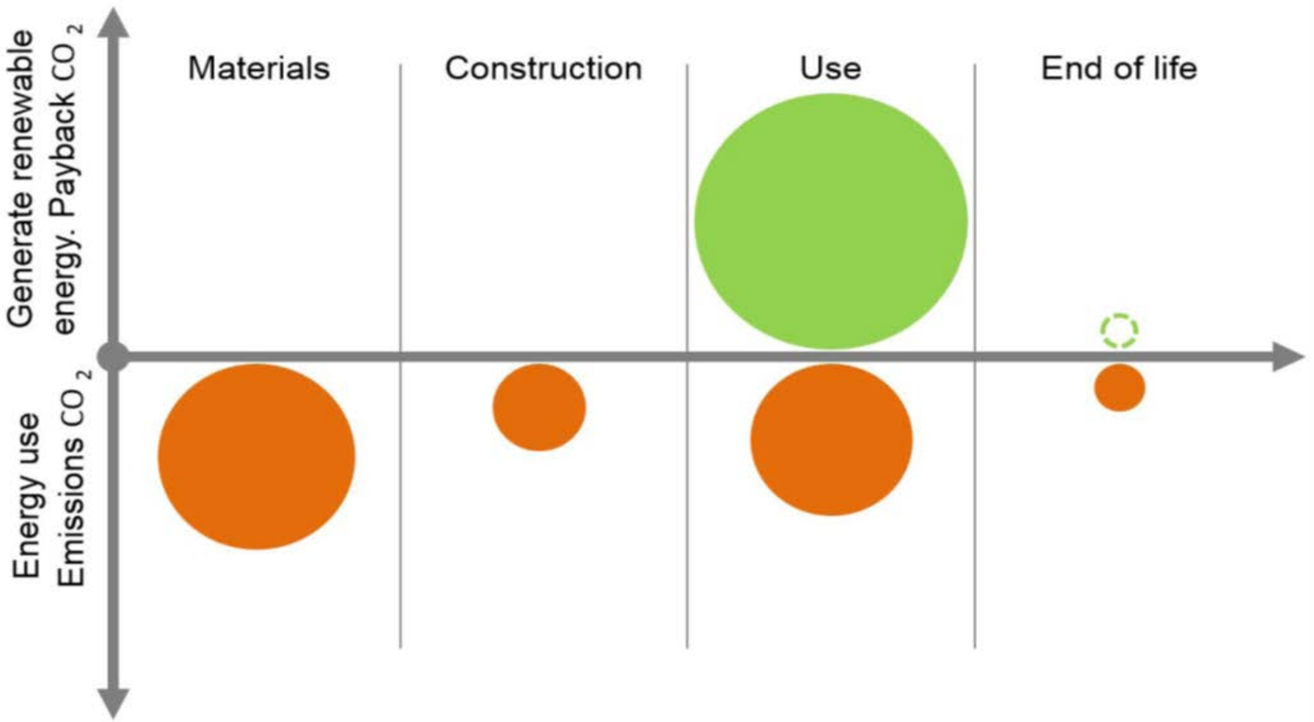
Life cycle GHG emissions calculation for materials use in Norwegian ZEBs

Zero Emission Building (ZEB)

- The aim of the Norwegian research centre on ZEB is to develop competitive products and solutions for new and existing buildings resulting in zero greenhouse gas (GHG) emissions over the lifetime of the building.



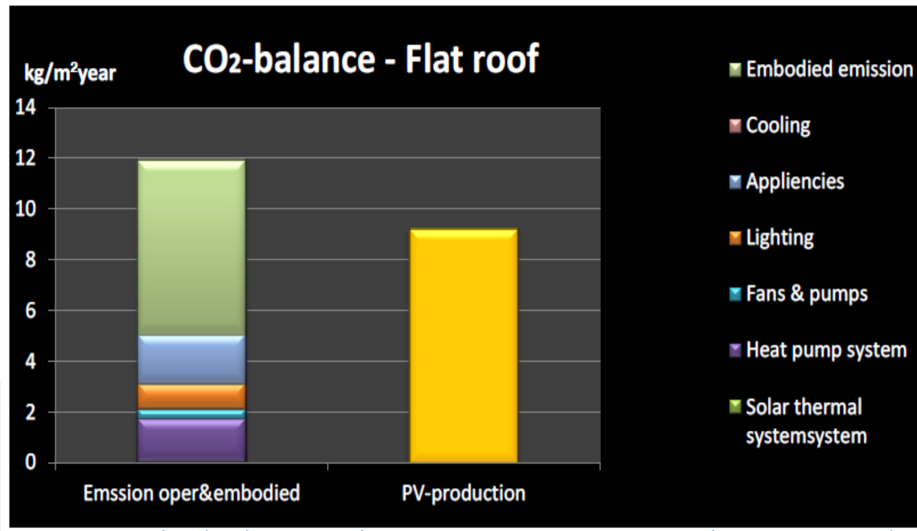
Embodied material emissions

- Achieving a net zero balance is challenging due to increase in embodied emission of ZEBs as a result of energy efficient measures.
  - ✓ E.g. ZEB single family house concept study

Building life cycle stages included in the study, according to EN15978(X=modules included in the study)																			
A1–A3 Product stage			A4–A5 Construction Process stage		B1–B7 Use stage							C1–C4 End-of-life				D1–D4 Benefits and loads beyond the system boundary			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D1	D2	D3	D4
Raw material supply	Transport	Manufacturing	Transport	Construction installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling	Exported energy /potential

BUILDING KEY FACTS	
No of floors	2
Floor area [m2]	160
Window area [m2]	36
Annual energy demand [MWh/year] -heating -cooling -electric	4,1 0 7,2

A timber framed two-story single-family house. The building consists of a well-insulated building envelope, combined with solar façade-mounted thermal collectors and an air-to-water heat pump. A roof-mounted and grid-connected photovoltaic (PV) system is implemented to generate enough electricity to offset the operational energy emissions.



59% embodied material emission, 41% operational emission and renewable energy production offsets 75% emissions from operation and materials

References

T.H. Dokka, A.H. Wiberg, L. Georges, S. Mellegård, B. Time, M. Haase, M. Maltha, A.G. Lien, A zero emission concept analysis of a single family house. ZEB Project report no 9, The Research Centre on Zero Emission Buildings (ZEB), 2013

A. Houlihan Wiberg, L. Georges, T.H. Dokka, M. Haase, B. Time, A.G. Lien, S. Mellegård, M. Maltha, A net zero emission concept analysis of a single-family house, Energy and Buildings, 74 (2014) 101-110.

Ambition levels

- The Norwegian ZEB center developed ZEB definition and calculation methodologies for operational energy and life cycle embodied material emissions.
- The ZEB definition is characterized through a range of various ambition levels to produce enough renewable energy to compensate for both operational and embodied emissions.

Ambition levels		**Building phases included**
ZEB-**O÷EQ**	**O**peration minus **EQ**uipment	Emissions related to all energy use for operation "**O**", except energy use for technical equipment and appliances (**EQ**), shall be compensated for with renewable energy generation.
ZEB - **O**	**O**peration	Emissions related to all operational energy "**O**" shall be compensated for with renewable energy generation.
ZEB - **OM**	**O**peration and **M**aterials	ZEB-O+ embodied emissions from materials "M" shall be compensated for with renewable energy generation.
ZEB - **COM**	**C**onstruction, **O**peration, and **M**aterials	ZEB-OM + emissions relating to the construction "C" phase shall be compensated for with renewable energy generation.
ZEB - **COME**	**C**onstruction, **O**peration **M**aterials , and **E**nd-of-life	ZEB-COM + emissions relating to the end of life "E" phase shall be compensated for with renewable energy generation.
ZEB - **COMPLETE**	**Complete life cycle**	Emissions related to a complete lifecycle have to be compensated for with renewable energy generation.

Reference
S.M. Fufa, R.D. Schlanbusch, K. Sørnes, M. Inman, I. Andresen, A Norwegian ZEB Definition Guideline. The Research Centre on Zero Emission Buildings. ZEB Project report no 29., 2016.

Ambition levels and system boundaries

- The scope has been defined in accordance with the modular system of life cycle stages as defined in EN 15978, and the Norwegian ZEB ambition levels.

System Boundary NS-EN 15978:2011																	
	A1-3 Product Stage			A4-5 Construction Process Stage		B1-7 Use Stage							C1-4 End of Life				D Benefits and loads
	A1: Raw Material Supply	A2: Transport to Manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance (incl. transport)	B3: Repair (incl. transport)	B4: Replacement (incl. transport)	B5: Refurbishment (incl. transport)	B6: Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end of life	C3: Waste Processing	C4: Disposal	D: Reuse, recovery, recycling
ZEB - O/EQ											green *						
ZEB - O											green						
ZEB - OM	green	green	green						green **		green						
ZEB - COM	green	green	green	green	green				green ***		green						
ZEB - COME	green	green	green	green	green				green		green		green	green	green	green	
ZEB - COMPLETE	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	green	

* Does not include operational energy of electrical equipment
** Does not include transport to building site (A4), installation into building (A5) or end of life treatment of the replaced materials
*** Does not include end of life treatment of the replaced materials
NB: Biogenic carbon should only be included at a ZEB-COME or ZEB-COMPLETE level

The mandatory lifecycle stages (A1-A5, B1-B7, C1-C4) for the different ZEB ambition levels are presented in green. Module D can be included as additional information in ZEB-COMPLETE.

ZEB pilot building projects

- The ZEB research centre has evaluated pilot buildings according to ZEB targets and calculation methodologies to find solutions that would balance out embodied and operational emissions with on-site renewable energy production.

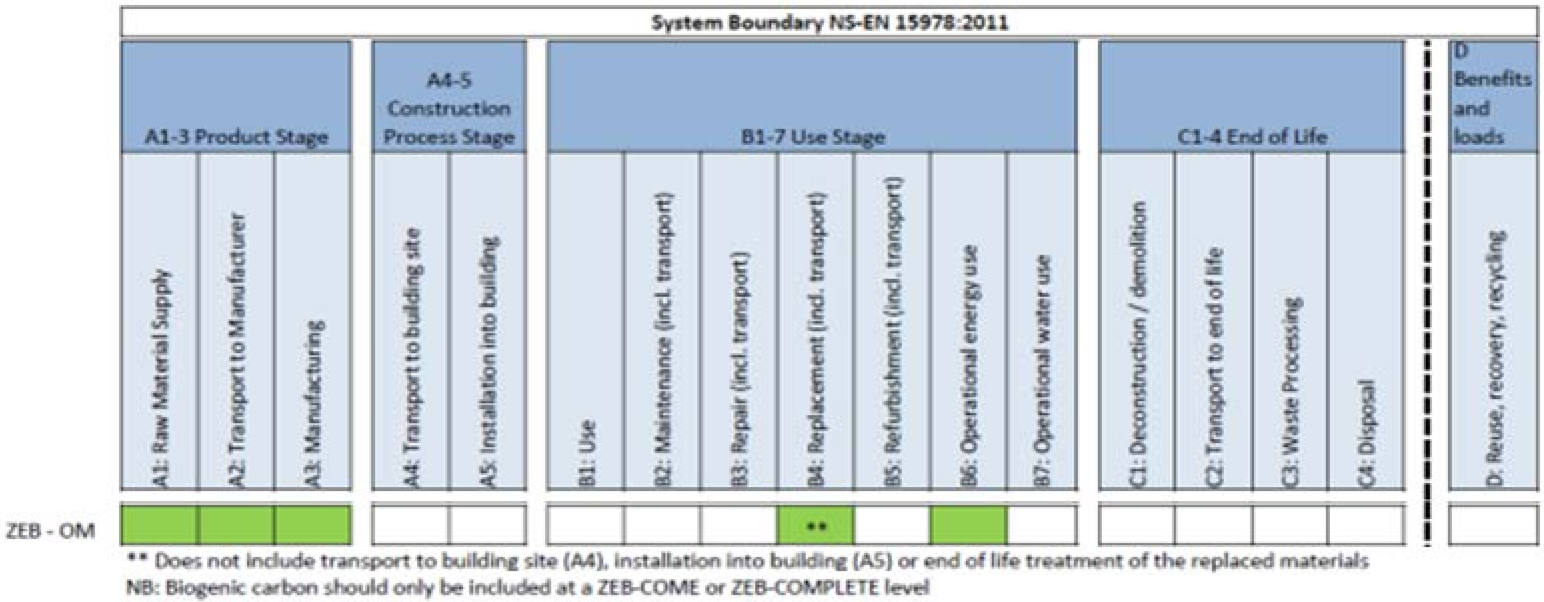
ZEB pilot buildings	Type of building	Ambition level	Location
Haakonsvern	Office building	ZEB-O÷EQ	Bergen
Powerhouse Brattøra	Office building	ZEB-OM÷EQ	Trondheim
Skarpnes	37 dwellings	ZEB-O	Arendal
Zero village Bergen	+500 dwellings	ZEB-O	Bergen
Multikomfort	Single family house	ZEB-OM	Larvik
ZEB Living Lab	Single family house	ZEB-OM	Trondheim
Heimdal VGS	School	ZEB-O20%M	Heimdal
Campus Evenstad	School	ZEB-COM	Hedmark
Powerhouse Kjørbo	Office building	ZEB-OM÷EQ	Sandvika

Reference
http://zeb.no/index.php/pilot-projects

Material emission calculation

- Goal and scope is defined according ZEB ambitions

  ✓ e.g. a building that compensates all greenhouse gas emissions from operational energy and material use – ZEB-OM (A1-A3, B4 & O6).



Material emission calculation

- System boundary for building parts included in the analysis according to NS 3451- Table of building elements.
  - ✓ To get an overview of the parts of the building that have been included.
  - ✓ To evaluate which materials and components contribute the most to embodied emissions.
  - ✓ To do a more structured and detailed comparison with other projects.

E.g. of list of building parts based on NS 3451	
2	**Building envelope**
21	Ground work and foundation
22	Superstructure
23	Outer wall
24	Inner wall
25	Floor structures
26	Outer roof
28	Stairs and balconies
3	**Building services**
32	Heating
36	Ventilation and air conditioning
4	**Electric power supply**
44	Lightning
45	Electric heating
49	Others- solar and other renewable energy

Material emission calculation

- Functional unit: 1m^2 of heated floor area over a building service life of 60 years.
  - ✓ The results are mainly presented for emissions on an annual basis.
  - ✓ In addition, it is also required to state total embodied emissions (kgCO_{2eq}) of the building, embodied emission results according to building component, materials and life cycle module.

E.g. CO_{2eq} emissions from material use in the ZEB Living Laboratory

Life Cycle Stage	kgCO_{2eq}	kgCO_{2eq}/yr	kgCO_{2eq}/m^2 60 years	kgCO_{2eq}/m^2/yr
Initial Material Use (A1 - A3)	74121	1235	727	12.1
Transport to Site (A4)	6188	103	61	1.0
Construction (A5)	7412	124	72	1.2
Replacement (B4)	56067	934	550	9.2
TOTAL	**143788**	**2396**	**1410**	**23.5**

The Living Laboratory is a single story, temporary, multi-purpose demonstration experimental facility. The building is characterised by a detached, single-family house typology, which represents over 52% of the Norwegian building stock.

Reference
M.R. Inman, A. Houlihan Wiberg, Life Cycle GHG Emissions of Material Use in the Living Laboratory. ZEB Project report no 24, The Research Centre on Zero Emission Buildings (ZEB), 2015

Building service life

- The current building service life used by the Norwegian ZEB research centre is 60 years.

  ✓ Consideration of different scenarios in a sensitivity analysis are recommended for buildings with shorter or longer service life than 60 years.

E.g. Sensitivity analysis results for 30, 0, 75 and 100 years SL for living lab

Service life (yr)	**A1-A3 ($kgCO_{2eq}/m^2/yr$)**	**B4 ($kgCO_{2eq}/m^2/yr$)**
30	89%	11%
60	57%	43%
75	47%	53%
100	38%	62%

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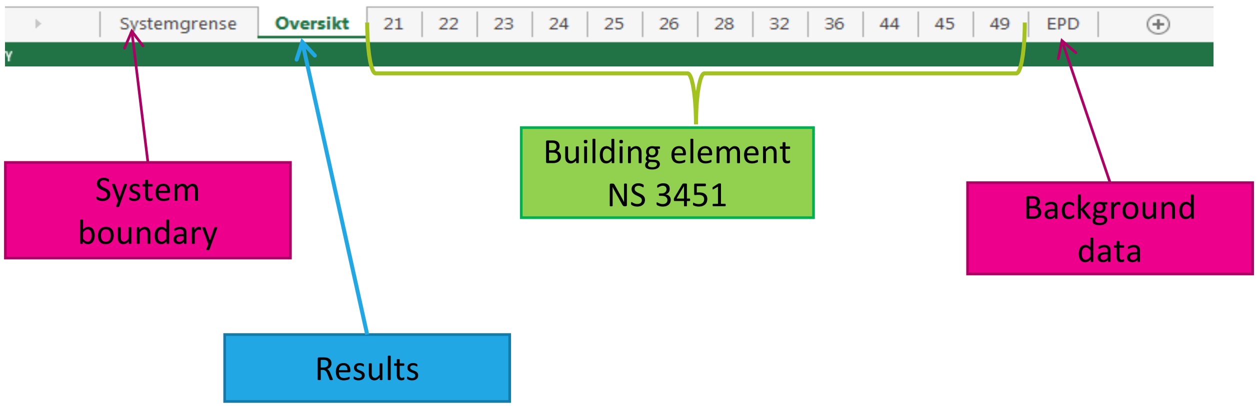
M.R. Inman, A. Houlihan Wiberg, Life Cycle GHG Emissions of Material Use in the Living Laboratory. ZEB Project report no 24, The Research Centre on Zero Emission Buildings (ZEB), 2015

Tools and data sources

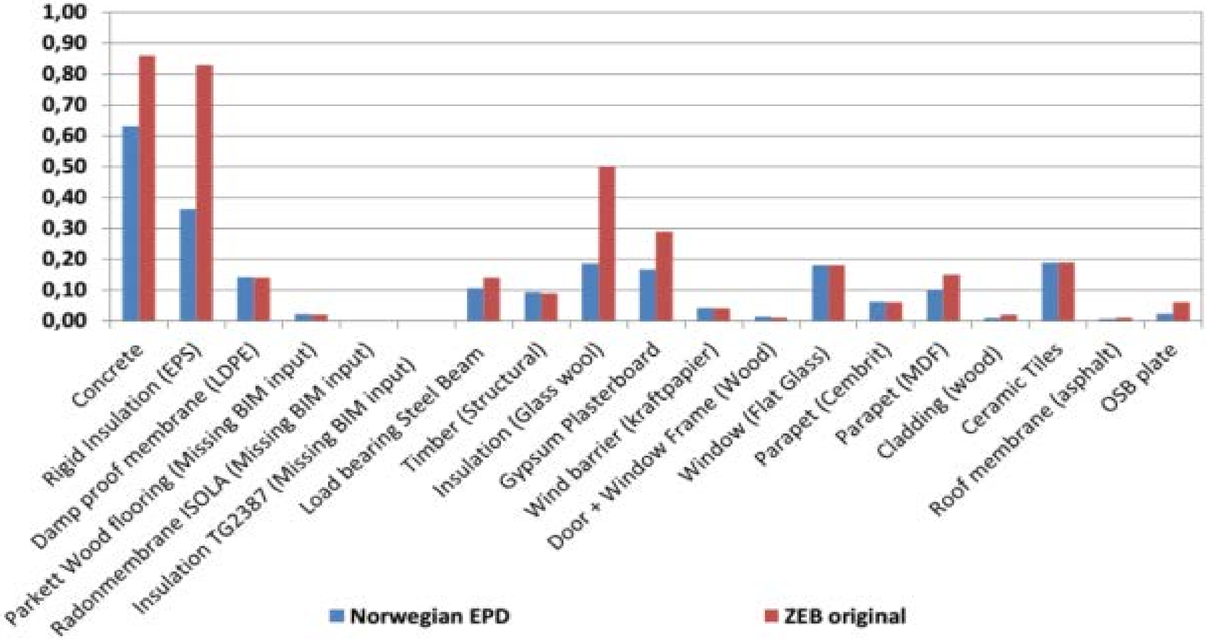
- Tools
  - ✓ Excel-based tool developed by the ZEB research centre



- Main source of background data
  - ✓ Product specific EPDs
  - ✓ Generic data from ecoinvent
  - ✓ Technical datasheets from producers

Tools and data sources

- A sensitivity analysis was performed on ZEB single family house concept study to investigate the influence of the choice of data.
  - ✓ Plasterboard, concrete, and insulation materials were selected for the sensitivity study since these materials were responsible for the highest emissions apart from PV in this case study.
  - ✓ It was found that the baseline emissions of 7.2 $kgCO_{2eq}/m^2/yr$ could be reduced to 5.8 $kgCO_{2eq}/m^2/yr$ if specific data for concrete, insulation, plasterboard, and wood were used.



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Houlihan Wiberg, L. Georges, S. Fufa Mamo, B. Risholt, G.C. Stina, A zero emission concept analysis of a single family house: Part 2 sensitivity analysis. ZEB Project report no 21, The Research Centre on Zero Emission Buildings (ZEB), 2015

A. Houlihan Wiberg, L. Georges, S. Fufa Mamo, Good Clara Stina, B. Risholt, Sensitivity analysis of the life cycle emissions from an NZEB concept, in: CISBAT 2015, Switzerland, Lausanne, 2015.

Replacement interval (B4)

- The number of replacement of materials is based on the estimated service life (ESL) from SINTEF Building Research Design Guide (BKS) 700.320 and EPDs.

Number of replacements of product (j) = E [ReqSL/ESL(j) -1] (according to EN 15978)

Whereby, ReqSL is the required service life of the building,

ESL is the estimated service life,

j is the product,

subtracting 1 represent the material used in initial construction at year 0

E rounds the factor to the nearest whole integer.

'If, after the last scheduled replacement of a product, the remaining service life of the building is short in proportion to the estimated service life of the installed product, the actual ***likelihood*** *of this scheduled replacement should be taken into account.'*

Replacement interval (B4)

- In most of the ZEB pilot cases, the number of replacements of products have been calculated without rounding up.

Example: Window ESL = 40 years

A1-A3 emission from window = 103 $kgCO_{2eq}$ (*NEPD 00176E Rev 1)*

Building service life = 60 years

Replacement interval = (60 / 40) - 1 = 0,5

Replacement interval	**A1-A3 ($kgCO_{2eq}$)**	**B4 ($kgCO_{2eq}$)**	**A1-A3 and B4 ($kgCO_{2eq}$)**
(60 / 40) - 1 = 1 (according to EN 15978)	103	103	206
(60 / 40) - 1 = 0,5 (using ZEB method)	103	51,5	154,5

➢ Whole number of replacements can be subjective, does it make sense to calculate partial cycles of replacement?

Reference

NEPD 00176E Rev 1, NorDan NTech Inward opening tilt & turn window 105/80, The Norwegian EPD Foundation, Oslo, Norway, 2014.

Replacement interval (B4)

- The calculation of the number of replacements based on todays practice, without considering the dynamic nature of buildings

- In ZEB research center, the replacement scenario (B4) of PV modules, a 50% reduction of the environmental impacts relative to the A1-A3 impacts can be used.
  - ✓ Assumption: the PV system will be produced 50% better in 30 years' time, with half the amount of material emissions per m^2.
  - ✓ The assumption is mainly considering increased material efficiency, improved production processes and the transition to increased use of renewable energy in the production process.
  - ✓ This assumption significantly affects the embodied material emission results, as PV modules are one of the main emission drivers in the Norwegian concept and pilot ZEBs.

➢ Why only the emission reduction for the replaced PV is considered? What about the influence of potential future technological advancements (e.g. advancements in windows and insulation materials)?