Building integrated photovoltaics: Examples from Norway

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Building Integrated Photovoltaics for Norway (BIPVNO) www.bipvno.no

• Competence project supported by Research Council of Norway (2015-2019): Identify and develop robust BIPV-solutions for Norwegian climate and irradiation conditions.


• Partners from building industry and PV suppliers:
Performance of BIPV (integrated) and BAPV (attached) installations in Norway

➢ Desired outcome: Learn what to expect from a system, practical experience & advice for future improvements.
  - What is the power production for PV installations in Norway?
  - How do results compare to international studies?
  - What are the challenges? (Integration and architecture, building techniques, installation, operation and maintenance.)

➢ BIPV defined as Construction product in EN 50583 “Photovoltaics in Buildings” – but some suppliers define it as ‘blends with’ the roof or façade.
Norwegian BAPV installations: Many similarities, e.g. flat rooftops
Norwegian BIPV installations: More varied, but mainly c-Si technology
Case: Oseana arts & culture centre (60.18°N, 5.47°E)

BIPV façade/roof installation (2011):
- Black mono-Si 63.5 kW_p (463 m²).
- Annual average 800 kWh/kW_p (2012-2015).
- Standard panels, slight adjustments to standard fastening components.

Why built?
Owner/initiators (municipality and architect) wanted outstanding environmental architecture.

Extra costs due to:
- Panel type changed late in project (architect); new lay-out.
- Small deviations in as-built dimensions.
- Difficult installation near water front, curved façade, scaffolding. Delays due to winter: Snow and icing of components.

Not commercially competitive solution (then):
Received public and private support.
Case: Solsmaragden office building (59.74°N, 10.19°E)

BIPV façade installation (2015):
- Frameless glass-glass mono-Si (1242 m²) facing West, South, East, (North).
- Annual average 580 kWh/kWp (estim.) for BIPV + BAPV rooftop system (115.2 kWp + 67.8 kWp).
- Developed own fastening method using standard brackets for façade (safety) glass.

Why built?
Owner (building developer) wanted highest energy mark and outstanding environmental architecture.

Extra costs due to:
- Special module design, green printed glass. Few suppliers to choose from.
- 22 different module sizes (arch. integration).
- Complex string design/installation.

Not commercially competitive solution (yet):
Received public support (Enova).
Case: Brynseng school and sports hall (59.91°N, 10.81°E)

BIPV façade installation (2016/17):

- All-black frameless glass-glass, mono-Si. 26 different module sizes for arch. integration.
- 166 kWp (South), aired cladding, insulation behind withstand moisture.
- Annual average 630 kWh/kWp (estim.).
- Fastening method developed by façade installer: Panel hooked onto standard glass-facade brackets on battens of climate wall.

Why built?

Test out near-ZEB as part of environmental strategy. Roof area not available; south façade ok.

Lessons learnt:

- Much work to clarify specifications; unclear regulations for fire safety and electrical requirements.
COSTS: Brynseng school and sports hall

Total costs: 7.7 Mill NOK (7360 NOK/m²) = 0.83 Mill Eur (791 €/m², or 5 €/Wₚ).

Subtract 'normal' tile facade: 3.1 Mill NOK (3000 NOK/m²) = 0.34 Mill Eur (323 €/m²).

Added BIPV costs: 4.6 Mill NOK (4400 NOK/m²) = 0.49 Mill Eur (473 €/m², or 3 €/Wₚ).

Support from Enova: 4.5 Mill NOK = 0.48 Mill Eur.

Not commercially competitive (yet) – but maybe next project, savings possible!
Case: Skarpnes residential ZEB (58.43°N, 8.72°E)

BIPV pitched roof installation (2014/15):
- Black mono-Si 7.4 kWp (40 m²), η ~19.5%.
- Yield 970 kWh/kWp (first year, avg 5 houses).
- Standard modules replacing tiles, Solrif fastening system.

Why built?
Building developer wanted competence and competitiveness; first Nordic ZEB-village.

Close to commercially competitive solution:
- PV system: 3000 NOK/m² (350 €/m², or 1.9 €/Wp) plus projecting/installation (Skanska).
- Project received public support (Enova).
- Market still immature; ZEB harder to sell.
- Aesthetically pleasing; happy inhabitants.
- Unclear who responsible for follow-up (performance monitoring, questions, etc).

Owner: Skanska/Private.
PV: Solcellespecialisten (DK).
Examples from suppliers: SunNet AS

- Technology (1): PV roof tiles
- Technology (2): Roof integration

Installation video: http://sun-net.no/taktegl/
PV roof tiles (before/after roof renovation)
Inverter for low voltage PV roof tiles:

- Parallell connections: Low voltage & High shade tolerance
- In: 5 inlets (70 / 35 V\textsubscript{DC})
- Out: 50 Hz, 230 V\textsubscript{AC}, $\eta$(EU) = 92.5 %
- 5-year warranty
COSTS: Roof tiles
5 kWp (55 m²) residential system

Total 14.8 k€ + vat ≈ 270 €/m² (3.0 €/Wp) + vat

- 555 roof tiles (9 Wp) = 94 kNOK (10.1 k€) + vat
- 4 inverters: 27 kNOK (2.9 k€) + vat
- Cables, monitoring (mob/app): 17 kNOK (1.8 k€) + vat
- Total 138 kNOK + vat = 14,8 k+ vat

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<tr>
<th>Pos</th>
<th>Artikel</th>
<th>Produkt beskrivelse</th>
<th>Antall</th>
<th>Pris pr stk</th>
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<td>kr</td>
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<td>SUM MED BATTERI</td>
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<td>kr 170 894,00</td>
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(1 Eur = ca 9.3 NOK)

• ‘Anyone’ can install (low voltage, quick, similar to normal roof tiles).
• Today no service agreement offered; «help out if the customer needs it»…
Integration, glass-glass modules
COSTS: Roof Integration
5 kW\textsubscript{p} (30 m\textsuperscript{2}) residential system

Total 8.3 k\texteuro{} + vat \approx 280 \texteuro{}/m\textsuperscript{2} (1.7 \texteuro{}/W\textsubscript{p}) + vat

- 18 PV modules (290 W\textsubscript{p}) = 49 kNOK (5.2 k\texteuro{}) + vat
- 1 inverter = 9 kNOK (1.0 k\texteuro{}) + vat
- Cables, overvoltage protection = 6 kNOK (0.7 k\texteuro{}) + vat
- Solrif construction with flashing = 13 kNOK (1.4 k\texteuro{}) + vat
- Total 77 kNOK + vat = 8.3 k\texteuro{} + vat

\begin{tabular}{|c|c|c|c|c|}
\hline
Pos & Artikel nr & Produkt beskrivelse & Antall & Pris pr stk & Total pris \\
\hline
1.0 &  & Solitak solcellpanel 290 Wp & 18 & 2 695,00 & 48 510,00 \\
1.1 &  & Inverter Sami Power SolarLake 5500 & 1 & 9 177,00 & 9 177,00 \\
1.2 &  & Kablingboks inkl. overvanningsvent. & 2 & 2 851,00 & 5 702,00 \\
1.3 &  & Kabler 4mm2 inkludert plugger & 50 & 15,00 & 750,00 \\
1.4 &  & Solrif konstruksjon med flashing pr pa & 18 & 704,00 & 12 672,00 \\
\hline
SUM &  &  &  &  & 76 811,00 \\
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\end{tabular}

(1 Eur = ca 9.3 NOK)

- Solarif-Solitak glass-glass modules; normal roof tiles around.
- Installers must have ‘Solrif certificate’ to install.
- In case of shading, more complex string design than roof tile system.
Examples from suppliers: Solel AS

- «Suited for Nordic weather conditions»
- REDAir system: Insulation system with few heat bridges, incombustible, easily adjusted to different designs/backwalls.

- ET Solar EliTe black mono-Si modules (265-275 W<sub>p</sub>), 1.63 m<sup>2</sup>, ~16-17%.
- In future: REC panels, aluminum from Raufoss, to lower the C-footprint.
- Uses ‘Norwegian definition’ for BIPV: <em>blends</em> with roof/facade.
Case: Kistefossdammen kindergarten
Commissioned Feb. 2017

- Futurebuilt project, Plus house
- ET Solar 275 W<sub>p</sub> mono-Si modules
- 54.5 kW<sub>p</sub>, >45 500 kWh/yr (835 kWh/kW<sub>p</sub> est.)
- SolarEdge inverters with optimizers
- BIPV: «Filled the whole roof exactly»
Case: Holmen swimming pool
Commissioned spring 2017

- Futurebuilt project, BIPV ‘adapted to the full facade’
- Facade (S) + rooftop (E/W)
- 93 kW_p black ET Solar mono-Si 270 W_p (E/W roof & south-facade, 198+116 panels).
- 4 SMA string inverters, 2 facade (10+20 kW).
Cases: Bjørkelangen school
Bråtealeen kindergarten
Commissioned 2017

- Facade integration, black ET Solar mono-Si, SMA inverters.
- **Bjørkelangen**: 35.2 kW$_p$, 125 panels (275 W$_p$), SMA 2 x 15 kW.
- **Bråtealeen**: 75.6 kW$_p$, 230 panels (280 W$_p$): Facade 40 all black; roof 190 with silver frame; SMA 3 x 20 kW + 1 x 9 kW.
- Bråtealeen: Pre-fabricated modules from Lithuania, insulated elements fitted into wall (demanding pre-preparation).
COSTS – Solel BIPV:

• Note: Projects sold two years ago (now finished) were more expensive; not comparable with today’s prices. Costs depend largely on amount of projecting.

• Today can deliver wall systems around same costs as roof, provided easy access to the wall.

• BIPV wall system, 25-75 kW\(_p\) range: \(~ 290 \, \text{€/m}^2 + \text{vat}\).
  – PV system: 13 NOK/W\(_p\) = 2150 NOK/m\(^2\) (231 €/m\(^2\)) + vat, installed
  – Insulation/fastening: 525 NOK/m\(^2\) (56 €/m\(^2\)) + vat, installed.
  – In total: 2675 NOK/m\(^2\) + vat = 287 €/m\(^2\) + vat.

• Replaced facade material costs may be subtracted.

• Currently seeing stop in price reduction, supply shortage.

(1 Eur = ca 9.3 NOK)
If time allows . . .

A brief look at PERFORMANCE ANALYSIS
Near-horizontal systems (E/W):

- **ASKO, Vestby (E/W, poly-Si, 370.5 kW<sub>p</sub>)**
  - (2015-2016): Estim. _ kWh/kW<sub>p</sub>/ Meas. 810-688 kWh/kW<sub>p</sub>

- **Haakonsvern, Bergen (E/W, mono-Si, 84.6 kW<sub>p</sub>) [1]:**
  - (2015-2016) Estim. 663 kWh/kW<sub>p</sub>/ Meas. 651 kWh/kW<sub>p</sub>
  - Malfunctioning circuit breaker: Corrected output 693 kWh/kW<sub>p</sub>

- **Kjørbo, Sandvika (E/W, N/E, mono-Si, 312 kW<sub>p</sub>):**
  - (2015-2016): Estim. 735 kWh/kW<sub>p</sub>/ Meas. 700-718 kWh/kW<sub>p</sub>

- **Kiwi Fjeldset, Elverum (E/W, mono-Si, 94 kW<sub>p</sub>) [1]:**
  - (2016): Estim. 746 kWh/kW<sub>p</sub>/ Meas. 624 kWh/kW<sub>p</sub>
  - Missing data: Corrected output 697 kWh/kW<sub>p</sub>

Tilted systems:

• Kjøita Kristiansand (20º tilt, S, poly-Si, 45 kW<sub>p</sub>):
  – (2012-2016): Estim. 885 kWh/kW<sub>p</sub>, Meas. 923 kWh/kW<sub>p</sub>
  – Downtime due to circuit breaker (inverter shut-down)

• Skarpnes, Arendal (32º tilt, SE/SW, mono-Si, 7.4 kW<sub>p</sub> x 5):
  – (2016): Estim. 924 kWh/kW<sub>p</sub>, Meas. 970 kWh/kW<sub>p</sub>

• Evenstad Låven, Hedmark (34º tilt, SE, poly-Si, 70.4 kW<sub>p</sub>):[1]
  – (2014-2016): Estim. 853 kWh/kW<sub>p</sub> / Meas. 889 kWh/kW<sub>p</sub>

• Grøndalen gård, Auli (35º tilt, SE, CIS, 70 kW<sub>p</sub>) [1]
  – (2016) Estim. 935 kWh/kW<sub>p</sub> / Meas. 752 kWh/kW<sub>p</sub>
  – Grid capacity/inverter shut-down: Corrected output 894 kWh/kW<sub>p</sub>

Facade systems (South):

- **Oseana, Bergen** (curved, mono-Si, 63.5 kW_p):
  - (2012-2016): Estim. 661 kWh/kW_p [2], **Meas. 804 kWh/kW_p**

- **Solsmaragden, Drammen** (vertical, green mono-Si, 27.1 kW_p):
  - (2016): Estim. _ kWh/kW_p, **Meas. 609 kWh/kW_p**

- **Lerkendal, Trondheim** (vertical, poly-Si, 27 kW_p):
  - (2014-2016): Estim. _ kWh/kW_p, **Meas. 407 kWh/kW_p**
  - Initially 530 kWh/kW_p, ~30% loss due to shading (buildings)

- **Kiwi Fjeldset, Elverum** (vertical, mono-Si, 2.6 kW_p) [1]:
  - (2016): Estim. _ kWh/kW_p, **Meas. 404 kWh/kW_p**
  - Missing data; corrected output 465 kWh/kW_p


Colors indicate different PV strings/inverters

Solsmaragden (facade)
Solsmaragden – Results 2016

<table>
<thead>
<tr>
<th>Location</th>
<th>Specific yield (kWh/kWp)</th>
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<tbody>
<tr>
<td>Facade East</td>
<td>324 kWh/kWp</td>
</tr>
<tr>
<td>Facade South</td>
<td>609 kWh/kWp</td>
</tr>
<tr>
<td>Facade West</td>
<td>331 kWh/kWp</td>
</tr>
<tr>
<td>Roof E/W</td>
<td>726 kWh/kWp</td>
</tr>
</tbody>
</table>

Note: Tilt 10°
Solsmaragden – Monthly performance results 2016/17

Efficiency and PR, South facade Solsmaragden

Efficiency (%)

PR

Eff Sør1 (inv7) (%)  Eff Sør2 (Inv8) (%)

PR Sør1 (inv7)  PR Sør2 (Inv8)
Summary

• Still most BAPV systems, mono- and poly-Si.
• Yield data from South/Mid-Norway correspond with expectations:
  – Flat roof E/W-systems: Annual yield ~700 kWh/kW_p
  – Facade systems: Large variation (orientation, shading).
  – Well-performing facade systems achieve annual yields similar to flat roof E/W systems, with better winter production.
  – Optimal tilt in Southern Norway >900 kWh/kW_p
  – PR ~0.8 achievable, less in winter (snow), downtime etc.
• Large losses associated with shading. Important that PV design is included early in building process.
• Increasing number of BIPV systems; black facade/roof, roof tiles.
• Costs BIPV: ‘Special’ is expensive, ‘standard’ is (soon) competitive.
Thank you!

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