Sand-Based High Temperature Seasonal Heat Storage by Polar Night Energy Oy

Avoided Emissions Framework – Level 2 version 0.8 assessment

≈100 MtCO_2e/year in 2030

Assessment conducted: 2020

Contents

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Overview

In Mission Innovation's Net-Zero Compatible Innovations Initiative, assessments are being performed following the Avoided Emissions Framework (AEF) guidance [1].The aim of the assessments is to estimate the potential avoided greenhouse gas (GHG) emissions per year in 2030[1] enabled by Sand-Based High Temperature Seasonal Heat Storage and other similar competing innovations.

Any assessment of this nature requires significant assumptions, and the result has a high degree of uncertainty. Thus, this report describes the calculation method, data sources and assumptions used for this avoided emission assessment.

The Sand-Based High Temperature Seasonal Heat Storage enables storage of renewable energy when the energy production conditions are beneficial. The stored renewable energy can then be used in different energy demanding processes, replacing fossil-based combustion technologies that are common nowadays for heating and electricity production. This innovation is provided by Polar Night Energy Oy (PNE), a company with headquarter in Tampere, Finland.

With the heat storage, surplus energy from solar and wind power can be stored during periods of high production. The stored heat can then be used to replace energy input from fossil fuels for internal heat and electricity generation. Compared to combustion-based technologies, combining solar and wind power with the PNE storage allows the reduction of CO_2 emissions from energy use by 772.8 gCO_2e/kWh.

Sand-Based High Temperature Seasonal Heat Storage enables the potential avoidance of 169.8 $MtCO_2e$/year in 2030.

A simplified sensitivity analysis gives potential lower and upper values of 56.6 $MtCO_2e$/year and 283.1 $MtCO_2e$/year, respectively.

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[1] Avoided emissions are calculated for the year 2030 as $MtCO_2$ equivalent per year. The estimation is NOT cumulative.

Method

This assessment estimates the annual avoided emissions potential of the innovation and potential competing innovations for the year 2030, as part of Mission Innovation's Net-Zero Compatible Innovations Initiative aiming at identifying innovations that can significantly contribute to decarbonisation by 2030.

The assessment method follows the guidance provided in the Avoided Emissions Framework (AEF) [1]. To demonstrate the benefit of the innovation to reduce overall system level GHG emissions, this assessment quantifies and compares the GHG emissions from a business-as-usual (BAU) baseline scenario with those from an innovation-enabled scenario. This involves calculating emissions in the following categories:

- **BAU scenario.** The emissions from the BAU baseline, without the introduction of the enabling innovation.
- **Innovation scenario**. The emissions from the innovation-enabled scenario: a scenario where the enabling innovation is introduced.
- **Potential enabled avoided emissions:** The potential avoided emissions due to the activities avoided as a result of using the innovation.

  $Enabled\ avoided\ emissions = Innovation\ scenario - BAU\ scenario$

- **Innovation emissions**: The life cycle emissions (i.e. direct and indirect emissions) of the innovation.
- **Rebound effects**: The increase in BAU emissions occurring as result of the enabling innovation implementation.

Further information required to quantify absolute potential avoided emissions, includes:

- **Market Volume.** Volume of potential deployment of the innovation in a specific geography by 2030.[2]
- **Market Share.** Proportion of the market volume that could be dominated by the innovation under assessment by 2030.[3]

[2] An important issue of future-oriented avoided emission assessments is the calculation of the future market for an innovation. There is no expert consensus yet on a systematic way to approach this issue. Thus, the future market volume is calculated ad-hoc and based on information from the innovation provider.

[3] The market share is normally based on an extrapolation of existing market developments or on the market that the innovation is expected to develop.

Using the information below we can derive:

- **Net potential avoided emissions**

$$= Potential\ enabled\ avoided\ emissions\ -\ Direct\ innovation\ emissions\ -\ Rebound\ emissions$$

- **Carbon Abatement Factor**[4] = Net potential avoided emissions per unit quantity of the innovation implemented.

This assessment evaluates future potential avoided emissions. Thus, there is uncertainty about the future development and deployment of this innovation that needs to be considered. The Avoided Emissions Framework (AEF) provides guidance on how to assess future potential scenarios. It suggests considering two factors: the **probability of success** of the innovation, and the **probability of adoption** of the innovation. In this assessment we have included the two probability factors together within a **'market share'** factor.

The calculation can then be summarised as follows:

Net Potential Avoided Emissions
= Carbon Abatement Factor × Market Volume × Market share

[4] A carbon abatement factor is a normalised factor reflecting the avoided emissions per unit of innovation implemented. This factor provides consistency and comparability among studies. It can be thought as an analogous to "emission factors" used in product footprints.

Assessment

Description of the innovation

The Sand-Based High Temperature Seasonal Heat Storage enables storage of renewable energy when the production conditions are beneficial. The stored renewable energy can be used in different energy demanding processes, replacing fossil-based combustion technologies that are common nowadays [2].

Readiness levels

The Technology Readiness Level (TRL) of this innovation is 7: System prototype demonstration in operational environment. Pilot plant operational and connected to local heating grid [2].

The Business Readiness Level (BRL) of this innovation is: 6: Full business model including pricing verified on customers. First offers have been sent and all components are verified in terms of prices and applicability [2].

The TRL and BRL were assessed using the innovators information and following the EU Horizon 2020 guidelines [3] and KTH Innovation Readiness level™ model [4].

Mechanism for avoiding carbon emissions

The Sand-Based High Temperature Seasonal Heat Storage avoids emissions through one main mechanism. The solution enables upscaling and more effective use of wind and solar energy as energy can be stored during periods of high supply and used during periods of high demand. As the solution enables heat storage up to 700°C it allows the replacement of fossil fuels used for both heating and steam production, as well as electricity generation [2].

Calculation

Market Volume

The market is defined in terms of renewable energy made available thanks to storage possibilities. Since the world energy use is to be transformed to 100% renewable energy, the energy storage capacity needs to be considerably developed. In this assessment it was assumed that 17% of the generated renewable energy will need to be stored by technologies similar to that offered by Polar Night Energy Oy [5]. With a projected gross electricity production of 4 390 TWh from solar and wind power in 2030 [6], the storage technologies will enable the replacement of 737 TWh of fossil-based energy. Hence, the total potential market is **737 TWh**.

Market share

The innovation is the most effective for industrial usage where high temperatures are needed. It is, however, difficult to forecast this kind of energy demand in 2030. The market share is an assumption made by the assessor and is set to 30% of the available renewable energy that needs to be stored.

The relatively high market share is chosen due to the solutions variety in use. As the solution can be used to generate both electricity and heat, for industrial use and in district heating system – the supply of excessive renewable energy will be a more significant limiting factor for the innovations carbon abatement potential than the ability to take market shares.

Net Potential Avoided Emissions

1. BAU scenario

According to IEA projections, the industry sector in 2030 will have a demand of 38 505 TWh of fossil-based energy from coal (42%), oil (28%) and natural gas (30%) [6]. The fossil-based energy has an average emission factor of **795.9 gCO_2e/kWh** (Coal 1 001 gCO_2e/kWh; oil 840 gCO_2e/kWh; natural gas 469 gCO_2e/kWh) [7].

2. Innovation scenario

Considering a technical lifetime of 30 years, the innovation has an emission factor of 2 gCO_2e/kWh related to production and deployment of the heat storage [2].

Energy supply forecasts from IEA suggest that the ratio between solar and wind energy will be approximately 1/3 solar energy and 2/3 wind energy in 2030 [6]. Using emission factors for wind power as 12 gCO_2e/kWh, solar photovoltaics (PV) as 46 gCO_2e/kWh and concentrated solar power (CSP) as 22 gCO_2e/kWh [8] gives an average emission factor of 23.12 gCO_2e/kWh for stored renewable electricity.

Including both deployment emissions and emissions from renewable electricity production, the emissions add up (23.12 gCO_2e/kWh + 2 gCO_2e/kWh) to 25.12 gCO_2e/kWh.

The storage has a thermal efficiency of 91% [2]. Assuming that the coal, oil and natural gas input to the industrial sector is primarily used for heat production, this gives a total impact from the innovation scenario as 25.12 / 91% = **27.61 gCO_2e/kWh**.

3. Rebound effects[5]

Potential negative rebound effects are e.g. increased energy usage when heat and power is clean (psychological effect) [2]. A positive indirect effect is reduced fuel transportation. However, the emissions from fuel transportation will have a minor effect on the total result and have therefore not been evaluated.

[5] Rebound effects may be caused by related consequential effects or by unrelated (and sometimes unintended) effects and are often caused by human behavioural changes in demand for carbon-intensive goods or activities.

4. Net potential avoided emissions

Carbon Abatement Factor

The carbon abatement factor is the difference between the avoided CO_2 emissions per kWh when using solar and wind power combined with the innovation, and those when using the fossil-based energy (oil, coal, natural gas):

795.9 gCO_2e/kWh (fossil-based energy) – 27.6 gCO_2e/kWh (renewable energy + innovation impact) = **772.8 gCO_2e/kWh**.

To increase transparency, the net avoided emissions are again presented using the equation from the Method section.

$$Net\ avoided\ emissions = 772.8\ \frac{gCO_2\mathrm{e}}{kWh} \times 736.8\ \mathrm{TWh} \times 30\ \% \ = \mathbf{170}\ \boldsymbol{MtCO_2}\mathbf{e}$$

Table 1 outlines the values of the terms in the equation above.

Table 1. Calculation factors and assessment result

	Unit	*Value*
Carbon Abatement Factor	gCO_2e/kWh	772.8
Market Volume	TWh	736.8
Market share	%	30
Net Potential Avoided Emissions	$MtCO_2e$/year	170

Sensitivity Analysis

In order to give some perspective to the results, a simple sensitivity analysis was performed by changing assumptions. The increased emissions from the innovation up to 10 gCO_2e/kWh is an assumption to show the relative insignificance of the factor on the total result.

According to calculations made by the innovator, forecasts regarding need for energy storage ranges between 10% and 20% of the renewable energy production. These lower and upper values have been tested in the sensitivity analysis in Table 2.

Table 2. Sensitivity analysis

Scenarios	Change from base case	Net potential avoided emissions ($MtCO_2e$/year)
Base case		169.8
Reduced market share	Reduced from 30% to 10%	56.6
Increased market share	Increased from 30% to 50%	283.1
Increased emission from innovation	Increased from 2 to 10 gCO_2e/kWh	167.9
Reduced need of stored energy	Reduced from 17% to 10%	101.2
Increased need of stored energy	Increased from 17% to 20%	202.4

Results and discussion

The Sand-Based High Temperature Seasonal Heat Storage and other innovations like it are estimated to enable the potential avoided emissions of 170 $MtCO_2e$/year in 2030.

A simplified sensitivity analysis gives potential lower and upper values of 57 $MtCO_2e$/year and 283 $MtCO_2e$/year, respectively.

This assessment can only provide an approximate estimate at best since it is attempting to calculate a figure of potential avoided emissions that the impact of a new technology will have in more than 10 years' time. It is therefore subject to considerable uncertainty.

The potential avoided emissions are dependent on the future development of renewable energy installations, as the magnitude of fossil fuel replacement is confined to the surplus renewable energy production. The other way around, possibilities to store intermittently produced renewable energy could also facilitate a growth of the renewable electricity sector.

In this assessment, the magnitude of potential carbon saving is limited by the generation of renewable energy that needs to be stored. However, it can be argued that the innovation also has the potential to enable the transformation from fossil-based combustion technologies to renewable ones, even though the energy comes from other sources than excessive solar and wind energy. In this way the carbon saving potential of the innovation is significantly larger than the assessment indicates.

One current obstacle on the European market is that EUs energy tax does not take the supply and demand of energy into consideration. One of the benefits of the innovation is that it can be charged with energy during periods when there is a large supply of energy at low cost. If the energy tax remains the same in periods of low demand, there is a risk that the profitability of the innovation is negatively affected. Regulations will probably have a large effect on how fast the innovation will be implemented in industries at a global scale.

The innovation also has the potential to be used in district heating systems. The innovator has done calculations on the application of the innovation in the district heating system of Helsinki, and the results indicate the 96% of CO_2e saving compared to a BAU scenario. However, this is a complex system and the efficiency of the system depends on further factors than the implementation of the innovation, e.g. the expansion of wind energy generation. Therefore, this market has not been evaluated in this assessment.

United Nation Sustainable Development Goals (SDG)

The innovation has been identified as potentially relevant to the Sustainable Development Goals (SDG) defined by the United Nations [8]. Based on the data acquired by the assessor the innovation may have the following effects:

- **Strong positive impact on SDG nr 7: Affordable and clean energy**
  Motivation: In alignment with SDG target 7.2: *"By 2030, increase substantially the share of renewable energy in the global energy mix".* The innovation enables upscaling of wind and solar energy. In that way clean energy is available during periods where it today is not available.
- **Partial positive impact on SDG nr 9: Industry, Innovation, and Infrastructure**
  Motivation: In alignment with SDG target 9.2 *"Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries".* The innovation enables access to cheap and clean energy during all hours.

Inventory of key data sources

Table 3. Summary of data sources for calculations

Data item description	Reference	Page number / location
Energy storage capacity in 100% renewable system	[5]	P. 27
Energy generation	[6]	"World" tab
Energy consumption	[6]	"World" tab
Electricity Emission Factor projections	[8]	"Global" tab

References

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