#	Page	Chapter, sub-chapter	Figure, table	Comment, Including justification when needed	Additional references
Etat des lieux, analyses et benchmark des documents et pratiques industriellies visant la maitrise des enjeux environmentaux associes aux systemes photovotaltaiques – Rapport de Tâche 2: Analyse comparée des documents					

General Comments on the Report

- The study seems **biased in favor of silicon PV technologies and dismissive of thin film PV technologies**.
- The study is equally **dismissive of some thin film technologies' positive environmental impact**, even though these were recently recognized as a best available technologies (BAT) by the European Commission
- In evaluating environmental risks, the study relies on a few precautionary studies with **non-standard experimental methods**.
- The study makes the **erroneous assumption that PV technology improvements are limited to single-junction PV**, and that PV can continue to thrive with just single-junction silicon PV (technology lock-in).
- This is at odds with most current scientific discussions on the future of solar PV technology. The research community understands the future of high-efficiency PV to extend beyond single-junction, and that tandem will be the next step of PV technology.
- The most likely structure of a **tandem PV device will have silicon as the bottom cell and a high-efficiency thin film top cell** (see Peters et al attached).
- **Technology lock-in with only single-junction silicon PV prevents the progress of PV technology and its broader role in global climate change mitigation**.

#	Page	Chapter, sub-chapter	Figure, table	Comment, Including justification when needed	Additional references
1	**5**	**1 / 1.1 / 1.1.1. Les enjeux des énergies renouvables**	1st paragraph	*The authors seem to underestimate the carbon reduction potential of solar photovoltaics by using outdated (non peer reviewed) references. The statement that "(…) d'électricité par énergie éolienne émet 150 fois moins de CO2eq. que celle résultant du charbon ; et le solaire photovoltaïque 16 à 6 fois moins de CO2eq., en fonction du lieu de fabrication des panneaux photovoltaïques)" should be corrected and updated with reliable references to reflect the correct reduction potential, which should be in the range of* ***11-67g CO2eq per kWh so 14-86 times less than coal plants.***	More appropriate reference for comparative life cycle greenhouse gas emissions per kWh of generated electricity: Hertwich, Edgar G., Thomas Gibon, Evert A. Bouman, Anders Arvesen, Sangwon Suh, Garvin A. Heath, Joseph D. Bergesen, Andrea Ramirez, Mabel I. Vega, und Lei Shi. „Integrated Life-Cycle Assessment of Electricity-Supply Scenarios Confirms Global Environmental Benefit of Low-Carbon Technologies". *Proceedings of the National Academy of Sciences* 112, Nr. 20 (19. Mai 2015): 6277–82. https://doi.org/10.1073/pnas.1312753111 And supplementary information available here: https://www.pnas.org/content/pnas/suppl/2014/10/02/1312753111.DCSupplemental/pnas.1312753111.sapp.pdf
2	**6**	**1 / 1.1 / 1.1.2. La filière photovoltaique**	Les filières technologiques	The authors claim that the most widespread thin-film PV technology ("deuxieme generation") is amorphous silicon thin film. This statement is outdated and should be revised to reflect the current technology status. **The manufacturing and deployment of a-Si technologies has (almost completely) disappeared due to low manufacturing and module efficiencies**. Today, the thin-film PV	**References for market share:** Figure 4 in: Ghosh, Bablu K., Ismail Saad, Kenneth Tze Kin Teo, und Swapan K. Ghosh. „McSi and CdTe Solar Photovoltaic Challenges: Pathways to Progress". *Optik* 206 (März 2020): 164278. https://doi.org/10.1016/j.ijleo.2020.164278.

				market is dominated by CdTe and CIGS technologies. As depicted in Fraunhofer ISE (2019) and relevant peer reviewed papers.	p. 22 in: Fraunhofer ISE Photovoltaics Report (2019), available here https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf
3	**6**	**1 / 1.2 Les enjeux environnementaux des systèmes PV**	2nd paragraph	The authors refer to potential environmental and health impacts of PV Systems in this section. They refer to the identified life cycle hotspots of PV technologies (supply chain of energy and raw materials) at the beginning of the section. However, they lose this hotspot approach in referring to the use of certain hazardous materials. Here the scope of their comments are unclear and tend toward generalizations. When referring to the reduction of risks associated with hazardous chemicals, it is essential to mention whether we are referring the chemicals used in manufacturing, and the risks associated with them, or those who remain present in final products, which have a different risk profile, at different life cycle stages. We recommend substantiating the reference to hazardous substances as follows: - Hazardous substance use in manufacturing? How many manufacturing facilities for PV do exist in France? What are the technologies produced there? - Hazardous substance use in PV products – what is the overall amount of hazardous materials used in PV products in France? Have those materials been detected in natural environments resulting from deployment of PV in France? We also believe the reference to risks associated with PV installations should be nuanced by a reference to the risks associated with all electrical installations in general.	Please refer to the environmental assessments available on the production and deployment of PV technologies (i.e. the PEF Screening Report) to prioritize the impact categories specified here. It is also advisable, to differentiate the different lifecycle stages clearly throughout the document and reference the potential impacts quoted in that regard, i.e. potential impacts coming from production emissions (air, water, soil), or production wastes, deployed & routinely maintained products, defective products, waste products etc. . An overview on hazardous materials use in manufacturing and products is available in standard literature and should be referred to instead of using generalizing statements. References: Practical Handbook of Photovoltaics: Fundamentals and Applications, General editors: T. Markvart and L. Castaner, ISBN 1-856-17390-9
4	**6/7**	**1 / 1.3. Les démarches des pouvoirs publics francais et européens pour evaluer et limiter les impacts des systemes PV**	All paragraphs	Whereas the authors refer to the particular regulations available in France in the context of CRE tenders, they only refer to the (failed) Ecolabel proposal, which was rejected by the European Commission and the Ecolabeling board in 2015. **Not referring to other EU developments after this date is misleading**. The authors fail to mention that from 2014 to 2018, the most comprehensive environmental impact evaluation, based on the product environmental footprint guidance, and the single market for green products initiative of the European Commission, was undertaken by a multi-stakeholder consortium under the Product Environmental Footprint Pilot Phase. The work of this multi-stakeholder consortium, as well as its deliverables, where widely published and made available for stakeholder consultation. They were reviewed by an international scientific committee with LCA sector experts. **The resulting publications (i.e. the PEF Screening Report, the final PEFCR, the supporting studies) should be referred to regularly in this study.**	**References:** Stolz, Philippe, und Rolf Frischknecht. „Product Environmental Footprint Category Rules (PEFCR) - PHOTOVOLTAIC MODULES USED IN PHOTOVOLTAIC POWER SYSTEMS FOR ELECTRICITY GENERATION (Version 1.0)“. European Commission, DG Environment, 9. November 2018. Wade, Andreas, Philippe Stolz, Rolf Frischknecht, Garvin Heath, und Parikhit Sinha. „The Product Environmental Footprint (PEF) of photovoltaic modules-Lessons learned from the environmental footprint pilot phase on the way to a single market for green products in the European Union“.

					Progress in Photovoltaics: Research and Applications, 2017. https://doi.org/10.1002/pip.2956.
5	**7**	**Ibid.**	Last paragraph	Need to refer to the extensive work conducted at EU level on the environmental impact of PV from 2014-2018, including the environmental life cycle hotspots already identified by the PEF– see previous comment.	
6	**8**	**1 / 1.4. Objectifs du projet**	Last paragraph	**Most of the technology references in the current draft of the report are dated**. it therefore seems clear that industry experts have only been, so far, consulted in a cursory manner. We **urge the authors to engage in an extensive consultation of industry experts, not only French, but also international, and representing all 4 generations of PV technology**, otherwise this report risks becoming irrelevant and dated before it is even published.	
7	**8**	**1 / 1.5. Objectifs du livrable**	All paragraphs	As the report is solely a literature review, we recommend this paragraph includes a disclaimer that its findings are not based on empirical data. Proposed wording: This report provides a literature review and aims to identify trends observed in the literature. Findings present in this report do not reflect empirical data, nor do they refer to environmental impacts identified while doing original research gathered from actual PV production, installations or recycling operations. The findings of this literature review require validation by comparison with observed and quantifiable environmental impacts from photovoltaic systems.	Please add a clear disclaimer to this section: ***Ce rapport est une recherche bibliographique. Il convient donc de rappeler que ses conclusions ne sont pas tirées de recherches empiriques.*** ***L'analyse de ce rapport ne reflète en aucun cas des impacts environnementaux avérés et identifiés lors de recherches empiriques effectuées sur des sites de production, des installations, ou des sites de recyclage de panneaux photovoltaïques.***
8	**10f.**	**2 / 2.1. / 2.1.1. Caractérisation bibliométrique du corpus**	Figure 3 and related text	The authors suggest a classification of literature according to a number of categories discussed and presented in Figure 3. **The selection of these categories seems ambiguous and arbitrary**. We recommend **defining these categories and their scope clearly**. • For example, the impact category of abiotic resource depletion is a standard indicator used in Life Cycle Assessment studies, as are a multitude of toxicity indicators. These indicators are therefore likely to be present in all the analysed papers and studies – even though the papers themselves, might focus on other issues.	Please refine the scope of each impact category, and explain the method used for counting a paper towards a specific topic.

				• The same statement is true for the topic of reducing impacts. **Using wide categories as indicators for the importance of a specific topic – especially when those impact categories are part of standard evaluations and methodologies – largely distorts the quantitative analysis suggested here**. The authors should refine their classification, and **explain how the impact categories depicted in Figure 3 have been measured in the analysed papers**: What thresholds have been used to count a paper towards significantly contributing to a specific area (or not)? **A clarification is also needed on the extent to which papers have been double or triple counted in this analysis**. **The classification methodology is also unclear, and should be stated in this report**. Was it done through word count or Delphi expert classification? Was there a peer review committee?	
9	**16**	**2 / 2.1. / 2.1.2.**	Figure 5	See previous comment – the figure requires clarification on double / triple / multiple counts of studies – it should be mentioned what portion of each bubble is counted multiple times.	
10	**17**	**2 / 2.1. / 2.1.3.**	Last paragrap h	The authors misunderstand the EU REACH regulation, and erroneously suggest that a candidate listing of substances under REACH prohibit their use in manufacturing processes. The author further goes on to misunderstand the REACH restriction and authorization procedures and their impact on manufacturing, chemical use as intermediates or in products. – This paragraph should be reworded after a full review of the REACH regulation. In the final sentences of the paragraph, the authors state that “Silicon, Indium, Selenium, Gallium, Tellurium, Silver, Zinc, Titane, Tin, Aluminium, Copper, Molybdenum, silicones, plastics, glass” are materials used in the PV value chain that do not feature on the REACH candidate list. **This list is misleading**. Hundreds of different materials and compounds are involved in the manufacturing of PV technologies, including a significant share of intermediates and process chemicals.	An overview on hazardous materials use in manufacturing and products is available in standard literature and should be referred to instead of using generalizing statements. References: Practical Handbook of Photovoltaics: Fundamentals and Applications, General editors: T. Markvart and L. Castaner, ISBN 1-856-17390-9
11	**18**	**Ibid.**	First paragrap h	The authors acknowledge the currently valid exclusion of photovoltaic panels from the RoHS directive. In the context of this study, we recommend not only referring to the exclusion as stipulated in Art. 2(4) of the Directive, but also to quote its recital 17, which justifies the exclusion in a manner that is aligned with the purpose of this study (see proposed text to the right.) The wording on the upcoming RoHS 3 directive is incomprehensible and does not reflect current work at the level of the EU Commission.	***Suggest to add the following paragraphs to the chapter:*** ***Consideration (17) Directive 2011/65/UE:*** ***Le développement de sources d’énergie renouvelables est l’un des objectifs clés de l’Union, et la contribution de ces sources d’énergie aux objectifs environnementaux et climatiques est essentielle. La directive 2009/28/CE du***

					Parlement européen et du Conseil du 23 avril 2009 relative à la promotion de l'utilisation de l'énergie produite à partir de sources renouvelables (12) rappelle que la cohérence entre ces objectifs et les autres actes législatifs de l'Union en matière d'environnement devrait être assurée. Par conséquent, la présente directive ne devrait pas empêcher le développement des technologies des énergies renouvelables qui n'ont pas d'incidences négatives sur la santé et l'environnement, et qui sont durables et économiquement viables.
12	**19**	**Ibid.**	Last paragraph	The authors seem to suggest, that PV systems and installations emit multiple hazardous and potentially dangerous materials into water and soil compartments, and that no regulations and technical solutions are in place to monitor or prevent this. This **statement is highly speculative and not based on any evidence presented in the report** – on the contrary, a multitude of studies have confirmed, that the potential for emissions from broken or damaged PV modules is very limited and does not pose a risk either to the environment or to human health (see references). **This statement should be removed, or reworded, to reflect the state of the current consensus in the scientific community, as documented.**	**References:** **Human Health Risk Assessment Methods for PV |** **Part 1: Fire Risks. IEA-PVPS Task 12: "PV Sustainability" (2018)** **Part 2: Breakage Risks. IEA-PVPS Task 12: "PV Sustainability" (2019)** **Part 3: Disposal Risks. IEA-PVPS Task 12: "PV Sustainability" (2020)** http://www.iea-pvps.org/index.php?id=520
13	**21**	**Ibid.**	Last paragraph	The authors fail to recognize that multiple studies have shown that the additional impacts of high value recycling (i.e. including semiconductor recovery) are far outweighed by the associated life cycle benefits.	Frischknecht, Rolf, Stolz, Philippe, Wambach, Karsten, Heath, Garvin, und Sinha, Parikhit. „Life Cycle Assessment of Current Photovoltaic Module Recycling" IEA PVPS T12-13:2018 (2018).
14	**22**	**Ibid.**	Table 1	**The authors misrepresent the results from this table.** All the "substitutes" identified in table 1 (presented as alternatives to the use of traditional perovskites), presumably to refer to alternative compositions without potentially hazardous materials (i.e. lead-halides). This is a misleading statement. The report should state clearly that even these alternatives contain MAPbI3 and MaSnI3, Ag and a variety of other materials. It is also essential to note that the substitutes have not been impact / life cycle assessed and that **comparison to the performance of technologies with the original composition is therefore impossible**. **The report must state that the performance measurements presented table 1 do not translate into stable cell or module efficiencies.**	

15	**29**	**2.2.2.2.**	1st paragraph	The authors seem to suggest, that available studies on thin film PV technologies only focus on resource availability and toxicity – **this is a misrepresentation of the bibliography available on these technologies**. There are a plethora of available studies, which quantify the **benefits and advantages of thin film technologies. Many of these are relevant to the subject of the present study since they illustrate the 'best in class' nature of the environmental footprint of Thin Film technology, compared not only to other PV technologies, but to all other forms of electricity generation**. Most recently, the European Commission's Joint Research Center (JRC) concluded in its ' Preparatory Study' for upcoming legislative and /or voluntary work on PV , that 2nd generation thin film technologies represent the Best Available Technologies from an environmental and economic viewpoint: Task 6 Report (revised) – Section 6.3.5.2 – Commercial Scale (p. 74): *"The best available technology from an environmental point of view (primary energy) and life cycle cost point of view is the CdTe system."* Task 6 Report (revised) – Section 6.3.5.3 – Utility Scale (p. 76): *"The best available technology from an environmental point of view (primary energy) are the systems using CdTe modules. (…) The system 'CdTe + reference inverter + reference BOS' has the lowest LCOE."* This should be reflected and referred to in the Ademe's study report.	**References which quantify the positive environmental impacts of 2nd generation PV technologies (in comparison to 1st generation technologies):** **V. M. Fthenakis, H. C. Kim, E. Alsema. 2008. Emissions from Photovoltaic Life Cycles. Environmental Science and Technology, 42, 2168-2174, DOI: 0.1021/es071763q.** **E. G. Hertwich, T. Gibon, E. A. Bouman, A. Arvesen, S. Suh, G. A. Heath, J. D. Bergesen, A. Ramirez, M. I. Vega, L. Shi. 2014. Integrated life cycle assessment of electricity supply scenarios confirms global environmental benefit of low-carbon technologies. Proceedings of the National Academy of Sciences. doi:10.1073/pnas.1312753111** **E. Lecissi, M. Raugei, V. Fthenakis. 2016. The Energy and Environmental Performance of Ground-Mounted Photovoltaic Systems—A Timely Update, Energies, 9, 622; doi:10.3390/en9080622.** **Pérez-López, P., Gschwind, B., Blanc, P., Frischknecht, R., Stolz, P., Durand, Y., Heath, G., Ménard, L., and Blanc, I. 2017. ENVI-PV: an interactive Web Client for multi-criteria life cycle assessment of photovoltaic systems worldwide. Prog. Photovolt: Res. Appl., 25: 484–498. doi: 10.1002/pip.2841.** **Louwen, R.E.I. Schropp, W.G.J.H.M. van Sark, A.P.C. Faaij. 2017. Geospatial analysis of the energy yield and environmental footprint of different photovoltaic module technologies. Solar Energy, 155, 1339-1353. http://dx.doi.org/10.1016/j.solener.2017.07.056** **J. Peng, L. Lu, and H. Yang. 2013. Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. Renewable and Sustainable Energy Reviews, 19, 255–274. http://dx.doi.org/10.1016/j.rser.2012.11.035** **M. Seitz, M. Kroban, T. Pitschke, and S. Kriebe. 2013. Eco-Efficiency Analysis of Photovoltaic Modules, Bifa Environmental Institute on behalf of Bavarian State Ministry of the Environment and Consumer Protection. http://www.bifa.de/en/news/detail-view/news/bifa-text-no-62-ecoefficiency-analysis-of-photovoltaic-modules**

					UNEP. 2015. Summary for Policymakers, Green Energy Choices: The Benefits, Risks and Trade-Offs of Low-Carbon Technologies for Electricity Production. http://web.unep.org/ourplanet/march-2016/unep-publications/green-energy-choices-benefits-risks-and-trade-offs-low-carbon **M. de Wild-Scholten. 2013. Energy payback time and carbon footprint of commercial photovoltaic systems. Solar Energy Materials & Solar Cells 119: 296–305.** http://dx.doi.org/10.1016/j.solmat.2013.08.037 **P. Stolz, R. Frischknecht, F. Wyss, M. de Wild-Scholten. 2016.** **PEF screening report of electricity from photovoltaic panels in the context of the EU Product Environmental Footprint Category Rules (PEFCR) Pilots.** **Product Environmental Footprint** **Supporting Study** **First Solar Series 4 PV System. 2016.** **Product Environmental Footprint Supporting Study First Solar Series 4 PV System. 2016. - Verification of information provided within supporting studies carried out within the Environmental Footprint pilot phase in compliance with the Commission EF method.Audit report 03 - 11 – 2016. Ernst&Young** **Sinha, Parikhit, und Andreas Wade. „Addressing Hotspots in the Product Environmental Footprint of CdTe Photovoltaics“. *IEEE Journal of Photovoltaics*, 2018, 1–5.** https://doi.org/10.1109/JPHOTOV.2018.2802786
16	**31**	**2.2.3. Analyse détaillée par couple document / technologie / enjeu**	Étude scientifique / Substances dangereuses	**This paragraph seems drafted to deliberately misrepresent CdTe technology**. It deliberately focusses on a single study, whose methodology strays from standardized leaching test, and which has been criticized and rebutted in a number of peer reviewed journals. By focusing solely on this study, and not discussing its results in comparison with other literature based on standardized leaching tests, fate and transport modeling and risk assessment standards, the authors misrepresent the current state-of-knowledge regarding the evaluation of the leaching behavior of end-of-life photovoltaic panels.	**References:** https://iopscience.iop.org/article/10.7567/JJAP.57.019101 Sinha, Parikhit, und Andreas Wade. „Comment on “Long-term leaching of photovoltaic modules””. *Japanese Journal of Applied Physics* 57, Nr. 1 (2018): 019101. https://doi.org/10.7567/JJAP.57.019101.

				When looking at mature technologies, with decades of field data, which is the case for silicon, CIGS and CdTe PV technologies, experimental data and test results should be crossed referenced with the safety track record of these technologies. **The statement on the lead content of c-Si technologies also needs to be corrected**. The amount of lead in c-Si technologies is typically higher than the amount of compound semiconductors used in thin-film technologies. It should also be noted, that the majority of standard tests for the waste characterization of c-Si PV modules show that lead is leached out at much higher rates and concentrations than compound semiconductors.	Sinha, Parikhit, und Andreas Wade. „Assessment of Leaching Tests for Evaluating Potential Environmental Impacts of PV Module Field Breakage“. *IEEE Journal of Photovoltaics*, 2015, 1–5. https://doi.org/10.1109/JPHOTOV.2015.2479459. Arp, Hans Peter. „Leaching from mc-Si PV module material - results from batch, column and availability tests. Comparison with thin film CdTe PV modules“. Oslo, Norway: NGI, 25. November 2010. Sinha, Parikhit, Robert Balas, Lisa Krueger, und Andreas Wade. „Fate and transport evaluation of potential leaching risks from cadmium telluride photovoltaics“. *Environmental Toxicology and Chemistry* 31, Nr. 7 (Juli 2012): 1670–75. https://doi.org/10.1002/etc.1865. Sinha, Parikhit. „Cadmium Telluride Leaching Behavior: Discussion of Zeng et al. (2015)“. *Journal of Environmental Management* 163 (November 2015): 184–85. https://doi.org/10.1016/j.jenvman.2015.08.015.
17	**39**	**3.1.1.**	Les tests expérimentaux de lixivation	The authors suggest, that the currently applicable standard leaching test protocols, applied to the characterization of all kinds of waste, cannot be applied to photovoltaic panels. **This misrepresents the regulatory framework in place, as well as the procedures laid out in the waste framework directive, the EU list of waste and subsequent implementing regulations at national level.** The authors fail to reference scientific studies from waste characterization experts which suggest that current tests are sufficient to meet policy objectives. Instead they refer to subjective statements from non-waste experts on the potential shortcomings of existing waste testing protocols and procedures. **This is misleading, and brings about erroneous conclusions. This section should be redrafted after a thorough review of existing EU regulations on the waste characterization protocols applicable to WEEE (and fractions thereof).**	See previous references which include detailed discussions of this topic.
18	**60**	**4.**	Elements relatifs …	See previous comments. Referring to the justification for the RoHS exclusion, as laid out in recital 17 is necessary here to prevent erroneous conclusions. Authors equally fail to recognize the presence of lead in the overwhelming majority of c-Si PV technologies – this must be corrected to avoid bias.	See comment above on the need to refer to the RoHS Directive (2011/65/EU) recital 17 which states the justification for the PV exclusion.