Statens vegvesen

Technology survey for renewable energy Integrated to bridge constructions

Solar energy

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Solar Energy Technology Survey for Ferry Free E39 Project

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Peter Kovacs och Peter Wahlgren

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Executive Summary

This report is the result of a potential study for solar energy utilization in the E39 Ferjefri project carried out by SP Technical Research Institute of Sweden on behalf of Statens vegvesen in Norway. The study is intends to give a basis for the work with solar energy integration in the project. The results can thus contribute to the definition of planning targets in a medium and long term perspective and to an increased awareness about the possibilities that are in solar energy utilization.

The study distinguishes between two forms of solar energy, namely conversion of solar irradiance into electricity or into heat. For integration into bridge constructions, only electricity production by means of PV technologies has been quantitatively assessed. Solar thermal technologies for heat production has only been considered qualitatively in terms of building mounted collectors serving parts of the heating- and hot water needs of the buildings and in snow melting systems using the roads as solar collectors.

The report gives an update on solar thermal and solar PV technologies including the applications foreseen in the E39 project, it explains the methodology, the input data and different assumptions that were used to assess the potential. It shortly describes the different bridge types that offer opportunities for solar energy production. The study reports a technical potential for heat and electricity production based on best available commercialized technology (BAT) but in other aspects it gives quite a conservative assessment of i.e. accessible surface. No government subsidies or other incitements such as e.g. feed in tariffs have been considered in the analysis.

The total estimated solar PV energy production is 321 GWh if suspension bridges are used for all crossings. This is equal to the annual demand of 64 000 single family houses using 5000 kWh each. If floating bridges are used for all crossings, the corresponding figures are 77 GWh and 15 400 single family houses. In a sensitivity analysis, an increase in module efficiency of 20% within five to ten years has been seen as highly probable and the impact on the total potential of this has therefore been calculated. The effect of changing the slope of modules mounted on the sides of the bridges from 90 to 45 degrees, thus achieving a more optimum energy collection, is also described. Finally the significance of using relevant irradiation data is elucidated by estimating the optional energy output using Trondheim instead of Bergen data. In this case the potential energy production would increase from 321 to 433 GWh and from 77 to 93 GWh for the cases described above.

It is assumed that all electricity being produced will meet an ”unlimited” demand. In the case of solar heat only a qualitative analysis has been performed since the potential in this case will be limited to the demand on site and this was not possible to assess.

The report does not assess the financial viability of the suggested applications but gives a platform for such calculations. The most important message in that respect is that feasibility studies should be updated frequently, in consideration of the conditions prevailing in each individual construction project and taking into account the rapid development of technologies and prices in this field.

1 Introduction

E39 is a road that is located along the west coast of Norway and extends from Kristiansand in the south to Trondheim in the north. Currently, a number of ferry crossings are required to traverse its entire length. The Transport Ministry has given a mandate for the project “Ferry Free E39” to assess the technological solutions for the crossing of eight large fjords without ferries. The fjords crossings range from 1.5 km to 25 km in length and have depths up to 1300 m. Proposed solutions for the crossings that are under consideration consist of suspension bridges, floating bridges and submerged floating tunnels.

The Energy part of the project is to consider how the construction of the crossings can be combined with devices that produce energy from waves, tides, wind and the sun. The idea is that by using the bridge construction as part of the facility, the production cost of renewable energy can be reduced and therefore become more competitive with non-renewable energy sources.

SP Technical Research Institute of Sweden has been commissioned by the Norwegian Public Roads Administration to perform a technology survey and generate a summary of the current state of the art ***solar energy conversion technologies***. As solar energy conversion into heat and electricity is mature technology and different tracks of development are well known, the state of the art can be clearly described. Furthermore, achievable conversion efficiencies are also well known and proven which we mean makes the potential assessment highly credible.

The study gives a basis for the work with solar energy integration in the Ferjefri project. The results can thus contribute to the definition of planning targets in a medium and long term perspective and to an increased awareness about the possibilities that lies in solar energy utilization. The study focuses on two bridge types, suspension bridge and floating bridge, and that potential has been calculated for each of the eight crossings.

The report does not contain a strategy or an action plan for the realization of this potential, but such work should be a natural next step.

2 Update on Solar thermal technologies

Solar thermal installations can be divided into two main categories:

- Solar thermal power production where solar light is concentrated with parabolic dishes or troughs and used to generate high temperatures, normally above 500°C. The heat is then used to generate electricity by means of e.g. a steam cycle or a sterling engine.

- Solar heat production where solar collectors are used to generate heat in the region of 30°C to 250°C to be used e.g. to heat swimming pools, tap water, buildings and industrial processes.

In this study only the latter is considered due to the fact that concentrating technologies for high temperature applications only uses a fraction of the total solar energy available namely the direct irradiance. In the region of E39 the fraction of direct to global irradiance is between 30 and 50 % which, in combination with the relatively low annual global irradiation makes these technologies inappropriate.

2.1.1 Conceivable applications and installation requirements

Even though we believe that Solar PV should be prioritized in the Ferjefri project, solar water heating could provide significant contribution in two applications, namely for tap water heating and for defrosting and snow melting.

Tap water heating is foreseen in conjunction to the construction projects and in roadside restaurants and rest areas. For this application, conventional solar water heating systems with freeze protected solar collectors (flat plate or vacuum tube) and short term (diurnal) heat store should be used together with a supplementary heat source. This could be a heat pump, an electrical resistance heater, a gas heater, a biofuel based heater or a combination of these. In case a large scale underground seasonal heat store would be built in combination with a defrost installation (see next paragraph) this store could then also be used to feed heating and hot water installations in nearby buildings. This would mean that a much higher fraction of the annual load could be covered. Due to the anticipated small scale of the water- and space heating installations it would however not be rational to build seasonal stores for this application alone. At least not with today’s costs for smaller seasonal stores.

In either case, all conventional solar collectors are expected to be placed either on the ground, onto or integrated in the buildings. From different practical reasons it is not desirable to have solar thermal collectors installed on the bridges.

Defrosting and snow melting by means of stored solar heat would sound like a very good idea for the entire Ferjefri project, or at least for all bridges. However, previous studies [14] , 15] have shown that such installations are in general very costly. Several projects were however realized. A conclusion from a Swedish Thesis work [16] is that in order to keep the peak power at a reasonable level and simultaneously achieving a high level of safety, i.e. efficient snow melting, the ground or bridge surface need to be constantly heated during the cold season. The fraction of energy needed for keeping the ground above the freezing point will thus be around 95% of the whole input and on the whole, huge amounts of energy will be required. Further complicating is the fact that a road on bridge has approximately twice the heat loss to the ambient compared to a road on the ground.

Thus, even if the road itself could function as a solar collector during the sunny season, the costs for having heating loops integrated in the road and for a seasonal heat store (normally bore holes or an aquifer) will in general by far exceed the cost for conventional snow removal.

It might nevertheless be motivated to use this concept in special cases where frequent snow or ice removal would be difficult to carry out with the required frequency using conventional methods. Examples are very steep parts of the road or at the exit of tunnels, in particular when the tunnel is connected to a bridge. Examples of some snow melting systems are given in chapter 8.4.1.

2.1.2 Operational characteristics

The main operational characteristic of a solar thermal energy installation in northern climate is that approximately 60% of the annual energy is harvested during four summer months and 5- 10% in the four winter months. Thus it is obvious that a seasonal store is necessary for any installation where heating needs during winter are to be covered. For conventional solar heating installations without seasonal storage this means that a significant heat demand during the summer season is required if the installation shall be economically feasible.

Freeze protection is required and can be solved in different ways, the state of the art solution being that of using a water/ glycol mixture as a heat carrier. This has some drawbacks both from cost, efficiency and environmental point of view and an alternative that is superior in all these respects is that of using water as a heat carrier in drain down systems. In such a system the heat carrier is drained from the collector loop to an insulated reservoir when there is no heat available. This technique has mainly been used in the Netherlands but so far all attempts to apply it in northern climates have failed with freezing and destruction of the installations as a result.

2.1.3 Performance characteristics

The intended application for solar heat will govern the required temperature level and this in turn decides which type of solar collector to use. The higher temperature level needed, the more efficient and thus more expensive collectors are needed. For any given collector type, the energy gain in a specific installation and thereby the return on investment will to a large extent depend on the mean operation temperature of the collector. The profitability of a solar thermal installation is therefore more dependent on proper dimensioning and system layout than in the case of a solar PV installation. Changes in an existing system, e.g. a reduced heat demand will have a negative effect on the profitability.

In our analysis of the solar thermal potential we are considering the two applications described in 2.1.1: Tap water heating and defrosting/snow melting. In the former case an estimated average operation temperature is 60 °C and thus the state of the art product is efficient flat plate collectors. Performance parameters used in the calculation are shown in Table 1. Vacuum tube collectors is also an option but these are mainly competitive at higher temperature levels. Furthermore flat plate collectors are considered to be more robust in their construction which is the main reason why this type is recommended.

Vacuum tube collectors or super-efficient flat plate collector would be an option if solar cooling applications were considered but as we cannot foresee any particular need for cooling it has not been addressed in the following.

Table 1. Performance parameters for the flat plate solar collector

Optical efficiency $\eta 0$ [-]	First order heat loss coefficient a1 [W/m^2/K]	Second order heat loss coefficient a2 [W/m^2/K^2]	Incidence angle modifier b0 [-]
0,82	3,2	0,015	0,15

In a well-designed system the energy losses from the collector to the point of usage are low, in the order of 10-20%, but in a poorly designed system they can completely ruin the economy of the installation.

Figure 1. Installation using flat plate collectors. Foto: Arcon/ ESTIF

Figure 2. Installation with vacuum tube collectors. Foto: Thermomax/ ESTIF

2.1.4 Quality assurance in solar thermal technologies

The solar thermal industry and research institutions have developed at set of European standards used for testing and characterization of solar thermal products and systems. These are mainly the EN 12975 for collectors, EN 12976 for small domestic hot water systems and EN 12977 which is a more general component- and system standard. Based on these standards a system for voluntary product certification, the Solar Keymark, has been developed [9]. The solar Keymark has been in operation since 2003 and almost every collector sold in Europe has a Keymark certificate. The standards and the certification system are continuously being developed in order to take new types of products into account. CE-marking of solar thermal collectors is about to be introduced, but only for collectors placed on, or integrated in buildings. There are no requirements for CE-marking of solar water heating systems.

2.1.5 Relevant critical issues and resources for R&D

A key issue for solar thermal technologies is the fact that supply and demand often do not coincide, e.g. in the case of space heating needs. Cost effective solutions to long term storage for solar heat would therefore be a door opener for this technology and several different tracks of development are being researched. Amongst them, underground thermal energy stores, as aquifers or borehole stores are already in frequent use but still need further development, or higher costs of competing energy sources, in order to become competitive in the application discussed here.

Another development that could increase the competitiveness of solar thermal technologies is new components that enable building integration of energy production. The idea is that by replacing conventional construction materials or components by “solar collectors” the cost of the replaced component can be deducted from the solar investment cost. The potential for this kind of products is even higher in the PV field where so called BIPV is an acknowledge concept since long, but it should be an option also for solar heating.

SP Technical Research Institute of Sweden and Chalmers University of Technology, both located in western Sweden within comfortable distance to the E39 project, have a well-developed cooperation within energy research. Particular focus lies on HVAC systems, solar thermal- and heat pump technologies including borehole storages. Combined with high class laboratory facilities and world class expertise in these fields, SP and Chalmers are well prepared and highly interested in further cooperation with the E39 consortium.

3 Update on Solar PV technologies

Solar PV installations are, considering todays state of the art, reasonably flexible in terms of how PV modules can be mounted and which type of PV technology one can use in a particular application. In other words modules built from mono- or multi crystalline cells or from thin film can all be optimally used in most applications and the main reason for choosing one or another will be the price. One strength of the crystalline technologies is that they have a proven track record of at least 20-30 years which is not the case for most thin film products. The latter on the other hand offers some more degrees of freedom in integration as it can be applied on a wide range of different substrates including flexible and ductile ones.

For the same reasons as in the case of solar thermal, concentrating technologies are not considered in this study.

3.1.1 Conceivable applications and installation requirements

As already mentioned, we believe that solar PV should be prioritized before solar thermal in the Ferjefri project. The main reason for that is that heat demands that would be financially sound to cover with solar thermal energy, in connection to the bridges, will be small. Furthermore, as long distance transport of heat in this case is not an option, the small local needs will be a limiting factor. Electricity on the other hand can easily be grid connected and transferred to a remote point of usage and therefore such restrictions do not apply in that case. This is also the reason why only grid connected PV and not stand alone applications are considered in this study. The type of application in terms of electricity use is therefore of minor interest.

Extensive shading of PV modules will naturally reduce the energy output significantly but also partial shading of modules and arrays can have a strong impact on the performance. This must be considered in detail in the design of each installation and may reduce the potentially available surface when also non-solar aspects are taken into consideration.

The weight of a PV module can be estimated to 10-15 kg/m^2 including mounting equipment and cables. In addition to modules and cables, inverters are needed to convert DC power from the modules to AC power that can be fed into the grid. If part of the energy produced is used to power e.g. defrosting or road lighting, the inverter is not needed but instead an energy store (battery) will be needed.

Two different secondary uses of PV modules mounted on a bridge or a roadside can be foreseen: Noise barriers and wind breaker/ snow protection. None of them is optimal in this use and both would require careful design if the intended function should be achieved.

3.1.2 Operational characteristics

The main operational characteristic of a solar electric energy installation in northern climate is, as in the case of solar thermal, that approximately 60% of the annual energy is harvested during four summer months and 5- 10% in the four winter months. However, as it is assumed that all PV installations are going to be connected to the national electric grid, the issue of energy storage is basically solved. The energy generated can be used “anywhere” in Norway, or in Europe, where there is a demand and therefore does not have to be stored. On the other hand, large quantities of solar electricity being generated in phase with the rapidly changing irradiation will mean new challenges for the operation of the main grid.

3.1.3 Performance characteristics

Choosing the appropriate PV technology (assuming todays state of the art) will in general not be dependent on the type of application. Instead the choice will be governed by:

I. Costs, presently dropping with more than 20% per year for some technologies
II. Aesthetic and environmental concerns and requirements
III. Space requirements, as the specific output can be quite different for different technologies, typically 1,5 times higher per unit area for crystalline silicon compared to thin film technologies

Three main cell technologies are recommended for consideration in the Ferjefri project. Cells made from mono crystalline silicon, from polycrystalline silicon and thin film cells where the active surface consists of amorphus silicone or different combinations of e.g. cadmium, indium, selenium and copper, known as CIGS, CIS or CdTe cells.

Yet another technology is so called “Dye sensitized cells” but this one is not yet fully commercialized.

Figure 3 Three PV modules built on different technologies. From left to right: Module from polycrystalline silicon, module from mono crystalline silicon and a thin film module.

For this potential study it is assumed that todays’ best available modules built on mono crystalline technology are used and thus the calculations are based on a conversion efficiency of 20%. The main rationale for this is that this is the most efficient of the commercially available technologies and that the price is lower than that of thin film modules.

Large scale power inverters that will be used have efficiencies in the range of 97-99% and together with other ”external” system losses a maximum loss of 10% is assumed in the calculations. This gives a so called performance ratio PR of 0,9. An interesting but not yet fully commercialized concept are the so called micro inverters intended to be built into the PV modules that would thus deliver AC directly. For upcoming technologies see chapter 10.

3.1.4 Quality assurance in solar PV technologies

Quality assurance in PV technology has until quite recently been focused on the quality of the PV modules and only in the last years, PV specific inverter- and system issues have been taken into account with own dedicated standards. The main standards for performance and reliability qualification of PV modules are the IEC 61215 for crystalline PV modules and the IEC 61646 for thin film modules. Additionally for safety testing and assessment, the IEC 61730 or “Safety class II” standard is used. There is no certification scheme comparable to the Solar thermal’s Keymark scheme in operation but testing according to the above mentioned standards is often referred to as “IEC certification”. CE-marking of modules is compulsory for the European market.

3.1.5 Relevant critical issues and resources for R&D

PV technologies are being extensively researched these days and it’s hard to give a short but all inclusive picture of this work. Different tracks of development are facing different challenges and as already mentioned about the market, the outcome of these efforts are very difficult to predict. An illustrative example is that of thin film technologies competing against classical crystalline cell technology. Three or four years back thin film was catching up on Si. Market shares were approaching 20% and still increasing and a better cost/performance ratio than that of Si was soon expected. Today, thin film is down on less than 10% of the market due to the fact that Chinese Si modules have pulled the cost level down significantly. Additionally, the life expectancy of emerging thin film concepts has been difficult to prove. The latter is therefore a main challenge for the thin film research.

On a more applied level, building integrated PV or BIPV is a research field were a lot of work still remain in order to fully utilize options for double or triple use of energy generating components as building shell, sun shading etc.

SP Technical Research Institute of Sweden and Chalmers University of Technology are also cooperating in the field of PV and smart grid technologies. Chalmers has world class research in the field of organic PV and together with SP covers several different tracks in applied research. Test facilities for PV modules are currently being established at SP and the same for PV cells in laboratory scale is on its way at Chalmers.

3.1.6 PV producers contacted

The following producers or developers in the PV sector have been identified, contacted and invited to the Trondheim workshop on April 19th arranged by Statens vegvesen.

Table 2 Scandinavian PV industry invited to the Trondheim workshop

Company	Midsummer (SE)	Innotech Solar (NO)	Scatecsolar (NO)	Solibro (SE)
Activity	Developing and manufacturing CiGS cell production equipment and a small volume of modules based on these cells	Producing Si modules	Turnkey PV supplier	Developing CiGS cells
Web	www.midsummer.se/	www.innotechsolar.com	www.scatecsolar.com	www.solibro.se
Contact person	Sven Lindström	Tommy Strömberg	Kristian Hall	Mats Ljunggren
E-mail	sven.lindstrom@midsummer.se	tommy.stromberg@innotechsolar.com	kristian.hall@scatecsolar.com	mats.ljunggren@solibro-solar.com

4 Method

The work to estimate the potential for solar energy production on the bridges have been made in a number of steps that finally leads up to the amount of energy that can be produced on the different bridge types and crossings.

The following key elements have been implemented:

I. Gathering information of bridge structure, design, location and direction

II. Identification of appropriate tools to work with, see Appendix 2.

III. Collection of data: Climate data, performance data for solar thermal and PV, see Appendix 3.

IV. Calculation of available space and irradiation on the different surfaces.

V. Calculation of potential power production taking into account the system efficiency and a module factor accounting for necessary spacing between modules.

VI. Sensitivity analysis on the effect on the power production from:

   a. increasing efficiency

   b. changing module tilt and

   c. change of weather data location

The various software's and Internet resources used in the project are largely freely available or possible to purchase at a reasonable cost. What they are and what they have been used for can be seen in Appendix 2.

Summary of input data, calculations and compilation of results were made using an Excel sheet. Aggregated results are reported in tabular form in chapter 8. The Excel sheet is explained in Appendix 4 and the Excel sheet itself is appended to the report as a separate Excel file.

The same approach has been used for the suspension bridge and the floating bridge. The data are presented both as specific potential per kilometre bridge and for the entire bridge(s) using unique data for each crossing as presented in Appendix 1.

5 Input data and evaluation criteria

Input data used for assessment of power production as well as a number of assumptions made to simplify the analysis to a reasonable level of detail are summarized in the following. Appendix 3gives a more detailed presentation of the data.

Identified space possible to use for mounting solar PV modules:

- On both suspension and floating bridge it is possible to install solar PV modules on the driveway/ bridge sides. In total 2,5 meters module height that stretches along the bridges' total length.(1,5 meters height on bridge side below the driveway plus 1 meters height on the roadside barrier)
- In principle, without taking any mechanical loads into consideration, it would be possible to use all of the area created between the vertical wires for solar PV, on both sides of the suspension bridge. However, in our analysis we have assumed that 50% of the surface is used.
- It is possible to install solar PV modules as a roof over the driveway.
- The pylons on the suspension bridge could be covered with solar PV on all four sides.

Assumptions:

- Solar PV or solar thermal is not applicable for the submerged floating tunnel type.
- The width of the suspension bridge is 14,5 meters.
- The width of the floating bridge is 13 meters.
- Dimensions from the suspension bridge of Hardanger bridge and the floating bridge of Bjørnafjorden have been used to calculate the power production potential, see Appendix 3.
- The calculation of the pylons are based on the Hardanger bridge data, see Appendix 3.
- Climate data been taken from Bergen and used for all fjord crossings along the coastline. The irradiation data have been generated for each unique direction, inclination and fjord crossing.
- The solar PV installations on the sides, wires and pylons are mounted in a vertical position. As an option however, the higher power production resulting from a 45° module tilt instead of 90°, has been calculated for these installations.
- PV modules are placed horizontally on the roof.
- "Module factor" (see chapter 4) for all installations is 0,95.
- The system efficiency for solar PV is 18% for all calculations.

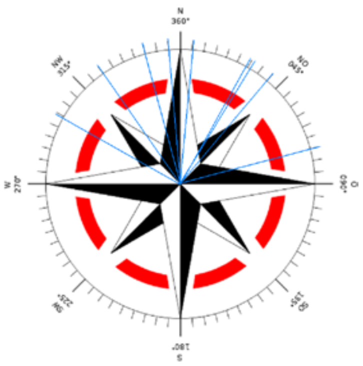

Figure 4 Direction of bridges are marked with blue lines

6 Description of bridge types and locations

There are three different kinds of bridges that are intended for use at the fjord crossings; suspension bridge, floating bridge and the submerged floating tunnel. The bridge types are illustrated with pictures and there is a brief description of the possibilities to integrate solar PV in the structures.

6.1 Suspension bridge

Figure 5 Illustration of Hålogalandsbrua (cowi/Statens vegvesen)

Identified potential areas on the suspension bridge type that could be exploited for PV are; On the sides of the bridge (in level with the driveway as well as underneath it), on the pylons, on a roof over the roadway and between the wires that goes from the top of the pylon down to the bridge.

6.2 Floating bridge

Figure 6 Concept of Floating bridge crossing Bjørnafjorden (Lmg Marin)

Identified potential areas on the floating bridge type that could be exploited for PV are; On the sides of the bridge (in level with the driveway as well as below it) and on a roof over the roadway. The surface on top of the pontoons have been assumed to have too extreme conditions in order to be suitable for solar PV.

6.3 Submerged floating tunnel

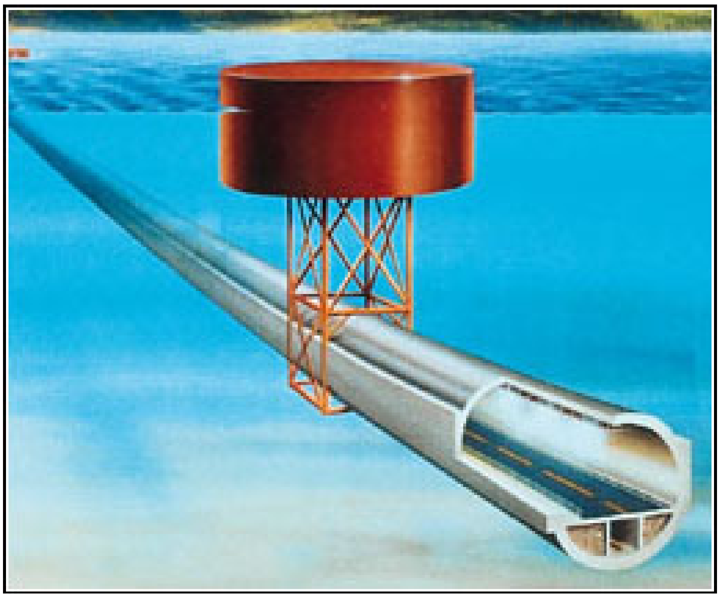

Figure 7 Submerged floating tunnel (http://www.ntnu.no/gemini/1998-01E/36.html)

For the submerged floating tunnel there are no possibilities to implement solar power in the structure. The surface on top of the pontoons have been assumed to have too extreme conditions in order to be suitable for solar PV.

6.4 Locations

The different locations of the fjord crossings are on the road E39 that stretches from Trondheim in the north to Kristiansand in the south of Norway. The length of the crossings vary from 1500 up to 8000 meters. Each crossing has different conditions and possibilities for solar energy implementation. Despite the northern location of Trondheim the solar resources are much more favourable there, than in Bergen and Stavanger. Bergen data was however used in the main analysis and the effect of using Trondheim data is studied in the sensitivity analysis.

Figure 8 Road E39 from Trondheim to Kristiansand with eight fjord crossings

7 Key figures for cost and life time expectancy

In the following we give an estimate of state of the art costs and expected technical lifetime for solar thermal and PV installations. We also present some scenarios for how these parameters could develop in the next five to ten years.

7.1 Solar thermal

From the Swedish market, todays average investment cost for large (>50m^2) solar thermal installations is estimated at 500 ± 110 €/m^2 [1]. This includes plant design, components including efficient collectors and piping but excluding heat exchangers, tanks or other types of stores and excluding VAT. The cost will vary in quite a big range depending on the conditions in the specific project. Costs for a conventional short term storage tank for water is estimated at 500 €/m^3. The estimated maintenance cost of a large solar installation is 1% of the investment cost per year. The COP for a large solar thermal installation can be in the range of 100 provided efficient pumps are used i.e. 1 unit electricity input will result in approximately 100 units of heat from the solar system.

Costs for solar heat has not had the same positive development as that of solar PV and are estimated to have decreased at the inflation rate i.e. 1-3 % per year. The two recent years have meant stagnation on the solar thermal market and in order to break this negative trend some significantly changed conditions are needed. Against this background some different scenarios can be envisioned:

I. That the price of heat energy increases significantly
II. That new forms of incentives for renewable heat are developed
III. That the solar thermal business manages to cut costs significantly e.g. through optimized and standardized products.
IV. That solar heating remains a niche market through the fact that solar PV is deemed so much more interesting and therefore optimally oriented surfaces are used for PV. Another development that will work in the same direction is the fact that waste heat recovery is becoming increasingly efficient.

I-III or a combination of these would make solar thermal energy more competitive which seems necessary if it shall be of interest for more extensive action. It should however be stressed that despite this rather dark picture, there are many cases in which solar thermal, given the right conditions can make a highly profitable investment with a very low environmental influence.

We are not able to assess the probability for either scenario but a qualified guess would be that a combination of I and III takes place in a positive scenario.

The lifetime of a well-designed, high quality solar heating installation is at least 20 but more likely 30 years.

7.2 Solar PV

From the Swedish market, todays average investment cost for large (>10 kWp) solar PV installations is estimated at 330 ± 60 €/m^2 module (mono crystalline silicone) [2]. This includes plant design and all components but it does not include VAT. The cost will vary depending on the conditions on site and the rapidly changing market situation. The options for integrating PV in building products, potentially replacing other materials should also be considered as it can enable a more favourable investment plan.

The module price has decreased with more than 20% per year in the past two years and globally installed capacity has increased by more than 20% per year. Following a 50% increase of the global production capacity in 2010 supply has by far exceeded the demand and thus there are currently many producers struggling for their survival.

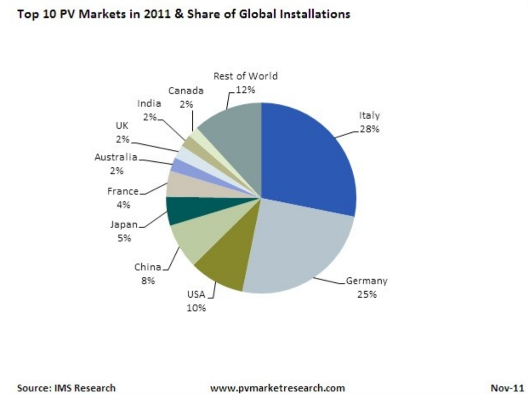

Figure 9 Showing where in the world PV is installed. The demand is largely determined by subventions and feed in tariffs.

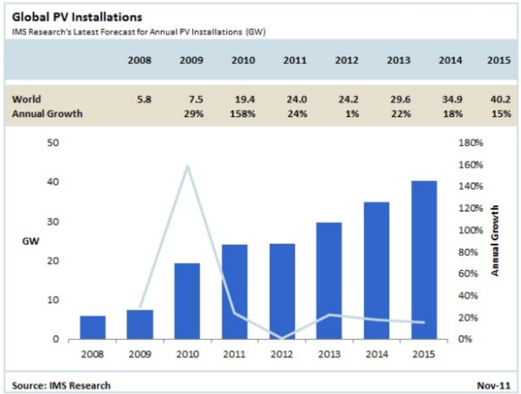

Figure 10 Mismatch between supply and demand makes it hard to predict price development.

Less than three years ago the cost of solar PV from crystalline silicone and thin film was nearly the same and market shares for thin film increased up to 20%. Today the situation is quite different, mainly due to the fact that Chinese crystalline modules have become very cheap. Thin film is thus back on 10% market shares gain. The conclusion is that the development of PV prices, even in a three to five year perspective is very hard to predict.

An option for cost reduction that will become more evident within five to ten years is that of building integrated PV or "BIPV" which is assumed to have a big growth potential. One already quite common example of BIPV is the use of modules as window shading. The cost of conventional shading can then be deducted from the solar PV investment cost.

The lifetime of a well-designed, high quality solar PV installation based on crystalline silicon modules is at least 25 years. Lifetime of the inverters are assumed to be 15 years. Costs for operation and maintenance for a high quality solar PV system are more or less negligible.

8 Results from potential assessment

The results are presented both as surfaces and as power production potential for each bridge, location and direction. The power production is also calculated and presented in specific numbers i.e. per km of bridge, which makes it easy to adapt to desired bridge length.

8.1 Exploitable surfaces

Available surfaces possible to exploit with solar PV are presented in Table 3. The submerged floating tunnel is not suitable for solar power integration due to a limited area above sea level. The only area that could be possible are on top of the floating pontoons but due to the tough an wet climate this is not suitable. The area in Table 3 has been calculated with the assumptions made in chapter 5.

Table 3 Area possible to exploit

	Suspension bridge	Floating bridge	Submerged floating tunnel
Roof over roadway [m²/km length]	14500	13000	na
Area on the sides of the bridge [m²/km length]	5000	5000	na
Solar PV mounted on wires [m²/km length]	72500	na	na
Solar PV mounted on pylons[m²]	16040	na	na

8.2 Accessible solar irradiance

Part of the region where the E39 project will be located, Stavanger-Bergen, has a rather modest solar resource according to the Meteonorm data that we have used [10]. The variation in the region is below ± 2%. In the Trondheim region however, the conditions are far more favourable, see Table 4. Data from Bergen was used in the following, but a sensitivity analysis with respect to irradiation data is performed in chapter 9.3. The irradiance data are based on 20 years of measured data and represents an average for this period.

Table 4 Irradiance data for the Bergen/ Stavanger region and for Trondheim

Annual global Irradiance on horizontal [kWh/m²]	
Bergen	760
Stavanger	788
Interpolated for a location between B&S	764
Trondheim	876

Table 5 Irradiance data for Bergen in three different directions

Annual global Irradiance [kWh/m²]	
Bergen Horizontal	760
Bergen 45°, South	836
Bergen 90°, South	611

Table 6 Irradiance data for Trondheim in three different directions

Annual global Irradiance [kWh/m²]	
Trondheim Horizontal	876
Trondheim 45°, South	1087
Trondheim 90°, South	860

8.3 Power production

The potential power production are presented for each crossing and identified exploitable area. For each bridge type there are four tables, two for specific data and two for the integrated bridge data. Note that for Bjørnafjord the shortest bridge crossing will be to build two separated bridges, see Appendix 1.

8.3.1 Suspension bridge

Table 7. Specific production. Modules on sides are placed in vertical position i.e. 90 ° slope

	Roof [MWh/km length/m width]	**Sides** [MWh/km length/m height]	**Wires** [MWh/km length]	**Pylons** [MWh/km height /m pylon width]
Halsafjorden	130	160	5830	1340
Moldefjorden	130	170	6290	1340
Storfjorden	130	170	6290	1340
Voldafjorden	130	170	6090	1340
Nordfjorden	130	170	6180	1340
Sognefjorden	130	170	6190	1340
Bjørnafjorden 1	130	170	6150	1340
Bjørnafjorden 2	130	170	6290	1340
Boknafjorden	130	160	5960	1340

Table 8 Specific production. Modules on sides are placed in 45 ° slope

	Roof [MWh/km length/m width]	**Sides** [MWh/km length/m height]	**Wires** [MWh/km length]	**Pylons** [MWh/km height /m pylon width]
Halsafjorden	130	230	8180	1340
Moldefjorden	130	240	8570	1340
Storfjorden	130	230	8550	1340
Voldafjorden	130	230	8390	1340
Nordfjorden	130	230	8470	1340
Sognefjorden	130	230	8440	1340
Bjørnafjorden 1	130	230	8440	1340
Bjørnafjorden 2	130	240	8550	1340
Boknafjorden	130	230	8260	1340

The specific production data can easily be used for optional bridge length.

Table 9 Bridge production. Modules on sides are placed in vertical position i.e. 90 ° slope

	Roof [GWh/year]	**Sides** [GWh/year]	**Wires** [GWh/year]	**Pylons** [GWh/year]	**Total** [GWh/year]
Halsafjorden	3,44	0,74	10,67	1,34	16,18
Moldefjorden	15,10	3,49	50,55	1,34	70,47
Storfjorden	6,39	1,48	21,39	1,34	30,60
Voldafjorden	3,79	0,85	12,27	1,35	18,25
Nordfjorden	3,20	0,73	10,51	1,34	15,77
Sognefjorden	7,16	1,63	23,59	1,35	33,72
Bjørnafjorden 1	3,01	0,68	9,84	1,34	14,87
Bjørnafjorden 2	10,77	2,49	36,06	1,34	50,66
Boknafjorden	15,82	3,46	50,13	1,34	70,75
% of total on each location	21	5	70	4	
Total, all crossings					**321,28**

Table 10 Bridge production. Modules on sides are placed in 45 ° slope

	Roof [GWh/year]	**Sides** [GWh/year]	**Wires** [GWh/year]	**Pylons** [GWh/year]	**Total** [GWh/year]
Halsafjorden	3,44	1,03	14,97	1,34	20,78
Moldefjorden	15,10	4,75	68,83	1,34	90,01
Storfjorden	6,39	2,00	29,06	1,34	38,80
Voldafjorden	3,79	1,17	16,89	1,35	23,19
Nordfjorden	3,20	0,99	14,41	1,34	19,94
Sognefjorden	7,16	2,23	32,26	1,35	42,99
Bjørnafjorden 1	3,01	0,93	13,51	1,34	18,79
Bjørnafjorden 2	10,77	3,38	49,00	1,34	64,49
Boknafjorden	15,82	4,80	69,54	1,34	91,50
% of total on each location	17	5	75	3	
Total, all crossings					**410,48**

Total power production for all crossings is 321 GWh per year if the suspension bridges are used for all of them and modules placed on sides are at 90° slope. This is equal to the annual demand of 64 000 single family houses using 5000 kWh each. The bridge data used for the calculation in Table 3 to Table 10 can be found in Appendix 1.

Halsafjorden and Boknafjorden are the two bridges having the “most northfacing sides” according to our estimated bridge orientations, see Appendix 1, resulting in a low power output from these sides. Assuming that no modules are placed on the northfacing sides of these two bridges would reduce the total production to 299 GWh per year.

If modules on the sides of all bridges are instead placed at the more optimum slope 45°, the total production would increase to 410 GWh per year.

8.3.2 Floating bridge

Table 11 Specific production. Modules on sides are placed in vertical position i.e. 90 ° slope

	Roof [MWh/km length/m width]	**Sides** [MWh/km length/m height]	**Wires** [MWh/km length]	**Pylons** [MWh/km height /m pylon width]
Halsafjorden	130	160	na	na
Moldefjorden	130	170	na	na
Storfjorden	130	170	na	na
Voldafjorden	130	170	na	na
Nordfjorden	130	170	na	na
Sognefjorden	130	170	na	na
Bjørnafjorden 1	130	170	na	na
Bjørnafjorden 2	130	170	na	na
Boknafjorden	130	160	na	na

Table 12 Specific production. Modules on sides are placed in 45 ° slope

	Roof [MWh/km length/m width]	**Sides** [MWh/km length/m height]	**Wires** [MWh/km length]	**Pylons** [MWh/km height /m pylon width]
Halsafjorden	130	230	na	na
Moldefjorden	130	240	na	na
Storfjorden	130	230	na	na
Voldafjorden	130	230	na	na
Nordfjorden	130	230	na	na
Sognefjorden	130	230	na	na
Bjørnafjorden 1	130	230	na	na
Bjørnafjorden 2	130	240	na	na
Boknafjorden	130	230	na	na

Table 13 Bridge production. Modules on sides are placed in vertical position i.e. 90 ° slope

	Roof [GWh/year]	**Sides** [GWh/year]	**Wires**	**Pylons**	**Total** [GWh/year]
Halsafjorden	3,08	0,74	na	na	3,82
Moldefjorden	13,54	3,49	na	na	17,02
Storfjorden	5,73	1,48	na	na	7,20
Voldafjorden	3,39	0,85	na	na	4,24
Nordfjorden	2,87	0,73	na	na	3,59
Sognefjorden	6,42	1,63	na	na	8,05
Björnafjorden 1	2,70	0,68	na	na	3,38
Björnafjorden 2	9,66	2,49	na	na	12,15
Boknafjorden	14,18	3,46	na	na	17,64
% of total on each location	80	20	na	na	
Total all crossings					**77,08**

Table 14 Bridge production. Modules on sides are placed in 45° slope

	Roof [GWh/year]	**Sides** [GWh/year]	**Wires**	**Pylons**	**Total** [GWh/year]
Halsafjorden	3,08	1,03	na	na	4,11
Moldefjorden	13,54	4,75	na	na	18,28
Storfjorden	5,73	2,00	na	na	7,73
Voldafjorden	3,39	1,17	na	na	4,56
Nordfjorden	2,87	0,99	na	na	3,86
Sognefjorden	6,42	2,23	na	na	8,65
Björnafjorden 1	2,70	0,93	na	na	3,63
Björnafjorden 2	9,66	3,38	na	na	13,04
Boknafjorden	14,18	4,80	na	na	18,98
% of total on each location	74	26	na	na	
Total all crossings					**82,84**

Total power production for all crossings is 77 GWh per year if the floating bridges are used for all of them and modules placed on sides are at 90° slope. This is equal to the annual demand of 15 400 single family houses using 5000 kWh each. The bridge data used for the calculation in Table 11 to Table 14 can be found in Appendix 1.

Halsafjorden and Boknafjorden are the two bridges having the “most northfacing sides” according to our estimated bridge orientations, resulting in a low power output from these sides. Assuming that no modules are placed on the northfacing sides of these two bridges would reduce the total production to 76 GWh per year.

If modules on the sides of all bridges are instead placed at the more optimum slope 45°, the total production would increase to 83 GWh per year.

8.4 Solar thermal energy production

Solar thermal installations are not considered appropriate on either of the bridges but in one application namely for ice and snow melting in particularly difficult sections of the bridges, see chapter 2.1.1. As mentioned in the same section, solar water heating is assumed to be a competitive technology in conjunction to the construction projects and in roadside restaurants and rest areas. Since the energy demand for such applications cannot be easily assessed and the energy demand will determine the actual potential only a qualitative assessment of this potential is made.

8.4.1 Snow and ice melting

Some characteristic data reported from one of few installations in the world where the road functions as a solar collector during the summer season and (in combination with a heat pump) defrosts the road surface during winter are listed in Table 15. The Gaia snow-melting system is installed in Ninohe, Iwate, Japan and data are presented from 1995-1998 [11].

Table 15 Characteristic data from a solar powered snow and ice melting system in Japan

Road surface temperature during summer	30-50°C
Average heat carrier in- and outlet temperature (summer)	22/ 28°C
Average “collector” annual efficiency @ 25°C	10%
Heat Recovering Rate (Wt/m2)	110
Operation time of the System in summer (h)	700
Operation time of the System in winter (h)	500
Heat Supply Rate per Unit Area (Wt/m2)	180

Two more recent Chinese publications reports practical/ theoretical studies focusing on the optimization of the snow melting and the heat collection and they also have a large number of adequate references to basic theoretical work in this field [12], [13].

A system of particular interest in this context should be the Swiss system shown in Figure 11. It was taken into operation in 1994, covers 1400m^2 of road surface and the cost including a borehole underground store was approximately 3 million US$ but with an estimated cost reduction of 50% for a follow up project.

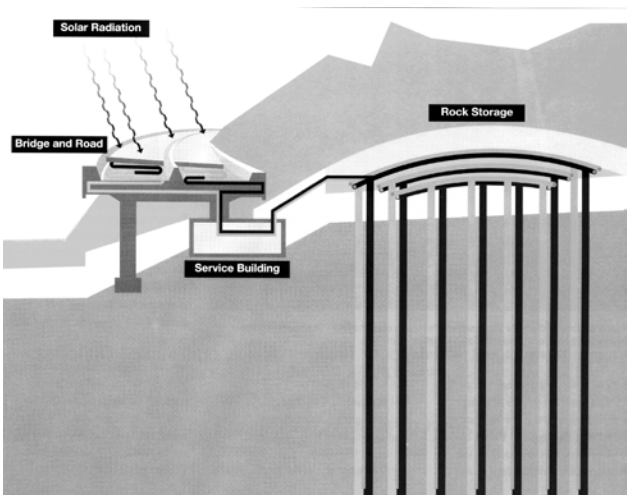

Figure 11 A system of great interest if solar heated bridges are considered is the Swiss system reported by Rauber, 1995

A review of Ashrae design criteria for snow melting systems including a set of basic equations is presented in [14] and an extensive overview of Japanese systems using underground thermal energy stores (UTES) and ice melting is presented in [15].

8.4.2 Solar water heating

A well sized solar thermal installation along the E39, using efficient flat plate collectors could cover most of the energy needs for hot water preparation during May to August and approximately 50 % of an annual, evenly distributed load. For significantly larger solar fractions, some form of seasonal storage would be required. As discussed in chapter 2.1.1 a seasonal storage could be of interest in combination with a defrosting installation and in that case it should also be considered to provide space heating to buildings from the solar thermal collectors. Such a system could actually cover all heating- and hot water loads in connected buildings [8] but the experience from such installations is still limited and the heat cost is not yet competitive.

An alternative way of using solar energy to cover heating- and hot water loads is by using PV modules to power heat pumps.

9 Sensitivity analysis

The efficiency of solar PV modules are still quite far from their theoretical maximum and several parallel tracks of development are running. An increase in module efficiency of 20% within five to ten years is therefore highly probable and the impact on the total potential of this has therefore been calculated. The effect of changing the slope of modules mounted on the sides of the bridges from 90 to 45 degrees, thus achieving a more optimum energy collection, is also described. Finally the significance of using relevant irradiation data is elucidated by estimation the optional energy output using Trondheim data instead of Bergen.

9.1 Improved efficiency

An assumed increase of the solar PV efficiency with 20% would lead to a much larger power production potential. The total potential for suspension bridges would increase from 321 GWh to 386 GWh. This is equal to the annual demand of 72000 single family houses using 5000 kWh each.

The result for the floating bridge would increase from 77 to 93 GWh. Table 16 and Table 17show the results for the increased efficiency.

Table 16 Suspension Bridge production with 20% efficiency increase

	Roof [GWh/year]	**Sides** [GWh/year]	**Wires** [GWh/year]	**Pylons** [GWh/year]	**Total** [GWh/year]
Halsafjorden	4,13	0,89	12,80	1,61	19,43
Moldefjorden	18,12	4,19	60,66	1,61	84,58
Storfjorden	7,67	1,78	25,67	1,61	36,73
Voldafjorden	4,55	1,02	14,72	1,62	21,91
Nordfjorden	3,84	0,88	12,61	1,61	18,94
Sognefjorden	8,60	1,96	28,31	1,62	40.49
Björnafjorden 1	3,61	0,82	11,81	1,61	17,85
Björnafjorden 2	12,92	2,99	43,27	1,61	60,79
Boknafjorden	18,98	4,15	60,16	1,61	84,90
Total all crossings					**385,62**

Table 17 Floating bridge production potential with 20% efficiency increase

	Roof [GWh/year]	**Sides** [GWh/year]	**Wires** [GWh/year]	**Pylons** [GWh/year]	**Total** [GWh/year]
Halsafjorden	3,70	0,89	na	na	4,58
Moldefjorden	16,25	4,19	na	na	20,42
Storfjorden	6,88	1,78	na	na	8,64
Voldafjorden	4,07	1,02	na	na	5,09
Nordfjorden	3,44	0,88	na	na	4,31
Sognefjorden	7,70	1,96	na	na	9,66
Björnafjorden 1	3,24	0,82	na	na	4,06
Björnafjorden 2	11,59	2,99	na	na	14,58
Boknafjorden	17,02	4,15	na	na	21,17
Total all crossings					**92,51**

9.2 Change of module slope

In general, it has been assumed that modules mounted on the sides of bridges are placed in vertical position. Tilting them 45 degrees with respect to the horizontal plane would increase the global annual irradiation received by 35% to 45% depending on the bridge orientation, assuming Bergen climate. On an average the increase would be 38% and approximately the same increase in energy production would be achieved, assuming that modules can be enough spaced in order to avoid shading each other.

For Trondheim data, the irradiation increase when changing slope from 90 to 45 degrees is less pronounced and reaches approximately 25%.

9.3 Change of weather data location

The main analysis is based on weather data from the Stavanger-Bergen region. This gives a conservative assessment of the available potential. Using Trondheim data, according to Meteonorm, would on the other hand give an overestimation as the Trondheim global irradiation on a horizontal surface is 15% higher than that of Bergen and 40% higher on a 90 degrees tilted surface facing south, see chapter 8.2. As detailed measured data for the individual sites are not available it has not made sense to apply any other assumption than using the same weather data for all bridge crossings.

Using Trondheim data on all crossings would increase the potential production from 321 to 433 GWh (35%) if all bridges were suspension bridges 8and modules on sides are vertically mounted) and from 77 to 93 GWh (20%) if all bridges were floating bridges.

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10 Future technology prospects

10.1 Solar thermal technologies

There is technical development work going on in several different solar thermal technologies, mainly focusing on the design and materials of solar collectors and heat stores but also, in particular for the concentrating solar power (CSP) systems, in system design. Considering the applications outlined in chapter 2.1.1 no ground breaking innovations are expected in the next 3-5 years. In a longer perspective, new storage concepts could make defrosting as well as tap water and space heating systems much more attractive in terms of higher solar fractions and energy efficiency.

In general the developments in the low to medium temperature range (60-250 °C) is aiming at reducing costs and increasing efficiency. In order to make flat plate collectors applicable to e.g. solar cooling and process heat applications they need to be more efficient at temperatures above 100°C. However this type of applications are not foreseen as having any significant potential in the current project.

10.2 Solar PV technologies

Solar PV is, as several other renewable energy technologies, growing and developing very fast. The price development, which is very hard to predict, was described in chapter 7.2. Figure 12 gives an idea about the foreseen developments in PV cell efficiency. It is important to keep in mind that there are often large differences between efficiencies achieved in laboratories and reported in the press and the efficiencies of commercially available and reasonably cost effective PV modules. For example, at the time of writing this report, the highest efficiency in commercially available mono crystalline PV modules is 20,4% and for modules built on CiGS cells it is 13,1% [5].

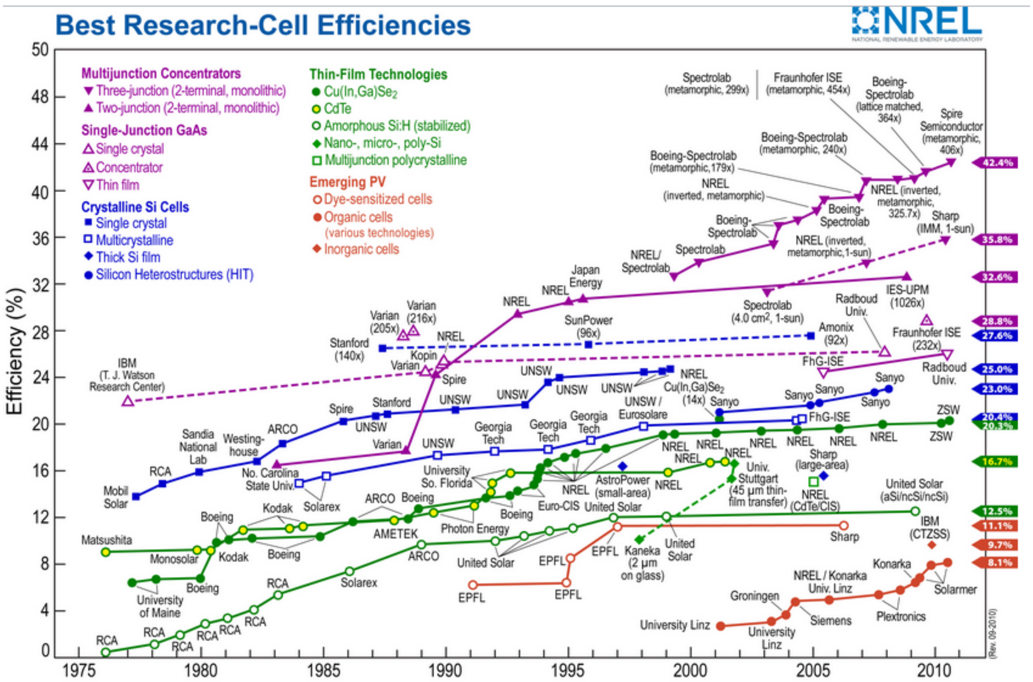

Figure 12. Efficiency development in research PV cells

The so called third generation of solar cells is still very young, but according to its proponents very promising for the future. The Grätzel PV, or Dye Sensitized Cells (DSCs), imitates the photosynthesis process in plants. In many aspects it can out-rule traditional cells e.g. the production process is foreseen to be simple and cheap and the modules can be very light and flexible without expensive silicon processing. It is also possible to make it in a big variety of colours, and degree of transparency. These properties make many novel applications possible. However, the low durability of the cells has been a difficult problem to overcome. The technique is still at research level so it is not interesting for the project at this point, but it could be interesting in some applications in the future.

In parallel to the development in PV technologies, the development on ”smart grids” and as part of that, efficient energy storage, is also of interest as there are several points in common. One example is the fact that PV modules produce DC current which most often is converted to AC and then back to DC for powering computers, lighting etc. Skipping the conversion steps could save money and increase efficiency at the same time. DC powered road lighting could be supplied by PV without conversion but that would require a certain storage capacity which, given today’s battery technology it is hardly a feasible option.

11 Discussion

As described in the previous, the solar energy market development is very difficult to predict. Many European and American companies are presently struggling for their survival in the race against Chinese competitors. One conclusion from this is that the results of this study in terms of performance and cost figures will have to be frequently updated in order to keep track of the development and get optimum deals in each individual construction project. Up to date information on the development can e.g. be found at [4], [5], [6] and [7].

Even though the solar resources in parts of the region are far from optimal, the results of this potential study gives quite a positive picture of the technical possibilities for integrating solar energy production facilities in the E39 project. This is particularly true when it comes to electricity production using PV technology. No economical assessment has been carried out in the study, but given the state of the art costs and lifetimes presented in chapter 7.2 it is feasible to achieve a net profit during the technical lifetime of the equipment. In addition to cost and performance the following parameters will be decisive for the profitability of an investment:

- Cost of capital
- Expected price increases on electricity
- National subsidies, net metering or feed in tariffs

As prices on PV products are projected to continue falling, performance to increase and the price on electricity is expected to continue to increase to some extent, the calculus is expected to become continuously more positive during the coming five to ten years.

12 References and Internet resources

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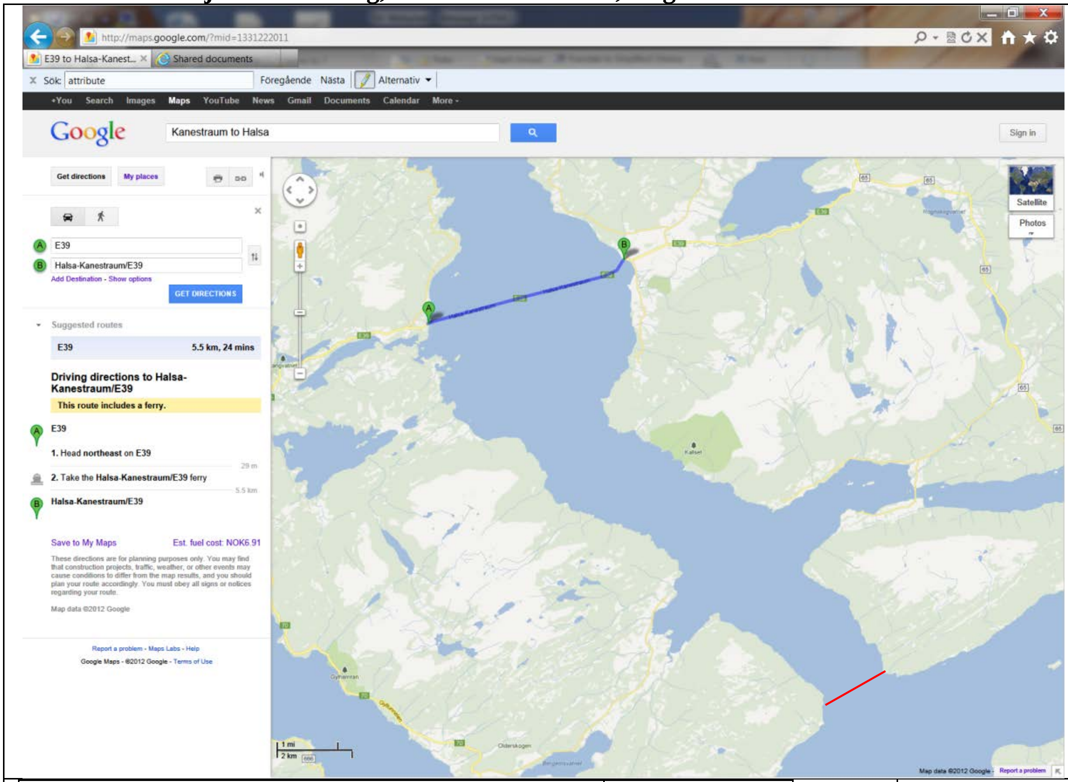
Appendices:

1. Object descriptions
2. Soft wares and Internet resources
3. Input data and assessment criteria
4. Description of Excel sheet for energy calculations
5. Excel sheet for energy calculations

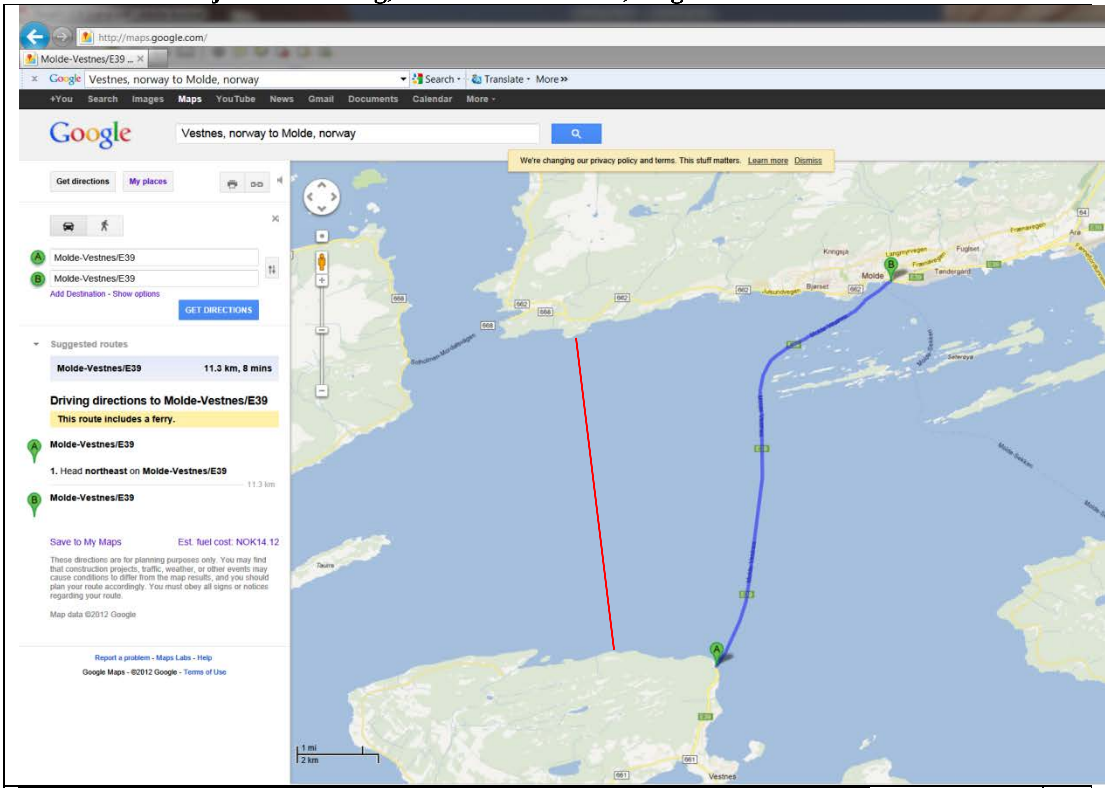
Appendix 1. Object descriptions

Table 18 Halsafjorden crossing, data for irradiation, length and direction



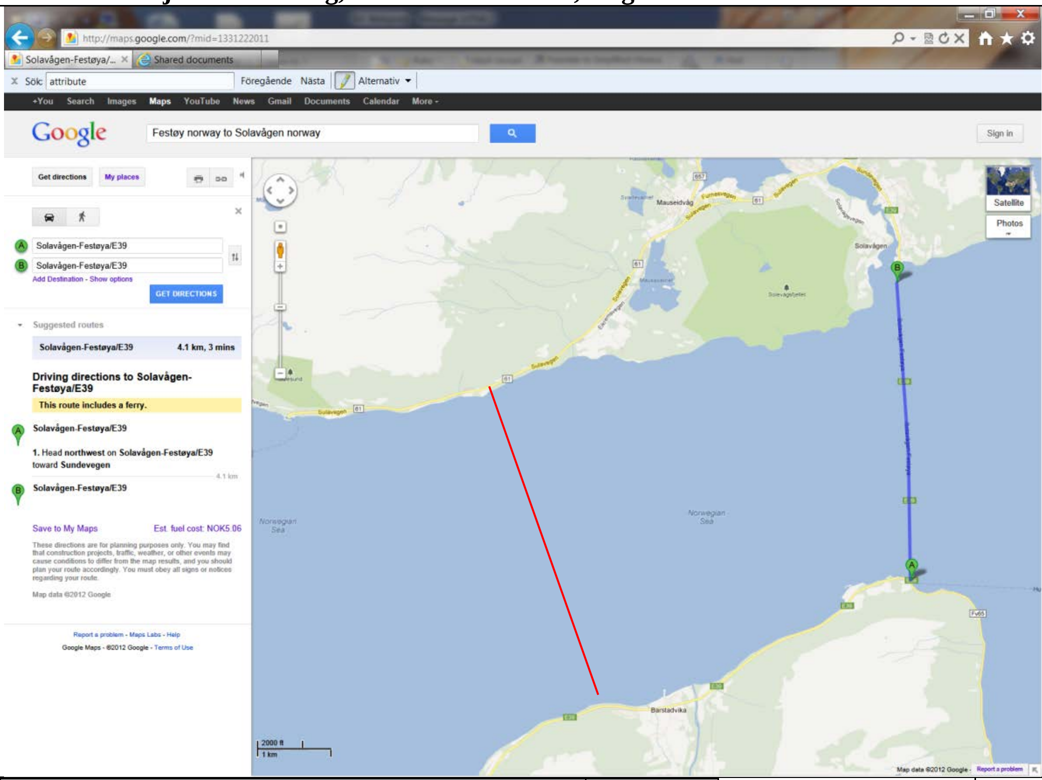
Direction	75°
Lenght of shortest crossing(marked red) [m]	1829
Irradiation on west side of bridge[kWh/m²]	332
Irradiation on east side of bridge [kWh/m²]	609
Irradiation northfacing (lenghtwise) [kWh/m²]	471
Irradiation southfacing (lenghtwise) [kWh/m²]	544
Irradiation Horizontal [kWh/m²)	758

Table 19 Moldefjorden crossing, data for irradiation, length and direction



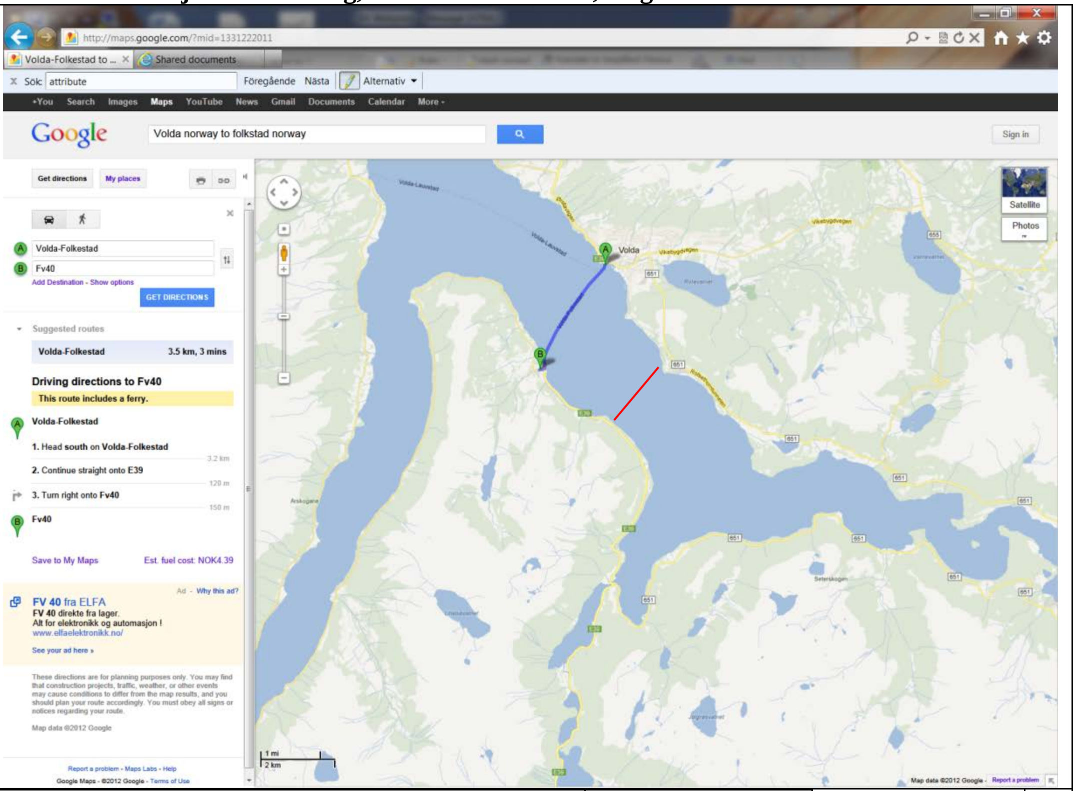
Direction	355°
Length of shortest crossing(marked red) [m]	8034
Irradiation on west side of bridge[kWh/m²]	519
Irradiation on east side of bridge [kWh/m²]	496
Irradiation north facing (lengthwise) [kWh/m²]	328
Irradiation south facing (lengthwise) [kWh/m²]	611
Irradiation Horizontal [kWh/m²]	758

Table 20 Storfjorden crossing, data for irradiation, length and direction



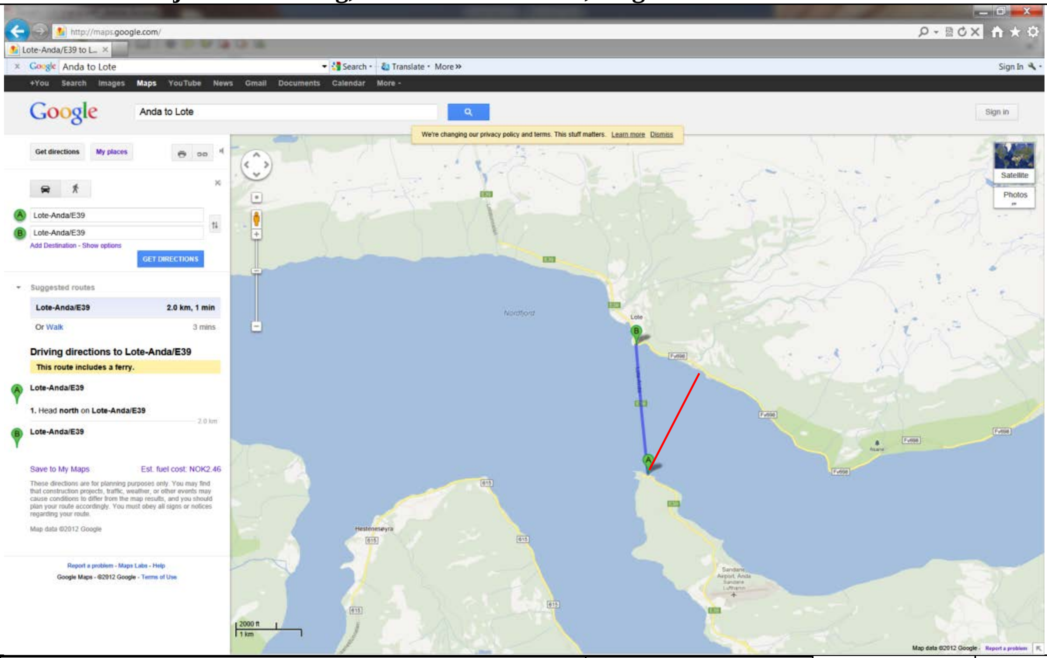
Direction	345°
Length of shortest crossing(marked red) [m]	3400
Irradiation on west side of bridge[kWh/m²]	544
Irradiation on east side of bridge [kWh/m²]	471
Irradiation north facing (lengthwise) [kWh/m²]	332
Irradiation south facing (lengthwise) [kWh/m²]	609
Irradiation Horizontal [kWh/m²]	758

Table 21 Voldafjorden crossing, data for irradiation, length and direction



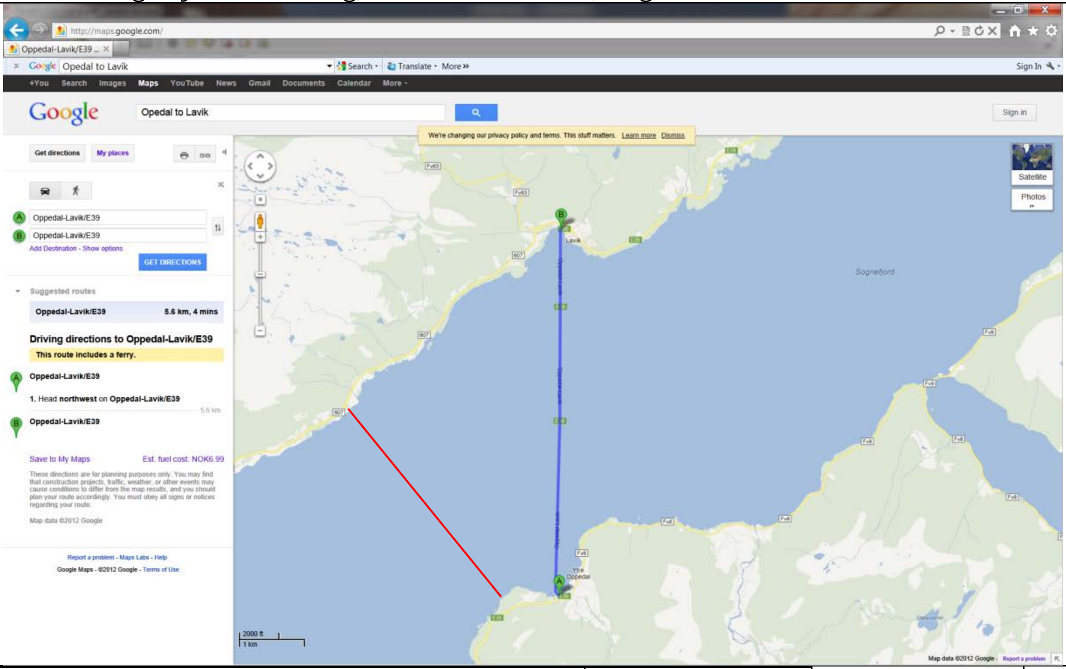
Direction	40°
Length of shortest crossing(marked red) [m]	2014
Irradiation on west side of bridge[kWh/m²]	399
Irradiation on east side of bridge [kWh/m²]	584
Irradiation north facing (lengthwise) [kWh/m²]	381
Irradiation south facing (lengthwise) [kWh/m²]	599
Irradiation Horizontal [kWh/m²]	758

Table 22 Nordfjorden crossing, data for irradiation, length and direction



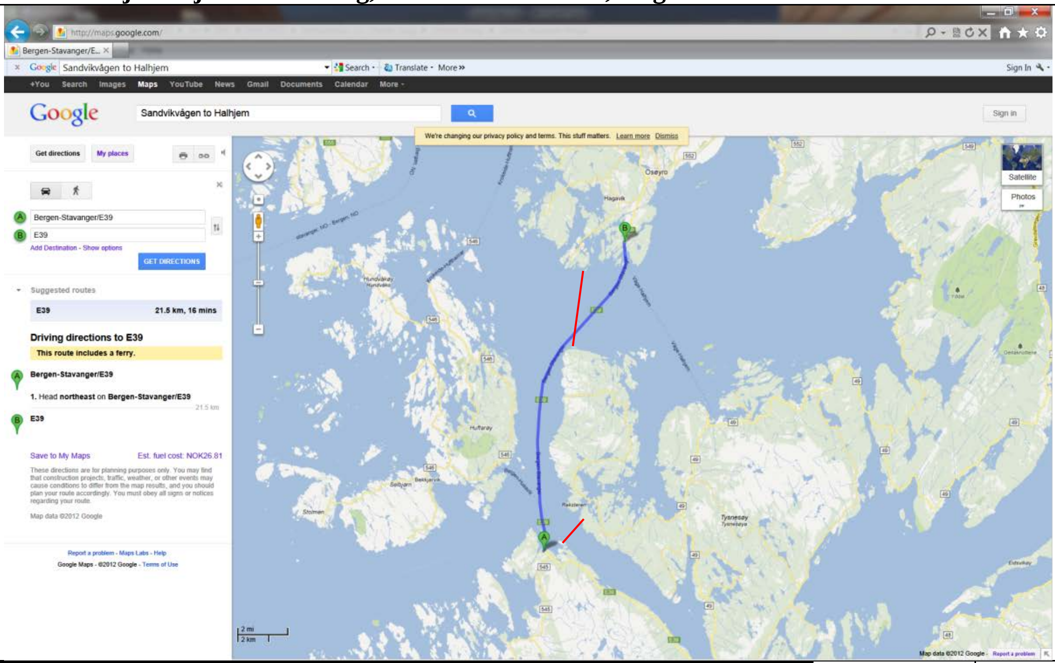
Direction	28°
Length of shortest crossing(marked red) [m]	1700
Irradiation on west side of bridge[kWh/m²]	431
Irradiation on east side of bridge [kWh/m²]	566
Irradiation north facing (lengthwise) [kWh/m²]	355
Irradiation south facing (lengthwise) [kWh/m²]	606
Irradiation Horizontal [kWh/m²]	758

Table 23 Sognefjorden crossing, data for irradiation, length and direction



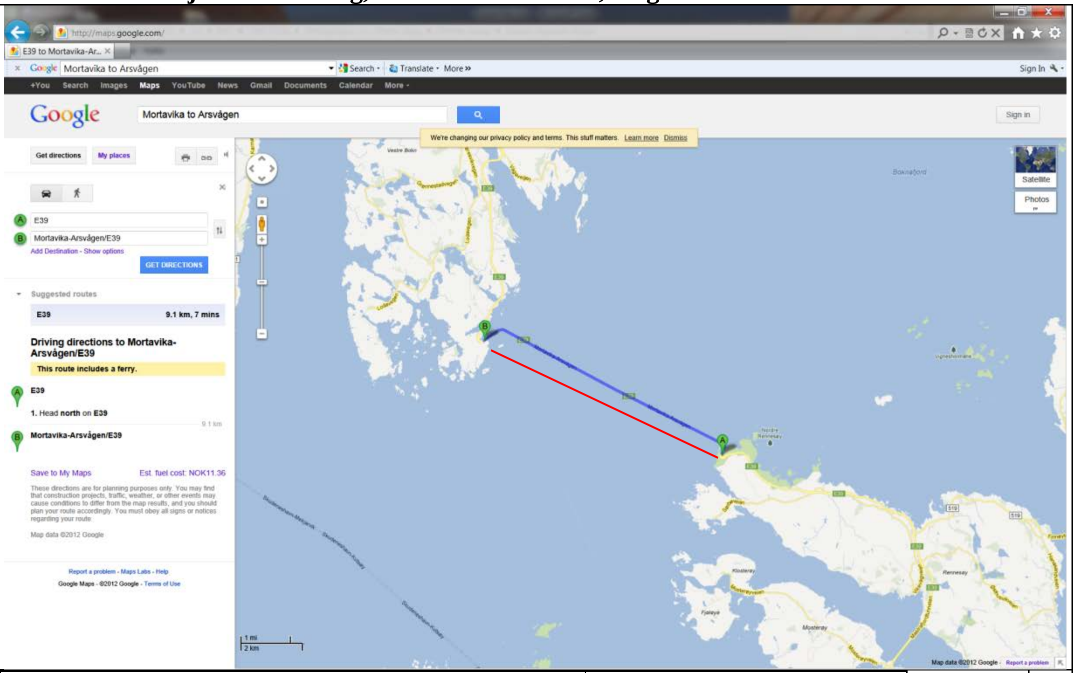
Direction	325°
Length of shortest crossing(marked red) [m]	3810
Irradiation on west side of bridge[kWh/m²]	581
Irradiation on east side of bridge [kWh/m²]	418
Irradiation north facing (lengthwise) [kWh/m²]	364
Irradiation south facing (lengthwise) [kWh/m²]	599
Irradiation Horizontal [kWh/m²]	758

Table 24 Bjørnafjorden crossing, data for irradiation, length and direction



Direction (”short” crossing)	32°
Length (”short” crossing) [m]	1600
Irradiation on west side of bridge[kWh/m²]	420
Irradiation on east side of bridge [kWh/m²]	572
Irradiation north facing (lengthwise) [kWh/m²]	363
Irradiation south facing (lengthwise) [kWh/m²]	604
Direction (”long” crossing)	6°
Length (”long crossing”) [m]	5732
Irradiation on west side of bridge[kWh/m²]	492
Irradiation on east side of bridge [kWh/m²]	523
Irradiation north facing (lengthwise) [kWh/m²]	327
Irradiation south facing (lengthwise) [kWh/m²]	611
Irradiation horizontal(valid for both) [kWh/m²]	758

Table 25 Boknafjorden crossing, data for irradiation, length and direction



Direction	298°
Length of shortest crossing(marked red) [m]	8416
Irradiation on west side of bridge[kWh/m²]	606
Irradiation on east side of bridge [kWh/m²]	355
Irradiation north facing (lengthwise) [kWh/m²]	431
Irradiation south facing (lengthwise) [kWh/m²]	566
Irradiation Horizontal [kWh/m²]	758

Appendix 2. Soft wares and Internet resources

The following section describes briefly the various tools used in the analysis. Some of these are freely available and a couple of them are commercial software.

Meteonorm

Meteonorm is a climate database with which it is possible to produce climate data for any inclination, orientation and location. The data is based partly on data from a number of real stations but it is also possible to choose an arbitrary geographic location for which the software then interpolates climate data based on the actual station data. It has been used to produce irradiation for a variety of orientations and inclinations of Bergen and Trondheim.

Google Earth

Google Earth is a graphical tool that consists of interconnected high-resolution satellite images which enable the user to zoom in on the desired geographical location on Earth and see details of buildings, streets and community structure. The program offers a variety of tools and features such as the opportunity to study the buildings in 3D, measure lengths and surfaces and orientation of these. In some places it is also possible to study satellite images from different times of the year, making it possible to form some idea of shading from buildings and vegetation.
Google Earth is best suited for use in large cities where there is better resolution than in rural areas. In this project, the program has primarily been used to measure the distance and orientation.

Appendix 3. Input data and assessment criteria

Climate data

The software Meteonorm have been used to calculate the global radiation as well as the irradiation on inclined planes. The climate in Bergen has been chosen to represent all the fjord crossings along E39 but the effect of using Trondheim data has also been analysed in the sensitivity analysis, see chapter 9.3.

The irradiation has been generated for each unique direction of the crossings. In total this means that 4 unique irradiations are used for each crossing and one horizontal which can be applied for all roof installations.

Table 26 Global radiation for Bergen [kWh/m²]

	Horizontal Irradiation	Irradiation1, 90° inclination	Irradiation2, 90° inclination	Irradiation, north facing	Irradiation south facing
Halsafjorden	758	609	332	471	544
Moldefjorden	758	519	496	328	611
Storfjorden	758	471	544	332	609
Voldafjorden	758	584	399	381	599
Nordfjorden	758	566	431	355	606
Sognefjorden	758	418	581	364	599
Bjørnafjorden 1	758	572	420	363	604
Bjørnafjorden 2	758	492	523	327	611
Boknafjorden	758	606	355	431	566

Bridge data

The shortest fjord passage have been measured for each fjord crossing and this has been used in the energy calculations for the bridges.

Table 27 Bridge and fjord crossing data

	Shortest crossing [m]	Direction of bridge
Halsafjorden	1829	75°(255)
Moldefjorden	8034	355°(175)
Storfjorden	3400	345°(165)
Voldafjorden	2014	40°(220)
Nordfjorden	1700	28°(208)
Sognefjorden	3810	325°(145)
Bjørnafjorden 1	1600	32°(212)
Bjørnafjorden 2	5732	6°(186)
Boknafjorden	8416	298°(118)

Hardangerbrua data

The data in Table 28 has been used to calculate the area covered by the wires on the suspension bridge as well as the area of the pylons.

Table 28 Hardangerbrua data

Span [m]	1310
Sail height [m]	55
Pylon height [m]	200
Width [m]	14,5
Area on one side [m²]	94975
Area on one side/km,bridge [m²/km bridge]	72500
50% exploitable [m²]	36250
Height of pylon [m]	200,5
Approx. Average width of pylon [m]	5

The width of Bjørnafjorden floating bridge is 13 meters.

Appendix 4. Description of Excel sheet for energy calculations

The excel document consists of three tabs where all the data used for the calculations can be found. The tab named “Potential power production @ slope 90” gathers the results for the energy calculations for each bridge type, fjord crossing and identified exploitable area. Here all side placed modules are assumed to be placed in vertical position. In the next tab “Potential power production @ slope 45”, the same calculations are done but then assuming 45 degrees tilt of the same modules.

Sheet named ”Bridge crossing data” includes all bridge and crossing data. Directions, irradiations, efficiency factor, wire calculations and pylon calculations are all compiled on this sheet.

To calculate the potential power production on a identified exploitable surface the following parameters are used;

- Irradiation based on the surface direction and inclination
- The area of the surface
- System efficiency of solar PV
- Module factor

To calculate the potential from installing solar PV on the wires data is used from Hardangerbrua, see Appendix 3. The wires creates two triangular shapes on each side of the bridge. This area i calculated and the assumption is made that 50% of the area can be exploited with solar PV. The height of the pylons is assumed to stay constant and independent from the length of the bridge.

The area calculation of the pylons is also based on the data of the Hardanger bridge. Each pylon consists of four sides with the approximate width of 5 meters. It is assumed that each suspension bridge consists of four pylons.

Appendix 5. Excel sheet for energy calculations

(Appended as a separate Excel file)

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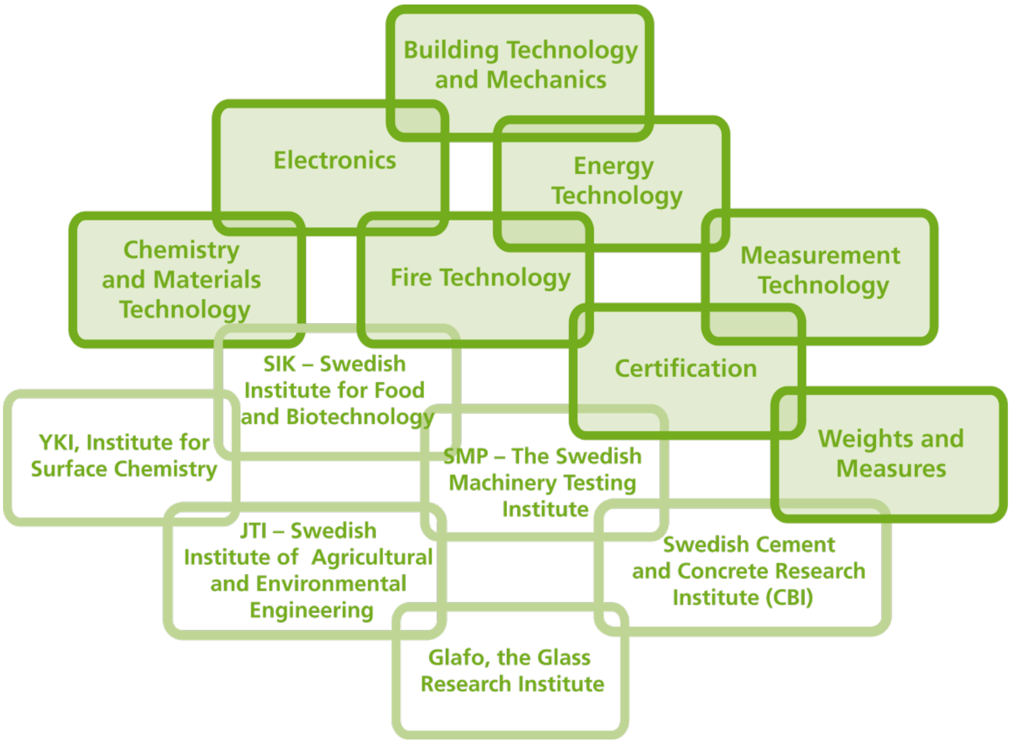

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