Life Cycle Assessment of Photovoltaic Electricity - Results from the PEF Pilot Phase & Lessons Learned -

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Key Message

Increasing emphasis on the inclusion of life cycle assessment based sustainability indicators in general and environmental indicators in particular in

- policy definitions,
- public and private tendering schemes for new photovoltaic capacity additions, and
- the recognition of photovoltaic electricity as tradeable and transferable green good in various markets (e.g. the RECs system)

demonstrates the importance of commonly accepted and validated LCI data and LCA methodology guidelines for the supply chain, manufacturing, installation, operation, and recycling of commercial PV technologies.

Agenda

- **Introduction & Background**
- The PEFCR for PV – a case study
- Way Forward: Eco-Design & Ecolabeling

Introduction

- Cumulative deployment of PV systems in 2016 reached more than 100 GW_p in the EU and over 300 GW_p globally.
- Global decarbonization and climate change mitigation efforts require **multiple terawatts of PV capacity additions over the next decades.**
- By mid of the century, **solar PV** is expected to be the largest, **least-cost and most relevant** source of energy globally.
- Shaping and **channeling this transformation** through regulatory frameworks requires an understanding and **appreciation of the life cycle environmental impacts of available technology options** – forming the foundation of a broad societal, scientific and political consensus.

Market Perspective – How Clean Is Your kWh?

- Buyers of PV power plants and PV electricity have an increased interest in understanding the **quality of the purchased components and, ultimately, the kWh of electricity generated**
- In a globalized 100 GW market with complex, international supply chains, **transparency with regard to quality and sustainability becomes the decisive factor in bankability**.
- In future tenders, it is expected that investors will **specify manufacturers' sustainability performance requirements** and integrate them into **due diligence and risk mitigation** for assets and projects.

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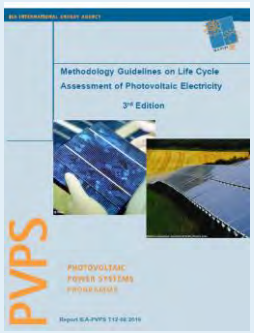
Background

- Already existing, established standards for the life cycle assessment (i.e. ISO 14044, IEA PVPS Task 12 Methodology Guidelines) **lack a political mandate for application in regulatory processes and policy discussions**.



- **Added value of PEF Pilot Phase** and the development of the Product Environmental Footprint Category Rules for PV was the **political mandate** given **to the European Commission by all EU Member States to develop and test a harmonized methodology**.
- Methodology can be implemented by all market actors and regulators alike across Europe.

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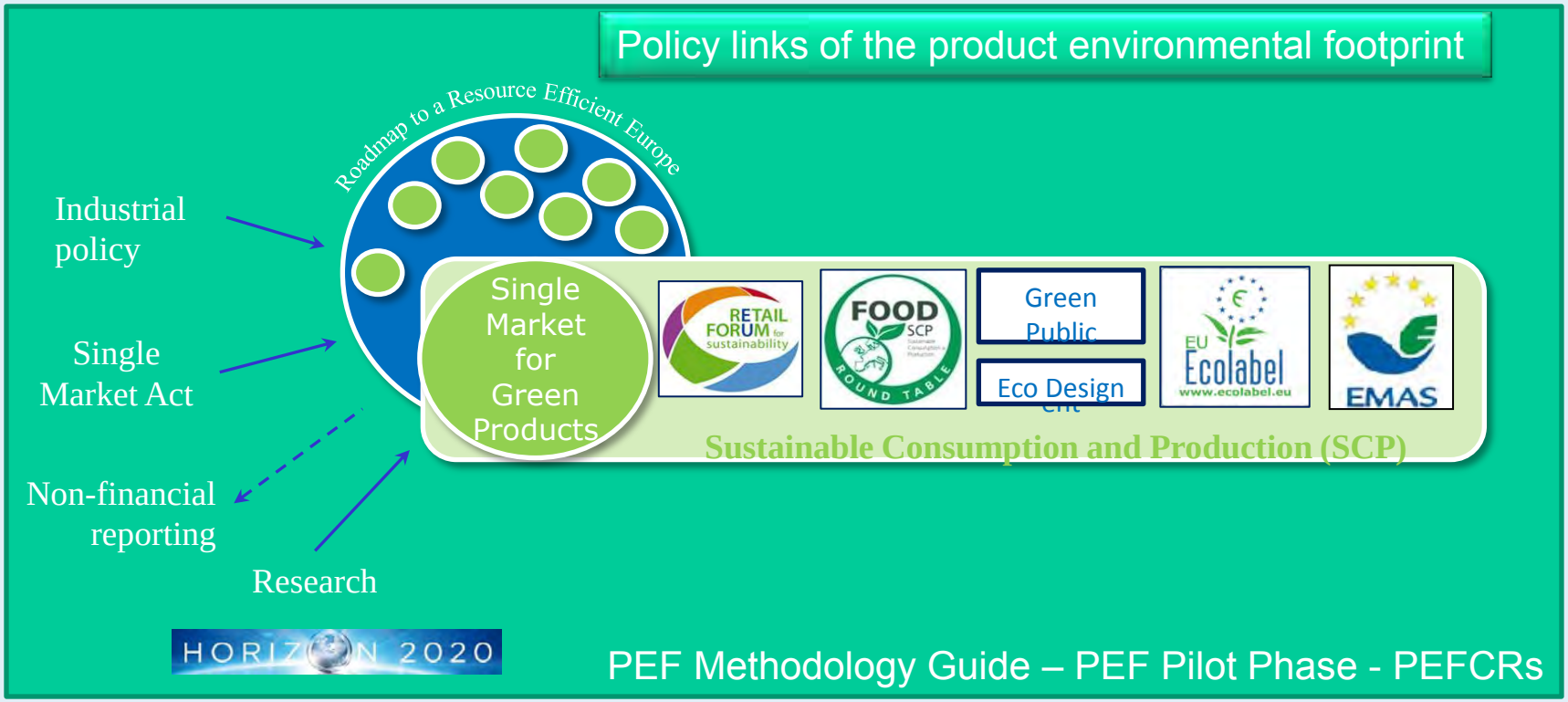
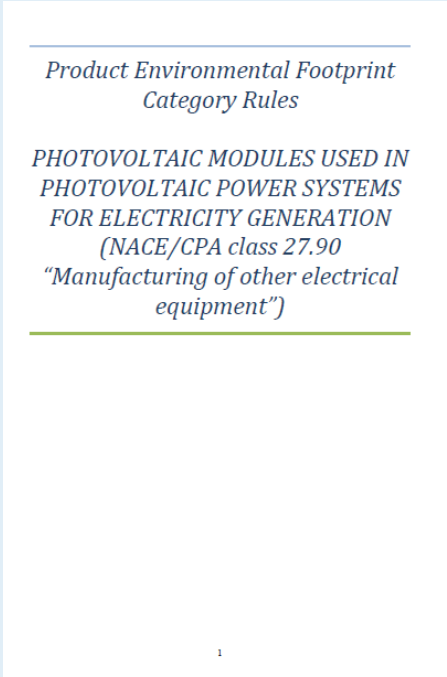
Policy Framework in the EU



Product Environmental Footprint Category Rules (PEFCR) for PV



Product Environmental Footprint Category Rules

PHOTOVOLTAIC MODULES USED IN PHOTOVOLTAIC POWER SYSTEMS FOR ELECTRICITY GENERATION (NACE/CPA class 27.90 "Manufacturing of other electrical equipment")

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The PEFCR provides a harmonized set of rules to evaluate the environmental impacts of electricity produced from photovoltaic modules installed in the region of the EU28 and EFTA countries.

PEFCR - Product Category

- Photovoltaic (PV) modules used in photovoltaic power systems for electricity generation
- PV technologies
  - Cadmium-Telluride photovoltaic panels (CdTe)
  - Copper-Indium-Gallium-Selenide photovoltaic panels (CIS)
  - Micromorphous Silicon photovoltaic panels (micro-Si)
  - Multicrystalline Silicon photovoltaic panels (multi-Si)
  - Monocrystalline Silicon photovoltaic panels (mono-Si)
  - Novel technology concepts if data quality is sufficient
- NACE/CPA class 27.90
  "Manufacturing of other electrical equipment"

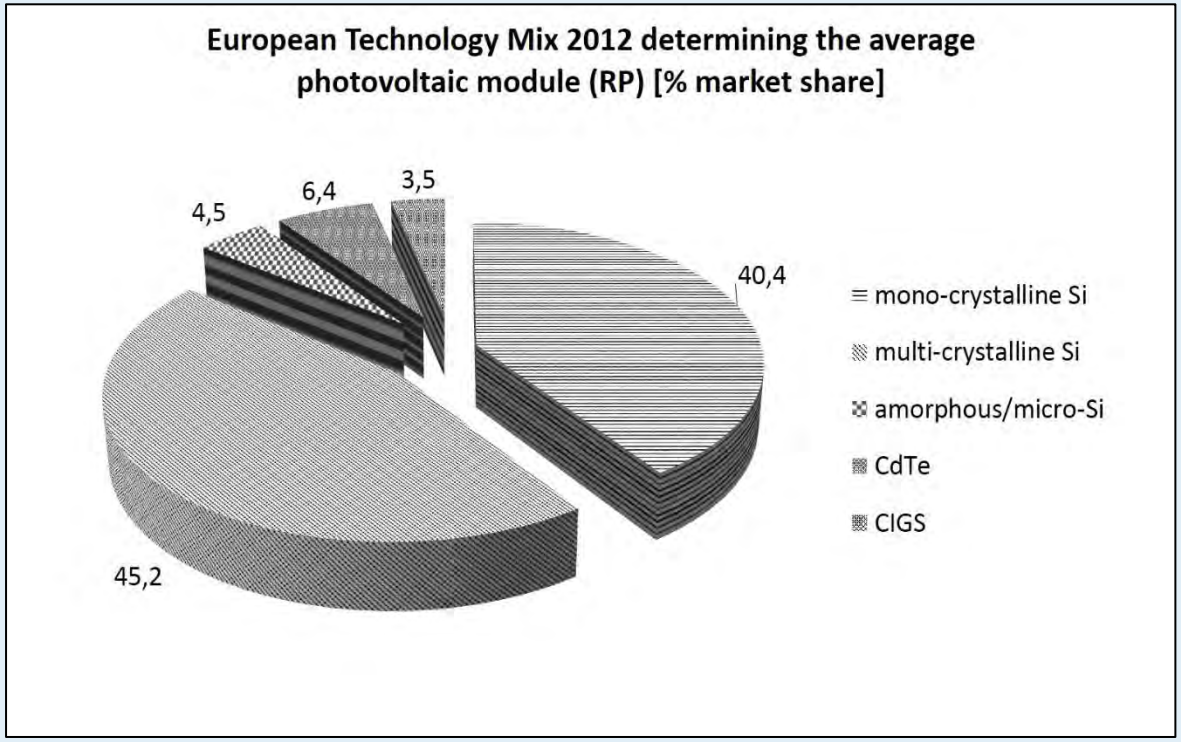
PEFCR - Unit of Analysis

- The unit of analysis is defined as 1 kWh net of electricity generated
- The function(s) / service(s) provided ("what"):
  - electrical energy measured in kWh (provided power times unit of time)
- The magnitude of the function or service ("how much"):
  - 1 kWh of electrical energy
- The expected level of quality ("how well"):
  - DC electrical energy fed into the inverter at a given voltage level
- The amount of service provided over the life time ("how long"):
  - electrical energy fed into the grid in kWh over the service life of 30 years

PEFCR - Impact Category Indicators

- Impact category indicators required by the PEF Guide
- 3 additional indicators
  - Renewable cumulative energy demand
  - Non-renewable cumulative energy demand
  - Nuclear waste
- Additional indicators shall
  - Be presented separate from default indicators
  - Not be normalized and weighted
- Long-term emissions shall be excluded

The EU Representative Product

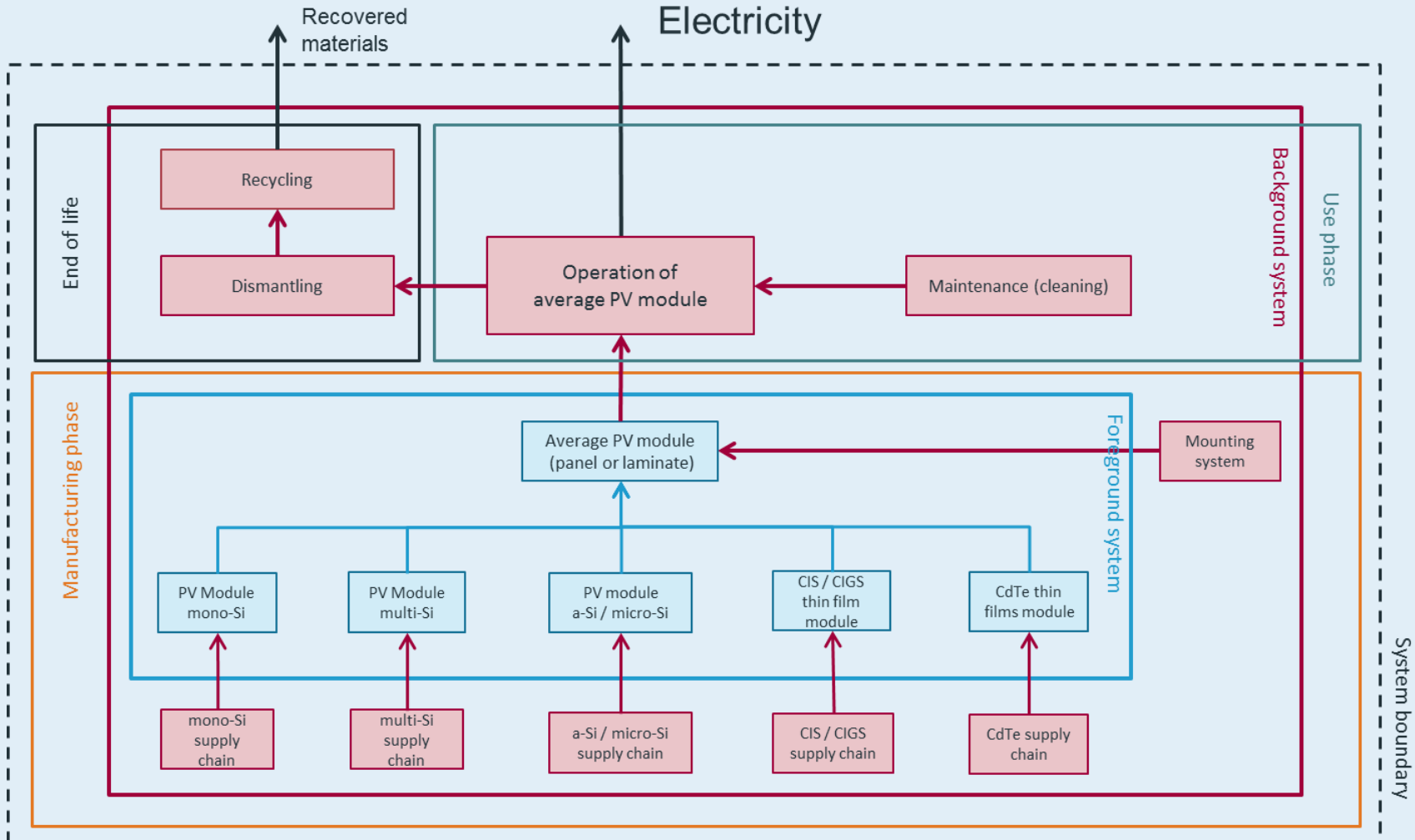


A virtual PV module was chosen as representative product to be able to develop a baseline for comparison and benchmarking of today's PV technologies.

Screening Study
Key Parameters and Assumptions

- Lifetime: 30 years
- Installation in Europe
- Annual yield: 975 kWh/kWp
  Installed capacity weighted average in the EU
  Degradation of 0.7% per year included
- Inverter is not included
- Recycling modelled in accordance with WEEE requirements
- Multi-functionality is disregarded because the reference PV system is mounted on a slanted roof

Screening Study
System Boundaries



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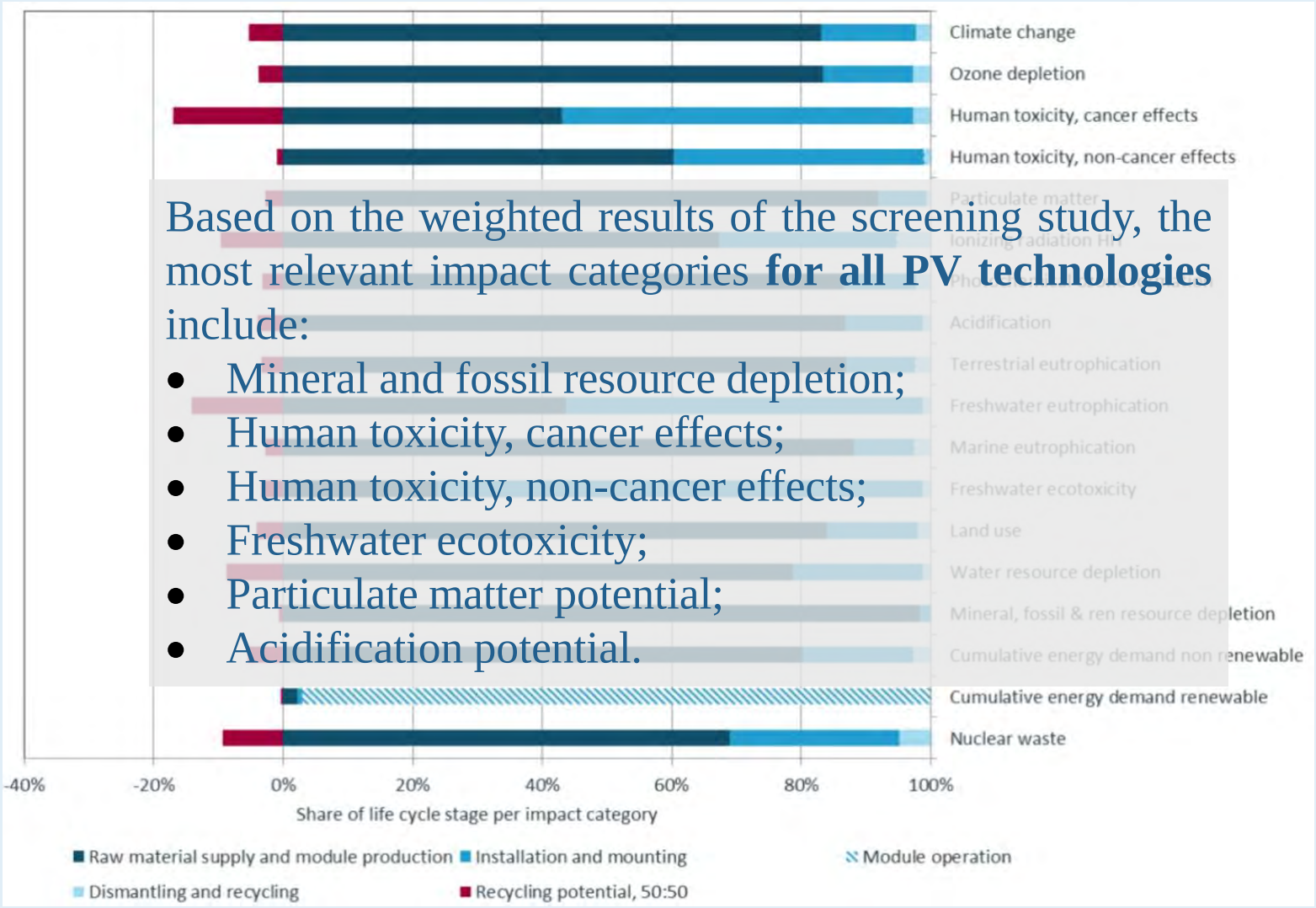
Hotspot Identification

Based on the weighted results of the screening study, the most relevant impact categories **for all PV technologies** include:

- Mineral and fossil resource depletion;
- Human toxicity, cancer effects;
- Human toxicity, non-cancer effects;
- Freshwater ecotoxicity;
- Particulate matter potential;
- Acidification potential.



Environmental impact (characterized, indexed to 100%) of 1 kWh of DC electricity produced with a 3 kWp residential system composed of the average EU PV module (Wyss et.al., PEF Screening Study, 2015)

Results of the Pilot Phase

- The PEFCR for PV modules has proven useful in guiding the development of environmental footprint studies
- The PEF screening study of PV modules (Stolz, Frischknecht, Wyss, & de Wild-Scholten, 2016) provided a clear template for documentation and interpretation of the PEF supporting study results and can serve as a basis for future PEF studies
- Supporting study and screening studies helped to identify and verify environmental impact categories and hot spots in the life cycle of the PV panel.
- Developing a better understanding that the impact categories and hot spots are similar in all investigated PV technologies will not only help to inform future decisions on product development, but will also help to shape regulatory measures in the field of ecodesign and eco-efficiency.

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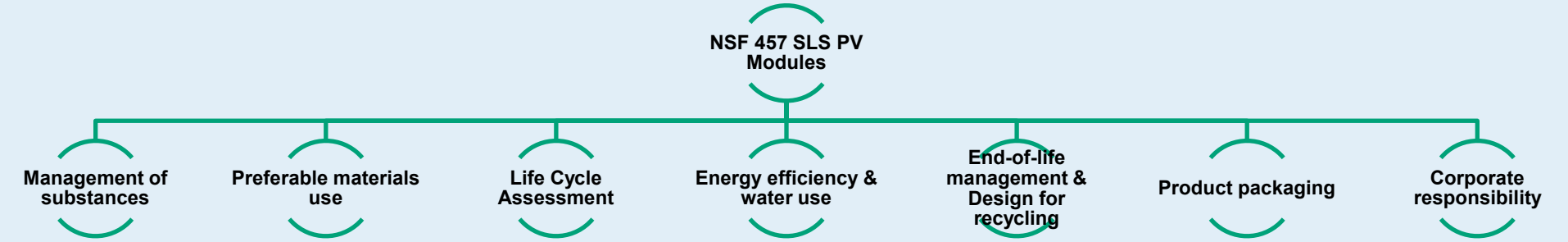
Manufacturing Sustainability Leadership



4 Required	1 Required	1 Required	1 Required	1 Required	3 Required	5 Required
7 Optional	1 Optional	4 Optional	5 Optional	3 Optional	2 Optional	5 Optional

- This Standard includes two types of criteria:
  - **Product criteria**: applies to the product declared to conform to the Standard
  - **Corporate criteria**: applies to the manufacturer that declares products to conform to this Standard
  - The manufacturer shall declare or certify conformance to the Standard by country, region, or globally
  - Unless specified otherwise, criteria must be met wherever the product is declared or certified to conform to the Standard

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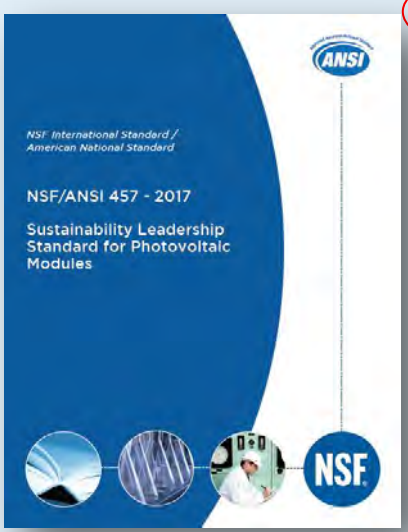
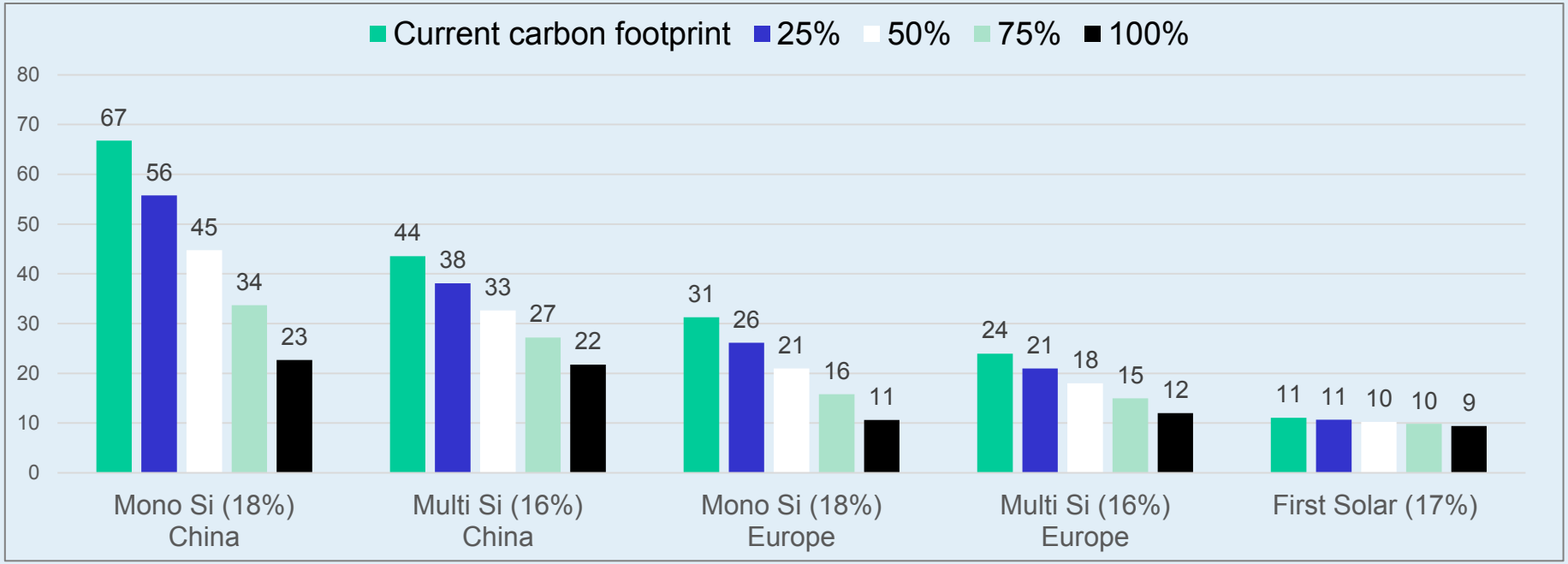
Overview of Sustainability criteria (cntd.)

List of declarable substances (R)	**Declaration of recycled content in product (R)**	**Conducting life cycle assessment (R)**	**Water inventory (R)**	**Product take-back service and processing requirements (corporate) (R)**	**Elimination of substances of concern in product packaging (R)**	**Environmental management system (EMS) certification (corporate) (R)**
List of declarable substances used in manufacturing (R)	Recycled content in product – achievement of higher percentages (O)	Public disclosure of LCA results (O)	Energy management system for manufacturing facilities (O)	Publicly available record of annual recycling and recovery achievement (corporate) (O)	**Elimination of chlorine in processing packaging materials (R)**	**Manufacturer conformance with occupational health and safety performance (corporate) (R)**
Disclosure of substances on the European Union REACH Regulation Candidate List of Substances of Very High Concern (R)		Public disclosure of LCI inventory data (O)	Certified energy management system (O)	Material recovery targets (corporate) (O)	**Enhancing recyclability of packaging materials (R)**	**Reporting on Key Performance Indicators (corporate) (R)**
Avoidance or reduction of high global warming potential (GWP) gas emissions resulting from photovoltaic module manufacturing (R)		Environmental hot spot identification (O)	Certified Energy Management Performance Improvement (O)	Identification of materials for EOL management (O)	Recycled content paper-based packaging (O)	**Commitment to Environmental and Social Responsibility (corporate) (R)**
Disclosure of declarable substances (O)		Environmental leadership compared to industry average (O)	Quality of wastewater discharges (O)		Postconsumer recycled content plastic in packaging (O)	**Public disclosure of use of conflict minerals in products (corporate) (R)**
Database of substances in product (O)			Improved water use efficiency (O)			Reporting Additional Key Performance Indicators (O)
Alternatives assessment (O)						Reporting on screening of Tier 1 suppliers (corporate) (O)
Making alternatives assessment publicly available (O)						Auditing or certification to social responsibility performance standard (corporate) (O)
Presence of substances on the European Union REACH Regulation Candidate List of Substances of Very High Concern (O)						Conflict mineral sourced only from validated conflict free smelters (corporate) (O)
Bromine, chlorine, and fluorine content in plastic parts other than electric cables (O)						Participation in in-region conflict-free sourcing program (corporate) (O)
Bromine, chlorine, and fluorine content in electric cables (O)						



NSF/ANSI 457 – 2017 Sustainability Leadership Standard for Photovoltaic Modules

Eco-Design: Carbon Footprint



- Manufacturing electricity consumption represents between 15% of (CdTe PV) and 60% (Mono Si) of the overall carbon footprint

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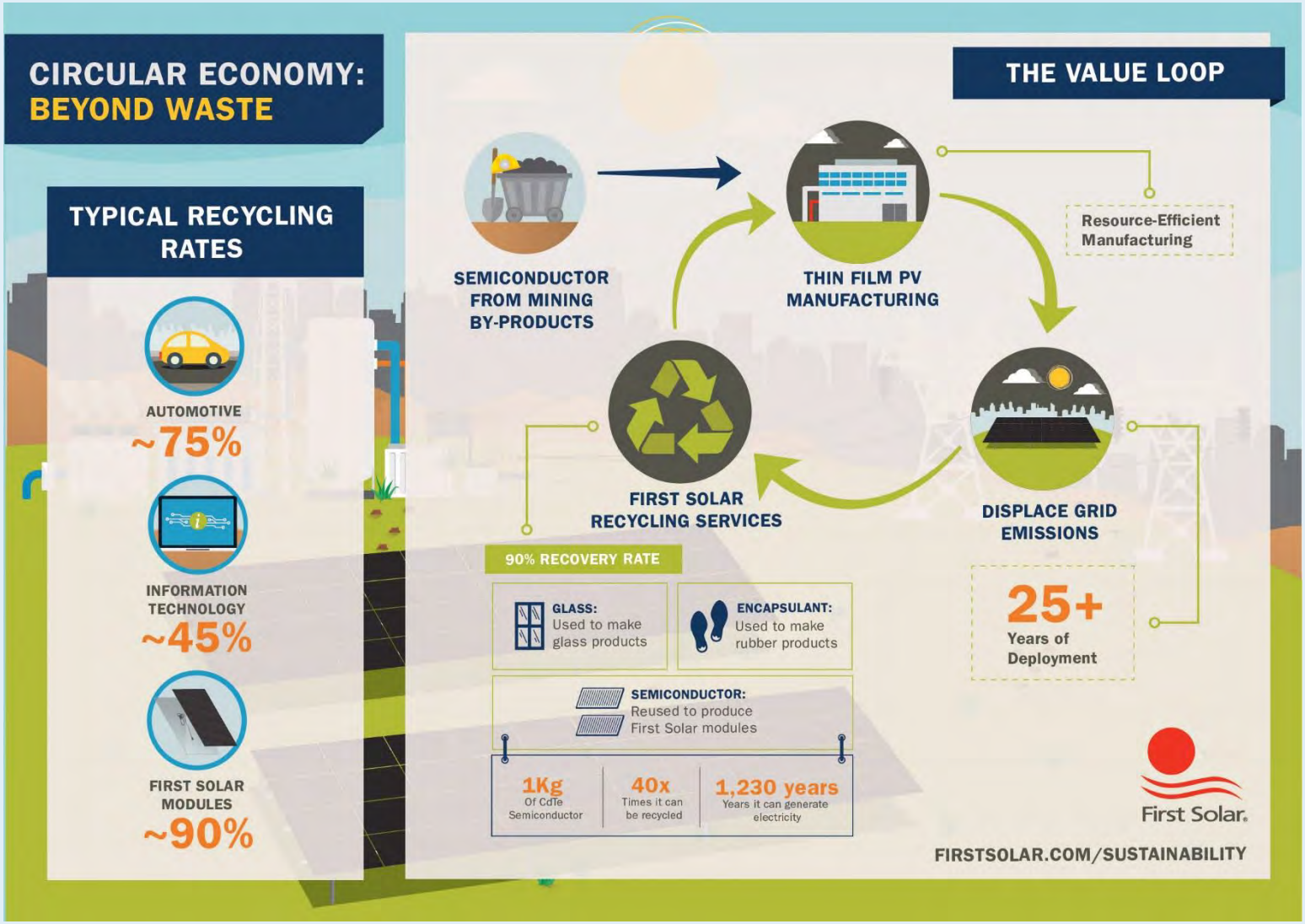
Eco-Design: High Value Recycling



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Way Forward – EU Policy

DG ENV / DG GROW / DG ENER are starting Ecodesign, Ecolabel, GPP and Energy Label processes in parallel for the product group

Synergies to be evaluated through joint **Preparatory Study**

18 months

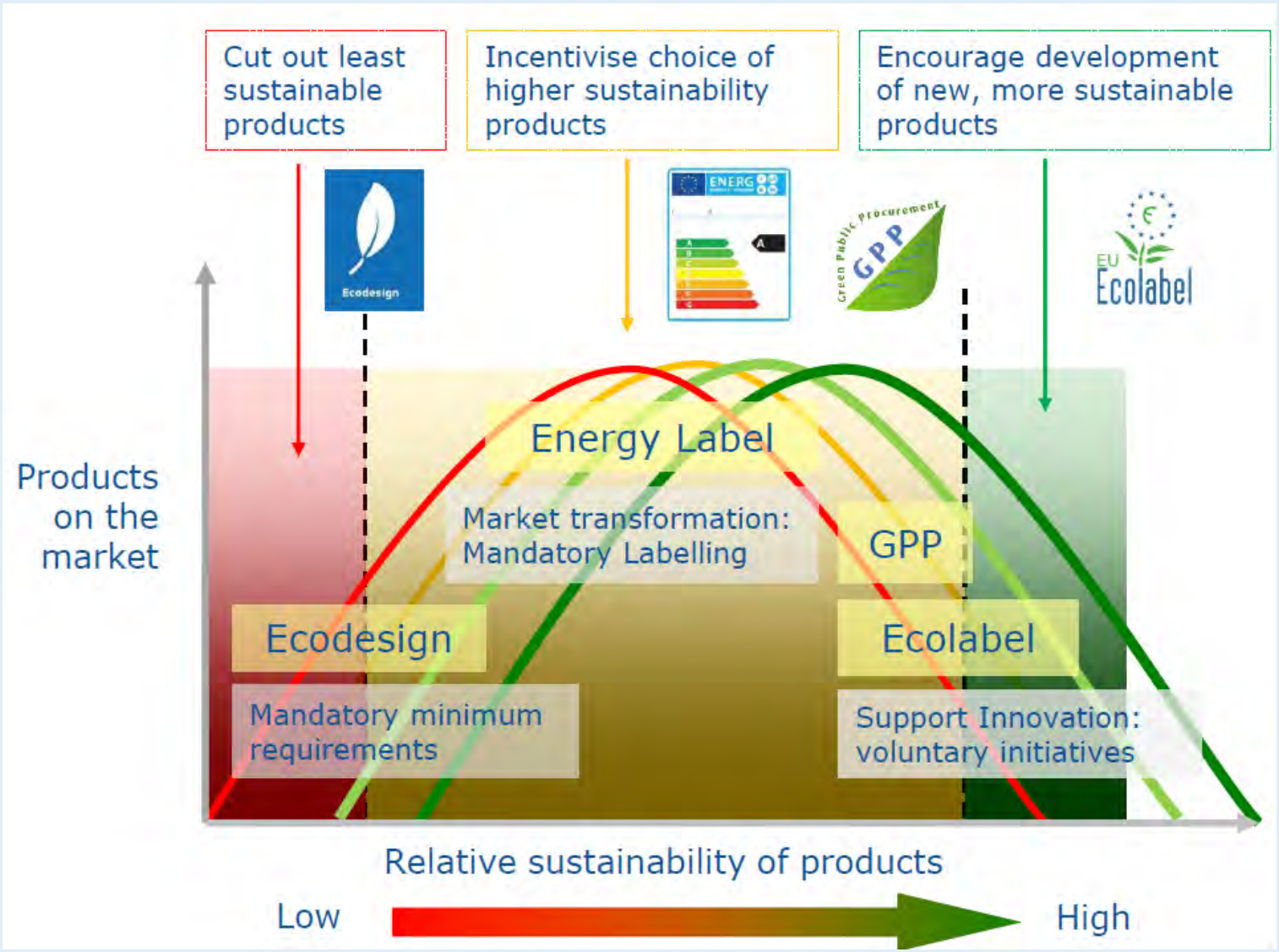
Faster - according to DG ENV

- Ad-Hoc Working Group (Consortium + COM) drafts EU Ecolabel criteria according to the results of the preparatory work (feasibility, environmental and market studies, improvement analysis, LCA)
- Circulation of EUEB approved draft among relevant COM services for approval
- Vote from Regulatory Ct'e of National Authorities
- COM Decision on Criteria => Comitology Process
- Publication of Criteria Catalogue in OJ => open for application

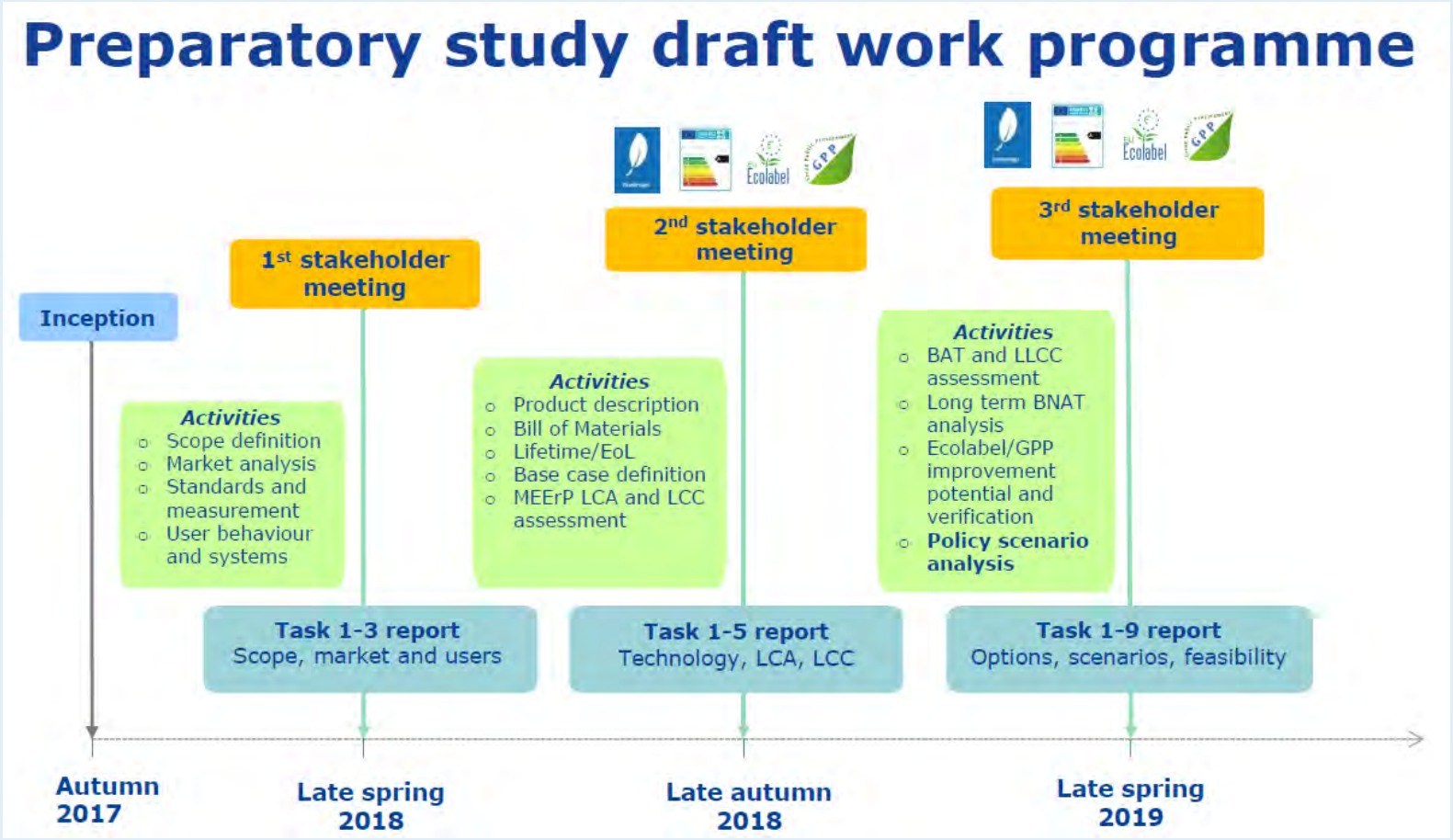
2 YEARS

2. Draft measures (i.e. the draft of the future eco-design regulation) presented by the Commission
3. Consultation with Member States and industry
4. Impact Assessment launched by the Commission
5. Regulatory Scrutiny Board of the Commission consulted
6. WTO consulted
7. Draft Regulation submitted to the vote of the Ecodesign Committee
8. Scrutiny period for EP and Council / Adoption / Entry into force

Where does the PEF fit in?



Way Forward ED/EnL/EL/GPP



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Conclusion

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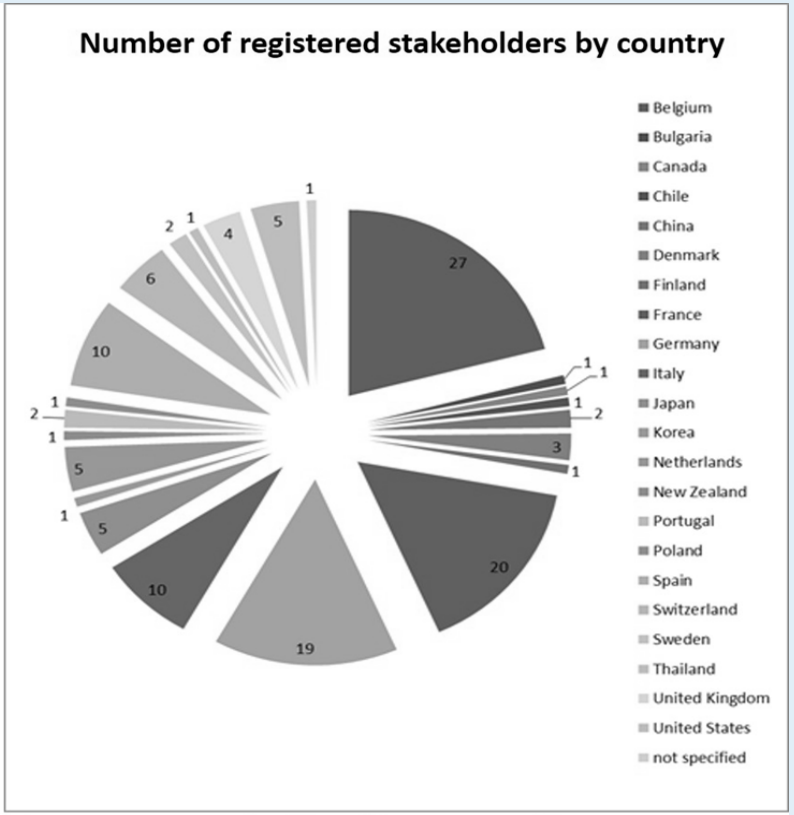
Thank You!

Backup

Stakeholder Participation



1st Public Consultation (April 2014): 64 Comments received and incorporated
2nd Public Consultation (July 2015): 58 Comments received and incorporated

Throughout the process, the framework parameters, the scope and the representative product – as well as the results – were subject to critical evaluation of 100s of stakeholders.

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Policy Outcomes?

	Scenario	2020	2025	2030
PV Panels & Inverters (2000 – 2030)	BAU (TWh/a)	115.81	180.83	246.53
	ED (TWh/a)	116.29	184.23	252.90
	Extra generation (TWh/a)	0.48	3.41	6.36

- The selection of policy options should allow to capture the maximum socio-economic & environmental benefit from future PV system installations in the EU:
- It is apparent, that single component measures (e.g. a PV panel only label, or an inverter only label) will not be sufficient to achieve any of the policy objectives, since the system configuration and installation has a major impact as the denominator will alway be linked to the lifetime energy yield of the system
- Single component measures would only be meaningful if combined with system level measures (e.g. installation requirements, grid integration requirements)
- These principles would be valid for front-runner policy options (Eco-Label) as well as minimum requirements (Eco-Design)

Extending the Carbon Footprint

Impact category	Indicator
Indicators required according to the PEF guide	
Climate change	Radiative forcing as Global Warming Potential (GWP100) [kg CO_2 eq.]
Ozone depletion	Ozone Depletion Potential (ODP) [kg CFC-11 eq.]
Human toxicity, cancer effects	Comparative Toxic Unit for humans [CTUh, c]
Human toxicity, non-cancer effects	Comparative Toxic Unit for humans [CTUh, n-c]
Particulate matter / respiratory effects	Intake fraction for fine particles [kg PM2.5 eq.]
Ionizing radiation, human health	Human exposure efficiency relative to U^{235} [kBq U^{235} eq.]
Photochemical ozone formation	Tropospheric ozone concentration increase [kg NMVOC eq.]
Acidification	Accumulated Exceedance (AE) [mol H^+ eq.]
Eutrophication, terrestrial	Accumulated Exceedance (AE) [mol N eq.]
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P) [kg P eq.]
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N) [kg N eq.]
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems [CTUe]
Land use	Soil Organic Matter [kg C deficit]
Resource depletion, water	Water abstraction related to local scarcity of water [m^3 water eq.]
Resource depletion, mineral, fossil, renewable	Scarcity [kg Sb eq.]
Additional indicators	
Cumulative energy demand, renewable	Gross energy content of renewable primary energy resources [MJ oil eq.]
Cumulative energy demand, non-renewable	Gross energy content of non-renewable primary energy resources [MJ oil eq.]
Nuclear waste	Radiotoxicity index, RTI [m^3 HAA eq.]