizons fore-sighting methodology according to Wahl (2017) and H3Uni.

Through this fore-sighting method, Bill Sharpe introduces three lenses or horizons (2013):

- Horizon 1 (H1): current mainstream system losing effectiveness and therefore losing dominance (red line)
- Horizon 2 (H2): innovations seeking to exploit opportunities in a changing world (blue line)
- Horizon 3 (H3): in tune with deeper trends and transformative changes that eventually emerges to a new dominant pattern – perhaps a generation from now (green line)

Table 1: characteristics of the three horizons, according to H3Uni.



H1: BUSINESS AS USUAL	H2: INNOVATION	H3: VISION
- Business as usual reaches its peak - Starts to decline when the world changes - Loses its 'fit for purpose - Self-reinforcing behaviour that no longer achieves desired results	requiring: - A temporary pattern of new activities & innovations - Temporary support for H1 Other innovations transitions to H3	- The long-term successor to 'business as usual' grows - Better fit to the changing world

Bill Sharpe (2013) compares the H1 perspective to the role of the *manager* responsible for keeping the lights on and the business operational without massive disruption to its basic functioning. The H2 perspective is that of the *entrepreneur* who sees the potential advantage of doing things differently, challenging the status quo in operational ways but often without questioning the cultural narrative that maintains the H1 culture. The perspective of the H3 *visionary* calls for profound transformation towards a better (more just, fair, equitable, thriving and sustainable) world.

2.2 FROM BARRIERS TO AN ENVISIONED FUTURE AND REQUIRED SYSTEMIC CHANGES

In order to meet the objectives of Task 1.2, as described in the introduction part of this report, the different Horizon perspectives were applied to develop a common understanding on what and how a circular solar power system should look like.

Within the CIRCUSOL project, the H1 perspective is used to describe the current barriers for a viable circular solar system. An overview of these barriers is listed in **Annex 2**. Most of these identified barriers have been detailed in **deliverable D1.1** ("*A systematic literature review of the photovoltaic and EV battery value chains for the development of a circular economy in the solar industry*") by Franco & Grösser (2018). The H3 perspective is used to describe the ideal situation and guiding principles, put forward by the CIRCUSOL consortium, to get there. This is detailed in **Chapter 3**. Both H2 and H3 perspectives are used to determine the systemic changes and innovations to support such desired future(s). These are further detailed in **Chapter 4**.

3 ENVISIONED SITUATION(S)

A long-term vision on what and how a circular solar power system should look like is not an easy task. A mental compass, guiding the CIRCUSOL partners (and their network) towards a shared image (or several ones) of an idealised future situation, is a first practical step. This **shared compass** consists of co-developed 'guiding principles', accepted by all members of the co-creating group and based on matching (inner) drivers. At this stage, no difference is made between (perceived) 'low hanging fruit' and (perceived) 'utopia'.

Box 4: a shared compass: What? Why? and How?

3.1 WHAT?

A co-developed set of guiding principles is a mental compass through which long-term objectives are translated into systemic actions on the field. These principles usually entail a positive and inspiring message.

It is important that the guiding principles are shared and supported by all members of the group, in order to move towards common objectives. However, the set of guiding principles is dynamic; the content can change over time.

3.2 WHY?

A long-term vision helps stakeholders/frontrunners to move away from the apparently obvious looking actions of roadmaps, often characterised by a short-term perspective. A long-term perspective needs to be collectively supported with a good orientation for systemic innovative initiatives. Co-creating such a vison (or multiple ones) is not something that happens from one day to another. A mature vision takes time and a lot of trans-disciplinary interactions. This interactive process of envisioning helps stakeholders learning about each other's framework and looking for a common ground. Developing guiding principles is a first step in co-creating a long-term vision but is at the same time already a useful instrument for defining a common agenda and experiments.

3.3 HOW?

The development of guiding principles resulted from two co-creation sessions in which different representatives of the CIRCUSOL consortium interacted with each other. During these physical interactions the CIRCUSOL partners debated on an envisioned future by juxtaposing it to the current situation. The outcome of this exercise is shown in ***Annex 2***. *Based on this a primary set of guiding principles for a future system was drafted. Finally, the opportunity of written feedback was provided by the entire consortium through an online survey. The result shown below is the latest version. During the course of the project, this shared moral compass may be subject to change, based on new insights.*

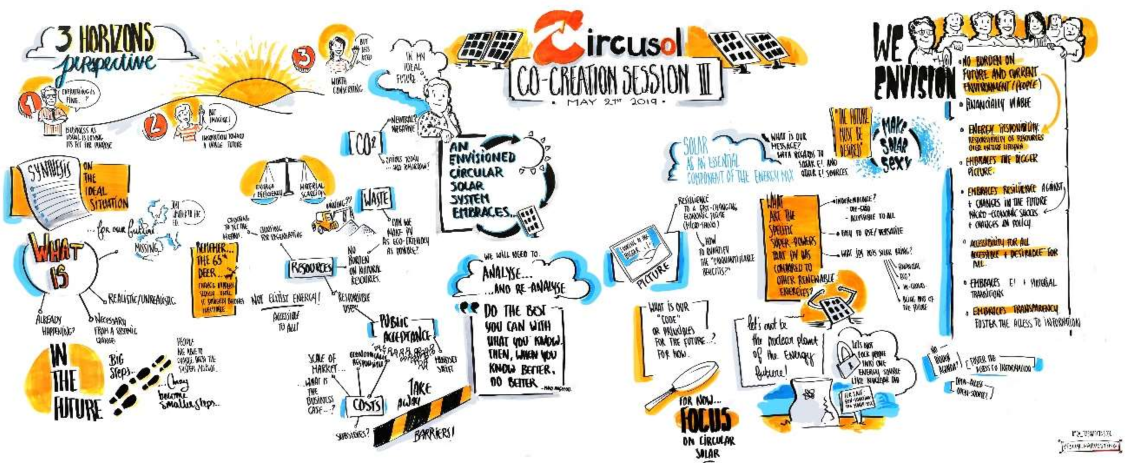


Figure 5: Developing a shared compass. (illustration by Visual Harvesting)

3.4 A SHARED COMPASS

AN ENVISIONED CIRCULAR SOLAR POWER SYSTEM …

(overall driver)

… creates added value for the future *and* the current natural & human environment.

AN ENVISIONED CIRCULAR SOLAR POWER SYSTEM …

(guiding principles)

… **embraces the bigger picture**

BY balancing economic, environmental, health, social and individual value(s) within decision-making or more specific within business definition and creation

BY creating long-term as well as short-term benefits through circular solar power services, without any (major) trade-offs.

BY aligning the (renewable) energy transition with the circular economy transition: this involves balancing operational energy benefits (for end users) of solar power solutions with embodied energy/resources benefits (for product/service providers).

BY taking into account the entire life span of renewable energy solutions (such as PV and battery systems), beyond their intended application and their initial service period. This includes key life cycle stages, such as manufacturing, installation, operation, monitoring, replacement, logistics, remanufacturing, reuse and recycling.

… **is resource responsible**

BY taking care – in an effective[3] *and* efficient[4] way – of natural, human and financial resources required for (solar) energy services.

BY avoiding the use of scarce primary resources and creating zero waste within the production, remanufacturing of renewable energy product systems, including photovoltaics and (stationary) batteries.

BY aiming for net carbon (or greenhouse gas) negative services, by using renewable energy sources in the operational phase as well as in the (re)manufacturing and logistic stages.

BY including the entire life cycle environmental impact of energy solutions in decision-making; integrating a comprehensive set of environmental indicators, instead of only looking at climate change.

… **embraces resilience towards future micro-economic shocks and policy shifts.**

BY adapting easily to social and technological evolutions, such as 'self-sufficiency', 'digitalization' and 'smart cities'.

BY developing robust businesses which are less or not sensitive to (modifications in) financial stimuli created by public authorities.

… **is accessible and desirable for all**

BY providing affordable solar power solutions for end-users, business stakeholders and society.

BY making circular solar power 'sexy' for end-users, business stakeholders and society, by being service-oriented and providing short-term as well as long-term benefits

BY deploying services that fit the needs of different types of users and operating at various scales.

… **embraces transparency over the entire value network**

BY fostering the access to (non-confidential) data and useful information.

BY sharing a diversity of knowledge within the value network (of PV and battery systems).

BY monitoring good and bad practices, in order to share valuable lessons

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[3] **'Effective'** focusses on whether or not the purpose(s) is/are accomplished – with the intended or expected result, e.g. creating no waste and using renewable energy instead of fossil fuels and nuclear power. It doesn't focus on *how* the purpose(s) is/are accomplished. Being 'effective' is about *doing the right things.*

[4] **'Efficient'** focusses on how the purpose(s) is/are performed, i.e. in the best possible manner with the least amount of use of resources (materials, energy, time, effort and/or currency). It doesn't focus on the *adequacy* to accomplish the purpose(s). Being efficient is *about doing things right*.

4 SYSTEMIC CHANGES

A shared compass, as described in the previous chapter, is not enough! A compass provides direction, but not '*the way*' to get there. One might think '*a detailed* map' will get you to your desired destination. However, regarding complex socio-technical issues such as addressed in this project, there is *no* single destination, nor a single defined pathway. Instead, it is crucial to focus on *different* compatible and reinforcing **structural changes** required to shift the current system towards one or several envisioned or idealised future system(s).

This chapter describes **three clustered systemic changes** that are required to create added value through a circular solar power system. Besides information on why these systemic changes are so important and so difficult to achieve today, some **key actions** (on long-term, short-term and during the CIRCUSOL project) are described as well.

Box 5: Required systemic change: What? Why? and How?

4.1 WHAT?

Defining systemic changes is a crucial step in setting up a common agenda and experiments, in order to shift from a current system losing its fit for purpose towards an envisioned or idealised future system.

In contrast with innovations seeking to optimise the characteristics of business-as-usual activities and processes, systemic changes involve fundamental (mental) shifts in the way society meets its needs and related patterns of actions.

4.2 WHY?

Having a common ground on the characterisation of systemic changes (and innovations) will move stakeholders a step closer towards action. It helps frontrunners to place their niche activities within a broader context and – together with – others to define a common agenda. The identification of potential leverages to meet these systemic changes is a next step to specify which (transition) experiments are required.

4.3 HOW?

The definition of systemic changes was done together with the envisioning of an ideal system/situation, described in previous chapter. Accordingly, it was the result of physical interaction with different representatives of the CIRCUSOL consortium during co-creation sessions. Based on the common guiding principles, the participants were asked to define and cluster the required systemic changes and innovations in order to get to (an) envisioned situation(s). Together with information gathered during the mapping exercise (see ***Annex 2****) possible leverages to induce these changes have been introduced by a 'back-casting' exercise, i.e. the writing of a retrospective article in the year 2050. Finally, written feedback was provided through an online survey.*

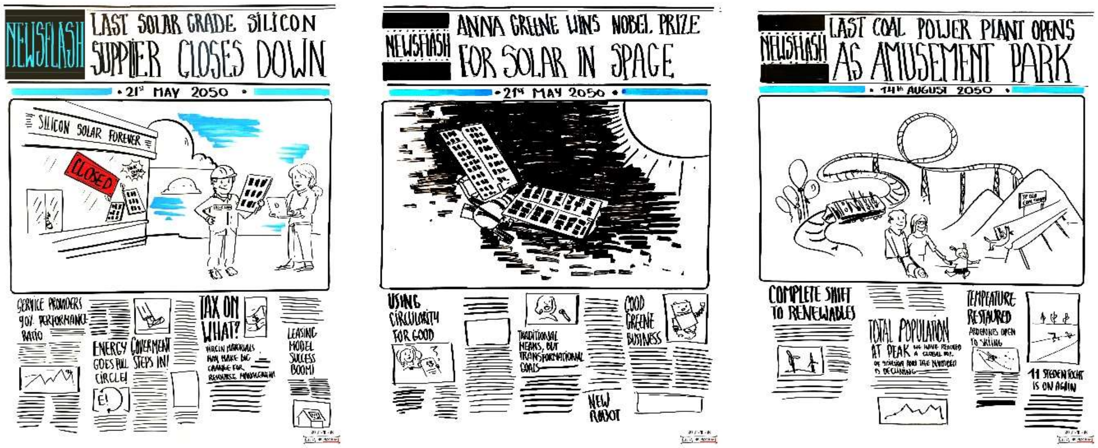

Figure 6: visual representation of the co-created retrospective articles. (illustration by Visual Harvesting)

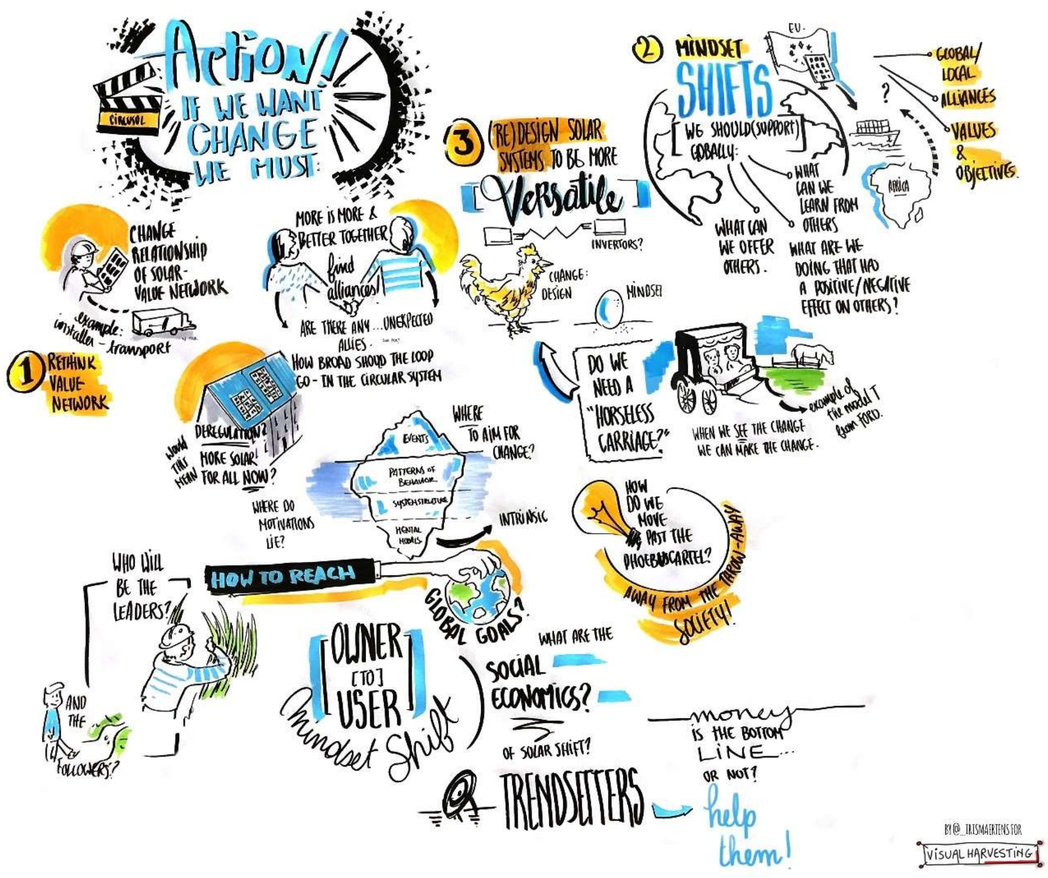

Figure 7: visual overview of some co-developed systemic changes and required actions (illustration by Visual Harvesting)

4.4 A REDESIGN OF INTERNAL RELATIONSHIPS WITHIN THE VALUE NETWORK

In order to improve collaboration within the value networks of PV and battery systems, the relationships between key actors will need to be rethought:

- **FROM** individual concerns **TOWARDS** a constructive cooperation and mutual concerns
- **FROM** punctual communication between privileged partners **TOWARDS** sharing of useful information along the value network
- **FROM** pre-consumption-oriented businesses (with a restricted relationship between provider and end-user(s) after purchase) **TOWARDS** life-cycle oriented businesses, through which responsibilities and rights are shared between (service) provider, client/end-user and post-consumption stakeholders

4.4.1 WHY IS IT SO IMPORTANT?

A circular economy - and more specific circular product service systems - within the solar power sector require(s) a strong interaction between all main stakeholders involved in the design, production, installation, repair/maintenance and repurposing of solar power solutions. In order to successfully improve the circularity of (second-life) PV and battery systems or their components, useful information on how it was designed and produced *(e.g. ease of disassembly, estimated technical lifespan, bill and origin of materials and (semi-manufactured) products, production cost)*, installed *(e.g. ease of handling, location, installation cost)*, used and managed *(e.g. frequency of maintenance/repair, estimated residual service life, function, service cost)* and repurposed *(e.g. recyclability, reusability, next destination, residual value of components)* needs to be shared within the entire value network. 'Trust' between all main stakeholders is crucial for success.

Because of the magnitude of information and variety of stakeholders within the building value network, a digital way of collecting, handling and exchanging data seems indispensable.

4.4.2 WHY IS IT SO DIFFICULT TODAY?

Severe **competition** between producers, service providers, installers and asset managers individually results often in concealing important information from other actors within the value network.

With currently only a few market players focussing on reuse and repurposing of PV panels and EV batteries and the current lack of demand for solar power solutions using reclaimed components, there is **no commercial incentive** (yet) for the above-mentioned stakeholders to share their information.

Furthermore, most **end-users are usually not involved** in how and if circular energy power solutions are provided. If they do so, costumers have usually concerns about **the reliability and safety** of reclaimed PV panels and EV batteries.

4.4.3 WHICH LEVERAGES ARE NEEDED?

4.4.3.1 ACTIONS WITHIN CIRCUSOL PROJECT

- Development of an extensive and user-friendly business model toolbox to guide solar power service providers towards sustainable and profitable circular business decisions.
- Initiation and monitoring of demonstration and pilot projects in which all main stakeholders of the value network, including end-users of second-life PV and battery systems, are involved in the co-creation and co-development of circular service models.
- Development of a (closed) asset data platform prototype, recording manufacturing, installation and usage data of each PV and battery product, to allow for easier repair, reuse, refurbishment and recycling at the end of first life.
- Development of labelling and (re-)certification protocols for second life PV modules and batteries and tested in real life conditions

4.4.3.2 SHORT-TERM ACTIONS

- Implementation of an open and reliable data platform with the asset history of installed PV and batteries, including their financial, environmental and social performance/value. This needs to compatible with existing information management systems, such as the International Dismantling Information System (IDIS - www.idis2.com) through which EV battery producers have enlisted their products on a central repository of manufacturer compiled treatment information for end-of-life vehicles.
- Development of a code of practice to determine the (residual) performance of second-life EV batteries for stationary applications.
- Upscaling and harmonising labelling and (re-)certification initiatives (such as protocols prepared within the CIRCUSOL project) within standardisation committees (e.g. IEC and CENELEC)

4.4.3.3 LONG-TERM ACTIONS

- Enforcing a "zero fossil fuel" policy introduced on EU level and broader guiding companies and governments towards circular renewable energy solutions
- Establishing "integrating companies" working and interacting along the entire value chain of PV and batteries solutions
- Digital monitoring of all new and second-life solar power solutions from production to remanufacturing/reuse and recycling>

NOTE: *More actions might be added, removed and refined based on the outcome of Task 1.5 (reflexive monitoring for collective learning).*

4.5 A MINDSHIFT OF DIFFERENT STAKEHOLDERS WITHIN THE VALUE NETWORK

In order to create added value along the entire value chain of (second-life) PV and battery systems, different stakeholders within the value network will need to assume new responsibilities and/or take up different roles compared to today:

- As service provider and producer: **FROM** (initial) financial cost-benefit driven **TOWARDS** creation of societal added value
- As end-user: **FROM** ownership **TOWARDS** usership
- As end-user and service provider: **FROM** (planned or unintended) obsolescence **TOWARDS** reuse, repair/remanufacturing and repurposing
- As policy maker: **FROM** regulation **TOWARDS** stimulation and facilitation
- As manufacturer/industry sector: **FROM** a dependency of a few global big producers of electronic devices (e.g. Asian PV panels) and cross-continental suppliers of primary resources **TOWARDS** a thriving local competition in supply of reclaimed and remanufactured components

4.5.1 WHY IS IT SO IMPORTANT?

Current design, exploitation and policy-making regarding electric power is often based on short-term decision-making, (in)directly favouring linear solutions and focussing on a short financial return-of investment. However, circular solar power solutions can provide long-term financial benefits and/or societal added value for a vast number of stakeholders:

- As a service provider: a continuous revenue stream
- As a producer/manufacturer: recovery of valuable materials/products
- As an end-user: performance warranties on provided product services
- As society: an increase in use of low/zero carbon energy source and job creation

Without a shift towards long-term thinking and handling of the main stakeholders within the value network the creation of short-term and long-term (financial and societal) added value is not guaranteed.

4.5.2 WHY IS IT SO DIFFICULT TODAY?

The solar power service sector (including PV and battery solutions) is still young and needs to keep up with big competitors such as grid operators, and in most EU regions this also means providers of electricity from nuclear power and fossil fuel electricity plants. Although the market share of solar power within the EU is still increasing in relation to non-renewable electricity, the main objective of this niche sector is to increase its electricity production performance and the stability in electricity supply. Hence, **'circularity' is currently not a primary concern for the solar power sector**. Furthermore, it is not always obvious for all stakeholders (including clients and end-users) what the financial, social and environmental benefits or costs are related to reclaimed PV and battery systems (or components), due to a **lack of decision support** and **lack of reliable asset data**. It is often easier for a service provider, producer and customers to opt for new components, with clear and guaranteed performance specifications.

4.5.3 WHICH LEVERAGES ARE NEEDED?

4.5.3.1 ACTIONS WITHIN CIRCUSOL PROJECT

- Development of ‘life cycle profiles’ of (solar) power solutions, through which possible environmental externalities related to particular power solutions are avoided/identified, by integrating environmental and financial life cycle assessment.
- Increasing public acceptance of circular solar power solutions through real-life demonstrators, in which the technical quality of second-life PV modules and batteries is improved, perceived risks for end-users and customers are removed via performance-based services and promotion of public awareness is created on circular economy/urban mining as a way to tackle resource scarcity.

4.5.3.2 SHORT-TERM ACTIONS

- A coordinated R&D program for solar power, in which equal importance is given to improve the energy efficiency *and* the circularity of solar power solutions
- In order to stimulate the use circular (solar) power solutions, public procurement can initiate a (service based) market, by putting a required performance level on energy efficiency *and* the circularity of (solar) power solutions.
- Targeting financial and business incentives towards middle-class end-users to lease, rent or share solar power solutions instead of buying them.
- Revising the EU Waste Directive - and legal references towards it- with a clear definition of waste (and how to address it) within the realm of a circular economy.
- Investment in new collection centres and recycling plants, in order to absorb the increasing amount of electric and electronic equipment waste (WEEE)

4.5.3.3 LONG-TERM ACTIONS

- Enforcing a "circular economy" policy introduced on EU level and broader guiding companies and governments to use secondary resources and products on a local and regional scale in an effective way.
- Full implementation of performance-based product services in the market. It is not clear yet if a push and/or pull business strategy is required for this.
- Internalization of external environmental and social costs and benefits of power solutions into the financial costs, to make stakeholders - in particular end-users - aware of potential societal impact and benefits on the long-term.

NOTE: *More actions might be added, removed and refined based on the outcome of Task 1.5 (reflexive monitoring for collective learning).*

4.6 A REDESIGN OF SOLAR POWER PRODUCTS AND SOLUTIONS

A redesign solar power products and solutions is required in order to shift:

- **FROM** a static design for single-use **TOWARDS** an adaptable or versatile design to support changing needs and standards (cf. reusability)
- **FROM** composite electronic devices using irreversible connections **TOWARDS** a kit of detachable single-material parts/components (cf. recyclability and reusability)
- **FROM** different PV cell and battery types using different shapes and dimensions **TOWARDS** interchangeable components (cf. compatibility)

4.6.1 WHY IS IT SO IMPORTANT?

Current PV and battery systems are still conceived from a linear perspective, neglecting a possible second use for other applications and creating (hazardous) waste or low-grade and/or energy intensive recycled products. In order to increase or maintain the (financial, environmental and social) value of existing and new power solutions, these solutions need to be conceived, installed and operated with a circular (business) model in mind. Without a technical redesign of power solutions and their components the creation of added value is not guaranteed.

4.6.2 WHY IS IT SO DIFFICULT TODAY?

The International Renewable Energy Agency (IRENA, 2016) estimates 1,7 to 8 million tons of PV Panel waste by 2030 and 60-78 million tons by 2050 cumulatively to enter the waste stream, unless mature circular business solutions are put in place by then. Currently, only a fraction of the installed PV systems has been removed for the first time. Similar trends are discerned within the even younger EV battery market. With a young solar power sector primarily focussing on efficiency, **'circularity' is not (yet) a primary concern**. Recycling, repairing, reconditioning, remanufacturing, refurbishment and reuse[5] of PV and battery components are difficult because the initial PV and EV battery systems were never designed to be (1) easily demountable and (2) used again for multiple and/or different applications. Due to a **lack of awareness and design guidelines or decision support instruments**, most producers do not have the knowledge - nor expertise - to design solar power solutions in a circular way. Furthermore, in a **traditional business practice**, in which panels and batteries are sold to customers, there is no (financial) incentive to make them demountable, robust or compatible.

[5] In **Annex 1** the differences between Recycling, repairing, reconditioning, remanufacturing, refurbishing and reusing are explained

4.6.3 WHICH LEVERAGES ARE NEEDED?

4.6.3.1 ACTIONS WITHIN CIRCUSOL PROJECT

- Description of technological innovations to enhance the circularity of the PV modules, and the financial implications within a business context.
- Demonstrating innovative circular solar power solutions to create awareness and provide tangible information for producers, manufacturers and service providers.

4.6.3.2 SHORT-TERM ACTIONS

- Development of circular design directives for components of PV and battery systems, in order to (1) reduce the number of components and materials in modules (hence, making it easier to recycle it afterwards), (2) increase the ability to disassemble PV and battery modules, without losing (3) robustness regarding heavy weather conditions, fire and wear and tear. First steps have been undertaken in other R&D projects, such as CABRISS[6] and SUPER PV[7]. Also, from a software perspective, guiding is required to integrate battery management systems with updatable software, in order to maximize reuse.
- Updating Eurocodes and other (national) building standards or directives to better design, dimension and install PV panels on flat roofs, in order to avoid premature failure due to heavy weather conditions.
- Implementation of design directives and standardisation rules into the development of new circular PV and battery products.
- Remote monitoring of performance of PV modules through e.g. performance-based service contracts, in order to anticipate failure and accordingly enhance reverse logistics of modules.
- Development of a code of practice to determine the residual performance of second-life EV batteries for stationary applications
- Development and/or implementation (e.g. through pilot projects) of mature (automated) technology to (1) better identify valuable (and interfering) materials, (2) to disassemble/recover components for reuse or remanufacturing and (3) to recycle into useful materials, in order to absorb the vast number of PV panels installed in the beginning of the 21st century or earlier

4.6.3.3 LONG-TERM ACTIONS

- Standardisation of shape and dimensions of battery and PV parts in order to increase the compatibility and interchangeability of components in different power solutions. This will make it easier to reuse them directly in multiple applications.

[6] Implementation of a **CircularAr** economy **Based** on **R**ecycled, reused and recovered **I**ndium, **S**ilicon and **S**ilver materials for photovoltaic and other applications (CABRISS): https://www.spire2030.eu/cabriss

[7] SUPER PV: https://www.superpv.eu/project/

NOTE: *More actions might be added, removed and refined based on the outcome of Task 1.5 (reflexive monitoring for collective learning).*

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The report is the result of joint efforts within the CIRCUSOL consortium, describing key elements of a common vision on a circular solar power system, the identification of systemic changes to get there and related actions to support these changes. It is based on the output of multiple co-creation activities, in which all CIRCUSOL partners were involved.

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ANNEX 1: A DETAILED DESCRIPTION OF THE COMMON LANGUAGE

SOLAR POWER SOLUTION

DEFINITION

A solar power (technical) solution is a physical assembly of multiple photovoltaic (PV) modules, a balance of systems (BOS), a rack system that holds the PV modules in place and optionally an electricity storage device, such a stationary lithium-ion battery LIB).

GUIDELINES

In the CIRCUSOL project solar power solutions are used as an umbrella for technical solutions combining second-life PV and/or reclaimed Electric Vehicle (EV) battery solutions for stationary applications. The term only refers to technical solutions and does not incorporate business, finance, policy or other aspects.

RELATED TERMS

PV module: an assembly of typically 6x10 or 6x12 series-connected solar cells, which are packaged into a protective multi-layered structure of 5 main components: the front cover (tempered glass), the interconnected solar cells matrix in an envelope of two encapsulant layers (front/back) and a back cover (back sheet or tempered glass). Such structure provides electrical insulation and long-term protection of the solar cells against external environmental stresses. Externally, metal frames consisting of racking components and brackets are used to better support the panel structure. Electrical cables (i.e. positive and negative terminals) are linked to a junction box, which is adhered on the back side of each PV module, and used to connect multiple modules at a PV system level (Franco & Grösser, 2018)

Balance of systems (BOS) is a set of components regulating and monitoring the energy produced by the PV panels and consists of cables, wiring, power electronics (e.g. charge controllers, over-current protection, PV current monitoring devices, a combiner box, lightening protection systems and one or more inverters). An inverter transforms direct current (DC) from the PV array into a form of alternating current (AC) electricity that can be connected to the electric utility grid. (Franco & Grösser, 2018)

Lithium-Ion Battery (LIB): is made of multiple power-generating compartments called cells. Each cell consists of four elements, namely: (i) a positive electrode or cathode, (ii) a negative electrode or anode, (iii) an electrolyte, or lithium salt dissolved in a liquid organic solvent, and (iv) a separator (a thin microporous polyolefin film) that separates the anode and cathode, thus preventing short circuiting (Stenzel et al., 2014; Zheng et al., 2018). Cathode and anode are separated and connected by an electrolyte, which transfers lithium ions from the anode to the cathode and vice-versa.

SECOND-LIFE

DEFINITION

A second-life product (or components) is a product (or components) that is/are used again directly or indirectly after some refurbishing, remanufacturing, reconditioning or repairing processes, without any changes in physical *and* chemical composition compared to the previous application of the product (or parts).

GUIDELINES

The term "second-life" refers to re-use, refurbish, remanufacture, reconditioning and repair. In second-life circular paths, the product remains as a product or components. It is different from recycling or bio-degradation, in which the product is disintegrated and recovered as raw materials.

The word "second-hand" should be avoided, as it has often a pejorative meaning.

Within the CIRCUSOL project, second-life PV are used modules which are repaired, refurbished, or suitable for direct re-use; second-life batteries are retired EV batteries which are remanufactured for stationary applications such as PV storage. (circusol.eu)

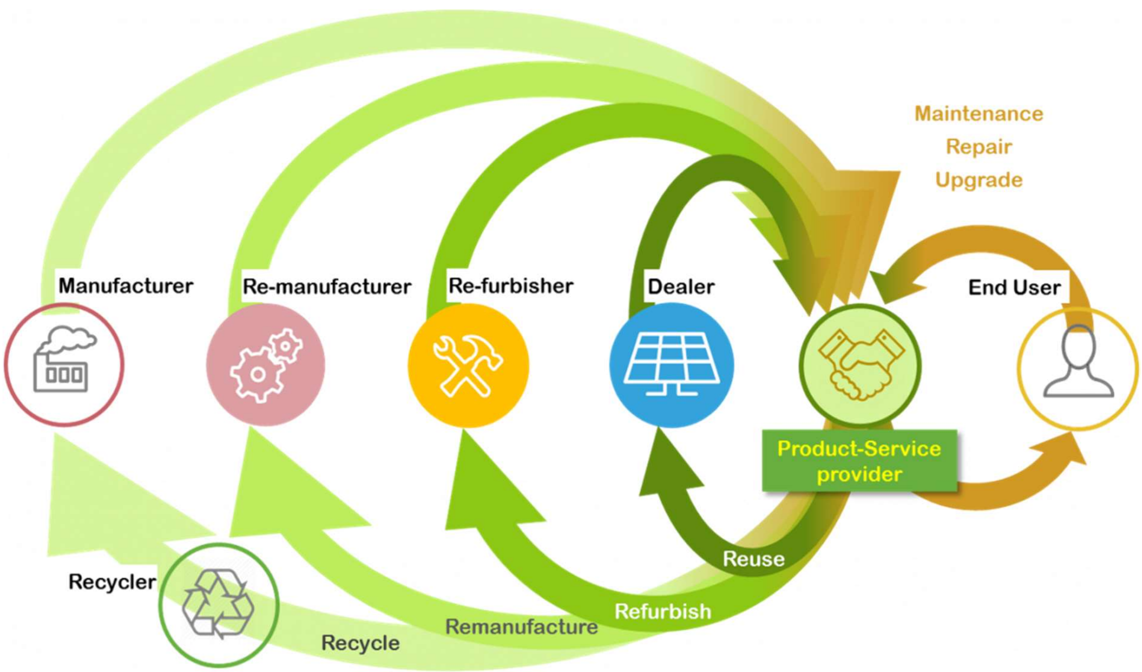

Figure 8: circular product service system model in which different types of second-life options are explained

RELATED TERMS

Recycling: the extraction of a product's raw materials for use in new products (APSRG & APMG, 2014). The physical and/or chemical composition has been altered during the recycling process.

Repairing: The fixing of a fault but with no guarantee on the product as a whole

Reconditioning: the potential adjustment to components bringing an item back to working order, although not necessarily to an 'as new' state (APSRG & APMG, 2014). A reconditioned product has undergone extensive testing (and possible repair) before being made available again. (Techwalla)

Refurbishing: The largely aesthetic improvement of a product which may involve making it look like new, with limited functionality improvements (APSRG & APMG, 2014).

Remanufacturing: A series of manufacturing steps acting on an end-of-life part or product in order to return it to like-new or better performance, with warranty to match (APSRG & APMG, 2014).

Reusing: The simple reuse of a product with no modifications (APSRG & APMG, 2014).

Second-life warranty: is a legal guarantee on the performance of a specific second-life product and/or that it is free form defects in materials and workmanship (under normal application, use and service conditions) for an (agreed/set) period. (Solitek, 2018)

CIRCULAR BUSINESS MODEL INNOVATION

DEFINITION

Circular Business Model Innovation (CBMI) is the process of innovating business modelling - by updating the elements of an existing business model or establishing a new organisation and associated business model - to embed, implement and capitalise on circular economy practices. Such practices may focus on different aspects of circular economy, such as product durability and design for product life extension to slow resource loops, and recycling approaches to close the loop (Bocken et al., 2016)

GUIDELINES

Circular business model innovation (CBMI) is a relatively recent field, with most tools and methods to support the business model innovation process only having recently emerged (Bocken et al., 2019). Although a plethora of tools and methods have been developed by scholars, the innovation of a business model is rarely a linear and straightforward process in which all micro-steps are defined from the beginning. Experimentation has been found to be a key factor that positively affects radical innovation (Chang et al., 2012; Koberg et al., 2003) and more recently it has also been suggested and applied in the context of circular business innovation (Antikainen et al., 2017; Bocken et al., 2018; Weissbrod and Bocken, 2017).

Given the dynamic business environment for the rapidly developing solar power industry and the relative absence of circular business practices and related business models in this sector, an experimental and iterative approach to business model innovation within the CIRCUSOL project is expected to be useful, next to the development and structuring of business modelling tools and methods.

RELATED TERMS

Business model: a 'systemic lens' to investigate businesses and the ways they operate (Stubbs and Cocklin, 2008); 'the way business is done' (Magretta, 2002) by illustrating how a business proposes, creates and delivers and captures value (Richardson, 2008) for the business, customer and wider group of stakeholders (Osterwalder et al., 2005). A business model is typically depicted by a value proposition (product/ service offering), value creation and delivery (how this value is provided e.g. through activities and sales channels) and value capture mechanisms (how money is made and other forms of value are captured) (Magretta, 2002).

Business plan: a detailed set of business goals, and the actions to reach those goals within a specific context and with real stakeholders. This is different from a business model, which (simple definition from Osterwalder) describes the rationale used by a company to create, deliver and capture value.

Circular business experimentation: a method that aims to set up experiments and control and manipulate certain variables of the business model, in order to create positive value for customers, a wider society and the environment. So, besides the customer proposition, an environmental and societal value proposition needs to be formulated and tested. (Bocken & Antikainen, 2019)

(CIRCULAR) PRODUCT SERVICE SYSTEM

DEFINITION

Product service system (PSS) is the result of an innovative strategy that shifts the centre of business from the design and sale of (physical) products alone, to the offer of product and service systems that are together able to satisfy a particular demand (Vezzoli et al., 2014). A **Circular PSS (or cPSS)** is a PSS model that delivers sustainable value by slowing, closing or narrowing resource loops.

GUIDELINES

While PSS is a broad term covering many different possible business models, they can be structured in three main categories (Figure 2.1)(Tukker, 2015): (1) product-oriented, (2) use-oriented and result-oriented PSS.

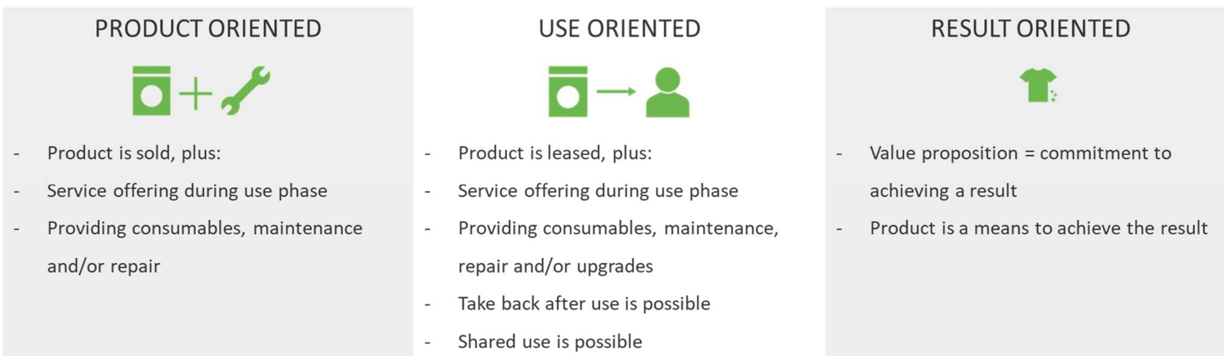

Figure 9: Three types of PSS models (source: VITO)

It is important to stress that, although PSS can enable circularity, circularity is not an explicit trait of PSS models. PSS design is first and foremost focused on finding an integrated bundle of products and services which creates customer utility and generates value (Boehm and Thomas, 2013). Whether a specific PSS model creates added value through circularity, is not only influenced by the business strategy, but also depends if the product is designed for robustness and/or (easy) disassembly (and re-assembly) and (3)

RELATED TERMS

Product-oriented PSS (pPSS): in this PSS category, selling products is combined with service offerings during the use phase. Potential services could be maintenance, repair, monitoring and insurance. For example: selling a washing machine and offering after-sales repair service. (Bocken et al., 2019)

Use-oriented PSS (uPSS): this type of PSS covers a wide variety of possible models, that all put the access to, or use of, a product to the forefront. Products are not sold, but rented or leased, and the user pays a fee to make use of or get access to the product. For example: a laundromat providing users access to a washing machine they don't own. (Bocken et al., 2019)

Result-oriented PSS (rPSS): in this PSS model, the value offered to the customer is not expressed as a product, but as the result that the user is looking for to address her or his needs. The specific product needed to obtain the wanted result, is of no or at least less concern to the user. For example, a dry-cleaning service picking up dirty clothes and returning them clean to the user. (Bocken et al., 2019)

Design for Robustness (DfR) is a design (and production) strategy striving for product longevity and product life extension. By doing so, it is a sustainable alternative of current design (and business) strategies opting for 'obsolesce' or premature failure. Robustness is the property of products that enables them to survive unforeseen or unusual circumstances. (Knoll F. & Vogel T., 2009)

Design for Disassembly (DfD) is a design (and production) strategy that enables the partial or total disassembly of a product. **Disassembly** is the act of removing components from an assembly resulting in either pure material flows, facilitating recycling or biodegradation, or sound components that can be used again. (Debacker & Manshoven, 2019)

CIRCULAR SERVICE DESIGN SUPPORT TOOLBOX

DEFINITION

The **Circular Service Design Support Toolbox** (CSDST) is a framework in which tools and processes are grouped in a coherent way in order to guide and support companies in designing and experimenting with circular product service systems (cPPS) in practice.

GUIDELINES

Although the CSDST is being developed within the CIRCUSOL project to support circularity within the solar power sector, the framework is generic and applicable for other sectors. Figure 10 explains the general structure of the method. There are three basic components: innovation modules, underlying approach and innovation process.

The method behind the toolbox is built upon a holistic foundation, which is reflected in the two underlying approaches: **(1) life cycle thinking** and **(2) co-creation.**

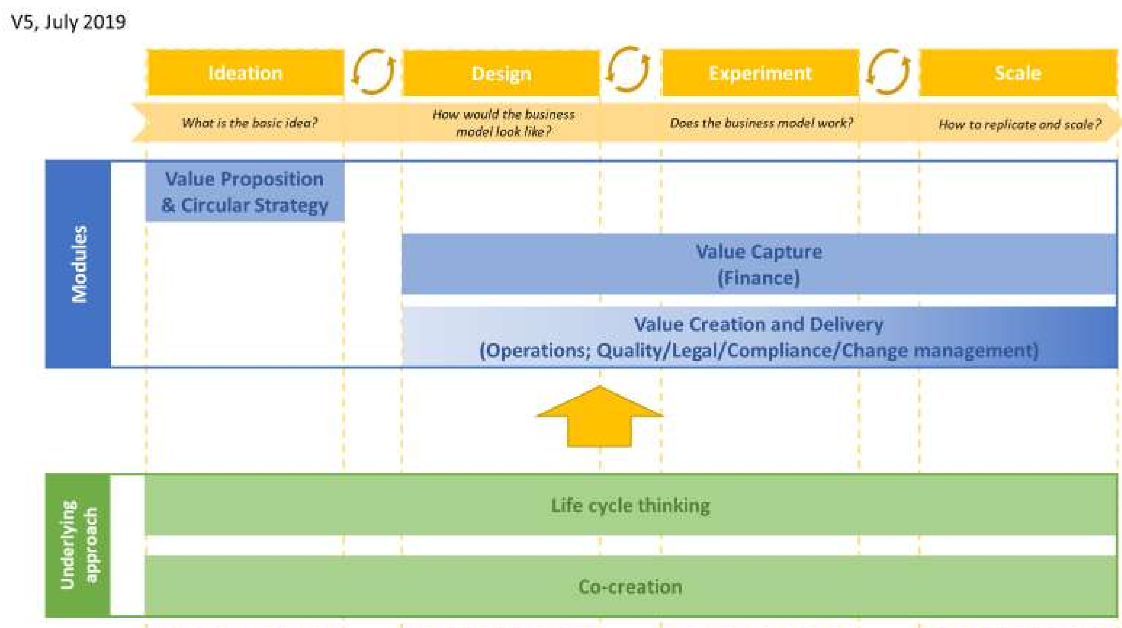

Figure 10: General structure of the circular service design support toolbox - version 5, July 2019

RELATED TERMS

Life cycle thinking: an holistic way at looking at product (service) systems, by considering environmental, social and economic impacts of a product system over its entire life cycle, including extraction of raw materials, design and production, packaging and distribution, use and maintenance, reuse, disposal, recycling and recovery, as well as incineration and landfill (UN Environment, 2018). Life cycle thinking avoids problem shifting from one phase to another. (Bocken et al., 2019)

Co-creation: an interactive, creative and social process between stakeholders that provides an opportunity for on-going interaction, with the aim to create superior value propositions – from a social, economic and environmental perspective (Agrawal et al., 2015). This fosters the widest acceptance and support of the new business model. (Bocken et al., 2019)

ASSET DATABASE

DEFINITION

An **asset database** is a central digital repository to record manufacturing, installation and usage data of each product, to allow for easier repair, reuse, refurbishment and recycling at the end of first life.

GUIDELINES

Within the CIRCUSOL project an asset database is currently developed focussing on EU solar power sector, in order to stimulate second-life usage (and recycling) of solar power solutions, including PV modules and EV batteries

The asset database will allow for better connection between market supply and demand of second-life products.

RELATED TERMS

Asset monitoring
Asset history of use

NOTE: Task 3.6 has just started. During the course of the project these terms will be further defined, and the guidelines will be accordingly refined.

ANNEX 2: MAPPING OF EXISTING BARRIERS AND ENVISIONED FUTURE SISTUATION

R&D, DESIGN AND TECHNICAL ASPECTS

Table 2: barriers and ideal situation(s) related to R&D, design and technical aspects

	Cluster	Encountered barrier (2019)	Envisioned ideal situation	When?
1	**R&D**	Most R&D funds are allocated towards improving the efficiencies of current architectural configurations for PV panels and EV batteries, neglecting research that favours EOL recovery.	R&D focusses equally on **improving energy efficiency as well as the recovery** (remanufacturing, reuse and recycling) of PV panels and EV batteries.	2020
2	**Design**	Manufacturers optimize product design for first life and not for use thereafter (i.e., design for disassembly, refurbish and recycling). Current PV module design configurations do not facilitate the proper separation of module components	(1) PV modules are made with **less components and less different materials** (no composites), which makes it easier to recycle it afterwards. (2) PV modules are **designed and installed to be easily disassembled,** without losing it robustness regarding heavy weather conditions and similar. By doing so failing components can easily be replaced on site and sound components can be reused for other or similar applications.	2025 2035
2b new!	**Design**	EU batteries design is specific to each manufacturer. This makes refurbishment/remanufacturing difficult.	Common practices are established, and **battery parts are standardized within EU and broader for compatibility,** i.e. direct (re)use of batteries in multiple applications)	2025
3	**Technical**	There are concerns about the performance of PV panels manufactured out of recycled materials (i.e., the more the recycled material in new PV	(1) Through performance-based service contracts electricity production is **monitored remotely.** In case modules/components fail, they are easily and quickly replaced.	2030 2050

		panels, the greater the probability for lower electricity generation) <is this a perception or a well-established fact?>	(2) **PV industry is completely circular**	
4	**Technical**	Particularly for EV batteries, there is uncertainty about the remaining battery capacity after its use in 1st life (i.e., the ageing performance of 2nd life batteries). Most tests measuring the efficiency and longevity of LIBs (for stationary energy storage) have been performed as demonstrations at the laboratory level only	The use of second-life EV batteries (for stationary applications) is well established. A **code of practice** is used to determine the performance of second-life EV batteries for stationary applications.	2025
5	**Technical**	Time delays in the deployment of 2nd life batteries for energy storage. Will there be other technical solutions for energy storage available by the time 2nd life LIBs become an industrial reality?	Many technical options are commercially viable	2025
6	**Technical**	It is unclear how new product launches (i.e. newer EV battery technologies) compete with refurbished batteries? Which new LIB chemistries will be used in the future and how will these perform in second-life applications for energy storage?	New chemistries are no problem for refurbished batteries, because a **battery management system** with updatable software is added to **all battery systems**	2025
21	**Grid**	If second-life battery storage is pursued at massive scale, how will the grid infrastructure be affected in terms of its capacity for external connections?	**Smart and flexible electricity grids** are deployed over most of EU member states	2030

COLLABORATION AND MARKET

Table 3: barriers and ideal situation(s) related to collaboration and market aspects

	Cluster	Encountered barrier (2019)	Envisioned ideal situation	When?
7	**Collaboration**	Lack of coordination between EV manufacturers, policy makers and recycling companies related to changes in product design	(1) A **"zero fossil fuel" policy vision** is implemented (2) A clear policy plan is in place to ensure coordination (3) **Integrated companies** encompassing the entire product value chain (4) Long-term (positive or negative) impact of policy measures is calculated before adoption as well as closely monitored during implementation to allow 'adaptive policy-making'	2050
8	**Collaboration**	Lack of incentives for utility provider to promote the use of second life EV batteries for energy storage in dwellings or other buildings.	(1) Batteries – energy storage units – are considered as **a flexible and modular commodity** (2) **Demand meets supply of second life EV batteries.** (tax reductions and subsidies were needed to stimulate uptake, in case of an environmental added value)	2050
10	**Market**	Lack of awareness and/or poor market confidence of refurbished/recycled PV panels and batteries. Customers perceive refurbished or recycled products as exhibiting lower performance	**Performance based service contracts** are well established. EU customers don't need to care about new vs. refurbished/recycled, as long as the performance is guaranteed.	2030
11	**Market**	Lack of empowerment of the end-users to opt for sustainable circular energy services	Sustainable circular energy services are thriving, because of **open and transparent communication** on their financial, environmental and social performance/value	2030

15	**Market**	Customer concerns about warranties, reliability, and safety of second-life PV panels and EV batteries hinder customer trust and product adoption	Risks related to the performance and safety of new as well as second-life products are **covered by the energy service provider.** (Trust is established by a transparent exchange of information on the history of products)	2030
16	**Market**	With a better understanding of battery chemistry and battery management systems, increases in the lifetime of 1st life batteries might be achieved so that the supply of second-life batteries gets delayed. This in turn might have effects on the supply/demand ratio and the price of second-life batteries.	see **barrier 8**	
18	**Market**	Lack of business models for second-life batteries	See barrier 8 An extensive and **user-friendly business model framework** helps energy service providers to develop sustainable circular business plans	2022
36	**Business model**	With higher cell efficiencies and lower material prices expected in the future, it is unclear if the recycling of PV panels makes economic sense	<not answered> This is more a trend than a barrier.	

RECYCLING AND REUSE

Table 4: barriers and ideal situation(s) related to recycling and reuse aspects

	Cluster	Encountered barrier (2019)	Envisioned ideal situation	When?
22	**Recycling**	Lack of transparency in the production of the battery makes the recycling process not efficient. Recycling firms have difficulties with some materials that take more time to process. The non-disclosure of proprietary product information and different material combinations in PV panels complicate the recycling process	All EV battery producers have enlisted their products on the **International Dismantling Information System** (IDIS - www.idis2.com), a central repository of manufacturer compiled treatment information for end-of-life vehicles.	2025
23	**Recycling / technical**	Lack of proper material recovery and recycling technologies for PV panels and EV batteries. Pilot projects to improve the efficiency of recycling are still underway	In order to absorb the vast number of PV panels installed in the beginning of the 21st century or earlier, **mature recovery and recycling technologies** are in place. This results from extensive R&D and pilot projects.	2030
24	**Recycling / technical**	Laminated technology for PV gives better protection against severe weather conditions but makes it more difficult to recycle; toxic chemicals (e.g., Pb, Cd, Cr) cannot be removed without breaking apart the entire panel. When the PV cells are separated from the glass that contains them, hazardous substances are likely to be released into the environment	(1) **Recycling processes are adapted to the identified materials** inside PV panels (2) PV panels are **designed to be easily disassembled,** separating different components, no hazardous substances are used	2040 2035
25	**Recycling / technical**	Because of the need for accurate handling, the disassembly of aluminium frames and other components in the PV panel is highly manual. This limits the production efficiency of the recycling process	In order to absorb the vast number of PV panels installed in the beginning of the 21st century or earlier, **mature automated technology to disassemble PV** components is in place. This results from extensive R&D and pilot projects.	2030

26	**Recycling / technical**	The type and efficiency of the recycling process is determined by the type of PV module, its design, and its dimensions	**Shape and dimensions of PV modules and components are standardized**, in order to (re)use modules and components in an effective way.	2060
27	**Recycling / technical**	Different cell types and battery chemistries make it difficult to repurpose EV batteries	**Shape and dimensions of battery modules and cells are standardized**, in order to (re)use modules and cells in an effective way.	2060
28	**Recycling / technical**	Many elements critical to emerging PV technologies, such as indium, tellurium, and gallium, today exhibit near-zero recycling rates	See barrier 24	2050
29	**Recycling / infrastructure**	Although some OEMs have implemented take back systems, collection centres and recycling systems/plants are lacking	**Sufficient collection centres and recycling plants** are in place in order to absorb increase of electric and electronic equipment waste (WEEE)	2025
30	**Recycling / geographical**	PV panels are manufactured in key locations, but they are geographically dispersed across the globe which complicates collection and recycling activities	<not answered> This is more a trend than a barrier.	
31	**Recycling / financial**	Risk of overinvesting in old PV panels due to the uncertainty in the material composition of future technologies and the difficulty in determining future PV waste volumes.	Investment is not only done on a financial basis, but also environmental benefits and social added value are taken into considerations. Non-issue, recyclers point of view!	
32	**Recycling / financial**	Risk of overinvesting in old EV batteries due to the uncertainty of future battery chemistries (and EV battery waste volumes).	Investment is not only done on a financial basis, but also environmental benefits and social added value are taken into considerations. Non-issue, recyclers point of view!	
33	**Recycling / financial**	Due to currently low volumes of waste, the recycling of PV panels and EV batteries is currently not profitable (high transportation, collection, and infrastructure costs). Also, many	An **increased demand meets the supply** of recycling and other recovery strategies.	2040

		consumers and OEMs prefer to landfill if it is cheaper than recycling.		
34	**Recycling / financial**	Lack of evidential data on the costs of collecting, disassembly and recycling both types of PV technologies (crystalline silicon and thin-film) and EV batteries, due to the low volume of decommissioned parts.	**Transparent data on costs on reverse logistics processes** <to be investigated if this could be done through IDIS system or extending it>	
35	**Recycling / financial**	The profitability of recycling also depends on the used technology. For instance, thin-film technologies promise higher profit thanks to the presence of precious materials. In the case of c-Si panels, the absence of valuable metals/materials produces economic losses	Not perceived as a barrier	
37	**Reuse / technical**	The repurposing process is demanding as each battery cell needs to be controlled and the BMS needs to be set up to fit the battery's new surroundings and application	All EV battery producers have enlisted their products on the **International Dismantling Information System** (IDIS - www.idis2.com), a central repository of manufacturer compiled treatment information for end-of-life vehicles.	2025

POLICY AND LEGAL

Table 5: barriers and ideal situation(s) related policy and legal aspects

	Cluster	Encountered barrier (2019)	Envisioned ideal situation	When?
20	**Logistics Regulation**	Used batteries are classified as hazardous wastes, increasing transportation, treatment, and disposal costs, as well as the effort needed to achieve regulatory compliance	Within an enhanced value chain of batteries a professional sorter makes the distinction between material streams for second-life products and material streams for recycling – or in the worst-case waste. **Regulations don't penalize, but stimulate the reuse and recycling for batteries**, as long as potential hazardous substances are not in contact with the environment.	2022
39	**Regulations**	Hardly any regulations/standards concerning second-life PV and EV batteries.	Besides a financial cost-benefit analysis, decision-making is based on a standardized life cycle assessment method, by establishing case-by-case the potential environmental impact or benefit of using PV and EV batteries again. By **integrating environmental and financial life cycle assessment into decision-making,** possible environmental externalities are avoided. Subsidies may be temporarily in place to stimulate the demand in case reclaimed PV or EV batteries are deemed environmentally fit, but lack financial competition with new products.	2022
40	**Regulations**	Building regulations can hamper third-party ownership models.	Creation of a **transparent ownership database**	2020

41	**Regulations**	Regulation at the local level affecting the financial benefits of energy storage	(1) A special **neighbouring distribution tariff** is in place, creating benefits for people to install PV panels. (2) Regulation (e.g. regarding **feed-in-tariffs)** is modified, in order to enhance sustainable (energy) **production and consumption within a local context.**	2020
47	**Policy**	Policy maker is not rewarding long life time aspect of PV panels	**Eco-design directives** on PV panels include longevity criteria By **integrating environmental and financial life cycle assessment in decision-making,** the potential (environmental and financial) benefits of PV panels with a long-life span are clearly identified.	2022
48	**Policy**	No standards for flat rooftops to install panels; main cause of defecting modules	Special attention how to design, dimension and install panels for flat roofs is provided by **updated Eurocodes.**	2020

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