Highly efficient multi-junction solar cells using silicon heterojunction and perovskite tandem: prospective life cycle environmental impacts

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Sustainability assessment of 3rd generation photovoltaics

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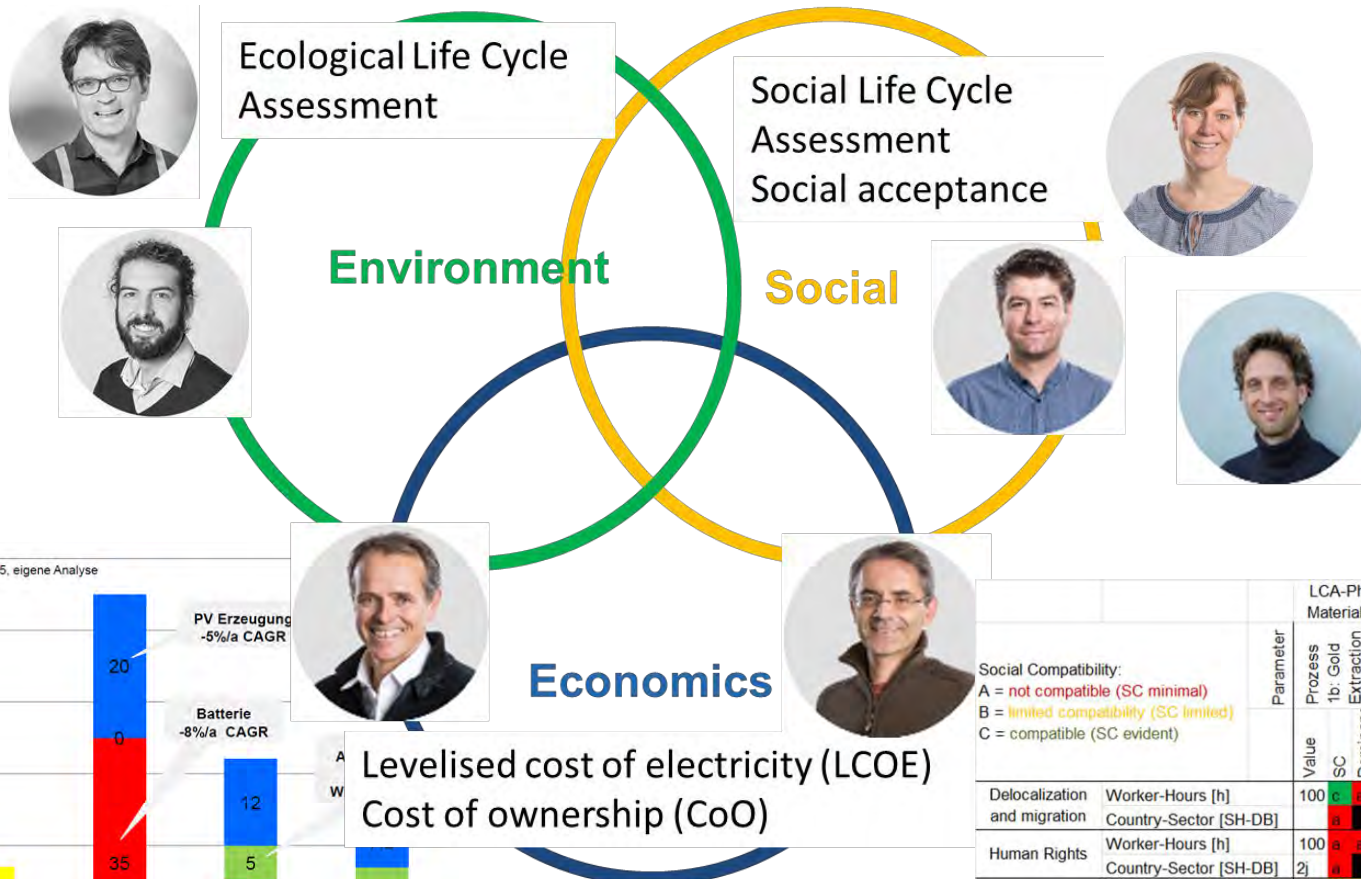

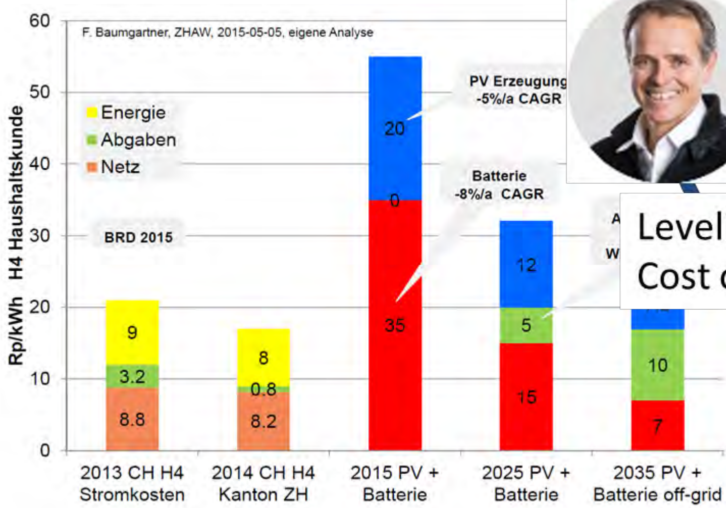

		LCA-Phase 1: Raw Materials Extraction						LCA-Phase 2:				
Social Compatibility: A = not compatible (SC minimal) B = limited compatibility (SC limited) C = compatible (SC evident)	Parameter	Prozess 1b: Gold Extraction			Prozess 1..n			Prozess 2..n			Prozess	
		Value	SC	Dominanc	Value	SC	Dominanc	Value	SC	Dominanc	Value	SC
Delocalization and migration	Worker-Hours [h]	100	c	a	0.5	c		100	c	b		
	Country-Sector [SH-DB]		a		1k	b			b			
Human Rights	Worker-Hours [h]	100	a	a	2	c	a					
	Country-Sector [SH-DB]	2j	a		2k	a						
Child labor	Worker-Hours [h]	50	b	b	50	b	b					
	Country-Sector [SH-DB]	3j	b		3k	c						
Fair Salary	Worker-Hours [h]	200	a	a	35	b	b					
	Country-Sector [SH-DB]	4j	b		4k	b						
Health and safety	Worker-Hours [h]	40	b	b	125	a	a					
	Country-Sector [SH-DB]	5j	c		5k	c						
Inventory Indicators	Worker-Hours [h]											

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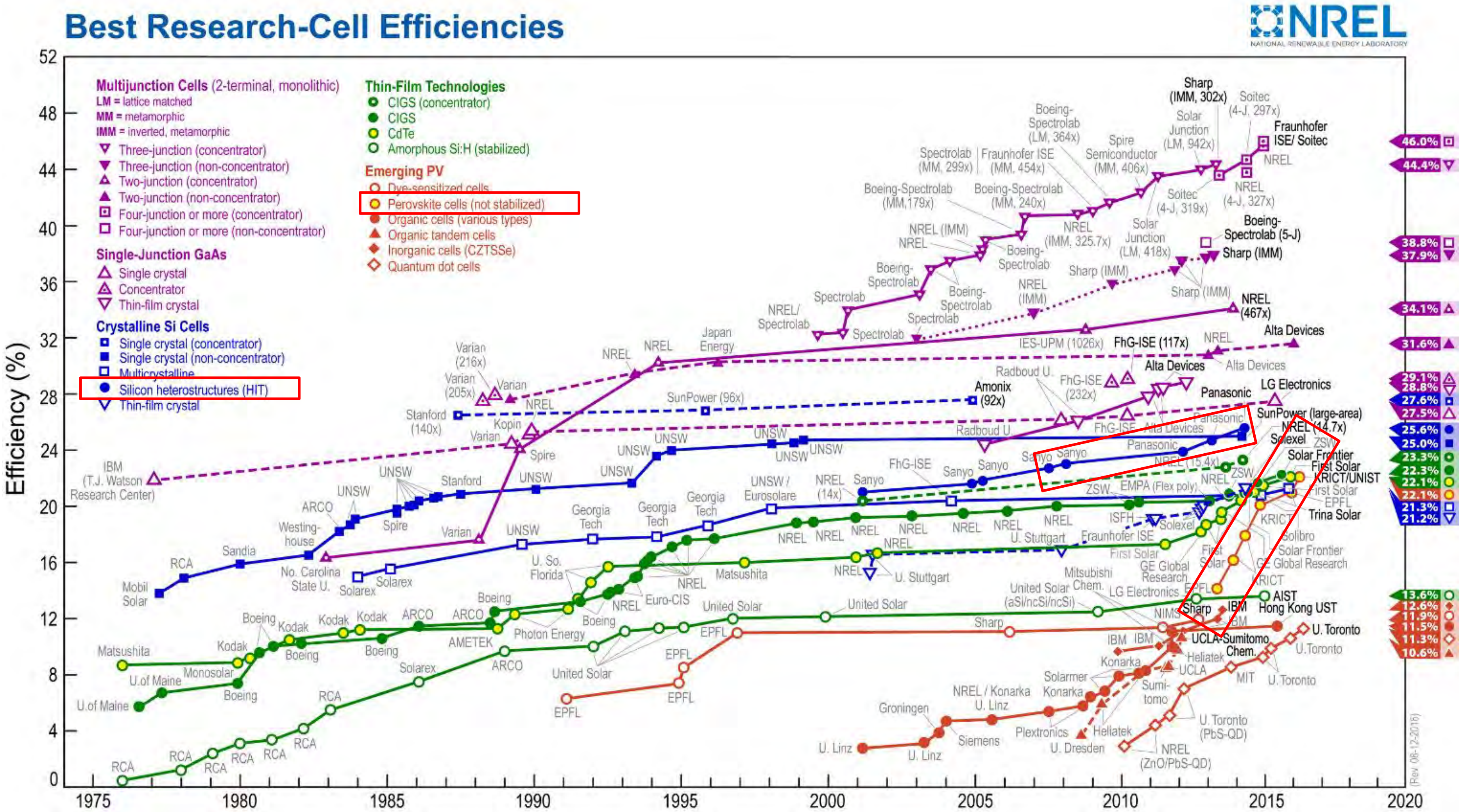
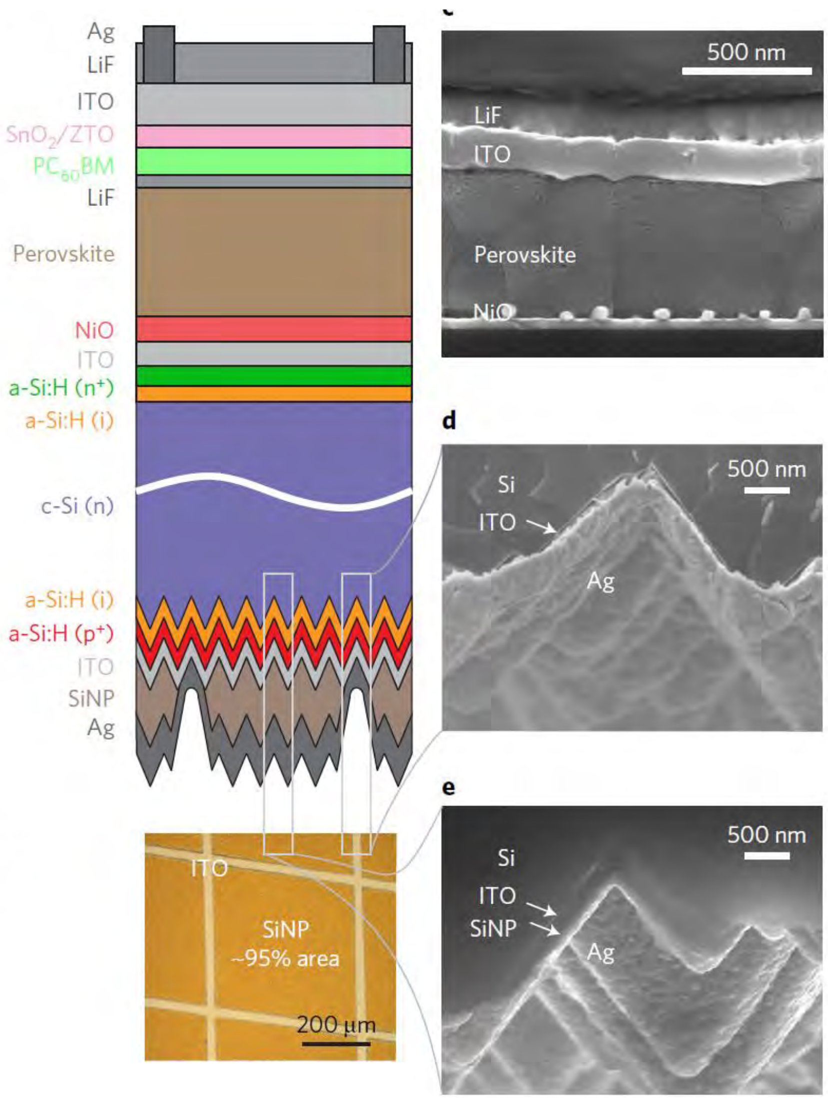
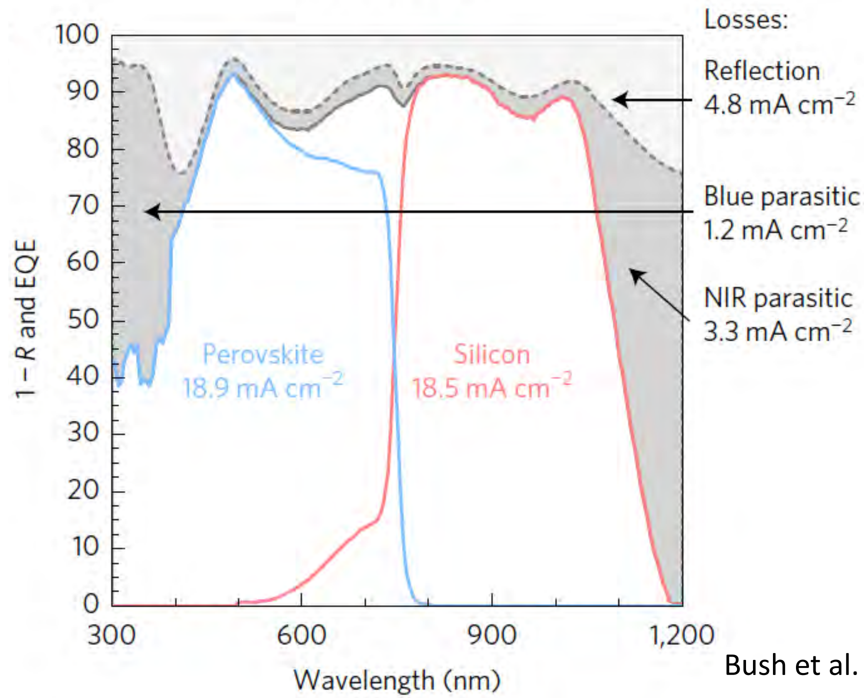
Highly efficient 3rd generation tandem solar cells (1)



Highly efficient 3rd generation tandem solar cells (2)



Bush et al. (2017)



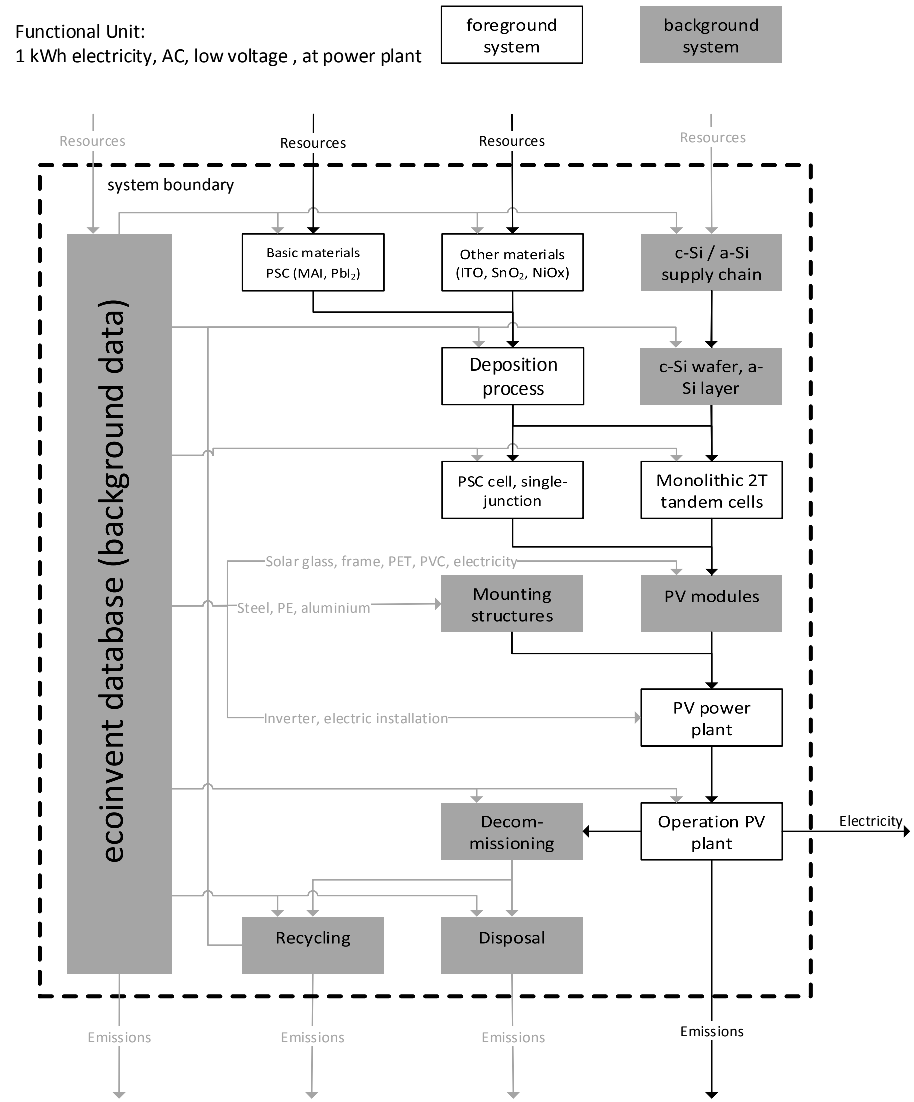
Sciences

Bush et al. (2017)

- Perovskite solar cell (PSC): organometallic perovskite layer made of methyl ammonium lead iodide (MALI, $CH_3NH_2PbI_3$)
- Silicon heterojunction (SHJ): crystalline Si wafer with amorphous and micromorphous silicon layers for passivation and recombination junction
- Monolithic tandem cell SHJ-PSC with extended absorption spectrum, conversion efficiency: >30%

Modules and system boundaries

Clua Longas et al. (2017)



- Module prototype with different coatings and colours
- Coated with aluminium, copper and plastics

Summary parameters and scenarios

Abbreviation	Technology	Efficiency in %		Thickness in micrometer	
		Cell	Module	Wafer	Kerf
Mono-Si REF	Mono-crystalline silicon, single-junction	16.5	15.1	295	145
Mono-Si ITRPV	Mono-crystalline silicon, single-junction	26.0	23.8	140	60
Poly-Si REF	Poly-crystalline silicon, single-junction	16.0	14.7	295	145
Poly-Si ITRPV	Poly-crystalline silicon, single-junction	20	18.3	150	60
PSC PESS	Perovskite single-junction	15.0	13.8	n.a.	n.a.
PSC OPT	Perovskite single-junction	20.0	18.3	n.a.	n.a.
M2T-SHJ-PSC PESS	Monolithic two terminal tandem cell using perovskite and silicon heterojunction tandem	26.0	23.8	295	145
M2T-SHJ-PSC OPT	Monolithic two terminal tandem cell using perovskite and silicon heterojunction tandem	30.0	27.5	120	60

- Yield 1027 kWh/kWp, slanted-roof installation in Switzerland, PR: 82%
- Lifetime 30 years, cell-to-module efficiency ratio: 0.915
- Degradation 0.7% per year (avg 10.5% for LT 30 years, eff. yield 919 kWh/kWp
- Identical mounting system, module and cell production

IEA PVPS. (2016)

Prospective life cycle environmental impacts

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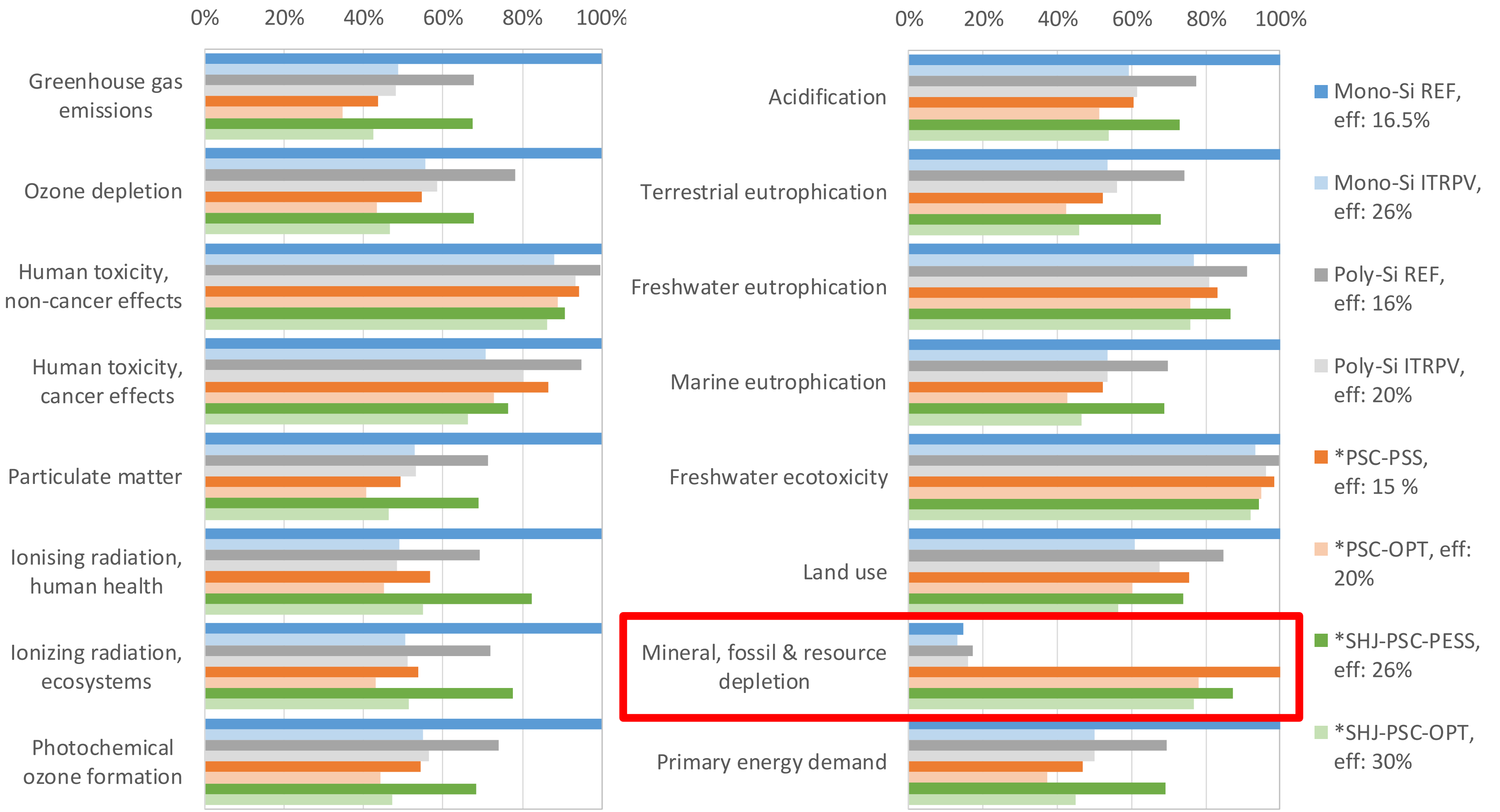
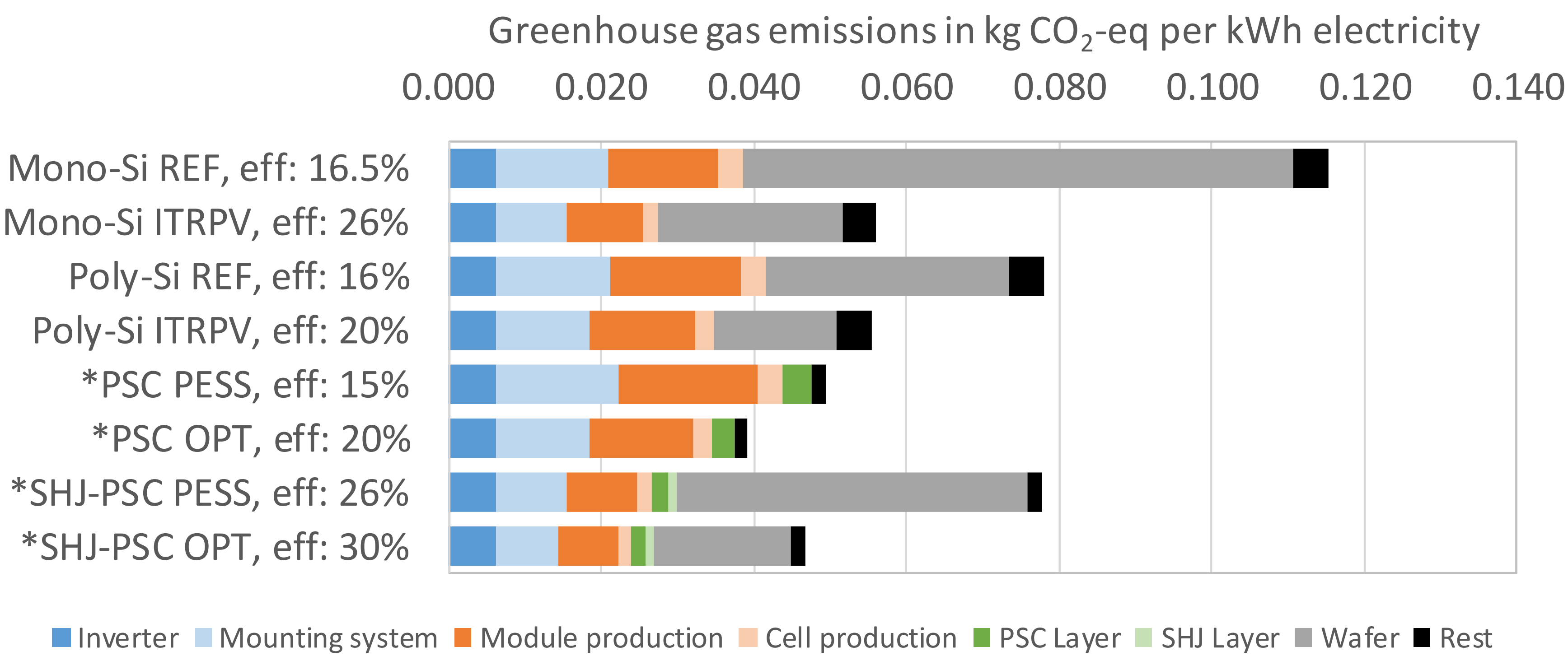


Itten & Stucki (2017)

* Optimistic lifetime of 30 years for PSC layer

Trade-off in mineral and fossil resource depletion due to use of ITO as TCO

Contribution analysis GHG



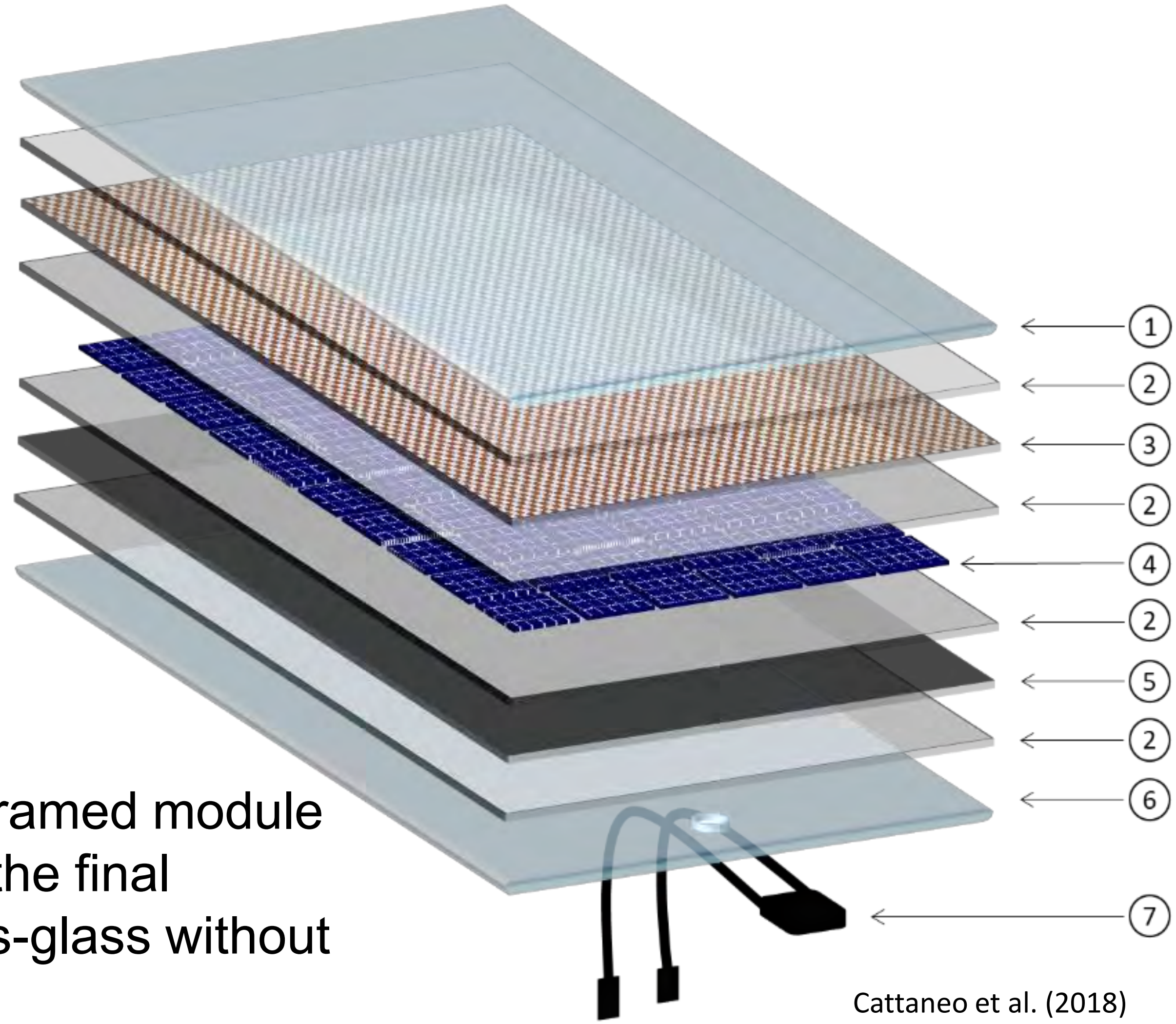
Itten & Stucki (2017)

* Optimistic lifetime of 30 years for PSC layer

- Yield 1027 kWh/kWp, degradation 0.7% per year, 30 year lifetime for all solar cells
- Identical mounting system, module and cell production
- Additional layers for SHJ and PSC in same order of magnitude
- Silicon wafer most important contribution (if used)

Glass-glass module without frame

1. Font glass
2. Clear interlayer
3. Colour filter
4. Cell matrix (cells, tabbing ribbons, bas-bar ribbons)
5. Black interlayer
6. Back glass
7. Junction box, cables and connectors



Cattaneo et al. (2018)

Current calculations with framed module with aluminium backside, the final encapsulation will be glass-glass without frame

GHG mono-Si vs PSC vs tandem

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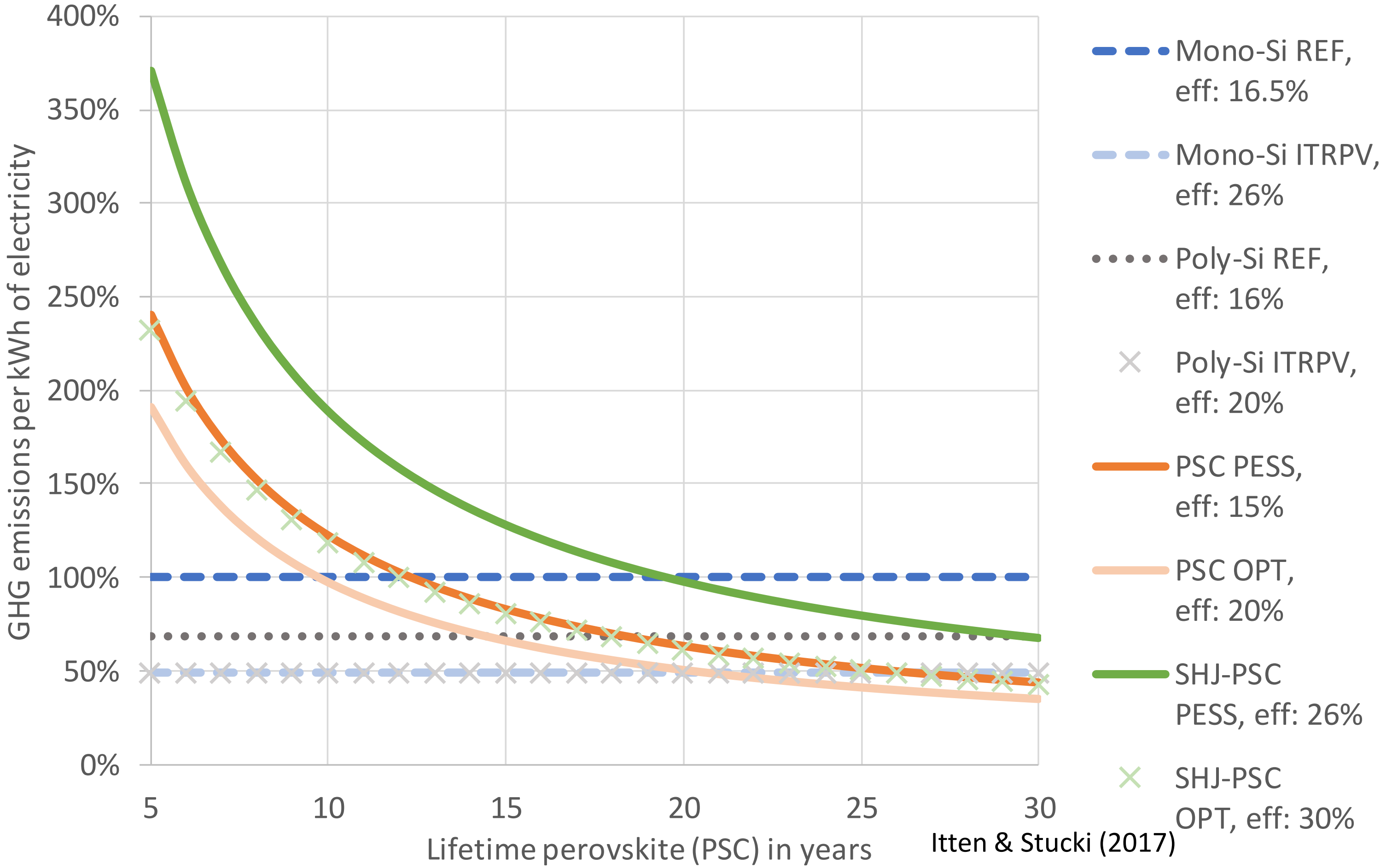

Itten & Stucki (2017)

- Blue lines for mono-Si modules, grey for Poly-Si with fixed lifetime of 30 years
- PSC: Perovskite single-junction, mono-Si: mono-crystalline silicon single-junction
- SHJ-PSC: monolithic tandem perovskite silicon heterojunction

Sensitivity degradation

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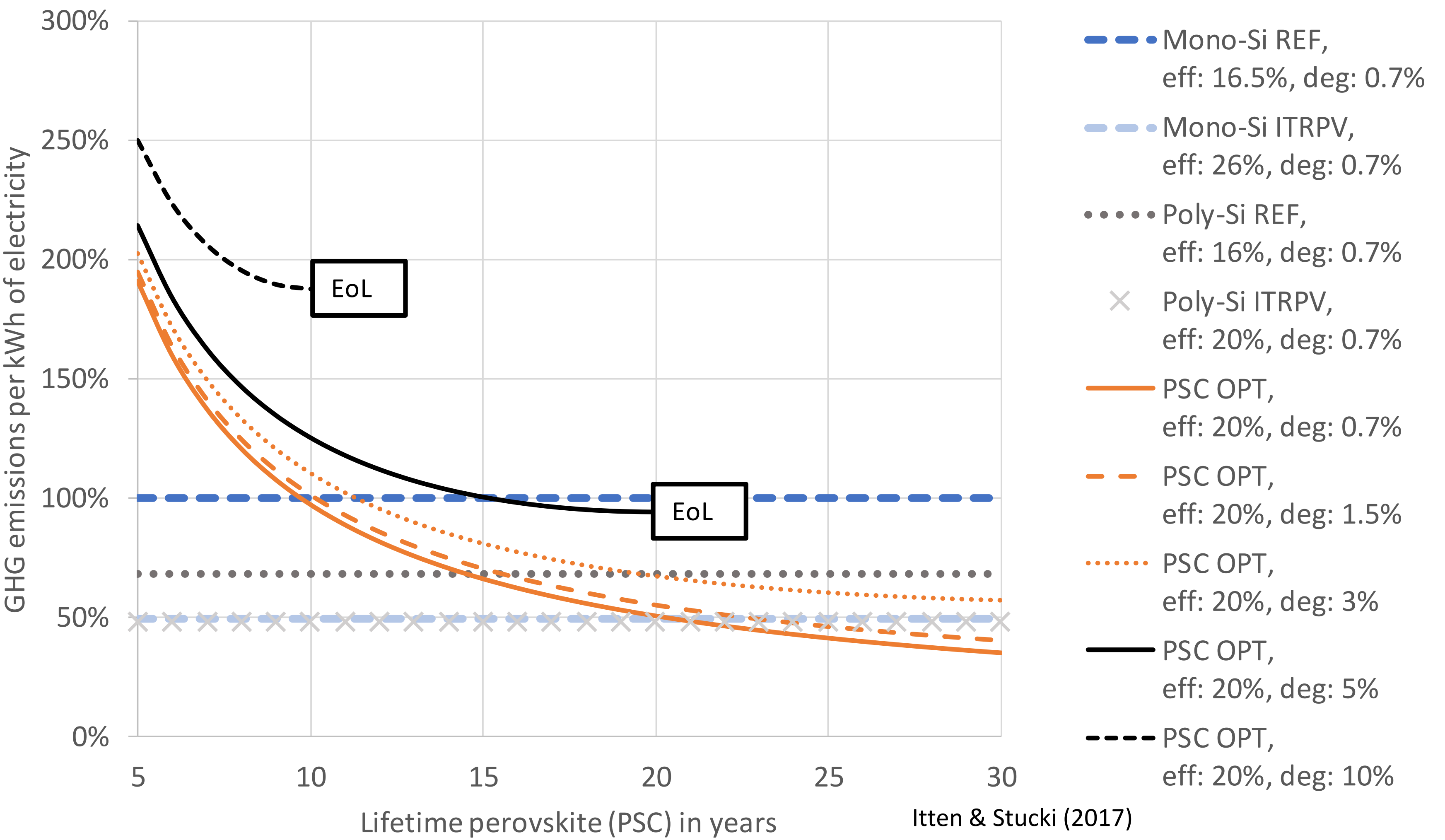
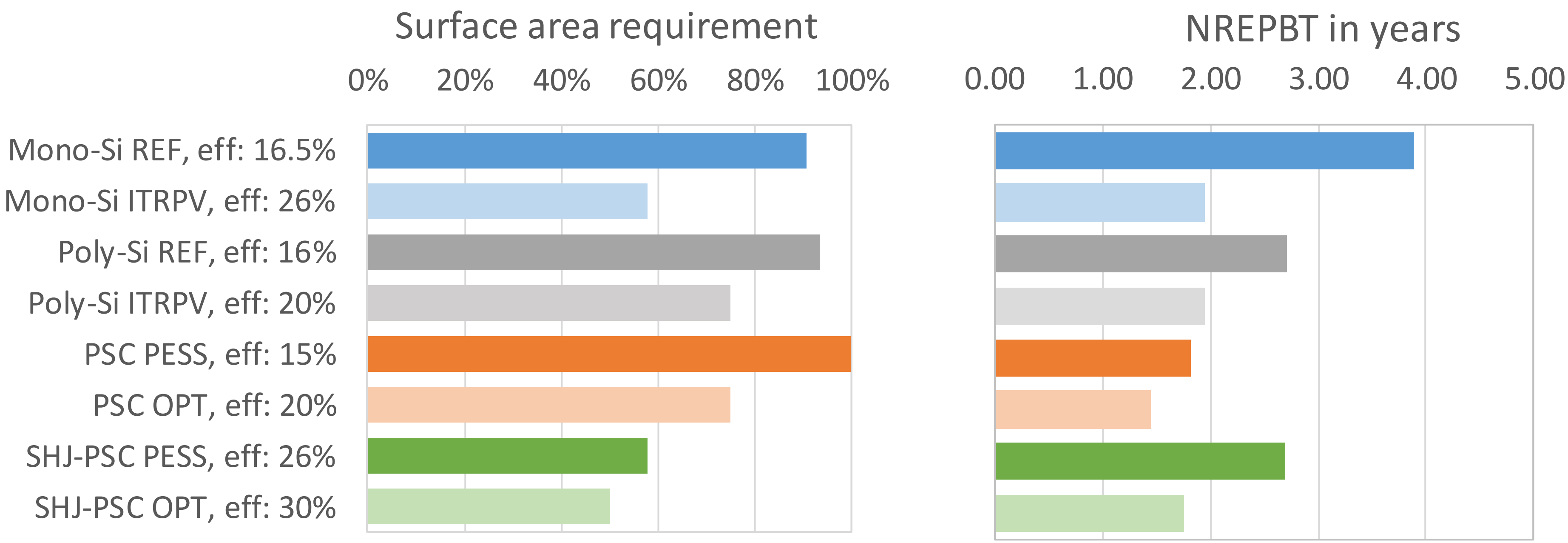


Itten & Stucki (2017)

- Dotted blue and grey lines for mono-Si and poly-Si modules with fixed lifetime of 30 years
- End of Life (EoL) for 10% and 5% annual degradation after 10 and 20 years lifetime

Surface area requirement and non-renewable energy payback time (NREPBT)



Itten & Stucki (2017)

$NREPBT = \frac{NRPE_{PV}}{NRPE_{kWh} * E_{PV}}$ according to IEA-PVPS Methodology Guideline for PV

NREPBT: Non Renewable Energy Payback Time

$NRPE_{PV}$: Non Renewable Primary Energy Demand PV Power Plant

E_{PV}: Annual Yield of the Solar Power Plant in kWh

$NRPE_{kWh}$: Non Renewable Primary Energy Demand per kWh replaced electricity

Conclusions

- Key parameters: module efficiency, lifetime and degradation
- Less than 10% of GHG from additional layers for perovskite and silicon heterojunction
- Trade-off resource depletion: use of indium for ITO
- If the perovskite layer is stabilized, the area demand for photovoltaic electricity reduction can be reduced up to 20%
- Toxicity: use of heavy metals (Pb and Sn)

Thanks for your attention!

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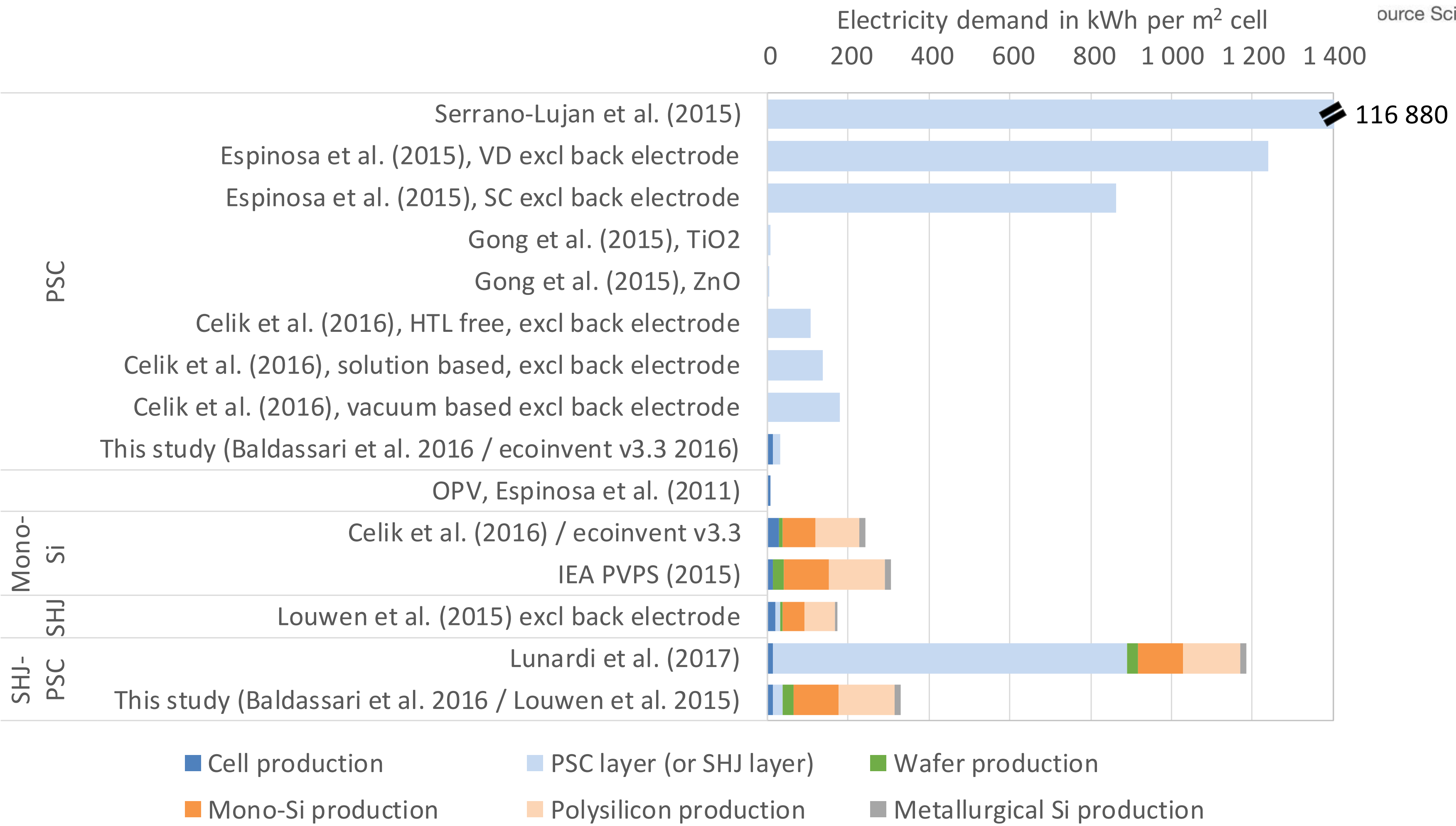
Electricity Demand production



Harmonised comparison with published results

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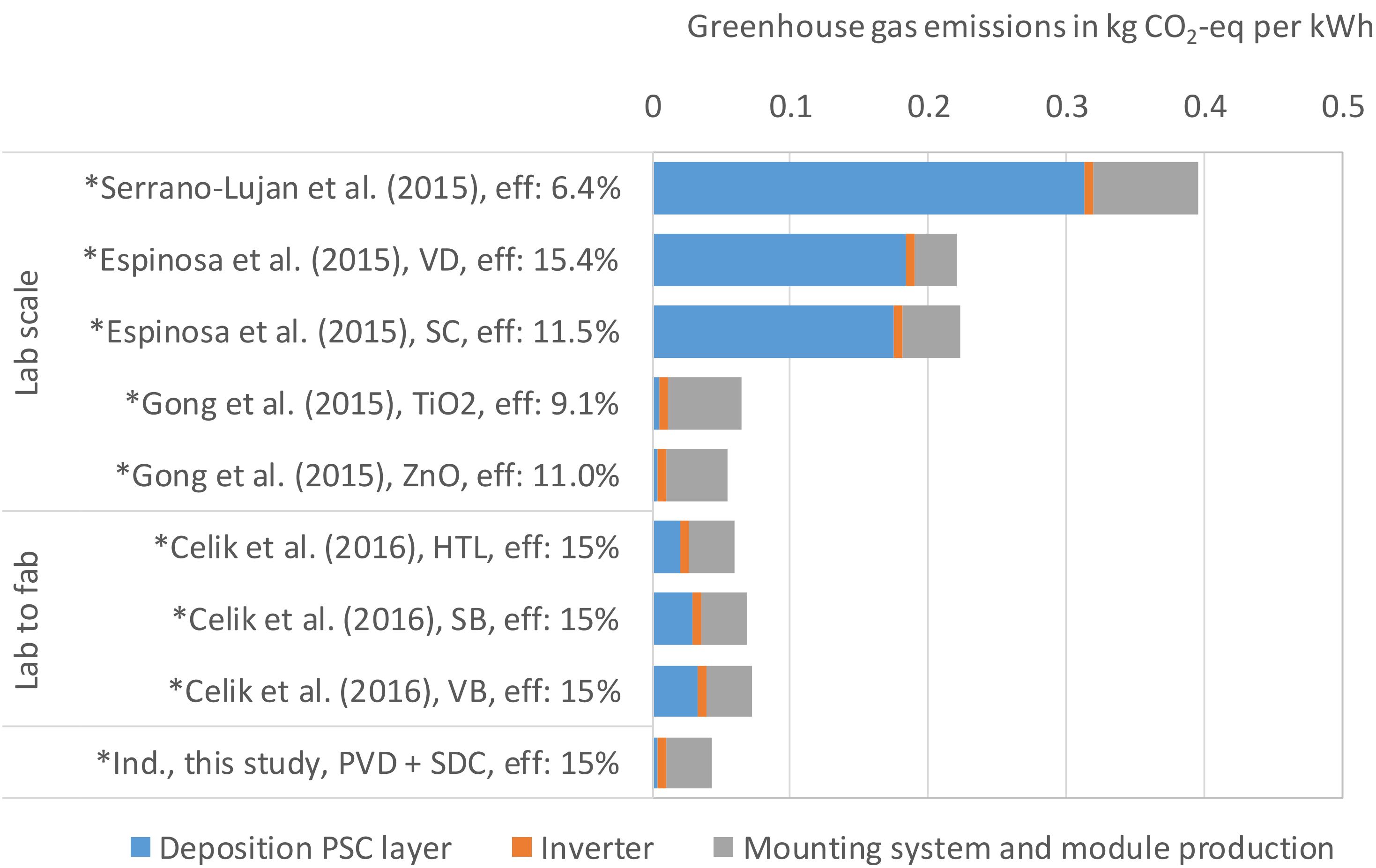

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Cell structure

Layer	Doping	Thickness	Application	Function
Indium tin oxide		120 nm	Sputtering	Top contact layer
Tin oxide	n	10 nm	Sputtering	Electron transport layer
Methyl ammonium lead iodide	i	500 nm	Thermal evaporation of PbI_2 followed by slot-die coating of MAI	Absorber layer
Nickel oxide	p	10 nm	Sputtering or atomic layer deposition	Hole transport material
Silver rear contact		150 nm	Sputtering	Back contact layer

Layer	Doping	Thickness	Application	Function
Ag front grid			Ag screen printing	Front grid
Indium tin oxide		80 nm	Sputtering	Top contact layer
Nickel oxide	p	10 nm	Sputtering or atomic layer deposition	Hole transport
Perovskite	i	500 nm	Thermal evaporation of PbI_2 followed by slot-die coating of MAI	Absorber layer
Tin oxide	n	10 nm	Sputtering	Electron transport
n-μ-c-Si	n	10 nm	PECVD	Recombination junction
p-μ-c-Si	p	10 nm	PECVD	Recombination junction
i-a-Si	i	10 nm	PECVD	Passivation
n-Si	n	295 and 120 micron	Base for others layers	Silicon substrate
i-a-Si	i	10 nm	PECVD	Passivation
n-a-Si	n	10 nm	PECVD	Back surface field
Indium tin oxide		100 nm	Sputtering	Back contact layer
Ag rear contact		200 nm	Sputtering	Back electrode

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