IDL TOWER: LCOE CALCULATION AND LCA

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Innovation call

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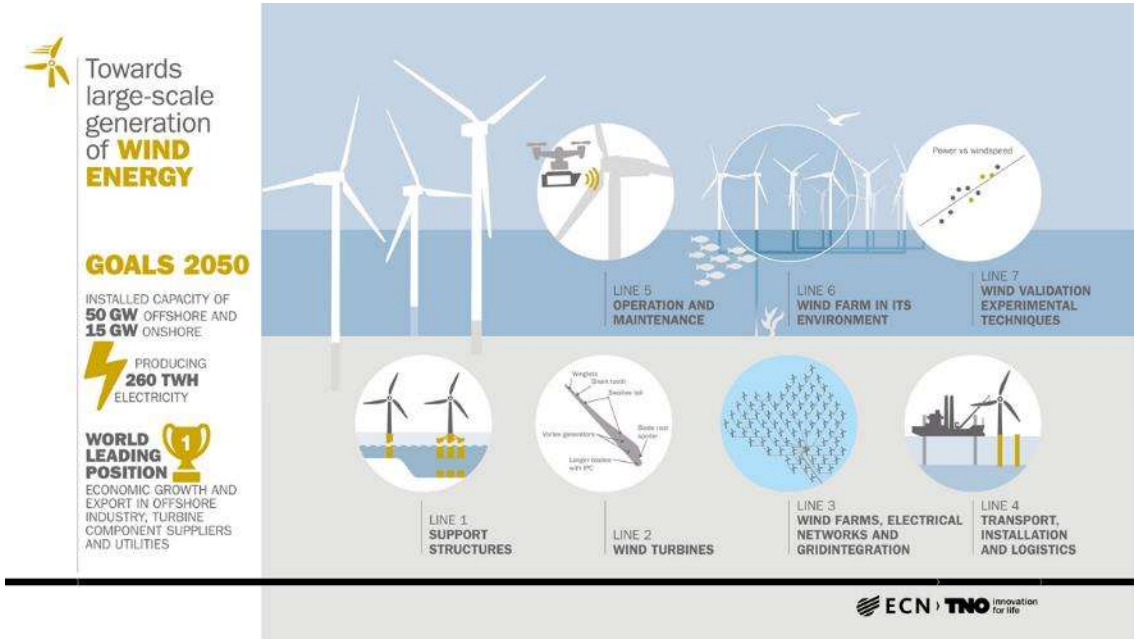
AGENDA

- Introduction & Motivation
- LCOE modelling and simulation
  - IDL tower case study: Comparing LCOE steel vs composite tower case
- Life cycle assessment
  - IDL tower case study: Comparing environment impact between steel vs composite tower case
- Conclusions and recommendations

TOWARDS LARGE-SCALE GENERATION OF WIND ENERGY



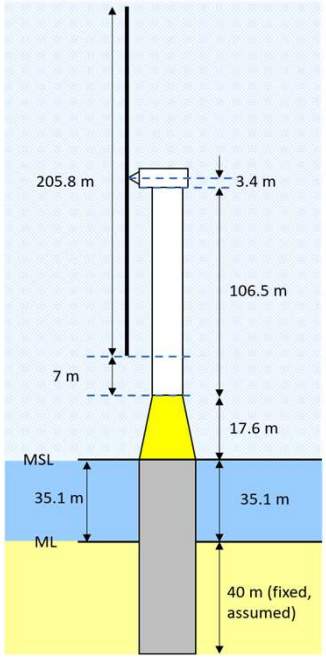
IDL TOWER BACKGROUND

- Continuation of C-Tower: >40% lighter tower concept based on GFRP
- The aim is to evaluate the technical, economic and environmental effects of a lighter, more flexible composite tower, with substantial lower eigen frequencies than a conventional steel tower.
- Alternative for steel tower
  - Energy intensive steel fabrication
  - Less weight in transportation
  - Less maintenance against corrosion and other environmental effects

IDL TOWER SCOPES & WORKS

- Integral Design Study
- Developing production methods
- Prototyping and laboratory testing
- LCoE including effects of installation and O&M
- LCA / end-of-life
- Valorisation, patenting and certification

IDL TOWER DESIGN



- Avatar 10 MW x 77 WT = 770 MW (Borssele area)
- For the integrated tower design, an offshore load set according to IEC 61400-3:2009 was used.
- The composite tower, steel transition piece and steel monopile were optimized using the FOCUS6 software and verified for ultimate, buckling and fatigue strength and eigenfrequency constraints
- Layup composite tower (GFRP polyester)

	Steel	IDL	Red
Material price (€/kg)	1.80	4.63	
Tower mass (mT)	790.3	320.5	**-59.4%**
MP Mass (mT)	1186.0	788.6	**-33.5%**
TP Mass (mT)	251.0	162.2	**-35.4%**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LCOE
CALCULATION

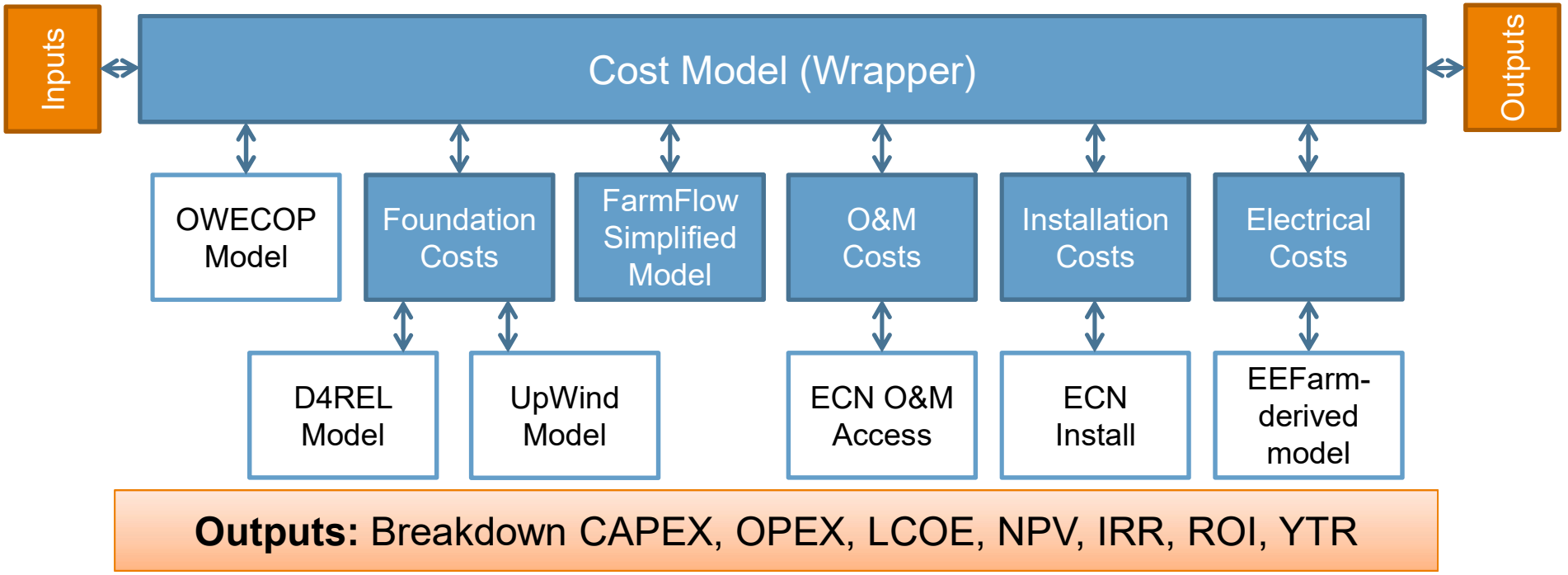
ECN COST MODEL

- The cost model is developed with the idea to provide an economic evaluation of an offshore wind farm:
- Currently is tuned for “traditional” OWF, but flexible enough to be expanded with new technologies/knowledge
  - Wind turbine with a single (3 bladed) rotor
  - Monopile support structure
  - Rectangular or square shape farm
  - Installation and O&M with SOVs and/or CTVs that are used in today’s market
  - Typical electrical infrastructure

$$LCoE = \frac{\left(\frac{CapEx}{a} + OpEx\right)}{AEP}$$

- Next development are: floating support structure, multi-rotor/airborne technology, etc.

ECN COST MODEL



STEEL VS. IDL TOWER CASES

Installation

- *Deck space: 3600m2*
- *Crane: 1000 mT*
- *Cargo 6000 mT*
- *Cases:*
  - Steel: 3 WTs or 3 foundations per trips
  - IDL: 4 WTs or 4 foundations per trips

A: 100%

- *Deck space: 4600m2*
- *Crane: 1500 mT*
- *Cargo 8000 mT*
- *Cases:*
  - IDL: 6 WTs or 6 foundations per trips

B: 160%

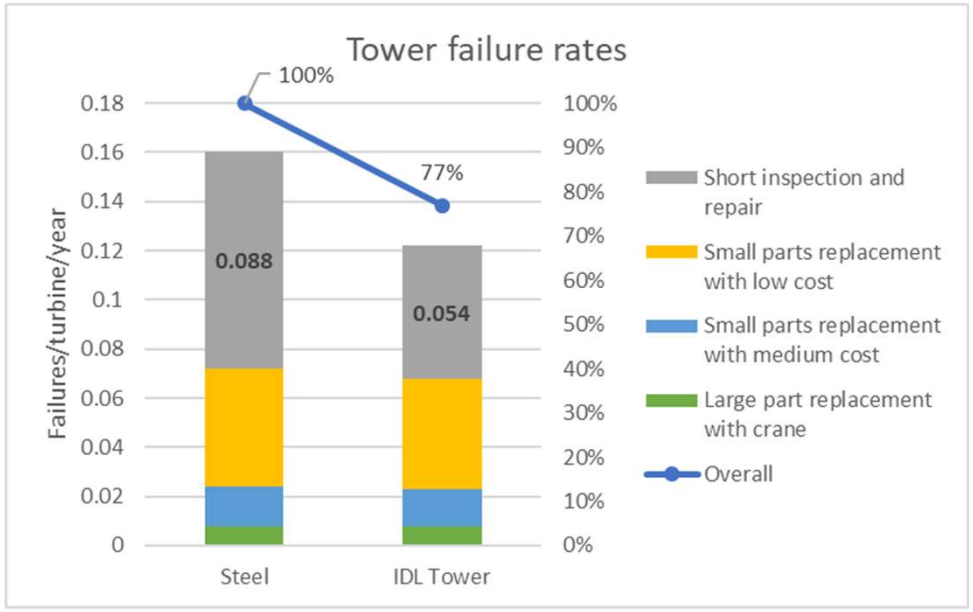
- *Deck space: 3200m2*
- *Crane: 600 mT*
- *Cargo 4000 mT*
- *Cases:*
  - IDL: 12 towers/trip
  - Add vessel type A to carry 5 nacelles, hubs and blades

C: 50%

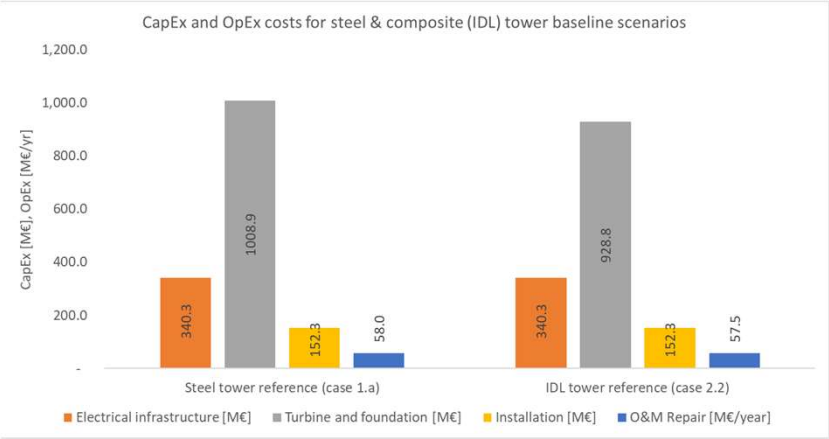
STEEL VS. IDL TOWER CASES

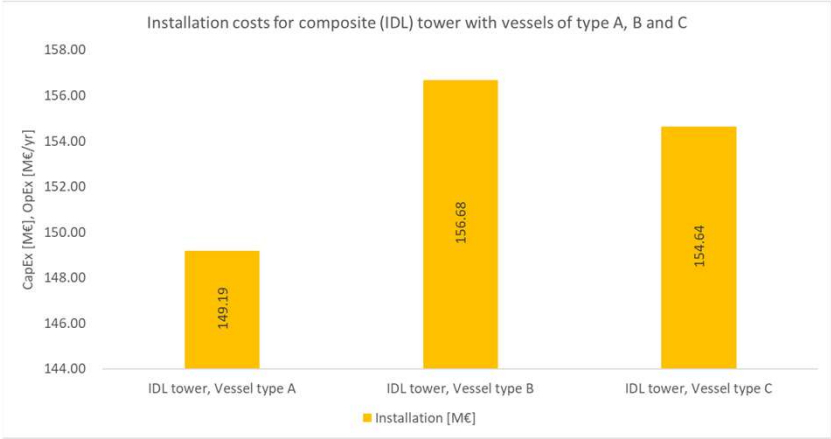
O&M

- Changes only in UMD – Turbine Structure / Tower failure rates
  - Reduction in short inspection and repair (bolts and welding)
- Same maintenance response as default
  - Short inspection and small repair
    - 4 hours
    - Using consumables
    - 3 technicians



RESULTS

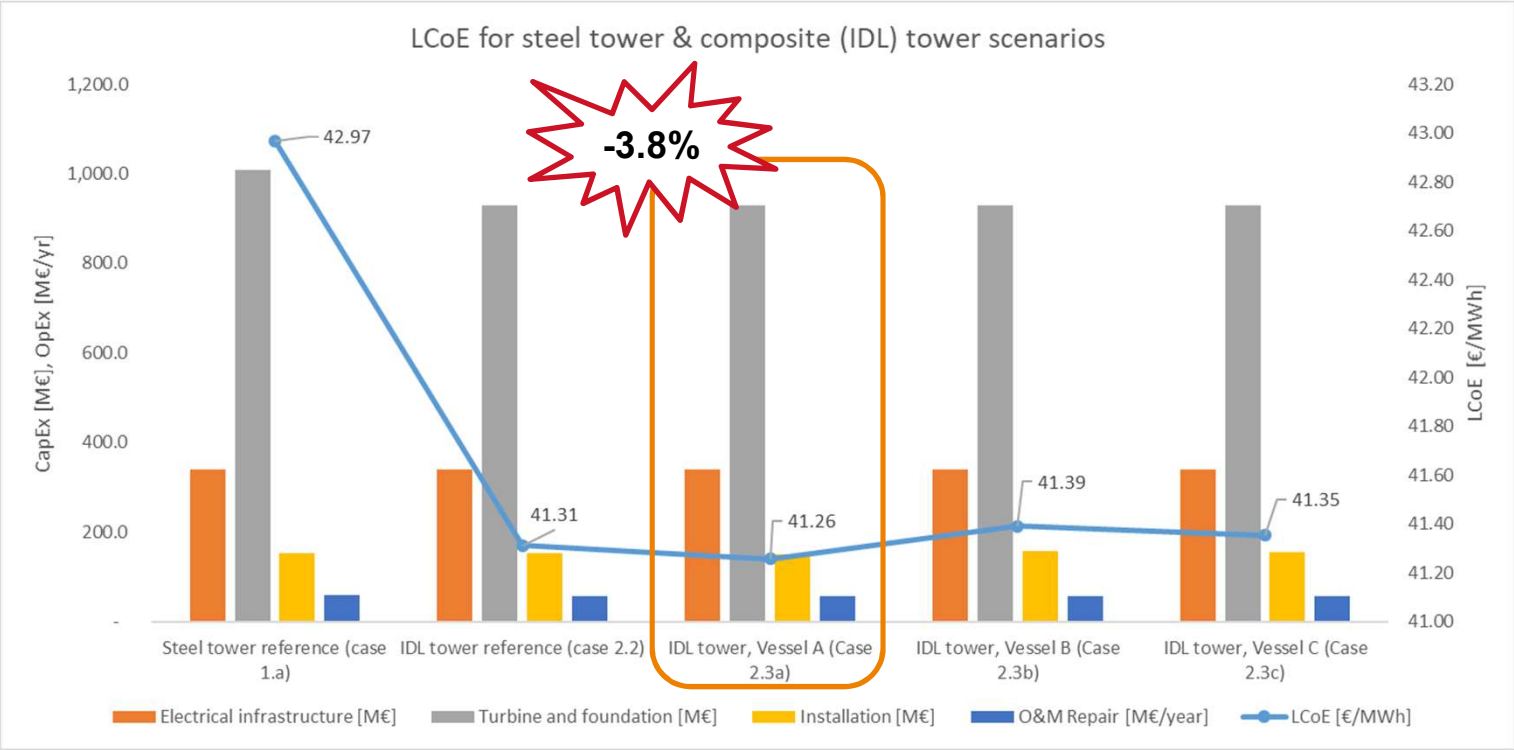




- Reductions
  - Tower & foundation costs: 80M€
  - O&M costs: ~0.5 M€/year

- Using vessel A (Carry 4 sets of WTs/trip and 4 sets of foundations/trip) is the cheapest
- Reduction of 3.1M€ or 2% of installation costs

SUMMARY


LCoE for steel tower & composite (IDL) tower scenarios
-3.8%
42.97
41.31
41.26
41.39
41.35
1,200.0
1,000.0
800.0
600.0
400.0
200.0
-
CapEx [M€], OpEx [M€/yr]
43.20
43.00
42.80
42.60
42.40
42.20
42.00
41.80
41.60
41.40
41.20
41.00
LCoE [€/MWh]
Steel tower reference (case 1.a)
IDL tower reference (case 2.2)
IDL tower, Vessel A (Case 2.3a)
IDL tower, Vessel B (Case 2.3b)
IDL tower, Vessel C (Case 2.3c)
Electrical infrastructure [M€]
Turbine and foundation [M€]
Installation [M€]
O&M Repair [M€/year]
LCoE [€/MWh]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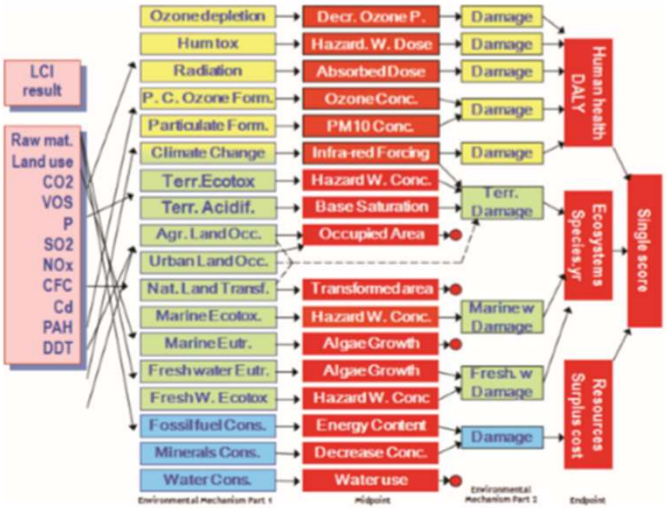
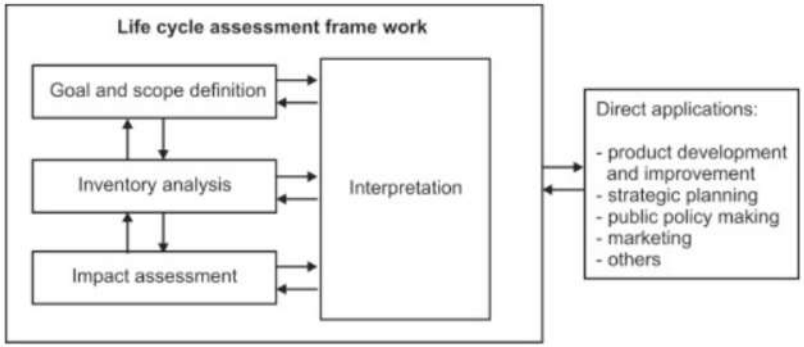
LIFE CYCLE ASSESSMENT

LIFE CYCLE ASSESSMENT

- LCA is a methodology used to evaluate the environmental impacts associated with a product or service throughout their life cycle, by
  - Compiling the environmental inputs and outputs
  - Evaluating their potential environment impacts
  - Considering their life cycle

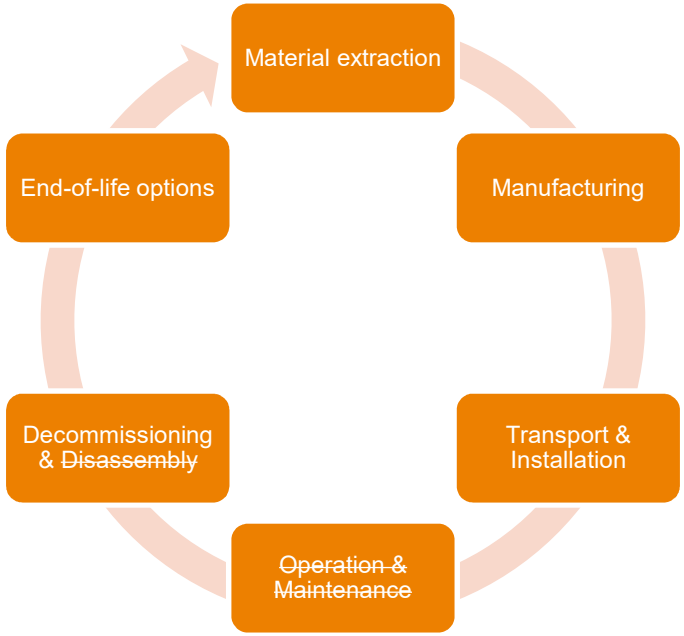




IDL VS STEEL CASE LCA

- Scope
  - Components:
    - Foundations: monopile + TP
    - Tower: steel vs composite
  - Process (see pictures)

- Functional unit: 1 piece of each component
- Methodology
  - ReCiPe 2016 Mid point / End point (E)
  - Energy cumulative demand
- Tool: SimaPro



MATERIAL & MANUFACTURING

- Foundations (monopile + TP)

Figure: © COWI A/S.

Steel case	IDL Case
• 99% steel (incl. rolling & welding) • 1% aluminium, alkyl resin, powder coating, copper, lead	
TP: 251 mT MP: 1186 mT	TP: 162.2 mT MP: 788.6 mT

  - 33.8% reduction in weight (foundations)
  - Add: heat, tap water, electricity mix based in NL

- Tower

Steel case	IDL Case
• 98.2% steel (incl. rolling, welding) • Rest: copper, steel coating, alkyl resin, etc.	• 62% glass fibres • 37% polyester resin • Organic chemical for curing agent and coating • Emission: 0.25%-w styrene
790.3 mT	320.5 mT

OTHER PHASES

Installation

- Perform by jack-up vessel “Transport, freight, sea, transoceanic ship”tonnes.km
- tonnes.km
  - Vessel usage
  - Fuel consumption
  - Maintenance
  - Port facilities
  - Emissions
  - Waste and waste treatments

O&M

- No large replacement (foundations, towers)
- Almost no difference in vessel use
- Calculation is excluded

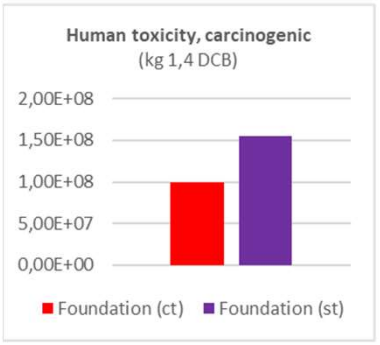
Decommissioning

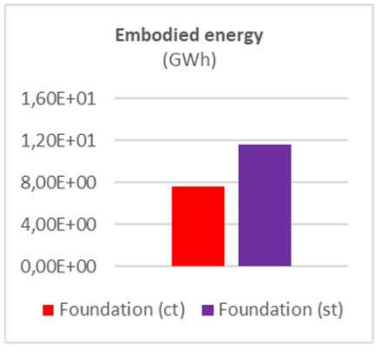
- Perform by same type of vessels as installation
- Decommissioning = installation port distance

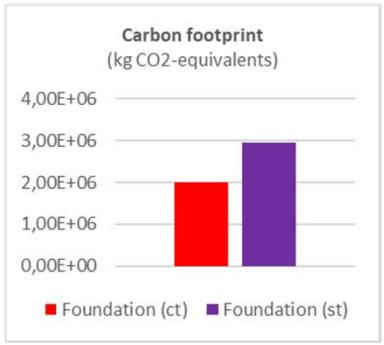
End of Life

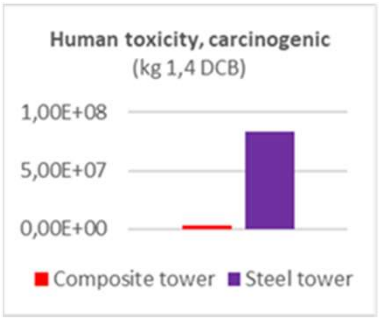
- Steel, copper, and aluminium are recycled (80-90%) based on TNO’s model
- GFRP is incinerated
- Other is sorted, incinerated, or landfill

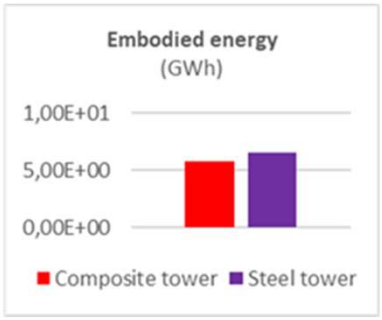
LCA RESULTS: MATERIAL COMPARISON

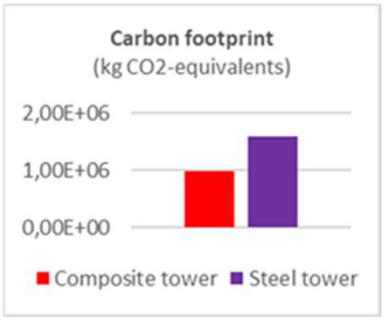










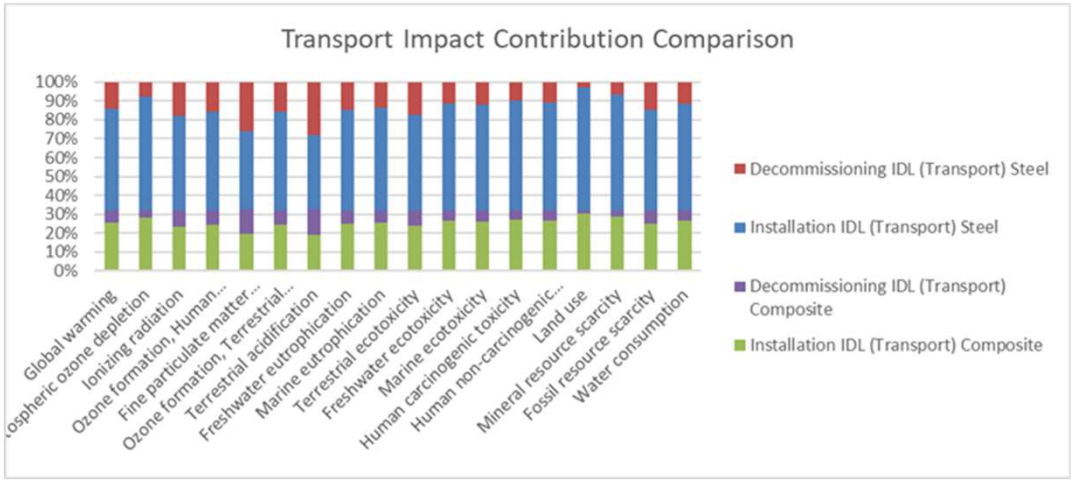


IDL Tower: LCOE Calculation and LCA

- Foundations: factors of the weight (reductions of 33.8%)
- Embodied energy difference is marginal (tower)
- Almost all impact categories, IDL tower < steel towers
  - Except 2/18 (stratospheric ozone depletion and land use)

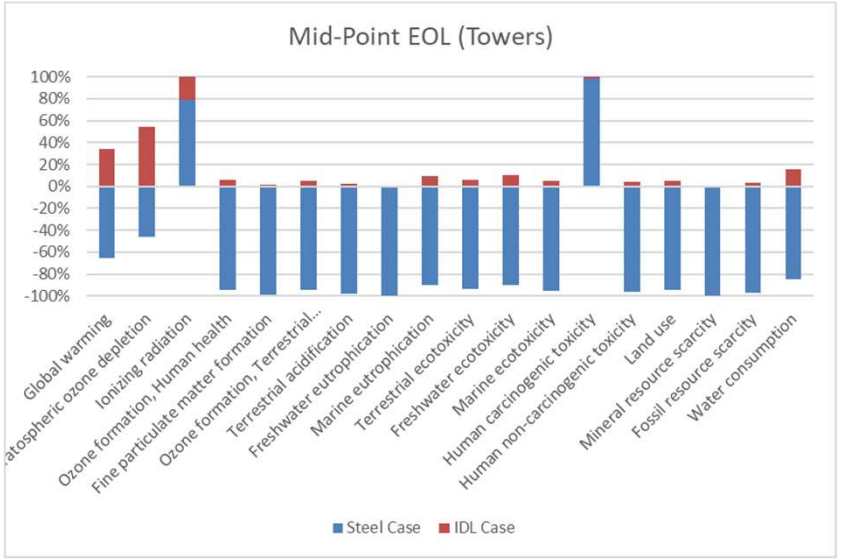
LCA RESULTS: TRANSPORT RELATED

- IDL tower case has less impact than the steel tower as it's less weight to carry (all proportional)
- Installation & Decommissioning contribution is very small compared to overall life cycle (<5%)

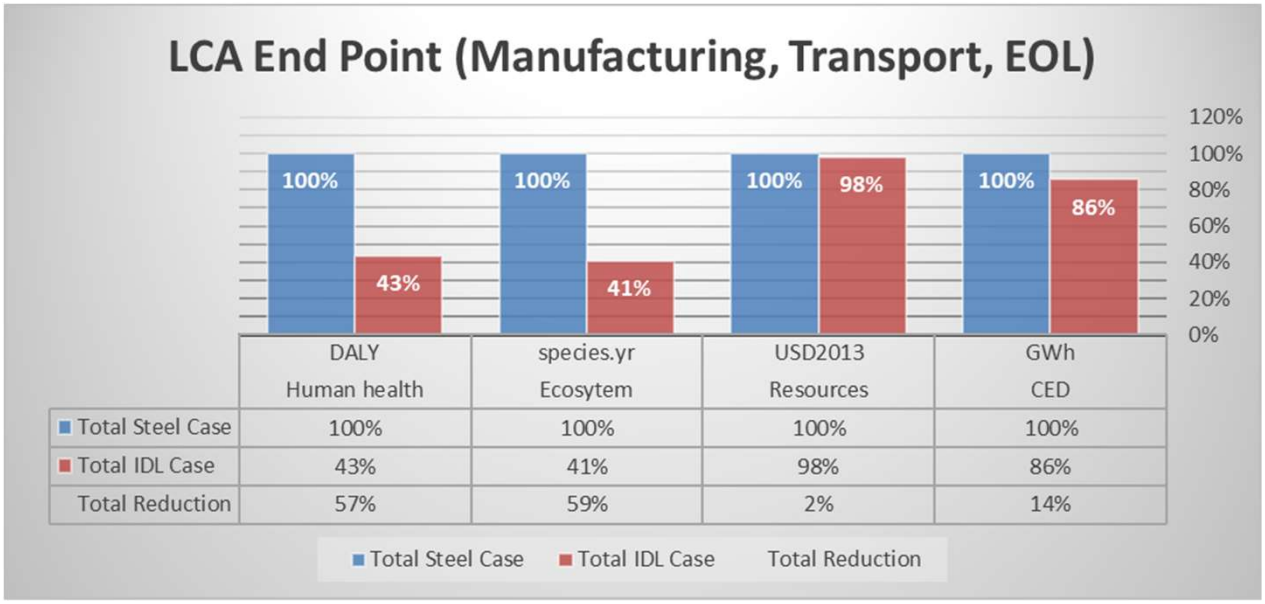


LCA RESULTS: END OF LIFE

- Steel is relatively easy to recycle → potential environment benefit or credit in the future
- For foundations, steel case gives higher benefit
- For towers
  - Steel tower gives high benefits as MP + TP
  - Composite tower is not recycled hence
    - Additional impacts at the end-of-life



OVERALL LCA COMPARISON

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CONCLUSION

CONCLUSIONS

- IDL Tower: reductions of 59.4% and 33.8% mass reduction in tower and foundation

- Costs and environment impacts/benefits can be evaluated,
  - ECN Cost model is used to get insight in LCOE or costs breakdown
  - LCA is used to evaluate technology beyond their economic values

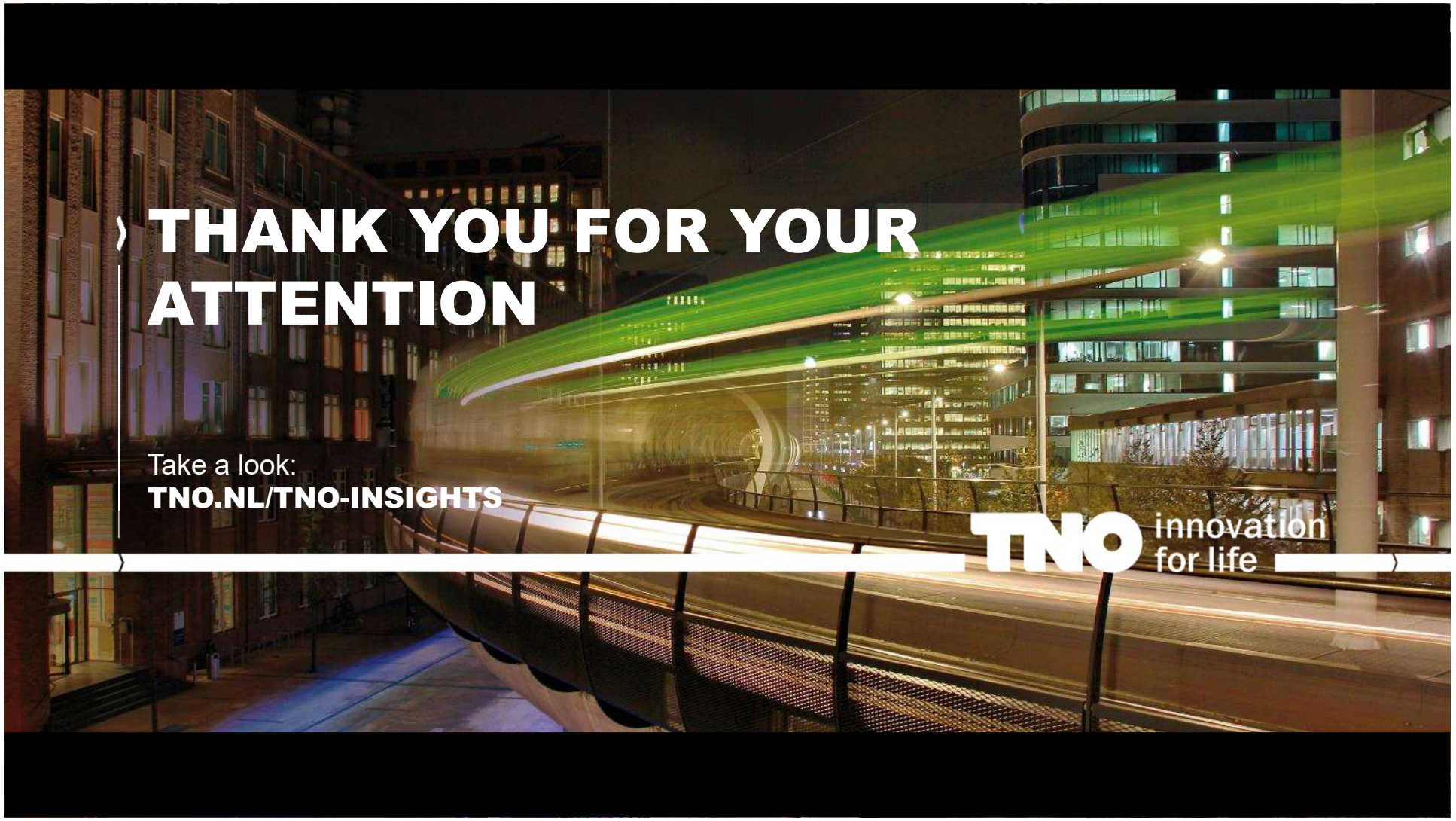
- IDL tower case led to ~3.9% LCOE reduction, mostly come from weight reduction but also installation
- IDL tower case led to lower environment impacts in total, even though at EoL composite tower shows higher impacts,
  - Steel is highly and easily recycled hence at the EoL there is potential environment credit
  - Potential benefit (not included) if composite is recycled

RECOMMENDATION & NEXT STEPS

- Further validation in the manufacturing, usage related to the O&M, and certification.
- Further roll out: real life demonstration to monitor the performance, degradation, load and vibration measurements

- Sensitivity (LCOE and LCA) when using IDL tower with current and future turbine sizes
- CAPEX of IDL tower will be influenced by economies of scale and production capacity

- Development of composite recycling within the wind industry
- When viable recycling processes are included, it is expected that the composite case will have potential environmental benefit as in steel tower case.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