June 2016

Technical Report

What does the Paris Climate Agreement mean for Finland and the European Union?

Marcia Rocha, Fabio Sferra, Michiel Schaeffer, Niklas Roming, Andrzej Ancygier, Paola Parra, Jasmin Cantzler, Alain Coimbra, Bill Hare

Climate Analytics gGmbH
Supporting science based policy to prevent dangerous climate change enabling sustainable development

Friedrichstraße 231 / Haus B
10969 Berlin / Germany

T / +49 (0)30 259 22 95 20
W / www.climateanalytics.org

Suomenkielinen tiivistelmä: EU:n ja Suomen päivitettävä päästötavoitteitaan Pariisin sopimuksen valossa

Pariisin sopimus

Pariisin ilmastokokouksessa hyväksyttiin uusi sopimus, joka velvoittaa kaikkia maita ilmastotoimiin. Sopimuksen tavoitteena on rajoittaa ilmastonmuutos selvästi alle kahden asteen ja pyrkiä toimiin, joilla lämpeneminen saataisiin rajattua vain 1,5 asteeseen.

Pariisin sopimus sisältää sitovan velvoitteen maille päivittää ilmastositoumuksiaan säännöllisin väliajoin. Ilmastokokous myös totesi, että mailta tarvitaan selvästi nykyistä kunnianhimoisempia ilmastotoimia sopimuksen tavoitteeseen pääsemiseksi.

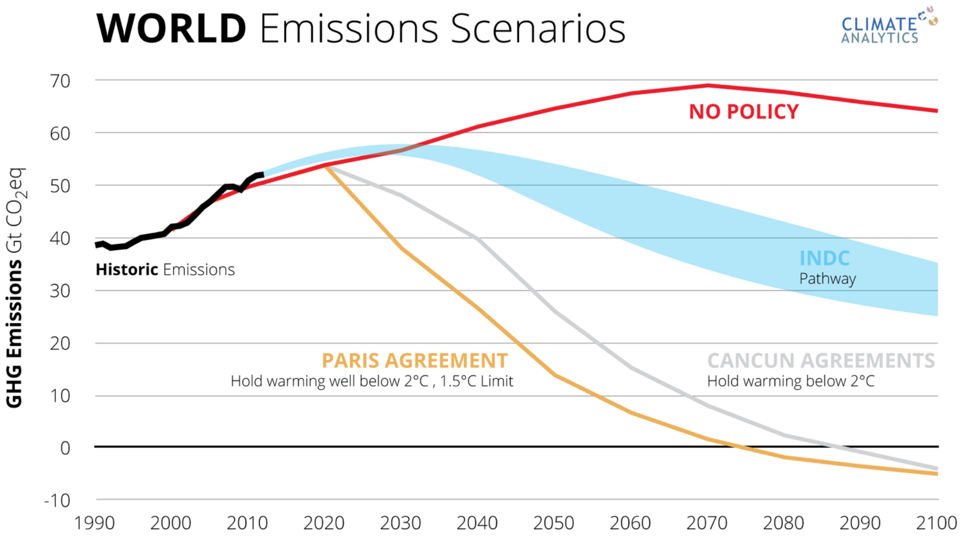
Miksi selvitys?

Tämä Sitran Climate Analytics -tutkimusyhtiöltä tilaama selvitys tarkastelee Pariisin sopimuksen merkitystä Suomen ja EU:n 2030 ja 2050 päästötavoitteiden kannalta. Selvitys on tarkoitettu tukemaan päätöksentekoa Suomen uudesta energia- ja ilmastostrategiasta sekä vuonna 2018 pidettävää maiden päästötavoitteiden väliarviointia.

Tarkastelussa kolme tulevaisuuspolkua

Selvityksessä tarkastellaan kolmea eri tulevaisuuspolkua:

1. Pariisin sopimus (1,5 °C): Polulla maailman ilmastotoimia vauhditetaan vuoden 2020 jälkeen niin, että lämpeneminen on vuosisadan lopulla jäänyt 1,5 asteeseen 50 prosentin todennäköisyydellä.
2. Cancúnin sitoumukset (2 °C): Polulla maailman ilmastotoimia vauhditetaan vuoden 2020 jälkeen niin, että lämpeneminen jää todennäköisesti alle kahteen asteeseen.
3. Ei lisätoimia: Vertailupolulla ei oleteta uusia ilmastotoimia nykyisten lisäksi vuoden 2020 jälkeen.



Kuva 1: Selvityksen tulevaisuuspolut verrattuna maiden tähän asti ilmoittamien sitoumusten mukaiseen maailman päästökehitykseen (INDC Pathway).

Lähestymistavat: taloudellisuus ja oikeudenmukaisuus

Pariisin sopimuksen mukaisten päästövähennysten laskemiseksi selvityksessä käytetään kahta lähestymistapaa: taloudellisuutta ja oikeudenmukaisuutta. Ensimmäisessä tarkastellaan taloudellisesti ja teknologisesti toteuttamiskelpoisia päästöpolkuja, jotka minimoivat kokonaiskustannukset maailman maille. Toisessa arvioidaan sitä, miten Suomen ja EU:n päästövähennykset suhteutuvat toisten maiden toimiin käyttäen joukkoa oikeudenmukaisuusperusteita kuten historiallista vastuuta ilmastonmuutoksesta ja kykyä vähentää päästöjä.

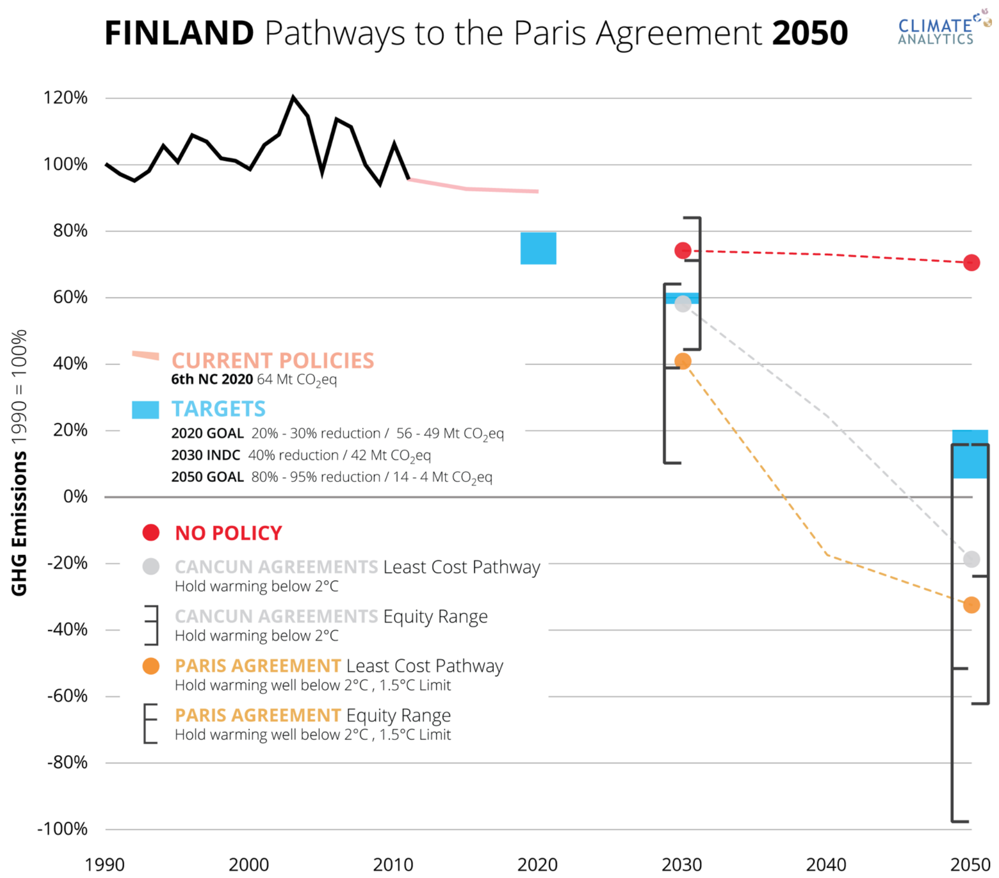
Pääsanoma: enemmän pitää tehdä

Selvitys osoittaa selvästi, että EU:n ja Suomen nykyiset sitoumukset eivät ole linjassa Pariisin sopimuksen lämpötilatavoitteen kanssa. Vuosien 2030 ja 2050 sitoumusten kunnianhimoa pitää nostaa selvästi nykyisestä. Nopea päästöjen vähentäminen säästää aikanaan myös rahaa, sillä se kohtuullistaa myöhemmin tarvittavia, muuten kalliita päästöleikkauksia.

Suomi: päästöt nollaan lähivuosikymmeninä

Suomen nykyiset päästösitoumukset vuosille 2030 ja 2050 eivät ole riittäviä Pariisin sopimuksen lämpötilatavoitteen kannalta. Pitäytyminen nykyisissä sitoumuksissa merkitsisi sitä, että muiden maiden oletettaisiin tekevän suhteessa Suomea enemmän ilmastonmuutoksen rajoittamiseksi.

Taloudellisuuteen perustuvassa mallissa Suomen pitäisi leikata päästöjä vuoden 1990 tasosta noin 60 prosenttia vuoteen 2030 ja 130 prosenttia vuoteen 2050 mennessä. Suomen oikeudenmukainen osuus olisi leikata päästöjä samaa suuruusluokkaa, vähintään 60 prosenttia vuoteen 2030 ja 150 prosenttia vuoteen 2050 mennessä. Kokonaispäästöjen tulisi siis kääntyä nettona negatiivisiksi jo ennen vuosisadan puoliväliä sekä kahden että puolentoista asteen mukaisilla päästöpoluilla.



Kuva 1: Suomen päästöpolut ja -tavoitteet. Oikeudenmukaista lähestymistapaa kuvaava haarukka esittää Suomen reilun osuuden päästövähennyksistä eri perusteilla. Keskikohta havainnollistaa tilannetta, jossa muiden maiden ei oleteta vähentävän päästöjä suhteessa enemmän.

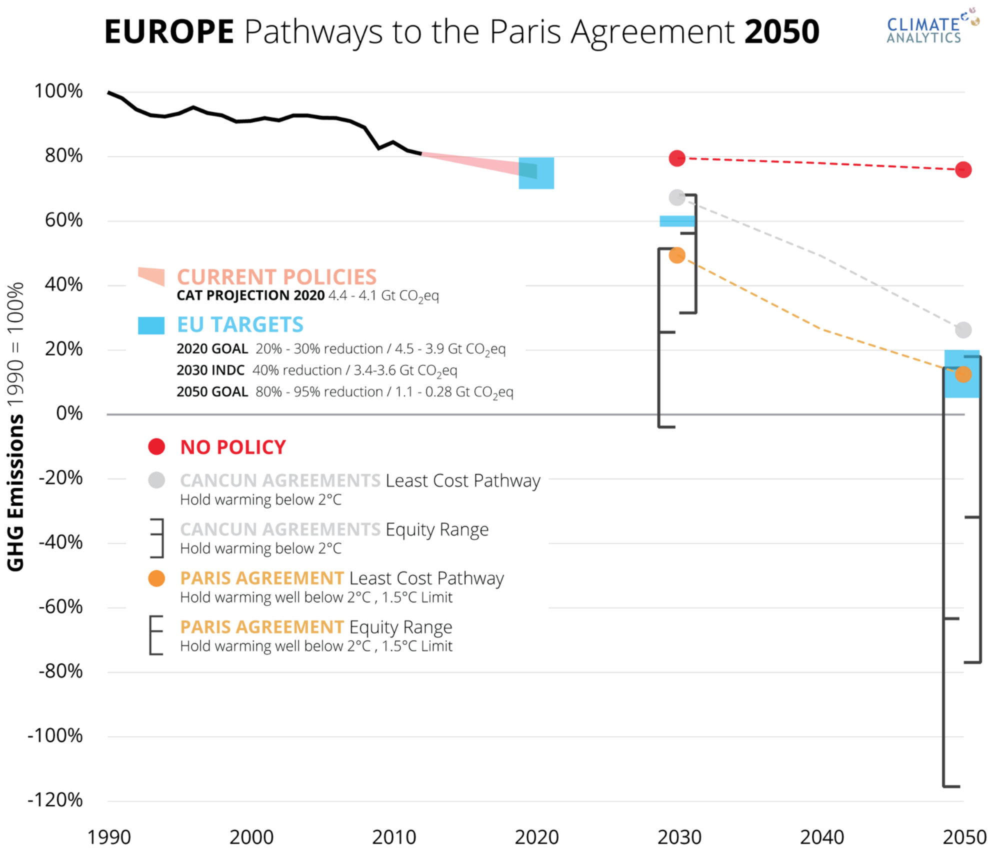
	2030	2050
Taloudellinen	–59 %	–133 %
Oikeudenmukainen	–61 %	–152 %
Nykyiset tavoitteet	–40 % (koko EU)	vähintään –80 %

Taulukko 1: Suomen päästövähennykset vuoden 1990 tasosta taloudellisen ja oikeudenmukaisen lähestymistavan mukaan.

EU: 2030 tavoitetta päivitettävä

Myöskään EU:n sitoumukset eivät ole linjassa Pariisin sopimuksen lämpötilatavoitteen kanssa. Unionin oikeudenmukainen osuus olisi leikata päästöjä vuoden 1990 tasosta vähintään 75 prosenttia vuoteen 2030 ja 164 prosenttia vuoteen 2050 mennessä.

Puhtaasti taloudellisin perustein määritellyt päästörajoitukset jäävät maltillisemmiksi, mutta edellyttävät silti vuoden 2030 tavoitteen tiukentamista 50 prosenttiin. Vuoden 2050 vähennys osuu suunnilleen EU:n nykyisen 80–95 prosentin päästötavoitteen keskipaikkeille.



Kuva 3. EU:n päästöpolut ja -tavoitteet. Oikeudenmukaista lähestymistapaa kuvaava haarukka esittää unionin reilun osuuden

	2030	2050
Taloudellinen	–47 %	–88 %
Oikeudenmukainen	–75 %	–164 %
Nykyiset tavoitteet	–40 %	–80–95 %

Taulukko 2: EU:n päästövähennykset vuoden 1990 tasosta taloudellisen ja oikeudenmukaisen lähestymistavan mukaan.

Edullisia päästövähennyksiä ulkomailta

Juopaa oikeudenmukaisten ja taloudellisten päästövähennysten välillä voi kuroa umpeen rahoittamalla ilmastotoimia maissa, joissa päästöjen vähentäminen on edullisempaa. Suomen rahoitusosuus voi olla sadan miljoonan euron luokkaa vuonna 2030 ja runsaan miljardin verran vuonna 2050.

Energiatehokkuuden parantaminen ja siirtymä päästöttömään energiantuotantoon ovat keskiössä. Climate Analyticsin selvityksen mukaan keskipitkällä aikavälillä pitää ottaa käyttöön myös päästöjä sitovaa teknologiaa kuten hiilen talteenottoa ja varastointia (CCS). Suomen oloissa lupaava vaihtoehto on bioenergia yhdistettynä hiilidioksidin talteenottoon CCS:llä, sillä näin voidaan sitoa ilmakehään jo vapautuneita päästöjä.

	2030	2050
Suomi (mrd. € 2005)	0,1	1,36
Suomi (% BKT:stä)	0,1 %	0,7 %
EU (mrd. € 2005)	92	421
EU (% BKT:stä)	0,6 %	2 %

Taulukko 3: Arvio Suomen ja EU:n vuotuisesta ilmastorahoitustarpeesta.

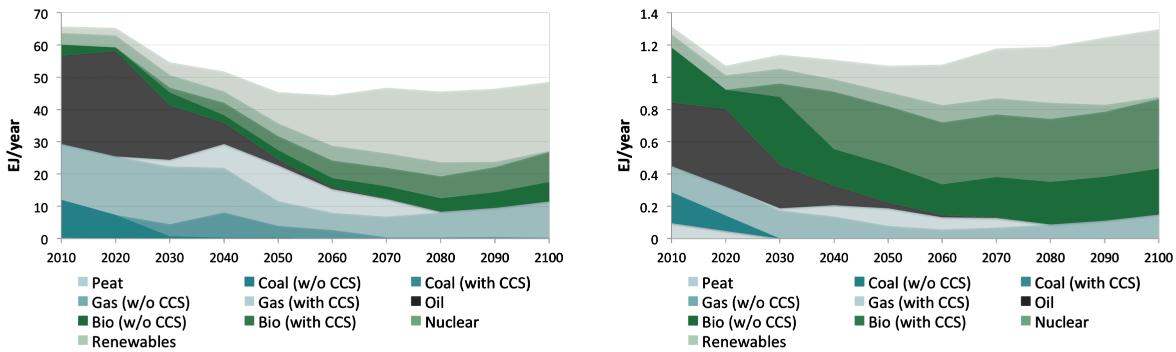
EU:n rahoitustarve voi jäädä vajaaseen sataan miljardiin euroon vuonna 2030 ja runsaaseen 400 miljardiin vuonna 2050. Arvioiden haarukka on laaja, koska eri oikeudenmukaisuusperusteiden edellyttämät päästövähennykset ja päästövähennysten kustannukset vaihtelevat merkittävästi.

Tehokkuus, uusiutuvat ja CCS energiamurroksen avaimia

Pariisin sopimuksen mukaiset päästöpolut merkitsevät suuria muutoksia energiataloudessa.

Päähavaintoja energiamallinnuksen tuloksista:

- Energiatehokkuus on avainroolissa erityisesti aloilla, joilla on lyhyellä aikavälillä niukasti tapoja kattaa energiantarve päästöttä: teollisuudessa, rakennuksissa ja liikenteessä.
- Uusiutuva energia korvaa fossiilisia polttoaineita sähköntuotannossa jo lyhyellä aikavälillä.
- Suomen oletetaan luopuvan kivihiilen käytöstä hallituksen linjausten mukaisesti vuoteen 2030 mennessä. EU:ssa hiilen käyttö ilman CCS:ää lakkaa samalla aikajänteellä, mutta CCS:n kanssa hiiltä voidaan käyttää vielä useita vuosikymmeniä.
- Öljyn käyttö vähenee selvästi ja lakkaa 2060-luvulle tultaessa.



Kuva 4: EU:n (vasemmalla) ja Suomen (oikealla) primäärienergian kulutus Pariisin sopimuksen mukaisella polulla.

- Maakaasun käyttö jatkuu myös tulevaisuudessa niin, että vuosisadan keskipaikkeilla osa sen hiilidioksidista otetaan talteen CCS:llä.
- Bioenergia yhdistettynä CCS:ään alkaa ensi vuosikymmenellä ja kasvaa merkittävästi seuraavina vuosikymmeninä.
- Ydinvoiman käyttö jatkuu suunnilleen nykytasolla vuosisadan loppupuolelle.

Rajoitteita ja epävarmuuksia

Tuloksia on syytä tulkita harkiten. Monella alalla tutkimus on parhaillaan vilkasta, ja selvityksiä 1,5 asteen mukaisista päästöpoluista on niukanlaisesti.

Raportissa käytetty energiamalli olettaa nykyisen teknologian olevan rajoituksetta käytettävissä. Todellisuudessa esimerkiksi kestävyyshuolet ja poliittiset painotukset voivat asettaa rajoja esimerkiksi biomassan ja ydinvoiman käytölle. On myös vielä auki, kuinka nopeasti hiilen talteenottoa ja varastointia saadaan kehitettyä tehokkaammaksi ja taloudellisemmaksi.

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CLIMATE ANALYTICS

Key findings

- The EU target to reduce greenhouse gas emissions by at least 40% below 1990 levels by 2030 is not yet sufficient to be in line with the Paris Agreement long-term temperature goal. The Paris Agreement requires faster reductions of greenhouse gas emissions in the EU and in Finland than presently envisaged.
- **According to least-cost energy-economic modelling approaches**, Finland would need to achieve about a 60% reduction and the EU as a whole a 50% reduction below 1990 levels by 2030. By 2050, emissions would need to become negative in Finland with reductions of 130% below 1990 levels. The EU would need to reduce greenhouse gas emissions by about 90%, which is within the 80-95% reduction range already adopted.
- As least-cost modelling does not account for different levels of capability to reduce emissions (e.g. wealth) and levels of responsibility for emissions, climate policy also looks at different approaches to fairness or equity in reducing emissions. The equity approach applied here finds reductions for each country consistent with the Paris Agreement whilst ensuring that no country does comparably more or less than another in equity terms. **According to the equity approach**, by 2030 Finland would need to have reduced greenhouse gas emissions by at least 60% and the EU by at least 75% below 1990 levels. By 2050, emissions would need to become negative in the EU region as whole with reductions of 150% of 1990 levels for Finland and 160% for the EU.
- Substantial changes in the energy system are needed to meet the Paris agreement 1.5°C scenario. The MESSAGE and SIAMESE energy-economic models used in this study find that**:**
    - **Energy efficiency is key over all time frames**, especially within sectors with limited near-term availability of low carbon technologies: industry, buildings and the transport sector.
    - Renewable energy sources are expected to replace fossil fuel based power plants in the short term.
    - In Finland, per assumption, coal is completely phased out by 2030 and the models find that in the EU, unabated coal is phased out in the same time-frame. While coal with Carbon Capture and Storage (CCS) could remain in a transition phase, this is phased out completely by 2070.
    - Oil is phased out by around the 2060s.
    - Unabated gas remains in the primary energy mix at a lower level than present throughout the 21st century. **CCS technologies** for gas come online, at **very low levels, in the 2020s** and then at scale until phase out of this technology for gas around 2080. Deployment of Bioenergy with CCS (**BECCS) starts at a low level in the 2020s** and is scaled up most rapidly from 2030 until 2040, with slower growth thereafter.
    - Nuclear power remains at about the present level until the 2080s, before phase-out around 2100.
- Equity approaches imply a need for investment and/or finance by wealthier countries beyond those required in domestic emission reductions in countries with lower capacity. Potential investments and/or mitigation finance needs in countries with lower climate change mitigation costs would be around € 0.1 Billion for Finland (0.1% of 2030 GDP) and € 92 Billion for the EU (0.6% of 2030 GDP) in 2030. In 2050 these costs would be € 1.36 Billion for Finland (0.7% of 2050 GDP) and € 421 Billion for the EU (2% of 2050 GDP).

Executive Summary

One of the key elements of the Paris Agreement is the goal to hold warming to **"well below 2°C and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels"**. This long-term temperature goal requires global emissions to peak as soon as possible and to reach globally aggregated zero emissions in the second half of this century. This indicates a need to increase the ambition of climate policies and goals. Indeed, recent literature shows that delaying climate action will increase the overall costs of mitigation and lower the probability to achieving the Paris Agreement goal. This report looks into the implications of the Paris Agreement's long-term goal for Finland and the European Union (EU). It finds the EU's targets adopted for 2030 and 2050, and therefore also concerning Finland, are not ambitious enough to achieve the Paris Agreement goals. This implies that ambition levels need to be revised upwards in order to reach the goals set in the Paris Agreement.

To calculate the emissions reductions in line with the Paris Agreement long-term temperature goal, two approaches are used here: the *least-cost* and the *equity* approach. The first approach looks into the optimal least-cost pathways (from the *Integrated Assessment Model (IAM)* MESSAGE). IAMs combine the current knowledge of energy systems and climate model projections to identify economically and technologically feasible emission pathways consistent with a temperature limit, while minimising global costs.

The second approach looks at how a country's (e.g. Finland) or region's (e.g. EU) reductions compare to those of others globally in terms of a range of equity (or fairness) indicators, such as a country's historical responsibility for global climate change, or its capability to contribute to global emission reduction efforts. Using our Equity Analysis tool, we evaluate a range of equity proposals, criteria and metrics in order to understand Finland's and the EU's responsibility for emissions reduction.

The comparison of the *least-cost* and *equity* approaches leads to the conclusion that for both 2030 and 2050 considerably deeper emissions reduction targets are needed than those currently adopted by the EU to be in line with necessary global reductions consistent with the long-term goals in the Paris Agreement.

Under a scenario in line with the Paris Agreement long-term temperature goal, emissions reductions estimated using the least-cost approach are not as large as from the equity approach, because, from an economic perspective, emission reductions in some other regions could be achieved at lower costs than in the EU, or in Finland. According to the least-cost approach, Finland would achieve about 60% reductions and the EU as a whole 50% reductions below 1990 levels by 2030, which is more stringent than the current 40% target put forward in the EU's INDC. By 2050, emissions reductions for Finland should be 130% below 1990 levels, and 90% for the EU, which is within the 80-95% emission reduction range adopted by the EU.

According to the equity approach, in 2030 Finland's emissions would need to decrease to 60% below 1990 to be in line with the Paris Agreement long-term goals. EU's emissions would need to be reduced by at least 75% instead of the 40% goal adopted in the INDC. By 2050 under the equity approach emission reductions for Finland and the EU would need to become negative in the EU region as whole with reductions of 150% for Finland and 160% for the EU below 1990 levels. The equity approach does not determine whether emissions reductions need to be achieved domestically. These could be achieved through a combination of both domestic measures and, for example, investment in or finance of emission reductions in less wealthy countries.

It should also be noted that this report evaluates many different perspectives on equity, so that very large ranges are associated with each of the central estimates of equitable emissions reductions.

The energy sector is a responsible for the majority of GHG emissions. The Paris Agreement requires faster reductions of carbon emissions in the EU and in Finland than presently envisaged. These steep reductions can be achieved, both in the EU and in Finland, through energy efficiency improvements – leading to lower energy demand, which is key over all time frames – and through decarbonisation, in particular of the power sector.

Renewable energy (and particularly biomass sources) are expected to replace fossil fuel based power plants in the short term. In the mid and longer term, the current generation of energy-economic models, which form the basis of the long-term emission scenarios in IPCC's Fifth Assessment Report, indicate both Carbon Capture and Storage (CCS) applied to some fossil fuels and negative emission technologies need to be deployed at scale.

CCS technologies come online coupled with fossil fuel energy for transitional periods of 40 to 60 years in the 2020s.

Negative CO_2 emission technologies – assumed to be Biomass with CCS (BECCS) – alongside carbon uptake through afforestation and reforestation become crucial in the second half of the century [1]. One particularity in the Finnish energy system is a considerably higher reliance on biomass consumption, compared to the EU as a whole. This makes BECCS an attractive option for Finland, although limited geological storage potential for CCS might undermine its effective deployment (VTT 2010). As an alternative, CCS may be able to be transported by pipeline to geological storage repositories in Norway, at an estimated cost of 4-16 Eur/tCO_2 (Kjärstad, Ramdani, Gomes, Rootzén, & Johnsson, 2011). However CO_2 transport costs are not explicitly taken into account in our analysis, so we assumed a maximum CCS storage potential for Finland of 45 MtCO_2 per year (based on Arasto et al. 2014[2]).

Key findings for Finland and the EU based on the MESSAGE and SIAMESE energy-economic models include:

- Energy efficiency is key over all time frames, especially within sectors with limited near-term availability of low carbon technologies: industry, buildings and the transport sector.
- Renewable energy sources are expected to replace fossil fuel based power plants in the short term.
- In Finland, per assumption, coal is completely phased out by 2030[3]. In the EU, the models find that unabated coal is phased out in the same time-frame but coal with CCS remains and is phased out by 2070.
- Oil is phased out by around the 2060s.[4]
- Unabated gas remains in the primary energy mix, at a lower level than present, throughout the 21st century. **CCS technologies** for gas comes online, at **very low levels, in the 2020s** and then at scale until phase out of this technology for gas around 2080.
- Deployment of BECCS should start at a low level in the 2020s and scaled up most rapidly from 2030 until 2040, with slower growth thereafter.
- Nuclear power plants remain producing energy at about the current scale until 2080, phasing out by around 2100.

These results need to be interpreted with care. Research in the scientific community is ongoing in many of these areas, including in relation to the consequences of technology limitations for sustainability, or other considerations, in achieving

[1] CCS is an emerging technology. A large number of large-scale CCS demonstration projects have been announced or planned around the world (Teir et al., 2010), although some of them have been cancelled. Under the Paris Agreement 1.5°C and the Cancun Agreements 2°C scenarios, CCS projects may need to be deployed at commercial scale by 2030. http://www.vtt.fi/inf/pdf/tiedotteet/2010/T2556.pdf

[2] In all scenarios, we consider an upper bound on CCS storage of 45 MtCO2e/yr for Finland, based on Arasto et al. (2014). According to Arasto and co-authors (2014), the maximum technical potential of biomass with CCS in Finland in 2030, is around 45 MtCO2 per year. In order to be conservative, we consider apply this constrain on total CCS storage (including coal and gas + CCS) and throughout the whole century.

[3] This is in accordance with current policies this is included as an explicit a priori constraint on the model, hence not necessarily a conclusion based on the model's least-cost strategy.

[4] The year for phase out is the year of reductions of 90% or more below 2010 levels, analogous to assessment of emissions from energy supply sector in IPCC AR5 WG3 (SPM).

global warming limits. These issues are not covered in this report, but remain important to any real-world deployment of options described here. Also, other models might provide different results and the current literature on 1.5°C scenarios is limited. For example, model inter-comparison projects focusing on 2°C scenarios show large deviations across models in terms of total energy use and fuel mix, within the same region, reflecting different model assumptions on fuel substitution rates, relative costs, etc. and leading to different trade-offs between mitigation options and technologies. Nevertheless, it is clear that the scope for choice in the technological mix, the timing and phasing of deployment of technologies and policies to improve efficiency and decarbonise the energy system, improve agriculture and forestry practices, and change transport modalities and technologies is much more limited under the 1.5°C limit than under a 2°C limit. It can also be expected that absolute mitigation cost estimates would differ widely across models for 1.5°C scenarios, just as they do for 2°C scenarios.

The gap between the *equity* and the *least-cost* approaches could be closed in different ways including by climate finance, investment and/or technology transfers to countries and regions, where climate mitigation can be achieved at a lower cost. With an estimated representative mitigation cost of around 69 €/tCO_2, the potential investments and/or mitigation finance needs in countries with lower climate change mitigation costs would be around € 0.1 Billion for Finland (0.1% of 2030 GDP) and € 92 Billion for the EU (0.6% of 2030 GDP) in 2030. In 2050 these costs would be € 1.36 Billion for Finland (0.7% of 2050 GDP) and € 421 Billion for the EU (2% of 2050 GDP), based on a representative mitigation cost of 99 €/tCO_2 by that time. These values are associated with large ranges, both due to the variety of views on equity indicators and due to uncertainties in mitigation cost estimates.

Background

At the COP21 in December 2015, 195 countries adopted the Paris Agreement including mitigation and other commitments for all Parties to the UNFCCC. The Paris Agreement has at its core a goal to hold warming **"well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels"** and a requirement that global aggregate emissions are brought to zero in the second half of this century.

This report investigates the implications of the Paris Agreement's long-term temperature goal for greenhouse gas emissions in Finland and in the European Union (EU[5]). A key element of the Paris Agreement are the Nationally Determined Contributions (NDCs), which specify countries' emissions reductions for the post-2020 period. The NDCs are based on the *Intended* Nationally Determined Contributions that almost all Parties to the UNFCCC submitted before the Climate Conference in Paris. It is clear now that the **INDCs in aggregate fall substantially short of what is necessary to put the world on a pathway in line with the Paris Agreement long-term temperature goal** (e.g. Climate Action Tracker, UNEP Gap Report 2015, UNFCCC Synthesis Report 2015[6]).).

The Paris Agreement includes legally binding commitments to prepare, communicate and maintain successive NDCs, every five years. Combined with other "ambition" elements, including the facilitative dialogue in 2018, a five-yearly "global stocktake", and strong transparency and accountability elements, the Agreement is designed to **pave the way for the mitigation efforts and ambition of GHG targets to be progressively improved**. In fact, the Decision that adopts the Agreement (Decision 1/CP.21) specifies that much greater emissions efforts will be required to close the emissions gap between the estimated aggregate greenhouse gas (GHG) emissions levels resulting from INDCs and emissions consistent with the long-term temperature goal of the Paris Agreement. The first cycle of global stocktake and review of progress is scheduled for 2018 through the facilitative dialogue and is linked with a global political moment by 2020 when countries will communicate new or updated NDCs. **The conclusions of this report are designated as an input into this process and to support the first review of NDC mitigation targets and to support Finland in crafting the new energy and climate strategy, due to come out late in 2016.**

[5] EU28 region, including: Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the UK

[6] See update including 1.5oC consistent pathways - http://unfccc.int/resource/docs/2016/cop22/eng/02.pdf

What do the Paris long-term goals mean for emissions globally?

The Paris Agreement long-term temperature and emissions goals

Before unpacking what the Paris Agreement's (UNFCCC, 2015b) long-term temperature and emissions goals mean for specific regions in the world, we need to understand what the Agreement means for emissions and energy transition globally. It is therefore crucial to carefully consider the formulation of the Paris Agreement long-term goals and find how they can be best reconciled with the most current scientific knowledge, given that, by necessity, much of this knowledge is based on scientific publications predating the Paris Agreement.

Under the long-term temperature goal (Article 2.1) of the Paris Agreement, Parties agree to "holding the increase in the global average temperature to **well below 2°C** above pre-industrial levels and pursuing efforts **to limit the temperature increase to 1.5 °C** above pre-industrial levels, recognising that this would significantly reduce the risk and impacts of climate change".

The long-term emissions goals in the Paris Agreement are expressed in Article 4.1 in order to achieve the long-term temperature goal of the Agreement and have three main elements:

- Reach global peaking of greenhouse gas (GHG) emissions as soon as possible, recognising that peaking will take longer for developing country Parties.
- Undertake rapid reductions after global peaking of GHG emissions.
- Achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century.

In round terms this means that the global aggregate sum of direct human induced emissions and removals by sinks of greenhouse gases needs to be zero in the second half of the century, with the timing based on the "best available science". It is important to note that this does not mean that the global aggregate sum of sources and sinks needs to be zero at the same time in every region of the world, as some regions may be sinks and other regions sources.

It is also important to note that these provisions of the Paris Agreement, as with others, are complimented by the package of decisions adopted at COP21 in Paris that relate to the implementation and operationalisation of the Agreement (UNFCCC, 2016). Of note are paragraphs 17 [7] and 21 [8] of Decision 1/CP.21 which relate to an IPCC Special Report for 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global GHG emission pathways. It can be expected that this Special Report will, amongst other factors assess the global emission levels for 2025 and 2030 and in the longer term, consistent with the long-term temperature and emission goals of the Paris Agreement, as well as the additional emission reduction efforts required to bring the aggregated emissions of NDCs within these limits. This is relevant to the issue of "best available science" in understanding the emission limits of Article 4.1. The May 2016 Update of the Synthesis Report of the UNFCCC Secretariat on the aggregated emissions

[7] "Notes with concern that the estimated aggregate GHG emission levels in 2025 and 2030 resulting from the intended nationally determined contributions do not fall within least-cost 2 ˚C scenarios but rather lead to a projected level of 55 gigatonnes in 2030, and also notes that much greater emission reduction efforts will be required than those associated with the intended nationally determined contributions in order to hold the increase in the global average temperature to below 2 ˚C above pre-industrial levels by reducing emissions to 40 Gigatonnes or to 1.5 ˚C above pre-industrial levels by reducing to a level to be identified in the special report referred to in paragraph 21 below;"

[8] "Invites the Intergovernmental Panel on Climate Change to provide a special report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global GHG emission pathways;"

effect of INDCs indicates that at present they are far from emission pathways consistent with scenarios holding warming to below 2°C or below 1.5°C limit (UFCCC, 2016).

Comparison of Paris Agreement long-term temperature goal with the EU/Cancun Agreement 2°C temperature limit

Prior to the adoption of the Paris Agreement and its temperature and emission limits described above, in 2007 EU heads of government adopted the 2°C degree limit (Council of the European Union, 2007). This limit was adopted at the international level in the Cancun Agreements in 2010 where it was expressed as an aim "to hold the increase in global average temperature below 2°C above preindustrial levels"[9]. Recognising concerns of vulnerable countries, in 2010 the UNFCCC established a review process to evaluate whether the long-term global temperature goal of holding warming below 2°C was adequate to avoid dangerous climate change and to consider "strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5°C". This process ended in 2015 with the final report of its scientific arm (Structured Expert Dialogue) concluding that a warming of 2°C cannot be considered safe (UNFCCC, 2015c), which ultimately led to the Paris Agreement's long-term temperature goal.

The Cancun Agreements' 2°C temperature limit, and the Paris Agreement's 1.5°C temperature limit have quite different implications for long-term emission levels and for the implementation of the long-term emission goals in Article 4.1.

The Cancun Agreements' 2°C temperature limit, interpreted as holding global mean temperature rise below 2°C during the 21st century with a likely (more than 66%) chance, implies that global greenhouse gas emissions need to be reduced by 40-70%[10] (35-55%) in 2050 below 2010 (1990) levels and reach globally aggregated zero emissions by 2080-2100. Globally, energy and industry CO_2 emissions[11] would need to be reduced by 2050 by 35-80% (10-70%) below 2010 (1990) levels, reaching zero around 2060-2075.

Given the available scenario literature, the Paris Agreement's long-term temperature goal to hold temperature rise well below 2°C, and to pursue effort to reach 1.5°C, is represented here as holding warming below 2°C with 85% probability, or greater, and with a more than 50% chance of being below 1.5°C by 2100[12]. This representation requires that global emissions are reduced by 70-95%[2] (65-90%) below 2010 (1990) levels by 2050, and reach globally aggregated zero emissions by 2060-2080. Global energy and industry CO_2 emissions will need to be reduced by 2050 by 95-120% (95-125%) below 2010 (1990) levels, and reach zero around 2050 (range 2045-2055).

The Paris Agreement temperature limit indicates that deeper reductions are needed by 2050 globally than under the former Cancun 2°C temperature limit, and significantly earlier achievement of globally aggregated zero GHG emissions and energy and industry CO_2 emissions. This means that the EU 2050 goal of a 50% reduction of global GHG emissions from 1990 levels consistent then with the EU 2°C limit (Council of the European Union, 2009) is no longer sufficient. In addition, the Paris Agreement temperature limit implies that under Article 4.1 globally aggregated zero GHG emissions (balance between anthropogenic sources and sinks of

[9] Decision 1.CP/16 Paragraph 4
http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf

[10] These numbers are drawn directly from the IPCC AR5 Working Group III Summary for Policymakers (2014). The other numbers in this section draw from all scenarios assessed by the IPCC Fifth Assessment Report and the 2014 UNEP Emissions Gap Report (2014)and follow the methodologies of the 2014 UNEP Emissions Gap Report, to enable a direct comparison of these other numbers with the information provided in the 2014 UNEP Emissions Gap Report for 2 °C.

[11] Referred to by the IPCC as "CO2 from fossil fuel and industrial sources" (see IPCC AR5 WGIII (2014) chapter 6 section 3.1.3).

[12] The 1.5°C scenarios underlying the emission numbers here have a more than 50% chance of returning to below 1.5°C by 2100 and simultaneously have a probability of about 85% to hold warming below 2°C during the 21st century.

greenhouse gases) needs to be achieved no later than 2080.

Choosing scenarios consistent with the Paris Agreement

Over the past decades, there has been a great deal of effort in the scientific community to better understand how we can meet temperature goals, by integrating the most current knowledge of energy and economic systems and climate model projections. This literature is clear: limiting warming to 1.5°C in 2100 and holding below 2°C throughout the 21st century is both technically and economically feasible. The required transformation of the global economy represents a major challenge. Energy-economic scenarios as analysed in this report, as well as in IPCC's Fifth Assessment Report by Working Group III, identify the technical and economic conditions for achieving long-term temperature goals. They lay out the technological options and estimate increases or decreases in overall costs, if certain options were to be included, excluded, or limited. They also estimate the implications of delaying actions globally, or in specific regions, compared to an optimal full technology and early global concerted action "least-cost" strategy. In general, achieving long-term temperature goals is shown to require rapid improvements in energy efficiency, and a tripling to nearly quadrupling of the share of zero- and low-carbon energy supply and the introduction of negative emission systems, such as bioenergy with CCS (BECCS) by 2050. These scenarios describe a wide range of changes in land use, reflecting different assumptions about the scale of bioenergy production, afforestation, and reduced deforestation. While these scenarios show how long-term temperature goals are technically and economically feasible, and under which conditions, achieving those goals clearly requires strong political will and as well engagement of civil society and the private sector.

The scenario literature provides ample energy-system emissions scenarios consistent with holding warming below 2°C and, to a lesser extent, to 1.5°C, and because we are dealing with a considerable level of uncertainty[13], with various degrees of likelihood of exceeding those temperatures. Based on the scientific literature and consensus built over the years, the Cancun Agreements' goal of holding warming below 2°C has been interpreted consistently (including in the IPCC AR5) with the "likely below" 2°C class scenarios, that is, 2°C scenarios that have a 66% chance, or greater, of staying below a 2°C global mean warming above pre-industrial levels throughout the 21st century.

The Paris Agreement goes well beyond the Cancun Agreements' 2°C limit and aims to hold warming to *well* below 2°C and to pursue efforts to *limit temperature increase to 1.5°C*. The range and depth of literature available for evaluation of this temperature limit is not as great as for the "likely below" 2° C class of scenarios. The 1.5°C consistent scenarios published to date overshoot a 1.5°C global mean warming above preindustrial in the 21st century by about 0.1 to 0.2°C, before returning to 1.5°C or below in 2100 with a 50% likelihood (median warming in 2100 of 1.4°C). There is a range of new scenarios under consideration and in preparation by different research groups which limit warming to 1.5°C with a higher probability and with a corresponding peak warming somewhat lower than indicated above. These are not yet in the publication phase and therefore cannot be cited or used with confidence at this point.

After careful consideration of the available scenarios, we have applied the 1.5°C consistent scenarios that have a 50% chance of limiting warming to 1.5°C or below as these are peer reviewed and fully available. We note however that the currently available range of 1.5°C scenarios does not fully meet all interpretations of the Paris Agreement long-term temperature goal. A new generation of low emission scenarios expected to

[13] Refer to Box 3 for details on the uncertainties relating to Climate sensitivity and GHG concentration assumptions

enter the peer-reviewed literature towards the end of 2016 will allow a broader assessment of the well below 2°C, 1.5°C limit than the set of existing scenarios available for this report. In concrete terms, these new scenarios would permit a different representation of the Paris Agreement than adopted above as these scenarios would limit warming to 1.5°C with a higher probability than 50% and/or achieve this at an earlier time during the 21st century.

Other criteria need to be taken into account in our choice of scenarios. Firstly, to ensure maximum relevance of this analysis for policy making focused on *the post-2020 timeframe*, we require scenarios with global GHG emissions by 2020 as close as possible to current emissions projections. We opt therefore to select from a class of scenarios in the literature that are often called *"delayed action"* scenarios for this analysis, as opposed to those that are often termed *"immediate action"* scenarios. Delayed action scenarios usually assume that countries will meet their Copenhagen Accord pledges for 2020, before beginning deeper action to meet the 2°C, or other assumed, long-term goal. The so-called immediate action scenarios, many of which were produced several years ago, assume strong global concerted climate action starting all in 2010. In such scenarios emissions in 2020 are significantly lower than those that are implied by full implementation of the Copenhagen Accord 2020 pledges.

In effect, using immediate action scenarios would imply that full global climate action to meet the 2°C or other limit started more than 5 years ago and that emission levels in 2020 would be much lower than presently projected. Such scenarios, whilst useful for analytical purposes, are unrealistic in the analysis conducted here. It is important to note, however, that if climate action is ramped up in the pre-2020 period, this would relieve pressure on the post-2020 targets (Box 2).

Moreover, all global scenarios considered here need to be consistent with each other, that is, they need to be produced by the same energy-economic model, using the same socio-economic assumptions and technological options portfolio, the same primary energy sources potentials etc., and to differ only on the stringency of their long-term goal. This ensures that the difference in the model's output of emission pathways and in energy-system characteristics are attributable only to the different levels of stringency of the long-term goal.

Scenario approaches

In addition to the Paris Agreement scenario, for comparative purposes we also look into the implications of scenarios that are in line with the Cancun Agreements' global goal and a reference case, a scenario in the absence of climate policy globally, for Finland and for the EU.

Based on considerations described above, we have selected three classes of scenarios consistent with these constraints from the Integrated Assessment energy-economic model MESSAGE (Rogelj et al 2015):

- ***Paris Agreement 1.5°C scenario***: Pathway that accelerates global action from 2020 onwards, return warming below 1.5°C by 2100 with about a 50% chance.
- ***Cancun Agreements 2°C scenario***: Pathway that accelerates global action from 2020 onwards to hold warming below 2°C with a likely chance by 2100.
- ***No Policy scenario***: Reference pathway reaching 2020 levels close to levels implied by Copenhagen pledges (no **additional climate policy** than in place by 2020).

Scenario limitations

The MESSAGE scenarios are based on high efficiency (low primary energy demand) and full technology availability. The latter means that technology such as nuclear power, fossil fuel CCS and negative CO_2 emissions technology, all of which may have important sustainability and other constraints, are assumed to be available for mitigation. Particularly for 1.5°C scenarios (such as the Paris Agreement 1.5°C), negative CO_2 emissions are now essential if this warming limit is to be met. Negative CO_2 emissions are also required to hold warming below 2°C with a likely probability (such as Cancun Agreement 2°C scenario studied in this report). After taking into account the assumed potential for carbon sequestration in forests and soils, there still remains a large need for industrial scale negative CO_2 emissions using technologies such as BECCS or Direct Air Capture. BECCS is the technology used in MESSAGE — and other IAMs — to achieve negative CO_2 emissions at scale.

In practice, there may be non-direct economic constraints placed upon technologies. For example, if there is a large need for negative CO_2 emissions to meet global warming goals, then policy makers may restrict this application only to geologically secure repositories. There may also be sustainability constraints placed upon the deployment of biomass energy systems, which have the potential for leading to land use and other environmental concerns, unless properly managed and deployed in a sustainable manner. Concerns with nuclear power in many jurisdictions are well known and may limit deployment in the future in at least some regions.

Research in the scientific community is ongoing in many of these areas, including in relation to the consequences of technology limitations for sustainability, or other considerations, in achieving global warming limits. These issues are not covered in this report, but remain important to any real-world deployment of options described here.

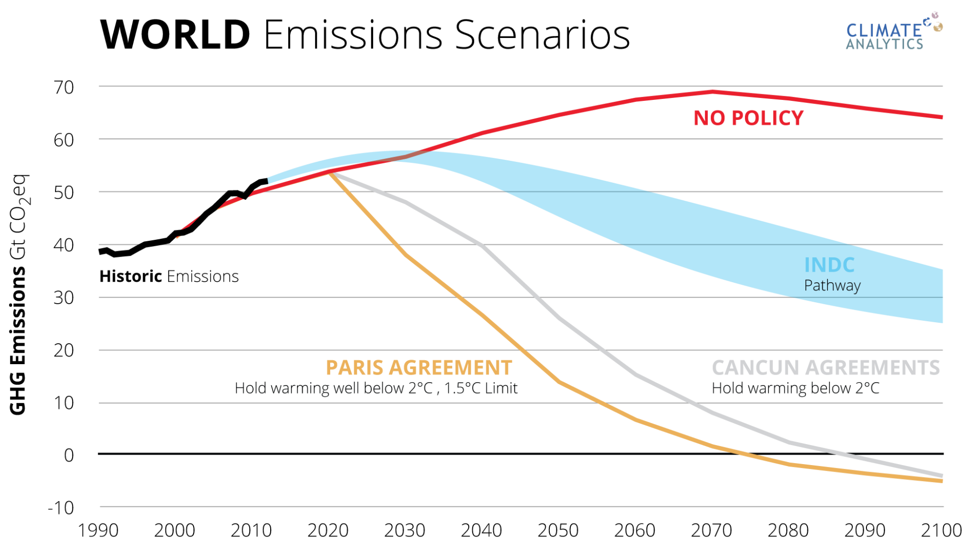

Figure 2: Global policy-relevant scenario cases assessed in this report compared to estimated global INDC pathway (Climate Action Tracker)

Approach

In this report we investigate the implications of the Paris long-term temperature goal for Finland and the EU. Inferring the consequences of a global temperature limit for a region or country requires splitting the global mitigation effort, necessary to meet that limit, to the country/regional level. We explore the implications of the three classes of scenarios described in the previous section —namely the Paris Agreement 1.5°C scenario, the Cancun Agreements 2°C scenario and the No Policy scenario — for GHG emissions, energy transition and level of investments abroad for Finland and the EU.

There has already been a great deal of effort by the scientific community to develop approaches to split global mitigation efforts to the country/regional level efforts. These approaches can be divided in two groups:

- The first group is using ***Integrated Assessment Models*** **(IAMs)** to assess emissions reductions using the mitigation costs as the main determinant. IAMs combine the current knowledge of energy systems and climate-model projections to identify economically and technologically feasible emissions pathways consistent with a temperature limit, while minimising global costs. These are the so-called optimal **"least-cost" pathways.** All IAMs come to the same conclusion: the earlier strong climate action is implemented, the cheaper it is to meet a temperature limit in total over the whole of the century. All results provided in this report are based on the IAM MESSAGE model[14].
- The second group of approaches is looking into ***equity indicators***, such as a country's historical responsibility for global climate changes, or capability to contribute to global emission reduction efforts. Many equity proposals, based on different criteria and metrics, have been put forward by the scientific community and by governments. Our approach is to consider these views, if quantifiable, and not limit the analysis to any particular one of these views**. We therefore evaluate a range of equity proposals, criteria and metrics in order to understand Finland's and the EU's responsibility for emissions reduction**, using our Equity Analysis tool**.**

The outcome of this analysis — the least-cost emissions pathways and equity ranges in line with the Paris Agreement long-term temperature goal — indicates the emissions reductions required of countries and their necessary contribution for energy transformation to put the world on a pathway avoiding the most adverse impacts of climate change.

[14] The MESSAGE model provides a flexible framework for the comprehensive assessment of major energy challenges and has been applied extensively for the development of energy scenarios and the identification of socioeconomic and technological response strategies to these challenges. Further details on the model can be found here.

Implications of the Paris Agreement for GHG emissions in Finland and the EU and relation to post-2020 emissions reduction targets

To evaluate the adequacy of the current level of ambition of post-2020[15] climate targets in the EU, and in Finland as one of its member states, emissions levels in line with the least-cost pathways and equity ranges are mapped against emissions levels in line with current EU emissions reduction targets.

In 2015, the EU submitted its INDC to the UNFCCC (European Union, 2015; UNFCCC, 2015a) formally putting forward a binding, economy-wide target of at least 40% domestic GHG emissions reductions below 1990 levels by 2030. Under the Copenhagen Accord the EU proposed to reduce emissions by 80%-95% below 1990 levels by 2050. For 2050, Finland has set a domestic long-term target to reduce emissions by at least 80% below by 1990 levels, which is in line with the EU target.

Finland: 2030 and 2050 targets not yet in line with the Paris Agreement

We extend the EU 2030 target to Finland by applying the above percentage reduction to Finland's emissions. Between 1990 and 2013 Finland's emissions have decreased by over 11%. That was less than reductions on average in the EU28, which reduced its emissions by over 21% below 1990 levels in the same period.[16] In absolute terms, Finland's emissions in 2030 should fall to 43 $MtCO_2$[17] to meet percentage emissions reductions equal to EU targets.

As shown in Figure 3, neither the 2030, nor the 2050 targets for Finland are in line with levels consistent with the Paris Agreement. Both the 2030 and 2050 emissions reduction targets are only in line with the very upper end of equity ranges in their respective year. This means that these targets are only consistent with a very small minority of equity assessments, and that, generally speaking, adopting these targets would mean that Finland would rely on other countries doing comparatively more.

A fair share of effort, i.e. without requiring any other country in the world to do comparatively more, would mean that Finland's emissions reductions should be at least 60% below 1990 levels by 2030 (as opposed to the 40% reduction proposed in the INDC) and at least 150% below 1990 levels by 2050 (as opposed to a 80-95% long-term target), to be in line with the long-term temperature goal in the Paris Agreement (Table 2).

[15] See Box 1 for details on reasons why this approach does not allow for assessment of the adequacy of the 2020 target.

[16] Own calculations based on Eurostat numbers. More recent data (http://tilastokeskus.fi/til/khki/2014/khki_2014_2016-04-15_tie_001_en.html) indicates that GHG emissions (excl. LULUCF) in 2014 have decreased by 7% compared to 2013, which means that emissions have reduced by 17% below 1990 levels. This data has been submitted to the UNFCCC, but background/methodological information has not yet been made available (e.g. GWP used, IPCC methodology employed). Because this does not alter our qualitative assessment, we refrain from using it in this report.

[17] Own calculation based on Eurostat numbers. Finland's GHGs emissions are strongly influenced by electricity imports: the higher the imports, the lower Finland's domestic emissions. But as the emissions occur somewhere else, the overall global emissions do not change. To avoid a situation in which emissions reduction would take place mainly as a result of increasing power imports, especially from carbon intensive energy sources, the calculation of absolute emissions assumes that the levels of power imports stay the same as in 1990.

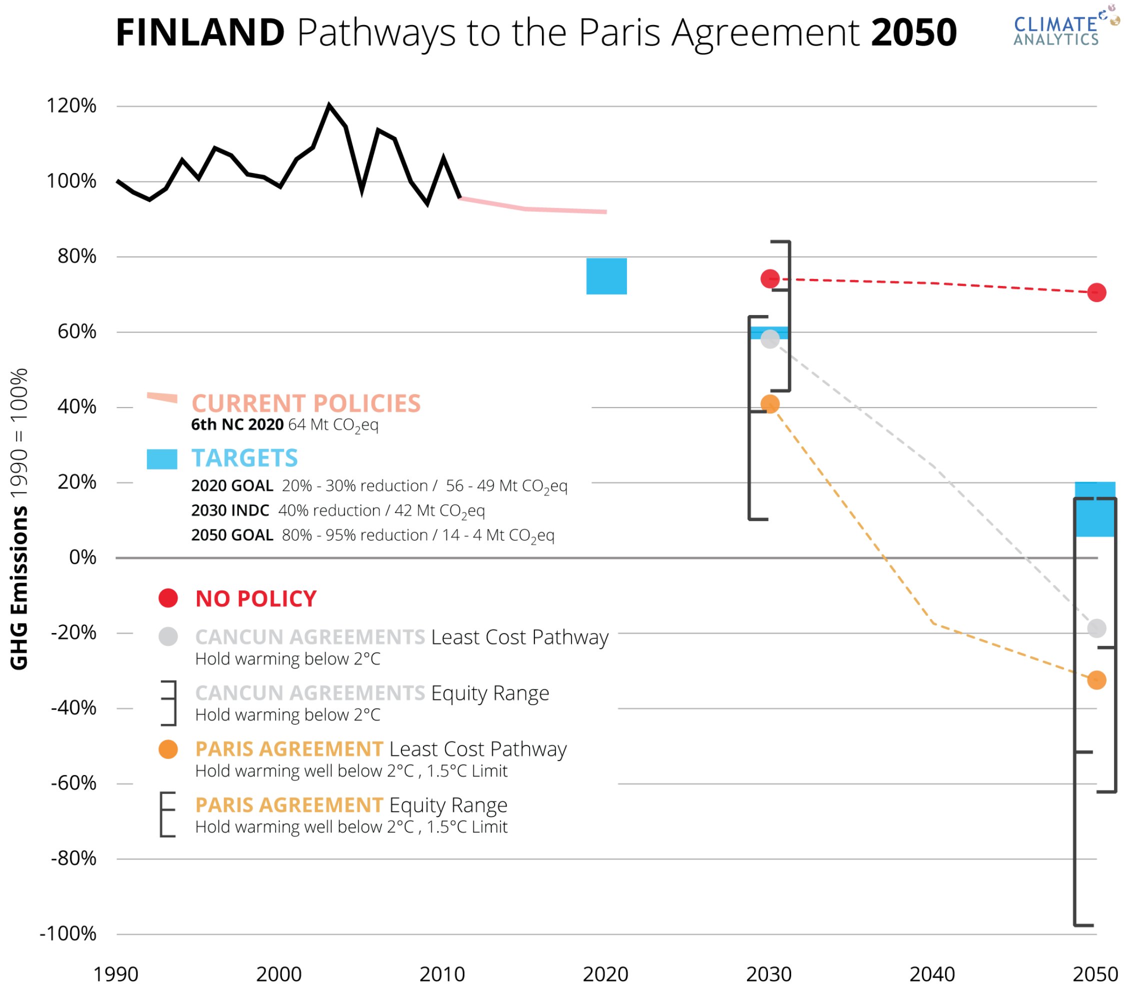

Figure 3: Emissions levels and targets for Finland. Equity range shows the full range and the level within that range that is in line with the Paris or Cancun Agreements, without requiring other countries in the world to do comparatively more. Current policies range based on Sixth National Communication (6th NC).

The emissions reductions resulting from the targets adopted by the EU for 2030, if applied to Finland, and from Finland's 2050 target, also fall short from what is needed to be in line with the least-cost pathways consistent with the Paris Agreement (Table 2). This indicates that emissions reductions in Finland are not in line with optimal emissions pathways from an economic and technical point of view. Similarly under the equity approach, by 2030, emissions reductions of about 60% below 1990 levels should be achieved, which is larger than the current EU goal of 40% below 1990 levels. By 2050, reductions in line with the least-cost approach should be about 130% below 1990 levels (compared to the 80-95% long-term goal), and thus less stringent than under the equity approach.

The existing discrepancy between emissions levels in line with the least-cost pathways and those in line with equity indicates that while strong emissions reductions are required by equity, it may be technologically and economically beneficial for Finland to achieve a share of these reductions abroad, that is, to invest in reducing emissions in other regions where reductions cost less than domestically. We provide estimates of those investments in the upcoming sections.

Table 2: Percentage GHG emissions reductions from 1990 levels in line with least-cost and equity approaches consistent with the Paris Agreement for Finland (based on GHG emissions excluding emissions from LULUCF). Equity estimate show the full range (between brackets) and the level required at least to be in line with the Paris Agreement (before brackets) without requiring other countries in the world to do comparatively more.

	2030	2050
Reductions below 1990 levels in line with least-cost	-59%	-133%
Reductions below 1990 levels in line with equity (full range)	-61% (-90 to -36%)	-152% (-198 to -84%)

European Union: post-2020 targets still fall far short of what is needed to be in line with the Paris Agreement

The EU emissions reduction targets for 2030 and 2050 are also not in line with the least-cost pathways, nor with the equity ranges for the region consistent with the Paris Agreement. According to the equity assessment, emissions reductions in the EU in line with the Paris Agreement (and without requiring other countries in the world to do comparatively more) should be at least 75% below 1990 levels by 2030, as opposed to 40% reduction proposed in the INDC. By 2050, EU's emissions should decrease by at least 164% of 1990 levels, almost twice as much as the 80-95% emissions reduction goal adopted by the EU.

Table 3: Percentage GHG emissions reductions below 1990 levels in line with least-cost and equity approaches consistent with the Paris Agreement for the EU (based on GHG emissions excluding emissions from LULUCF). Equity estimate show the full range (between brackets) and the level required at least to be in line with the Paris Agreement (before brackets) without requiring other countries in the world to do comparatively more.

	2030	2050
Reductions below 1990 levels in line with least-cost	-47%	-88%
Reductions below 1990 levels in line with equity (full range)	-75% (-105 to -49%)	-164% (-216 to -86%)

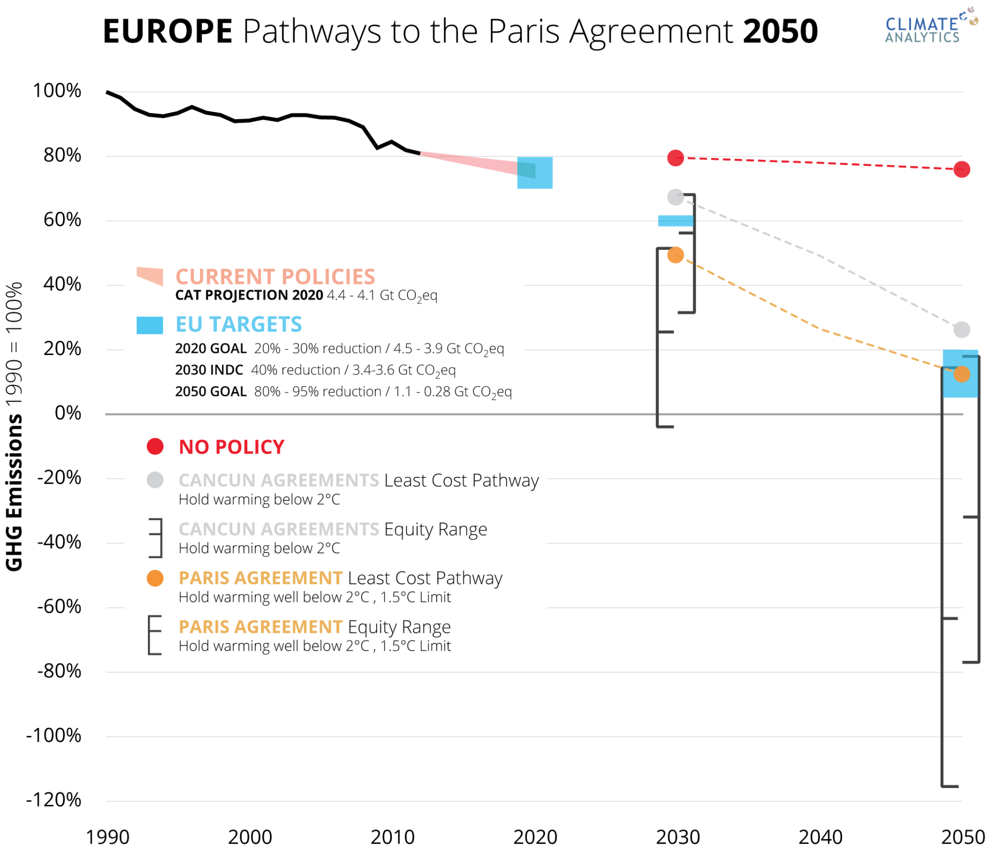

Figure 4. Emissions levels and targets for the European Union (EU28). Equity range shows the full range and the level within that range that is in line with the Paris or Cancun Agreements, without requiring other countries in the world to do comparatively more. Current policies range based on Climate Action Tracker (CAT).

The emissions reductions consistent with the least-cost pathways are lower than those resulting from the equity approach, but nonetheless require more action than the implementation of the goals adopted by the EU for 2030. By then the EU's emissions should be halved compared to 1990 levels. For 2050 emissions reductions for the EU resulting from the least-cost approach would be roughly in the middle of the 80-95% range adopted by the EU.

The considerable difference between the emissions reductions resulting from the least-cost and equity approaches indicates that it would be economically beneficial for the EU to finance a share of its required emissions reductions abroad, rather than achieve all reductions in the EU itself. We provide estimates of those investments in the final section of this report.

Box 1: Considerations on 2020 targets and methodological clarification

This assessment does not allow for the evaluation of the adequacy of the 2020 targets. To ensure maximum relevance of this analysis for policy making focused on *the post-2020 time frame*, we require scenarios with global GHG emissions by 2020 as close as possible to current emissions projections. This has led us to choose "delayed-action scenarios" as target scenarios in our analysis, which are scenarios that start global concerted climate action by 2020 and still achieve the long-term temperature goal (further details in section "What do the Paris long-term goals mean for emissions globally?"). These do not allow for the assessment of the 2020 targets.

Under the Copenhagen Accord, the EU proposed to decrease emissions by 20% unconditionally (and to 30% conditionally) below 1990 by 2020, that is, emissions in the EU cannot exceed 4.5GtCO_2e in order to meet its unconditional pledge (or 3.9 GtCO_2e for the conditional pledge). As Figure 4 shows, currently implemented policies in the EU (as assessed by the Climate Action Tracker) will allow the EU to meet its target, which is, however, rated "Inadequate", meaning that it is not in line with any fairness consideration available.

If we extend the EU target to Finland, emissions levels consistent with a reduction of 20% below 1990 levels would not exceed 56 MtCO_2e. According to Finland's 6th National Communication, currently implemented policies will result in emissions levels (excl. LULUCF) of about 64 MtCO_2e and fall short from what is needed for Finland to meet this target (Ministry of the Environment and Statistics Finland, 2013).

Carbon budgets

IPCC's Fifth Assessment Report confirmed the scientific basis for the approximate linear relation between global temperature increases and cumulative carbon emissions. This allows an estimate of the cumulative CO_2 emissions "allowed" for a particular long-term temperature goal, commonly referred to as a carbon budget. Of course, non-CO_2 emissions have a large effect on warming as well, so that the relation between cumulative CO_2 emissions and long-term temperature goals are subject to not only uncertainties in the climate system response, but also in the emission pathways of non-CO_2 emissions.

The table below shows the cumulative carbon budget from 2010 up to 2100 in line with the Paris and Cancun Agreements for Finland, Europe and the World, under a least-cost approach, along with cumulative CO_2 emissions in the No Policy scenario.

It is very important to note that a total carbon budget over the 21st century does not give a good indication of its evolution in time. Particularly for the lowest scenarios including for the Paris Agreement 1.5°C scenario and the Cancun Agreements 2°C scenario used here, global negative CO_2 emissions play an important role in the second half of the 21st century (see also Box 2). In such scenarios, the 21st century budget would initially be exceeded by a significant amount towards mid-century, before cumulative emissions drop down by the end of the century to the values indicated in Table 3. It is crucial to keep this in mind, to avoid the idea that the current levels of GHG emissions would soon exceed the 21st century budgets as indicated in the table, thus rendering the associated long-term temperature goals infeasible.

Table 4: Cumulative global total CO_2 emissions (2010-2100) in line with least-cost approach.

Cumulative global total CO_2 emissions (2010-2100) – $GtCO_2$	Paris Agreement 1.5°C Scenario	Cancun Agreements 2°C Scenario	No Policy
Global	447	950	3979
Europe	83	116	285
Finland	-0.9	-0.3	3.3

In the Paris Agreement 1.5°C scenario, the global carbon budget is around 450 $GtCO_2$, of which roughly 80 $GtCO_2$ is allocated to Europe. In the case of Finland, the cumulative carbon budget is negative, due to relatively strong negative carbon emissions from BECCS in the second half of the century. In the Cancun Agreements 2°C Scenario, the global carbon budget is around 950 $GtCO_2$, of which 12% assigned to Europe. The carbon budget for Finland is still negative, at around -0.3 $GtCO_2$. We re-emphasize the fact that these numbers are subject to uncertainties, and that weaker (stronger) action on non-CO_2 emissions might allow for a smaller (larger) carbon budget.

Box 2: The earlier the better

The IPCC AR5 and subsequent literature shows clearly that a delay in mitigation action increases the overall mitigation costs and undermines the probability of limiting warming below 2°C - with the same qualitative result also applying to 1.5°C scenarios. A further consequence of delay in emission reduction action, in addition to increasing overall mitigation costs, is the increasing reliance on negative CO_2 emissions (also termed carbon dioxide removal) (e.g. with BECCS - Biomass with Carbon Capture and Storage). For illustration, the graph below shows the relationship between 2030 emission levels (as a % of 2010 emission levels) and cumulative negative CO_2 emissions from BECCS, for a subset of emissions scenarios assessed in the LIMITS project that have a probability to hold warming below 2°C by 2100 close to 70% (within the boundary of the 66-100% "likely" confidence level according to the AR5 uncertainty guidance). The relation between 2030 emissions and required cumulative negative CO_2 emissions is not perfectly linear, since 2°C probability levels are also affected by non-CO_2 forcing that varies across these scenarios. However, these scenarios do indicate deeper emission reductions in the period to 2030 lower the need for later compensation by negative CO_2 emissions.

Note this is a relatively small set of scenarios that provides only an illustrative indication of the issue at hand, and should be subject to further research, including an assessment of the influence of carbon sequestration potential in the LULUCF sector and measures to reduce non-CO_2 emissions.

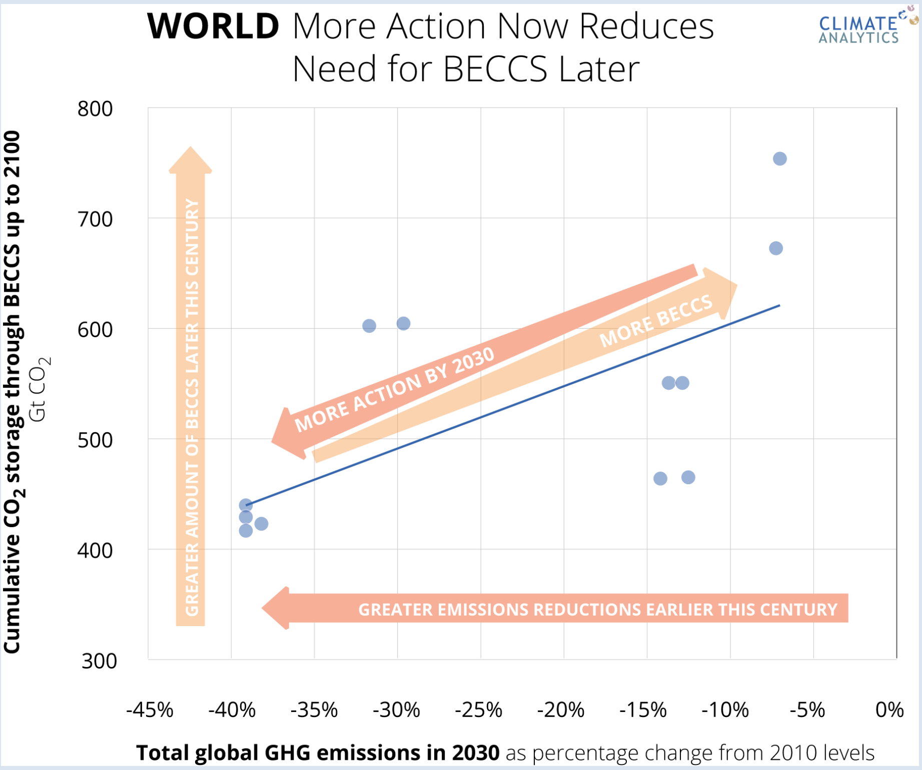

Figure 5 GHG Emission levels in 2030 in percentage from 2010 levels and cumulative negative emissions from BECCS under a selection of 2°C scenarios (about 70% of holding warming below 2°C by 2100) that in 2020 approximate global total GHG emissions levels estimated from Copenhagen pledges. Source: own calculations based on IPCC AR5 LIMITS database.

Implications of the Paris Agreement for energy transition in Finland and the EU

The energy sector is a key driver of emissions, as continued investments in fossil energy could lock in emissions for many years. A lock in of unmitigated fossil fuel sources in the energy mix can seriously threaten the achievement of the Paris Agreement. We will look into the primary energy mix development under a scenario in line with the Paris Agreement long-term temperature goal. For comparison, we also explore how the energy mix would evolve in the Cancun Agreements 2°C and the No policy scenarios.

Global consumption of biomass will increase over time under the Paris Agreement and approach 220 EJ/yr. This level is well below the threshold of 300 EJ/yr noted in the scientific literature (Creutzig et al., 2015) as sustainable in the long-term.

The Paris Agreement 1.5°C scenario requires fast reductions of carbon emissions in the EU and, as a consequence, also in Finland. Primary energy mix developments in the EU are very similar to those needed in Finland. For both, steep emissions reductions are achieved through energy efficiency improvements – leading to lower energy demand – and through decarbonisation, particularly of the energy sector. Biomass with CCS (BECCS) will become crucial in the second half of the century, responsible for a very large share of the necessary negative carbon emissions.

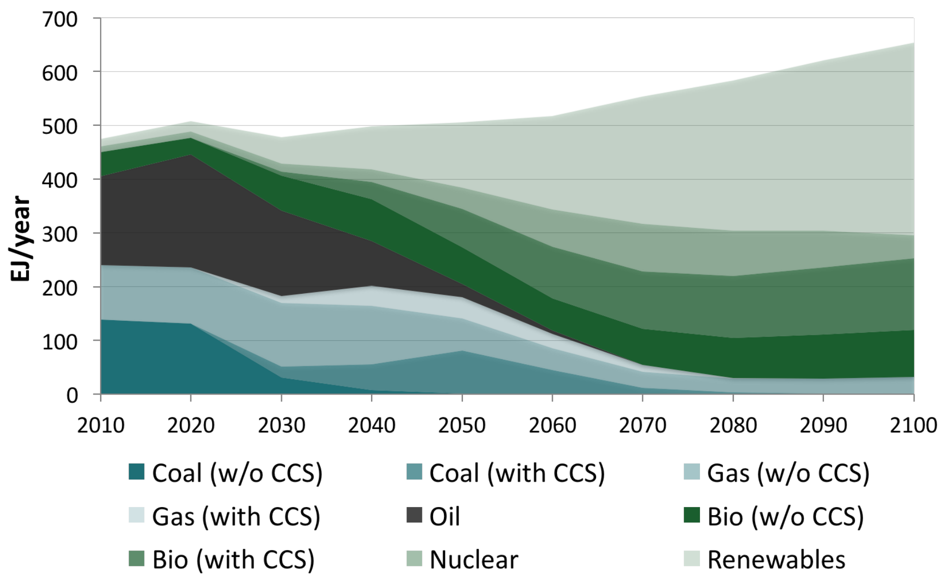

Figure 6. Global primary energy-mix developments in line with the Paris Agreement

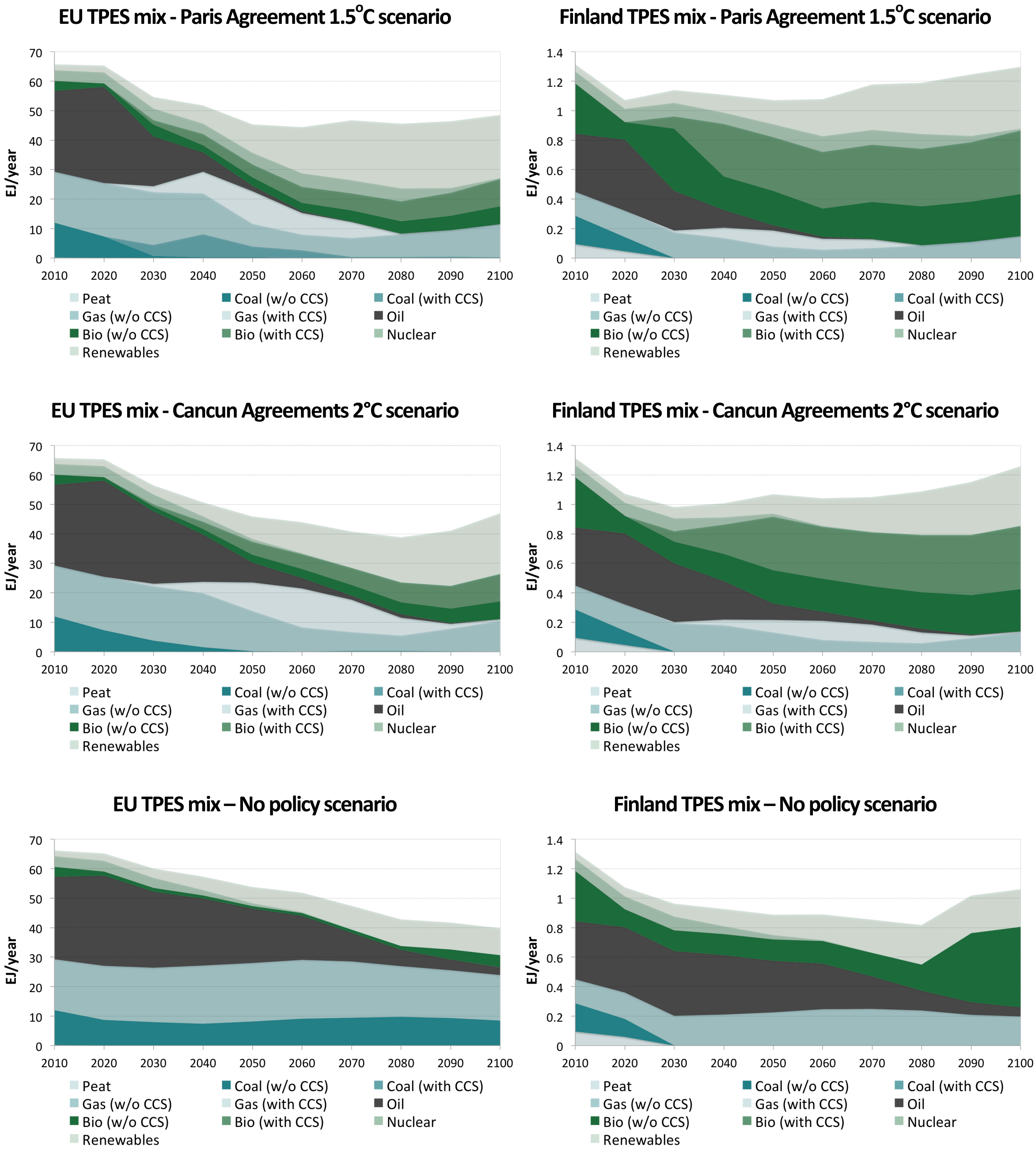

Figure 7. Total primary energy mix in the EU and Finland for the Paris Agreement 1.5°C, the Cancun Agreements 2°C and the No policy scenarios. Note: Total Primary Energy supply in the No policy scenario towards the end of the century is lower than in the two low-carbon scenarios due to higher need for Biomass with CCS (leading to negative emissions) in the low-carbon scenarios.

Key findings for Finland and the EU under the Paris Agreement pathway include:

- Energy efficiency is key over all time frames, especially within sectors with limited near-term availability of low carbon technologies: industry, buildings and the transport sector.
- This increase in energy efficiency needs to be accompanied by a fast decarbonisation, which is crucial in the power sector.
- Renewable energy sources are expected to replace fossil fuel based power plants in the short term. One particularity of the Finnish system, compared to the EU, is its high reliance on biomass.
- In Finland, per assumption, coal is completely phased out by 2030[18]. In the EU, the models find that unabated coal is phased out in the same time-frame, but coal with CCS remains and is phased out by 2070.
- Oil is phased out by around the 2060s.
- Unabated gas remains in the primary energy mix at a lower level than at present throughout the 21st century. CCS technologies for gas come online, at very low levels, in the 2020s and then at scale until phase out of this technology for gas around 2080.
- Deployment of BECCS starts at a low level in the 2020s and is scaled up most rapidly from 2030 until 2040, with slower growth thereafter. Despite BECCS being an expensive technology, its deployment is necessary to achieve negative emissions. This tends to increase primary energy consumption. Primary energy consumption is higher than in the baseline, no-policy case due to BECCs and CCS. The latter makes other options more competitive such as renewables and nuclear (Uyterlinde et al 2006). As a result, primary energy consumption is higher compared to a 'no policy' scenario.
- Nuclear power remains in the energy mix at about present levels until the 2080s, after which reduces to phase out by around 2100

The Cancun Agreements 2°C scenario shows very similar patterns to the Paris Agreement 1.5°C scenario in energy mix transition, but deploys BECCS about 10 years later compared to the Paris Agreement 1.5°C scenario. In the No policy scenario, primary energy consumption is projected to slightly decline over time, both in Finland and in the EU, as a result of energy efficiency improvements. Fossil fuels will be partly replaced by renewables. Coal and peat for energy use is phased out in Finland by 2030, leading to a slight decline in GHG emissions. In the Cancun Agreements 2°C and the No Policy scenarios, nuclear power plants are projected to be progressively shut down both in Finland and Europe.

[18] In accordance with current policies this is included as an explicit a priori constraint on the model, hence not necessarily a conclusion based on the model's least-cost strategy

Implications for investments in mitigation abroad

The two groups of approaches used here, the least-cost and equity, provide valuable insights and complement the discussion about what level of mitigation is needed from the EU and Finland under the Paris Agreement. From an economic viewpoint the least-cost estimates are the advisable pathways to be taken by the EU and Finland domestically. However, there may be a gap between the domestic least-cost pathways and the emission reductions needed for a fair and equitable contribution to global mitigation efforts. This gap may be closed in different ways, including through financial flows to countries and regions in which climate mitigation can be achieved at a lower cost. Quantifying the amount of external mitigation effort needed, including boundaries on climate finance and/or investment that may be needed, is therefore crucial to policy assessments of an equitable contribution to mitigating climate change.

Our approach allows for estimates of financial support or investment in mitigation abroad for Europe and Finland. This can be achieved by determining a representative cost of mitigation in line with the Paris Agreement 1.5°C scenario (see Annexes). Overall costs of investments abroad can be estimated as the product of the representative mitigation cost and the additional emissions reductions needed from the EU and Finland's least-cost emissions levels to achieve levels in line with equity.

Table 5 shows a range of investments estimated to bridge the gap between equitable and least-cost pathways under the Paris Agreement. In our calculations we compare the Paris Agreement least-cost pathway with the full equity range and the level within that range that is in line with the Paris Agreement, without requiring other countries in the world to do comparatively more, as depicted in Figure 3 and Figure 4.

By 2030, Finland's required contribution to investments abroad may be negligible under some equity considerations, but could be as high as € 1.5 billion per year at the other end of the equity range, corresponding to roughly 1% of its 2030 GDP. For the level in 2030 that would not require other countries in the world to do comparatively more than Finland this would be around € 0.1 billion per year corresponding to about 0.1% of its 2030 GDP. By 2050 investments range from negligible under some equity considerations and could increase up to € 4.4 billion (2.2% of its 2050 GDP) for others. For the level in 2050 that would not require other countries in the world to do comparatively more than Finland this would be around € 1.4 billion per year corresponding to roughly 0.7% of its 2050 GDP.

Likewise, under some equity considerations Europe would not need to invest abroad, but the other end of equity considerations would mobilise low-carbon investments abroad up to € 212 billion by 2030 (1.3% of 2030 GDP) and up to almost € 708 billion by 2050 (3.3% by 2050), to provide adequate finance for the Paris Agreement. For the level that would not require other countries in the world to do comparatively more than the EU this would be around € 92 billion per year corresponding to about 0.6% of its GDP by 2030 and around € 421 billion per year corresponding to about 2% of its GDP by 2050.

These results are associated with large uncertainties. On the one hand, we look at a large range of equity considerations, which leads to a large range in the investments level. On the other hand, mitigation costs vary widely across different energy-economic models. Our results are based on the results of the MESSAGE model alone; therefore, we do not take into account the broader range of mitigation costs available in the literature. Considering different cost estimates from other models would increase the range of investment estimates further.

Table 5 Annual investments for mitigation abroad in line with Paris Agreement 1.5°C scenario. We compare the Paris Agreement least-cost pathway with the full equity range (in brackets) and the level within that range that is in line with the Paris Agreement, without requiring other countries in the world to do comparatively more (provided as the central estimate). The figures relative to GDP are in relation to the estimated GDP (in Purchasing Power Parity) on the given year, namely 2030 and 2050, respectively.

Annual investment range for mitigation abroad	2030	2050
Finland (Billion €2005)	0.1 (0 – 1.5)	1.36 (0 – 4.4)
Finland (% of 2030 and 2050 GDP)	0.1% (0% – 1.0%)	0.7% (0% – 2.2%)
Europe (Billion €2005)	92 (0 – 212)	421 (0 – 708)
Europe(% of 2030 and 2050 GDP)	0.6% (0% – 1.3%)	2% (0% – 3.3%)

Conclusions

This report finds that the European Union (EU) emission reduction targets previously adopted for 2030 are not yet sufficient to be in line with the Paris Agreement long-term temperature goal. As a consequence, ambition and action levels need to be revised upwards in order to reach the Paris Agreement's 1.5°C limit.

From an economic point of view, least-cost pathways provide reasonable options to be deployed and benchmarks to be achieved by the EU and Finland domestically. To be in line with the Paris Agreement 1.5°C scenario, Finland would need to reduce emissions by 60% below 1990 levels by 2030 (the EU slightly less at about 50% reductions below 1990 levels by 2030). By 2050, emissions reductions for Finland should be 130% below 1990 levels, implying a need for significant negative CO_2 emissions by that time. For the EU around 90% reductions by 2050 would be needed, which is within the 80-95% emission reduction range by 2050 already adopted by the EU.

These steep domestic emissions reductions can be achieved with a comprehensive set of measures and technologies. On the one hand efficiency improvements can lead to lower energy demand. On the other hand decarbonisation is key in the long term (particularly in the energy sector). Renewable sources of energy are expected to replace fossil-fuel based power plants in the short term. Per assumption in this study, coal is phased out completely in Finland by 2030, while the models find that in a cost-optimal strategy in the EU as a whole, unabated coal is indeed phased out in the same time-frame. Coal with CCS remains and is phased out by 2070. Oil is phased out by around the 2060s, while gas is rapidly reduced, but not quite phased out by the end of the century. CCS technologies for gas are used at scale from the 2030s until phase out of this technology for gas around 2080.

Biomass with CCS (BECCS) is projected to become crucial in the second half of the century to achieve the necessary negative carbon emissions. To achieve the required scale deployment of BECCS would need to start at a low level in the 2020s before being scaled up rapidly from 2030.

Nuclear power is projected to remain at about present levels until 2080 before phasing out around 2100.

These energy system results need to be interpreted with care as research in the scientific community is ongoing in many of these areas, including in relation to the consequences of technology limitations for sustainability, or other considerations, in achieving global warming limits. These issues are not covered in this report, but remain important to any real-world deployment of options described here.

From an equity point of view, Finland and the EU would however be required to contribute more to global mitigation efforts than from a least-cost modelling perspective to be in line with the Paris Agreement 1.5°C scenario.

According to equity approaches, by 2030, emissions for Finland would need to decrease to about 60% below 1990 levels. For the EU the reduction would need to be at least 75% instead of the 40% reduction from 1990 levels goal in the EU INDC. By 2050 emissions would need to become negative in the EU as a whole and in Finland and the EU with reductions of 150% of 1990 levels for Finland and 160% for the EU.

The gap between the equity and the least-cost approaches could be closed in different ways including financial flows, investment and/or technology transfers to countries and regions in which climate mitigation can be achieved at a lower cost. These financial flows are estimated to amount to around € 0.1 Billion for Finland (0.1% of 2030 GDP) and € 92 Billion for the EU (0.6% of 2030 GDP) in 2030. For 2050 the numbers are € 1.36 Billion (0.7% of 2050 GDP) and € 421 Billion (2% of 2050 GDP) respectively, using a representative mitigation cost of 99 €/tCO2. These values are associated with large ranges, both due to the various different views on equity indicators and due to uncertainties in mitigation cost estimates.

Annex: Methodological details and assumptions

Optimal least-cost scenarios

Integrated Assessment Models (IAMs) combine the current knowledge of energy systems and climate-model projections to identify economically and technologically feasible emissions pathways consistent with a temperature limit, while minimising global costs. They are numerical tools to develop quantified narratives of internally consistent energy-economic pathways satisfying energy needs across the world and maximizing economic welfare, while being influenced by pre-defined external constraints, like a limited global carbon budget. These models play a crucial role in assessing options for and characteristics of long-term mitigation pathways in the contribution of IPCC Working Group III to its Fifth Assessment Report (IPCC AR5 WGIII chapter 6).

Once an external constraint is defined, an IAM balances supply and demand, optimizes deployment of regional energy technologies, etc., and ultimately estimates regional greenhouse-gas emissions that satisfy the external constraints at lowest overall global costs. Hence, we label such scenarios in this report as "least-cost" scenarios.

A crucial characteristic of such scenarios is that the global mitigation effort required to satisfy the demand is allocated "optimally" in an economic sense globally, thus taking place in the regions where costs are lowest at a particular point in time, until all regional mitigation efforts are balanced under a single global carbon price. Note that this carbon price is an internal model parameter that is simply a numerical representation of "stringency" of mitigation efforts, and does by no means imply that, in fact, a global carbon price is assumed to be enforced.

All IAMs results lead to the same conclusion: the earlier strong climate action is implemented, the cheaper it is to meet a temperature limit in total over the whole of the century. While there is a strong economic incentive not to postpone action (i.e. "immediate action" scenarios), the world is not ruled by economic principles alone and one has to look as well into economically non-optimal and alternative ways to meet a temperature limit. As a result, this study focuses on "delayed-action" scenarios, where climate policy is assumed to start after 2020 and pre-2020 climate policy is in general in line with the current policies already implemented across countries.

The scenarios assessed in this report were developed by the International Institute of Applied Systems Analysis (IIASA) using their MESSAGE IAM (e.g. Rogelj et al., 2015). MESSAGE, like other IAMs, provides scenarios consistent with limiting global warming below 2°C and 1.5°C by calculating the optimal emission pathway over time and the associated primary energy mix until 2100. It was crucial that these scenarios share the same assumptions in terms of technological availability and energy demand in order to be comparable. The chosen scenarios are based on low energy demand (high efficiency) and full technology availability. The latter is especially important with respect to debated technologies such as Bioenergy with Carbon Capture and Storage (BECCS) and Nuclear. Especially BECCS is crucial for MESSAGE — and other IAMs — to make low global warming targets possible.[19] Like most other IAMs of the current model generation, the MESSAGE model includes a coherent representation of the land-use sector and biomass availability. The models generally include an approximate consideration of inter-related land use issues, such as food production, bioenergy, afforestation and reforestation. In parallel to negative emissions through BECCS, the low emission scenarios

[19] Downscaling the results to Finland and Europe

from MESSAGE also include sequestration through afforestation and reforestation, reaching cumulative sequestration of around 22-230 $GtCO_2$ by the end of the century in the Paris Agreement 1.5°C and Cancun Agreements 2°C scenarios.

MESSAGE models the world in a highly stylized manner. For example, there exists the assumption of perfect foresight, which means that at any point in time, all economically relevant information, even regarding future developments, is available. Also, perfect international capital and commodity markets exist which facilitate international exchange and trade. Because of these and similar assumptions, MESSAGE delivers so called first-best-world solutions, which should never be taken literally, but are rather useful for comparisons of different future scenarios and also act as a reference point for real world decision makers.

Like IAMs in general, the regional resolution of MESSAGE is limited and we apply a downscaling technique for developing the pathways for individual countries (Finland) based on the SIAMESE model developed by Climate Analytics. SIAMESE was developed to emulate the energy-system characteristics of a particular IAM to reproduce energy and emission scenarios of that IAM, and extend the field of application by applying this particular IAM's effective behaviour to different sub-regions, or countries. In addition, it would be possible to include external constraints. For example, this study assumes a phase out of coal consumption in Finland by 2030 in all scenarios, based on the target set by the Finnish government.

In order to downscale the MESSAGE regional output to Finland, the results of the MESSAGE model are inputted to the SIAMESE model, in terms of GDP and energy consumption. The basic idea is that the Western Europe region (of the MESSAGE model) can be decomposed into two inner regions: Finland and Rest of Western Europe (so that the sum of the two matches the total for Western Europe). At the base year (2010), the model is calibrated to replicate observed energy consumption. In a way, this calibration process sets some preferences regarding the energy mix composition. For example, biomass consumption in Finland in 2010 represented 26% of total primary energy consumption. The model will try to maintain this preference, while at the same time maintaining consistency with the source results from the MESSAGE model. More precisely, SIAMESE allocates energy consumption in the two regions by equalising the marginal utility of energy, under a welfare maximisation approach. Energy prices are endogenous in the model[20] and coincide with the marginal utility of energy.

In terms of the equations, SIAMESE mimics the structure of Integrated Assessment Model. Similarly to other IAMs, the economic output (GDP) is a function of capital, labour and energy consumption and TFP (total factor productivity), by using a CES (Constant Elasticity of Substitution) production function. The basic idea behind the CES production function is that it would be possible, to some extent (and at increasing cost), to replace one factor of production with another (e.g. capital with energy consumption). Therefore, GDP is an endogenous variable. In order to provide realistic results, we harmonise the GDP with external projections[21] by changing the TFP assumptions. The TFP is exogenous and it can be interpreted as a proxy of technological progress.

[20] SIAMESE determines the energy prices for each fuel, based on energy consumption levels of the Western Europe region (from the MESSAGE model).

[21] GDP projections are based on Finland Statistics, Bank on Finland and SSP2 ("SSP Database," n.d.)(Shared Socio Economic Pathways – "middle of the road" scenario).

Table 6: GDP (in Purchasing Power Parity) and Population assumptions in Finland

Finland Projections	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
GDP (billion $2005)	170.1	181.5	204.4	230.3	259.5	292.4	329.5	371.2	418.2	471.2
Population (Million)	5.365	5.617	5.845	6.012	6.176	6.366	6.541	6.684	6.786	6.824

Labour force is also an exogenous variable. For sake of simplicity SIAMESE assumes that labour coincides with total population[22].

Capital for production of final goods, is modelled via a capital accumulation equation, and can be increased by means of investments.

Regarding Europe, MESSAGE provides results for two regions: Western and Eastern Europe. EU28 is therefore a hybrid aggregate that comprises part of the Western and Eastern Europe regions. Like Finland, we used SIAMESE, to single out the EU28 region from the MESSAGE model. To do so we first subtracted Turkey, Iceland, Norway and Switzerland from the Western Europe region, by creating new region: "Rest of Western Europe". Similarly, we subtracted Albania, former Yugoslavia and Bosnia and Herzegovina from the Eastern Europe region. Finally, we summed up the results of the "Rest of Western Europe" and "Rest of Eastern Europe" regions.

The focus of SIAMESE is on CO_2 emissions (excluding LULUCF) and on primary energy consumption. SIAMESE does not cover other GHG such (e.g. CH_4, N_2O etc.). Emissions of other gases can be downscaled by using a simple (proportional) downscaling technique. For example for Finland, we assume other GHG emissions to follow the same trajectory as in the Western Europe region (from the MESSAGE model), relative to 2010 emission levels.

Finally, we calculate total GHG emission by summing up CO_2 emissions (from SIAMESE) and other GHG emissions.

[22] Population projections are based on SSP2 ("SSP Database," n.d.) (Shared Socio Economic Pathways – "middle of the road" scenario).

Box 3: Climate sensitivity and GHG concentration assumptions

The response of the global climate system to anthropogenic emissions of GHGs is associated with a range of uncertainties. The scientific community works on narrowing down the uncertainty ranges, for example in the carbon cycle, determining atmospheric CO_2 concentrations; in the atmospheric radiation balance, affected by greenhouse gas concentrations and aerosols; and in the temperature and more generally climate-system response to changes in radiation balance. The "Model for the Assessment of Greenhouse Gas Induced Climate Change" (MAGICC) is a reduced complexity coupled carbon-cycle/climate model that directly accounts for these uncertainties by selecting specific values for climate relevant parameters – including the "climate sensitivity" – and then computing greenhouse gas concentrations and ultimately a global-mean temperature outcome.

Cross-correlations between uncertainty parameters are accounted for explicitly, allowing the calculation of probabilistic pathways of greenhouse-gas concentrations and global-mean temperatures as part of the climate-system response to greenhouse gas and aerosol emissions. One example of such cross-correlations is the radiation impact of sulphate aerosols and climate sensitivity: If climate sensitivity is high, the radiative (cooling) effect of sulphate aerosols must also be high, since otherwise historical observations could not be matched closely by MAGICC. However, this relation depends in turn on other parameters, such as ocean heat uptake. Similar considerations are taken into account for the most important parameters of the model. The model framework draws from more than 3 million MAGICC simulations, each with a different set of values for each of those 82 parameters. The final model run selects the 600 parameter sets that allow the model to most closely reproduce past climate observations and for a particular emission scenario the model is run for each of these 600 sets. The percentage of the 600 model runs for that particular emission scenario that for example hold warming below 2°C is used as a numerical estimate of the probability that warming is held below 2°C in that particular emission scenario.

Based on this method, the scenarios chosen here have the following implications in terms of climate projections (see Figure 2 and Figure 8):

	Max CO_2 conc. (ppm)	2100 CO_2 conc. (ppm)	Max Temp (°C)	2100 Temp (°C)	Min prob. below 2°C	2100 prob. below 2°C	2100 prob. below 1.5°C
Baseline	680	680	3.4	3.4	0%	1%	0%
Cancun Agreements 2°C	460	410	1.9	1.8	55%	68%	23%
Paris Agreement 1.5°C	440	380	1.7	1.5	86%	86%	52%

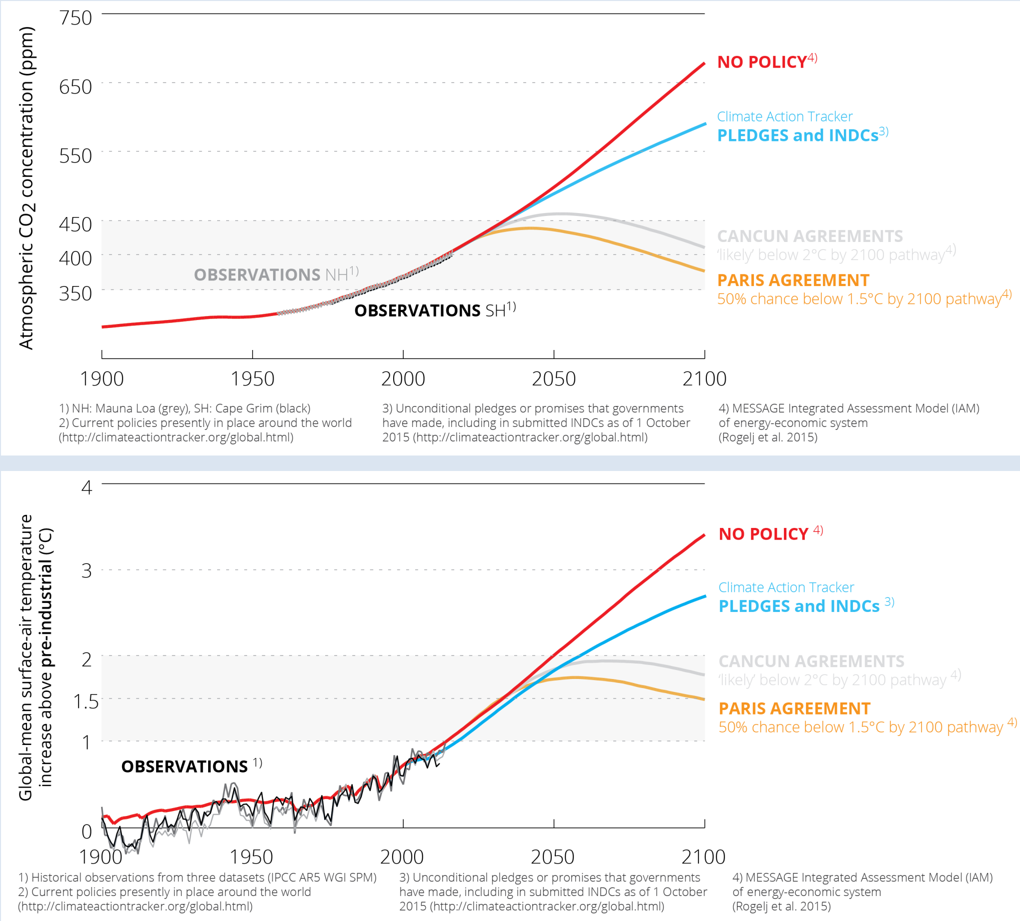

Figure 8: Global CO_2 concentrations (top) and global-mean temperature projections based on policy-relevant scenario cases assessed in this report (as described in section "What do the Paris long-term goals mean for emissions globally?").

Equity methodology

Description of the Equity Analysis Tool

The PRIMAP group at the Potsdam Institute for Climate Impact Research (PIK) developed the Potsdam Real-time Integrated Model for the probabilistic Assessment of emission Paths (PRIMAP model) (Potsdam Institute of Climate Impact Research, n.d.). The Emissions Module (Nabel et al., 2011) has been developed as part of this model and allows for the flexible combination of data sources into composite datasets, and the calculation of national, regional and global emission pathways following various emission allocation schemes. At the core of the Emissions Module is a custom-built emissions database, the so-called PRIMAPDB.

Climate Analytics and the PRIMAP group developed an Equity Analysis Tool for the assessment of equity principles and indicators, embedded in the Emissions Module. Currently implemented in the tool we have the following published equity methodology proposals:

- Greenhouse Development Rights (Kartha, Baer, Athanasiou, & Kemp-Benedict, 2009)
- South North Proposal (Ott et al., 2004) with own methodology for downscaling emissions from groups to country level based on GDP and population projections (details available upon request)
- Per capita convergence (Agarwal & Narain, 1991; Meyer, 2000)

- South-African Proposal (Winkler, Letete, & Marquard, 2013)
- Chinese proposal (BASIC Experts, 2011)

Building on a range of methodologies and equity criteria put forward by the scientific community and Parties for sharing the burden of reducing emissions, the PRIMAP equity tool also offers a modality that allows users to emulate equity regimes based on various equity criteria - and for each criterion a range of possible empirical metrics to quantify them is available. The equity criteria selected and the different empirical metrics available to evaluate them in the Equity Tool are:

Historical Responsibility: this remains the main argument often used by many developing countries that the greenhouse gas problem is primarily caused by emissions from industrialized countries. The metrics used as a proxy for historical responsibility in this exercise are based on per capita cumulative emissions i.e. the quotient of cumulative emissions for each country and its cumulative population within the pre-set time frame:

- Cumulative greenhouse gases emissions per capita, excluding deforestation emissions: starting and end years for accounting cumulative emissions are flexible
- Cumulative greenhouse gases emissions per capita, including deforestation emissions: starting and end years for accounting cumulative emissions are flexible

Capacity to mitigate: the overall capacity to mitigate in a country is often related to a country's wealth or degree of development, as these relate to the country's ability to pay for and implement measures to reduce greenhouse gases emissions. Metrics available to evaluate this criterion are:

- GDP Purchasing Power Parity (PPP) per capita
- Human Development Index (HDI) at a certain year

Potential to mitigate is a measure of the actual room for improvement existing in a country. Among proposals that consider potential as a criteria are the Triptych methodology [23] and the South North Proposal. The following intensities can be used to estimate a country's potential to mitigate:

- Emissions intensity: Energy related greenhouse gas emissions per unit of GDP
- Emissions per capita: Total national greenhouse gas emissions per capita, including deforestation emissions.
- Carbon intensity: greenhouse gas emissions per unit of energy production

Weights can be attributed to each one of the criteria selected. This means that allocation regimes based on only one of the criteria, e.g. responsibility, or based on more than one criterion, and assuming either equal or different weighting among the different criteria can be studied. For each criterion, one or a set of empirical measures to evaluate them can be selected, also with different weights. Such an approach allows for full flexibility of assumptions in regard to criteria and metrics.

Another important feature of the tool is that is that it allows for the calculation of **ranges of responsibilities** for countries, based on the different indicators. To calculate ranges, (1) **random weights** are attributed to each indicator and measure, (2) resulting emissions pathways calculated and finally (3) calculations are repeated multiple times to define a range of possible pathways. Such an approach allows capturing the full range of emissions allowances of a country and to determine how different criteria and metrics influence its outcome. Results from this analysis are only provided in the Excel sheet accompanying this document.

[23] The Triptych methodology contains elements of cost–effectiveness in that those with high specific emissions (i.e. high potential for reductions) have to reduce more. It was used as a basis to share the emissions reductions of the first commitment period for the Kyoto Protocol within the EU.

Index Calculation: The selected quantitative measures are weighted, normalized and added, to obtain an interim index. The split of the mitigation burden is calculated proportionally to a final index, which is obtained by normalizing and weighting the interim index by the population share of each country. To avoid using projections, we calculated the index based on the last common historical year shared between all selected metrics, which was 2010. The index is calculated for as many countries as possible, which is the number of common countries available for all selected metrics.

Because the index is the result of the normalization of variables, we investigated the presence of extreme countries in each one of the metrics and excluded those countries (potentially a different set of countries at each iteration of the model) to avoid the over or under-estimation of countries' share of responsibility.

Box 4: Data collection

Data availability and quality represents a major challenge for this exercise. Even though the Equity Analysis Tool is embedded in the PRIMAP database (Nabel et al., 2011), which offers a wide range of choices of data sources, a few restrictions prevent a free choice. First, as we are interested in the relative contribution of countries to a certain qualitative metric, top-down data provides a more adequate frame for comparison, as it usually implies that a set of requirements have been met to ensure quality and comparability of data (as opposed to data provided on a national level, following e.g. own – nonstandard – inventory methodologies). Second, for each metric resulting from two single metrics e.g. emissions per GDP, we consistently used data from the same data source. For the current exercise, we have used the following data sources: UNFCCC Common Reporting Framework (CRF) GHG data, World Development Indicators 2013, Carbon Dioxide Information Analysis Center (CDIAC), International Energy Agency (IEA) data for energy, United Nations 2012 for population and Human Development Index (HDI).

The data used here are from state-of-the-art sources and are regularly updated in the PRIMAP database. We have consistently used the same datasets across all scenario runs, ensuring that the differences between emissions allowances across scenarios arise from criteria/metric choices alone and not through data divergences. For business-as-usual projections, we used RCP8.5 scenario downscaled to country level using SSP scenarios. From the few SSP scenario families, we have used the PIK implementations of the SSP2 narrative (for detail, refer to detailed methodology), which provides a global median of estimates. The RCP regional emissions are downscaled to country level using the SSP GDP pathways for individual countries, the IPAT equation and the assumption of (partial) convergence of regional emission intensities. The methodology is based on van Vuuren et al. (2007).

Global mitigation burden: Equity methodologies often fit global emissions to levels that are in line with temperature targets. The two target scenarios investigated in this report are the Paris Agreement 1.5°C and the Cancun Agreements 2°C scenarios, which are delayed-action least-cost scenarios consistent with maintaining temperatures at 1.5°C in 2100 with a 50% probability and below 2°C with a 66% probability in the 21st century respectively (for details refer to section "What do the Paris long-term goals mean for emissions globally?" in the main report)[24].

Based on the selected low-carbon scenario, an emissions mitigation burden is calculated as the difference between global business-as-usual emissions (here, RCP8.5) and an emissions trajectory that avoids the worst effects of global warming (here consistent with the Paris Agreement 1.5°C and the Cancun Agreements 2°C scenarios).

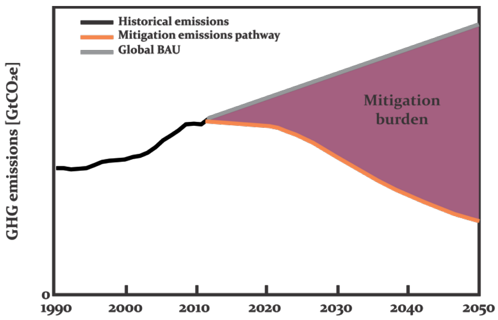

Figure 9: Mitigation burden

Calculation of emissions allowances: The index calculated using the methodology described above is then used to split the mitigation burden across countries, in such way that the country's index share of the sum of all indices will be proportional to its share of the mitigation burden. Countries with high indices will be attributed a high share of the mitigation burden and vice-versa. The share of the global mitigation burden of a country is subsequently subtracted from this country's business-as-usual emissions to obtain its final emissions allocations[25]. Provided that the LULUCF sector does not represent a large share of national emissions for any of the countries assessed here, the assessment of fairness of all commitments was done against emissions allowances excl. land-use, land-use change and forestry (LULUCF) emissions. This is due to two main reasons. First, emissions projections in the LULUCF sector are generally highly doubtful and would add a considerable amount of uncertainty to the overall assessment. Second, while the LULUCF sector requires important emissions reductions (and increasing sinks), a pathway towards 1.5°C requires decarbonisation of the world energy system. The use of sinks to achieve targets may mask e.g. an increase in emissions from the energy and industrial emissions which would be inconsistent with a low carbon, transformational pathway towards 1.5°C goal. Real, substantial reductions in emissions from all sectors need to be made by all countries to set the world on a pathway towards a decarbonised economy. The emissions allowance ranges presented in this report constitute the 20th to 80th percentile of the overall range, which is consistent with IPCC AR5 methodology (Höhne, den Elzen, & Escalante, 2014).

Emissions levels within the equity range that guarantees the target scenario is met: The goal of the

Table 7 Relative level (from bottom to top end of the range) of equity range in line with the Paris Agreement 1.5°C and the Cancun Agreements 2°C

Year	2030	2050	2100
Paris Agreement 1.5°C	53%	40%	38%
Cancun Agreements 2°C	68%	48%	38%

[24] Since the 2 and 1.5°C scenarios comprise total global emissions, they take into account efforts in all sectors, including international aviation and marine shipping and the land-use and land-use change (LULUCF) sectors. In this exercise, we have opted to treat these two sectors separately, because: First, addressing emissions from international aviation and marine shipping is challenging, as they are produced along routes where no single nation has regulatory authority (the Kyoto Protocol excludes international emissions from aviation and marine transport from developed countries' national targets, unlike all other sources of emissions). Secondly, emissions from the LULUCF sector add a very high level of uncertainty to the overall results of individual countries. Methodological details upon request. This approach implies that emissions reductions in these two sectors will be achieved.

[25] Such an approach allows for attribution of negative emissions allocations.

present analysis is to evaluate a range of responsibility for the countries of interest. Given the large variability of equity proposals, criteria and metrics, we can have wildly different outcomes for a country leading to very wide equity ranges. However, even if all outcomes behind the equity ranges were in line with the target scenario in question, if all countries would meet reductions in line with the top of the ranges, the resulting global emissions would be far higher than the emissions levels in that scenario. It is therefore crucial to determine the maximum level of emissions within countries' equity ranges, which when aggregated, would result in the target scenario. This level is determined as follows:

- Calculate emissions levels consistent with:
    - **a global equity best case scenario**: where all countries choose to reduce emissions to the very bottom of their range, which is numerically equivalent to the total of the minima of all countries' equity ranges, and necessarily below the target scenario.
    - **a global equity worst case scenario**: where all countries choose to reduce emissions only to the top of their equity range, which is numerically equivalent to the total of the maxima of all countries' equity ranges, and necessarily below the target scenario.
    - The global equity best case scenario and the global equity worst case scenario points result in a global equity range.
- In a next step the Paris Agreement 1.5°C (or Cancun Agreements 2°C) pathway is then overlaid with the global equity range to determine the intersection between global equity scenarios and the target scenario. We calculate what is the relative level of that intersection.
- Apply that relative level to all countries' equity ranges

Selection of scenarios

Based on the range of equity proposals, criteria and quantification metrics described above, **we defined roughly 40 equity regimes to allocate mitigation efforts across countries** in the world, with the goal of capturing the widest possible range of and outcomes in terms of emissions reductions for Finland and for the European Union. These regimes are based on the following proposals, criteria and metrics:

- Different methodologies: GDR, per capita convergence, South North Proposal, South African proposal, Chinese proposal, proposal based solely on historical responsibility, proposal based on historical responsibility and capability, proposal based on potential, historical responsibility, and capability.
- Different starting years for historical period (1950, 1970, 1990)
- Different weighting schemes for the criteria (e.g. 50/50 responsibility and capability vs 75/25
- Different metrics for the criteria (e.g. capability measures in terms of HDI or GDPPPP and their different impacts)

Methodology: Financial Transfers for mitigation abroad

At any point in time and for any region, or country, emissions levels calculated from the least-cost methodology on the one hand, and from equity considerations on the other hand, will generally differ. For instance, if economically optimal, least-cost emission levels for a country are higher than the allowances under equity considerations, one could argue the country would aim to achieve further emission reductions elsewhere, at lower cost than would be required to achieve those further reductions domestically. The gap could be covered by this country through financing emission reductions in other countries, where emission allowances are higher than the emission levels that are economically feasible at least cost.

In this report, we provide estimates of the investments for mitigation abroad for a region and country (Europe and Finland) to bridge the gap between what is feasible at least cost domestically, and the lower emission level consistent with equity-based allowances. The gap, in absolute GHG emission reductions, is calculated for the region and country at a point in time.

Regarding financial transfers, IAM typically assume global emission trading schemes, where a global carbon price emerges instantaneously (in each time period) as the outcome of supply and demand dynamics. The outcome is that all countries will share the same marginal abatement cost. As a result, each region will buy or sell carbon credits based on a global carbon price, which coincides with the marginal (highest) carbon cost in each region. From an economic point of view, this makes perfectly sense, given the assumptions stated above. However, if compared with the real world, these assumptions might provide inflated financial transfers. In fact, the implementation of a global emission-trading scheme appears to be unrealistic if compared with the current developments in climate negotiations. A possible way to reconcile economic theory with real world developments would be to assume that donor countries would provide financial contributions on a project-by-project basis. Actual mitigation projects such as under the CDM (clean development mechanism) differ widely in terms of marginal costs and mitigation potential. As a result, we assume that different mitigation projects abroad entail different mitigation costs. At first, investments will be allocated on the cheapest mitigation options given the same level of abatement. Further investments will focus on the remaining projects with increasing carbon costs. To this end, we calculated a representative MAC (Marginal Abatement Cost) curve from the Message model, using a piecewise linear function. The MAC curve captures, in a stylised way, the relationship between the marginal cost of carbon and the percentage of abatement level, ranging from zero cost at zero emission reductions, to the level of carbon costs associated with limiting warming to 2°C and 1.5°C by 2100. Based on this MAC curve, we assume that not all projects will be financed at the same carbon cost. Each project will be financed on the basis of its actual abatement cost (depending on the abatement level associated with the MAC curve). As a result, we assume different mitigation costs for different projects[26]. To estimate the implications of this perspective we use the MAC curve to calculate a representative mitigation cost for all mitigation projects abroad. Finally, we determine the amount of investments for mitigation abroad by multiplying the emission gap for Europe and Finland in 2030 and 2050 by the representative mitigation cost.

[26] This methodology differs from the standard methodology employed in IAMs, as they assume a unique carbon price for all mitigation projects (determined by the highest – marginal – cost among all projects). This implies extra-profits for many mitigation projects. Our methodology instead, assume lower profits (hence financial transfers) as finance is based on the actual mitigation cost (represented by different carbon prices). Since the MAC curve from IAM is a convex function, we use a linearly approximated piecewise MAC, which ensures that all mitigation projects remain profitable.

Acknowledgements

The authors of this report would like to thank on behalf of Climate Analytics Dr Joeri Rogelj at IIASA for kindly making emissions scenarios from the MESSAGE model available for this report and the PRIMAP (Potsdam Real-time Integrated Model for probabilistic Assessment of emissions Paths) research group at the Potsdam Institute for Climate Impact Research for co-development of the Equity Analysis tool used in this report and for maintenance of its database, in particular scientists Dr. Louise Jeffery and Dr. Johannes Gütschow.

References

Agarwal, A., & Narain, S. (1991). *Global Warming in an unequal world, a case of environmental colonialism*. Delhi; India: Centre for Science and Environment (CSE). http://doi.org/10.1007/SpringerReference_82653

Arasto, A., Onarheim, K., Tsupari, E., & Kärki, J. (2014). Bio-CCS: Feasibility comparison of large scale carbon-negative solutions. *Energy Procedia*, *63*, 6756–6769. Retrieved from http://www.sciencedirect.com/science/article/pii/S1876610214025260

BASIC Experts. (2011). Equitable access to sustainable development: Contribution to the body of scientific knowledge. BASIC expert group: Beijing, Brasilia, Cape Town and Mumbai.

Council of the European Union. (2007). Presidency Conclusions Brussels European Council 8/9 March 2007. *Presidency Conclusions*, *7224/1/07*(REV 1), 1–25. http://doi.org/7224/1/07

Council of the European Union. (2009). Council Conclusions on EU position for the Copenhagen Climate Conference (7-18 December 2009), 1–13.

Creutzig, F., Ravindranath, N. H., Berndes, G., Bolwig, S., Bright, R., Cherubini, F., … Masera, O. (2015). Bioenergy and climate change mitigation: an assessment. *GCB Bioenergy*, *7*(5), 916–944. http://doi.org/10.1111/gcbb.12205

European Union. (2015). *Submission by Latvia and the European Commission on behalf of the European Union and its Member States: Intended Nationally Determined Contribution of the EU and its Member States*.

Höhne, N., den Elzen, M., & Escalante, D. (2014). Regional GHG reduction targets based on effort sharing: a comparison of studies. *Climate Policy*, *14*(1), 122–147. http://doi.org/10.1080/14693062.2014.849452

IPCC. (2014). Summary for Policymakers. In Stocker & V. B. and P. M. M. (eds T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia (Eds.), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Kartha, S., Baer, P., Athanasiou, T., & Kemp-Benedict, E. (2009). *The Greenhouse Development Rights framework*. *Climate and Development* (Vol. 1). http://doi.org/10.3763/cdev.2009.0010

Meyer, A. (2000). *Contraction & convergence. The global solution to climate change*. Bristol, UK: Green Books.

Nabel, J. E. M. S., Rogelj, J., Chen, C. M., Markmann, K., Gutzmann, D. J. H., & Meinshausen, M. (2011). Decision support for international climate policy – The PRIMAP emission module. *Environmental Modelling & Software*, *26*(12), 1419–1433. Retrieved from http://www.sciencedirect.com/science/article/pii/S1364815211001873

Ott, H. E., Winkler, H., Brouns, B., Kartha, S., Mace, M. J., Huq, S., … Rahman, A. A. (2004). *South-North dialogue on equity in the greenhouse : a* *proposal for an adequate and equitable global climate agreement*. Eschborn: Dt. Ges. für Techn. Zusammenarbeit. Retrieved from https://epub.wupperinst.org/frontdoor/index/index/docId/1885

Potsdam Institute of Climate Impact Research. (n.d.). The PRIMAP model. Retrieved May 15, 2016, from https://sites.google.com/a/primap.org/www/the-primap-model

Rogelj, J., Luderer, G., Pietzcker, R. C., Kriegler, E., Schaeffer, M., Krey, V., & Riahi, K. (2015). Energy system transformations for limiting end-of-century warming to below 1.5 °C. *Nature Climate Change*, *5*(6), 519–527. http://doi.org/10.1038/nclimate2572

SSP Database. (n.d.). Retrieved May 15, 2016, from https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=welcome

The Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. http://doi.org/10.1017/CBO9781107415416

UFCCC. (2016). Aggregate effect of the intended nationally determined contributions : an update, (May), 1–75.

UNEP. (2014). *The Emissions Gap Report 2014: A UNEP synthesis Report*. *Unep*. Retrieved from http://www.unep.org/pdf/SEI.pdf

UNFCCC. (2015a). EU Submits its Climate Action Plan ahead of Paris 2015 Agreement. Retrieved May 14, 2016, from http://newsroom.unfccc.int/unfccc-newsroom/eu-submits-its-climate-action-plan/

UNFCCC. (2015b). Paris Agreement, 1–16.

UNFCCC. (2015c). Report on the structured expert dialogue on the 2013–2015 review, 1–182.

UNFCCC. (2016). Decision 1/CP.21 III, 1–37.

van Vuuren, D. P., Lucas, P. L., & Hilderink, H. (2007). Downscaling drivers of global environmental change: Enabling use of global SRES scenarios at the national and grid levels. *Global Environmental Change*, *17*(1), 114–130. Retrieved from http://www.sciencedirect.com/science/article/pii/S0959378006000501

Winkler, H., Letete, T., & Marquard, A. (2013). Equitable access to sustainable development: operationalizing key criteria. *Climate Policy*, *13*(4), 411–432. http://doi.org/10.1080/14693062.2013.777610