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Preface

This report synthesises the results of a workshop on explorative scenarios for the global social, economic, technological and political development from 2020 to 2050. The 19 participants included national and international researchers and experts in the transdisciplinary Forum of the project – see http://www.ssb.no/en/forskning/energi-og-miljookonomi/klimapolitikk-og-okonomi/smart-paths-smart-paths-and-costly-detours-towards-a-sustainable-low-emission-society. The work resulted in a handful of alternative, internally consistent, qualitative scenarios for the forthcoming global social, economic, technological, and political development. These will serve as a starting point for the numerical scenarios to be generated and analysed in the project *SMART PATHS* (Research Council of Norway #268200). Thanks to workshop participants for this work being possible and for valuable input to this report. We also appreciate the comments on earlier drafts from Kristine Grimsrud and Cathrine Hagem and are grateful for research grants from the Research Council of Norway (Klimaforsk #268200).

Statistisk sentralbyrå, 5 December 2017.

Kjetil Telle

Abstract

This report describes the approach and results of a scenario workshop for a transdisciplinary team of 18 experts held in the project SMART PATHS in June 2017. The purpose was to span out a handful of alternative qualitative scenarios for the forthcoming global development. The specified question that the scenarios set out to shed light on is: *what future external drivers are particularly decisive for the design and performance of national climate strategies in the period of 2020-2050*? The work resulted in four, internally consistent, qualitative narratives of the global social, economic, technological, and political future and, in particular, of what they would mean for the external surroundings of the small, open Norwegian economy and its climate strategy ahead.

The scenarios will be exploited in the remaining work of the research project *SMART PATHS* as a basis for quantitative global scenarios, which as a next step will be used to simulate how robust Norwegian climate strategies will be to variation in external impulses. Notwithstanding, the results from the workshop, summed up in this report, are useful in their own right for researchers and stakeholders studying the low-emission transformation. In a logical way, they span out a set of potential future worlds based on qualitatively different, equally plausible, outcomes of a few uncertain driving forces.

The explorative scenario approach was based on the *Probabilistic Modified Trends* methodology (Amer, 2013; van der Heijden, 2005; Stoknes and Hermansen, 2004). It consists of three main working stages: (i) identifying driving forces for global changes ahead, (ii) discussing and assessing their uncertainty and impact, and (iii) systemising the driving forces into a few selected scenarios.

During stage (i) around 60 proposed driving forces were collected, clustered and selected by the participants into 11 distinct factors assessed as the most significant and decisive. These included the strictness of a global climate treaty and of EU's policies, the development of different technologies, the incidence of extreme weather events, energy demand, norms and preferences and the role of cities as political agents.

Stage (ii) of assessing the drivers was performed in groups of 3-4 persons. The work involved judging how the driver was expected to develop and the degree of certainty of the outcome. The drivers with a low uncertainty are assumed to affect any future. The drivers with a high uncertainty and high impact, however, are considered critical or key drivers. They can take the future in very different directions. The assessment ranking resulted in these three drivers being critical, with fairly equal impact and uncertainty: *the strictness of a global climate treaty, oil demand and norms and preferences*. Their internal correlation implies that four scenarios materialise.

The last step (iii) of the workshop was to "visit" these four scenarios, and describe the demographic, economic, political and technological aspects of these possible futures over time. The workshop described the following scenarios: Scenario A (SPLIT!) is characterised by a still sustained high demand for oil and other fossil fuels in the less developed world, while rapid evolvement of green norms and preferences takes place in the developed part of the world, including Norway. This is facilitated by compliant and ambitious treaties among the richer countries. The clue is that we get a split world with increasing tension between the regions.

Scenario B (CLEAN!) resembles many of the existing scenario analyses of a successful transformation to a 2˚C world. It shows the coincidence of a rapid global

shift to green norms and preferences, significantly lower oil demand, and a compliant and ambitious climate agreement. Coordinated efforts worldwide alleviate the transformation process for Norway. Scenario C (DARK!) has the opposite characteristics. National security and near-term interests split the world, increase internal conflicts and result in severe climate change and expensive climate policies. Last, the occurrence of low oil demand despite only slow and insignificant changes in norms and preferences constitutes Scenario D (RICH!). The reduction of fossil fuels use is driven by renewable energy technologies breaking though and become highly competitive. The prosperity of the world is high, but unevenly distributed. The temperature rise is moderate.

Sammendrag

Rapporten beskriver prosessen og resultatene fra et todagers arbeidsmøte i juni 2017 med 18 forskere og eksperter fra prosjektet *SMART PATHS*. Formålet var å spenne ut noen alternative scenarioer for verdens utvikling fremover. Spørsmålet scenarioene er ment å svare på er *hvilke fremtidige eksterne drivere som vil ha særlig innvirkning på hvordan utformingen og utfallet av Norges klimapolitikk blir i perioden 2020-2050*. Arbeidet resulterte i fire internt konsistente fortellinger om fremtidens globale utvikling, beskrevet ved deres sosiale, økonomiske, teknologiske og politiske trekk, samt hvordan dette kan tenkes å virke inn på Norges klimastrategi.

Scenarioene vil bli benyttet i det videre arbeidet innenfor forskningsprosjektet *SMART PATHS* som grunnlag for å kvantifisere globale scenarioer. Scenarioene vil så brukes til å simulere hvor robuste ulike klimastrategier for Norge vil være under ulike antakelser om den globale utviklingen. Resultatene fra det kvalitative scenarioarbeidet som rapporteres her har også nytte i kraft av seg selv. Til sammen representerer de en logisk sammenstilling av mulige utfall for viktige og usikre drivkrefter. Både forskere og andre eksperter som arbeider med omstillingen mot lavutslippssamfunnet vil ha nytte av slike konsistente beskrivelser av mulige framtider.

Den eksplorative scenariotilnærmingen som ble benyttet er basert på metoden Probabilistic Modified Trends (Amer, 2013; van der Heijden, 2005; Stoknes and Hermansen, 2004). Den består av tre arbeidstrinn: (i) identifisering av drivkrefter for den globale utviklingen fremover, (ii) diskusjon og vurdering av deres påvirkning og usikkerhet og (iii) ordning av drivkreftene i noen få, ulike scenarioer.

Under trinn (i) ble rundt 60 drivkrefter foreslått, samlet i hovedgrupper og sorter etter signifikans. De 11 mest betydningsfulle ble plukket ut. De inkluderte styrken på internasjonale klimaavtaler og på Europas klimapolitikk, teknologiske utviklingstrekk, forekomsten av ekstreme værforhold, energipriser, normer og preferanser, samt rollen til byer som politiske aktører.

Vurderingen av driverne i trinn (ii) ble utført i grupper på 3-4 personer. Hensikten med denne vurderingen var å undersøke hvor sterke drivkreftene var og hvor sikkert de ville slå til. Mens de mest sikre ble benyttet som fellestrekk for alle scenarioene, var rollen til de mest usikre å skille scenarioene fra hverandre. Disse vil kunne ta verden i helt ulike retninger. Vurderingen identifiserte tre av signifikante drivkreftene som de mest usikre: *Styrken på en global klimaavtale, oljeetterspørsel og utviklingen av normer og preferanser.*

Da vi tok hensyn til korrelasjonene mellom drivkreftene, endte vi opp med fire scenarioer. Det siste trinnet av arbeidet (iii) var å beskrive scenarioenes ulike aspekter over tid, både demografiske, økonomiske, politiske og teknologiske. Scenario A (SPLIT!) beskriver en framtid der det fortsatt opprettholdes en høy etterspørsel etter olje og andre fossile brensler i den minst utviklede del av verden, mens det i de rikere landene, derunder Norge, skjer en rask endring mot grønne normer og preferanser. Det siste støttes opp av at landene inngår forpliktende og ambisiøse klimaavtaler seg imellom. Poenget er altså at verden følger to parallelle, motstridende spor. Spenningen øker mellom regionene.

Scenario B (CLEAN!) ligner mange allerede foreliggende scenarioanalyser av hvordan verden når togradersmålet. Her faller tre, gjensidig forsterkende, utviklingstrekk sammen: Et raskt globalt skifte mot grønne normer og preferanser, betydelig lavere oljeetterspørsel og forpliktende, ambisiøse internasjonale

klimasamarbeid. Koordinert satsing mellom verdens land letter omstillingsprosessen i Norge. Scenario C (DARK!) har de motsatte trekkene, noe som vanskeliggjør klimaarbeidet. Nasjonal sikkerhet og kortsiktige interesser blir viktigst og fører til internasjonale konflikter og dyr klimapolitikk. Det siste scenarioet D (RICH!) kjennetegnes av lav oljeetterspørsel, men samtidig trege og små endringer mot grønnere normer og preferanser. Forklaringen på redusert bruk av fossile brensler er at fornybare energiteknologier får robuste gjennombrudd og blir konkurransedyktige i store deler av verden. Velstanden blir høy i dette scenarioet, selv om store ulikheter består. Oppvarmingen av kloden blir moderat.

Contents

1. Introduction

This report describes the approach and results of a scenario workshop held in the project *SMART PATHS* in June 2017. Participants were the research group plus experts from the business, government and research sector. The workshop constituted the first milestone of the project. The purpose was to span out a handful of alternative scenarios for the global development towards 2050, a year that Norway is aiming to having transformed to a low-emission society. Below, we introduce *SMART PATHS* and scenario-building task of the project, and we describe the main ideas behind the explorative scenario approach applied for the scenario work.

1.1. *SMART PATHS* and scenarios

Norway can choose different routes to the low-emission society. The project *SMART PATHS* aims to distinguish smart paths from costly detours. As the transition to a low-emission society will need up-front investments, new knowledge and changes in behaviour, decisions already today will form premises for the pathways Norway can take.

The project is organised in three working packages (WPs). WP1 will identify the crucial external factors that the Norwegian climate strategies will have to relate to and assess their likely developments. *External* in this context does not mean that they are completely beyond control or independent of Norwegian decisions, but rather that they are exogenous to the domestic agents and mechanisms we model. WP1 will map global technological progress, demographical changes and international, particularly European, economic and political drivers. WP1 will also consider how social norms and attitudes might develop and their potential effects on consumer behaviour. At the following stage of WP1, the explorative scenarios will serve as a basis. The main research question to be studied by this qualitative approach is: *What likely future external impulses are particularly decisive for the performance of national climate strategies?* The drivers in each global scenario will be translated into relevant parameters and exogenous variables and quantified within two different global models. The first is an energy system model, which has its particular strength in capturing energy technological aspects of the scenarios. The other is a computational general equilibrium (CGE) model that focuses on how regional economic resources and trade relations among countries affect the economies. The two model traditions will complement each other in describing the scenarios.

WP2 responds to the overarching objective of our proposal, which is to craft medium-term national climate strategies that will take us on a smart path to the low-emission society. This part of the project will largely be approached by model simulations of a country model for Norway. We see national 'climate strategies' as the combined choices of domestic emission targets, climate policy instruments and monitoring procedures underway to watch the transformation path. 'Smart' refers to climate strategies that are 'persistent', 'cost-effective' and 'robust'. By 'persistent' we mean that emission abatement along the path should involve measures with longer-term transformation potential. We hypothesise that picking only low-hanging fruits in the nearer term would easily lead the society on a costly detour to the low-emission society, because sluggish investments and other behavioural responses can imply fossil-fuel lock-in. The 'cost-effectiveness' criterion will call for well-targeted policies to transcend the lock-in challenge. Finally, a 'robust' path is characterised by being smart even if external circumstances are changing. WP2 addresses all these three aspects of a 'smart' path.

The scenario workshop can be regarded as the first milestone in WP1 of qualitatively assessing how the world might develop, which will again be the basis for the research on ‘robust’ national climate strategies in WP2. Notwithstanding, the results from the workshop, summed up in this report, are useful in their own right. The results constitute a complementary set of four internally consistent narratives of the global development for the next 3-4 decades, and in particular, of what they imply for the climate strategy of the small, open Norwegian economy. Based on this report, the explorative scenarios will be communicated to Norwegian and international stakeholders.

We concentrate on particularly decisive factors for the *Norwegian* climate strategies because the global scenarios will eventually be used to answer the following research question in WP2: *How robust are Norwegian climate strategies to external impulses?* A pivotal quality criterion for the domestic energy and climate policy design is its robustness to changes in global surroundings and other external conditions when it comes to effectively obtaining its objectives. This includes the ability of the economy to respond to such changes under various choices of policy instruments and targets. Some instruments can, for instance, be too tailored or too reliant on predictability to be effective under shifting circumstances.

The project is linked to a Transdisciplinary Science-Policy Forum (the Forum) with a variety of backgrounds from the business, government and research sector. The experts are carefully picked to provide complementary competence to the project’s research team. The Forum will be involved from the outset and throughout the project to give input to research questions, approaches and communication of results. It will meet at least once a year with the whole project group and regularly be consulted when relevant to discuss approaches, progress and societal relevance. The workshop was the first occasion to have important input from the Forum; see Table 1.1 for the workshop participants.

1.2. The explorative scenario workshop

Strategic scenarios are narratives that explore possible and plausible futures. The main aim of scenario development is to give an in-depth, nuanced understanding of how key uncertainties in the decision makers’ surroundings may play out and impact the future outcomes of our current-day decisions.

Hence, the aim of the *SMART PATHS*’ 2-days workshop was to work out a small number of explorative scenarios for how the global development can look like for the next 3-4 decades. The final scenarios will offer specific descriptions of different possible and plausible pathways for the external environment around Norway’s national climate strategies, like EU regulations, technology trends, learning curves, global cooperation, etc. A key point is that the scenarios are not predictions. Rather, each represents an internally consistent pathway to a clear and possible global future in 2050. As a set of four different scenarios, they span out potential future worlds based on qualitatively different, equally plausible, outcomes of a few uncertain driving forces.

The *explorative scenario approach* is based on three main working stages:

(i) Brainstorming, identifying and defining driving forces for global changes ahead,

(ii) discussing and assessing their uncertainty and impact, and

(iii) systemise the driving forces into a few selected scenarios.

With a broad, interdisciplinary team, it is possible to have a wide-ranging discussion of drivers and impacts of the global development for the next decades. Ideally, the inner diversity of the group's ideas should match the diversity of the future domain being mapped. It is, thus, important to include drivers from technological, political, social, demographic and economic domains and involve experts that are well acquainted with these domains.

The workshop was led and facilitated by PhD Per Espen Stoknes, Senior Researcher and Director of Center for Green Growth at BI, who is well experienced in similar applications of the method. The scenario method for the workshop was based on the *Probabilistic Modified Trends* (PMT) methodology (Amer, 2013; van der Heijden, 2005; Stoknes and Hermansen, 2004). See also the project description for *SMART PATHS* in the Appendix.

The scenarios from the workshop are expected to form the basis for model simulations of alternative global futures and the implications for the Norwegian societal and economic development. Besides being valuable research contributions in themselves (presented below in 4.2), the outcomes of the workshop and the simulated scenarios will be pivotal for investigating how Norwegian climate strategies perform within different external settings. This is one of the research questions in the project *SMART PATHS* (especially in the Work Package 1).

Table 1.1 List of workshop participants

Surname	First name	Institution	Position
Aslaksen	Iulie	SSB	Senior Researcher
Bye	Brita	SSB	Senior Researcher
Böhringer	Christoph	University of Oldenbourg	Professor
Cuesta	Helena Cabal	Ciemat	Senior Researcher
Ditlev-Simonsen	Caroline D	BI	Associate Professor
Fæhn	Taran	SSB	Senior Researcher
Gade	Henrik	Miljødirektoratet	Chief Engineer
Greaker	Mads	SSB	Senior Researcher
Lind	Arne	Institutt for energiteknikk (IFE)	Senior Researcher
Lindegaard	Are	Miljødirektoratet	Senior Climate Advicer
Løfsnes	Ole	Norsk Industri	Senior Expert
Rosnes	Orvika	SSB	Researcher
Seljom	Pernille	Institutt for energiteknikk (IFE)	Researcher
Skjærseth	Jon Birger	FNI	Senior Researcher
Stene	Janne	Stortinget	Political Advisor
Stoknes	Per Espen	BI	Director
Storrøsten	Halvor	SSB	Senior Researcher
Turner	Karen	University of Strathclyde	Professor

2. Scenario question, strategy scope and target group

2.1. The scenario question

The scenario question is a question that guides the scenario research and writing. Each of the selected scenarios will formulate one, specific answer to the same question. Yet each scenario will be fundamentally different from the others.

The scenario question was taken from the project description, discussed and adjusted somewhat by the team. The final formulation of the scenario question is:

> *What future external drivers are particularly decisive for the design and performance of national climate strategies in the period of 2020-2050?*

Subsequent quantification of the scenarios by means of numerical global models is an important aim of the qualitative scenario building process. The qualitative scenario descriptions are useful for determining exogenous variables in a consistent manner in the numerical modelling. Conversely, the quantitative model results will be useful for checking the implications of the qualitative reasoning in the explorative phase. Thus, iterations between qualitative descriptions and quantitative modelling are both wanted and necessary in rigorous scenario development to obtain reasonable and consistent scenarios. See chapter 6 for further elaboration on quantification.

2.2. The strategy scope and target group

One key insight from experience with and research on strategic scenarios is that it is essential to be clear and thorough on the specific use of the scenario set before the scenario development starts. This means to be explicit on the decision-making process that will employ the scenarios, and who the sponsors/owners and other stakeholders involved in the decision-making process are (Lindgren 2014, Stoknes and Hermansen 2004, van der Heijden 2005).

After discussion in the scenario team and the project forum group, the following strategy scope was formulated and agreed upon:

> *The purpose and the use of these scenarios is to provide (high-quality) research that can inform the Norwegian policy-making during the time period 2019-2023 in its design of a robust national climate and energy strategy to reach the low-emission society (including the formulation of the new Norwegian NDC to the 2023 COP[1]).*

The key target groups for the scenarios and the research results to emerge from them were identified to include Norwegian decision-makers and opinion as well as the international research community.

Among Norwegian stakeholders in the target group are:

- ministries, parliamentarians, The Norwegian Environmental Agency (MDIR)
- businesses, labour unions and NGOs
- public media and communication fora

[1] NDCs are the *Nationally Determined Contributions* decided by each nation participating in the *Conferences Of the Parties* (COPs) of the *United Nations Framework Convention on Climate Change* (UNFCCC). The first NDCs and the further process were negotiated at COP21 and constitute the Paris climate agreement.

The research community is the primary target group for the results of the project-internal use of the explorative scenarios in *SMART PATHS*. Here, the first objective will be to exploit the scenarios as a basis for a complementary set of quantitative global scenarios. They will aim at complementing the five *Shared Socio-Economic Pathways* (SSPs) developed to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation; see O'Neill et al. (2017). Previous comparable pathway studies include Nakicenovic and Swart (2000) and IPCC (2014). The scenarios to be developed will focus on medium-term quantitative implications and on differences in countries' preconditions and objectives. Energy systemic and technological aspects will be accounted for through simulations of a global energy system model (*ETSAP-TIAM*; Loulou (2008); Loulou and Labriet, 2008). These aspects will be combined with other socio-economic characteristics that will be quantified by means of a global *computational general equilibrium* (CGE) model (*SNOW*; Böhringer et al., 2012; Böhringer et al., 2015) that accounts for how regional economic resources and trade relations among countries affect the economies at large.

The second use of the scenarios will involve designing robustness tests of selected national climate strategies by means of a country model for Norway (SNOW-NO). A pivotal quality criterion for the domestic energy and climate policy design is how robust it is to the changes in global surroundings and other external conditions when it comes to effectively obtaining its objectives. This includes how flexible the economy will likely respond to such changes under various choices of policy instruments and targets.

3. Drivers

Framing and scoping the analysis of driving forces by reviewing the past

When thinking and analysing the coming 20-30 years, it is often useful to review what has happened duringa previous time period of the same length. Since scenarios are about exploring uncertainties and discontinuities, it is particularly useful to reflect on what driving forces for change that were underestimated by the ‘conventional wisdom’ of Norwegian policy makers at the beginning of the previous time period. This may provide us with insights into how mainstream thoughts are locked into certain patterns of perception, leading to skewed assumptions and biases when – in the past – trying to think ahead towards today.

The team was therefore given the task of coming up with issues and/or driving forces for change that – in their individual view – was underestimated or overlooked by mainstream thinkers and analysts around 25 years ago, i.e., since 1992. After some time for individual reflection, each participant was invited to write down two such underestimated drivers on two post-its. They could then come forward to present these two while attaching them to the whiteboard. A rapid clustering – based on facilitated plenary discussion – was performed both during and afterwards of this plenary discussion.

What follows are the results, in the form of a clustered list, that emerged during this group session on the past:

“What was underestimated by Norwegian policy makers 25 years ago (i.e. since around 1992)?” (in non-prioritised order):

- Growth of emerging economies, particularly China
- How difficult it has been to negotiate a global climate treaty on global CO2 price
- The political determination to continue annual climate negotiations
- The resilience and persistence of fossil fuels (no production ‘peak oil’)
- The incredible speed of digital technology change
- The recent growth of electric cars and cost reductions on batteries
- The possibility of another severe and long-term global financial recession
- The large and rapid price drops on solar and wind
- The broad (scientific) acceptance of global warming seriousness
- The persistence of rebound effects.

On this historical background, the group was invited to explore – by divergent thinking – the future. Each individual in the highly interdisciplinary team was invited to come up with 4 suggestions of external driving forces that will impact the Norwegian climate policy and strategies in the future leading up to 2050. Two of the four could be more well-known and acknowledged, while the next two could be more uncertain, novel or possibly unexpected according to current 'conventional wisdom’.

With 15 participants and 4 driving forces each, around 60 proposed driving forces were collected on a shared wall space, each one represented by a post-it note, and each of them verbally presented and explained to the plenary group. During the presentation obvious overlaps and related drivers were clustered by proximity on the wall.

After this divergent, creative process of exploring a broad range of possible future driving forces, the process turned around towards convergent and more evaluative thinking. Each participant was then asked to review the entire wall, and given 3 votes. After time for reflection, these 3 votes from each participants were expressed as pen-tip marks on the post-it cluster they were deeming to be *the most significant and decisive drivers*.

Through this process, 11 distinct drivers emerged from the full range of 60, each of these 11 with several votes (or at least one). These selected 11 were then subject to further elaboration, discussion and definition in smaller groups of 3 or 4 people. A shared Google-sheets document was used for capturing the shared knowledge in the team regarding these 11 drivers. Each driver was then fleshed out by one of the groups. The group's task was to formulate the following characteristics for each driver:

- driver name
- definition
- future impacts
- strengthening/accelerating factors
- weakening/counteracting factors
- assessment of the degree of certainty of the driver and the two extreme outcomes, if uncertain

Table 2.1 sums up the 11 drivers, their impacts and assessments, as they were elaborated on by the groups. The following subsections 3.1-3.11 give more thorough and refined descriptions.

Table 3.1 Summary of impacts and assessment of drivers

Driver name	Future impacts	Certainty assessment
#1 Strong Climate Treaties	Higher global commitments Higher Norwegian commitments Cheaper abatement domestically Cheaper abatement abroad New innovation and business opportunities No carbon leakage	Uncertain (ambitious & compliant vs. unambitious or uncompliant)
#2 Clean technology development	Higher global commitments Higher Norwegian commitments Cheaper abatement domestically Cheaper abatement abroad New innovation and business opportunities	Uncertain (weak vs. strong)
#3 Power storage technology development	Higher global commitments Higher Norwegian commitments Cheaper abatement domestically Cheaper abatement abroad New innovation and business opportunities	Uncertain (weak vs. strong)
#4 Extreme weather events	Reconstruction and adaptation costs Emergency and adaption aid Migration	Certain
#5 Strong EU policy	Higher global commitments Higher Norwegian commitments Cheaper abatement domestically Cheaper abatement in the EU and RoW CO_2 pricing	Certain
#6 Lower oil demand	Drop in oil price and petroleum profitability Less exploration and extraction	Uncertain (high vs. low)
#7 Increased electricity demand	Higher European/Norwegian electricity prices Loss of competitiveness for energy-intensive manufacturing More cross-border grids Energy security and distribution concerns	Certain
#8 Green norms and preferences	Consumption sufficiency, leisure demand, sharing economy Less energy demand, particularly fossil fuels Higher global commitments Higher Norwegian commitments	Uncertain (rapid vs. slow)
#9 Cities as political agents	Novel technological and structural solutions Shifts in consumption/modes of living Local differences	Certain
#10 Technological success of CCS	Higher global commitments Higher Norwegian commitments Cheaper abatement domestically Cheaper abatement abroad Global fossil fuel demand High oil price and petroleum profitability Continued exploration and extraction	Uncertain (Success vs. failure)
#11 Evolvement of the digital economy	Benefits the greening of the economy: Cheaper abatement domestically Cheaper abatement abroad New innovation and business opportunities	Certain

3.1. #1 Strong climate treaties

This possible driving force for change, #1 Strong climate treaties, is defined by that in the coming global stocktake by 2023 in the wake of the Paris agreement, commitments will be taken on by most of the world's countries and be consistent with the 2℃, or possibly a 1.5 ℃, target. That means that the world will be on the track to the goal set in the 2016 Paris agreement. The 2023 negotiations may thus force Norway to take on larger commitments by 2030 than in the original Paris agreement. The low-emission goal from 2050 may also have to be strengthened.

For the Norwegian climate strategies, the main impacts will be that the global development of low and zero-emission technologies will be spurred. Technological development facilitates access to cheap and effective abatement options for Norwegian firms and households. The same applies to other countries. The treaty will make it profitable for some domestic firms to develop and export abatement technologies.

A broad participation by countries setting curbing, even if some set relative lax, national targets will also mean that we will avoid carbon leakage from national and European abatement. Even if competitiveness can be lost to foreign firms with laxer regulations, their binding national targets will keep total emissions in their jurisdiction unaltered through bringing about mitigation in other parts of their economies.

Strengthening and weakening factors: The plausibility of strong treaties will be strengthened if for some reason particularly effective abatement options are invented and effectively spread. Other accelerating factors would be the leadership by large, influential countries or if global institutions are established that help compliance and enforcement of the treaties.

On the other hand, if further technological development is slow, or if no global institutions or strong powers ensure compliance, strong treaties will become less likely. The EU, China and the US are examples of actors that could take leadership. Their willingness and capability will weaken in case of other challenges crowding out the climate change issue, like economic crises, geopolitical conflicts or acute natural disasters.

Certainty assessment: Just as likely as the driver #1 Strong climate treaties that are *ambitious and compliant* for most nations of the world is the opposite outcome of *unambitious and non-compliant* treaties, possibly only involving few countries.

3.2. #2 Clean technology development

Technological development can facilitate inexpensive and effective abatement. We can even develop effective methods for obtaining negative emissions (e.g., BECCS[2]). As described above, technological development gives access to cheap and effective abatement options, which makes ambitious targets easier to set and reach.

Strengthening and weakening factors: The development and marketing of new technologies can achieve more political and financial support if business and employment opportunities are attached. This also applies to the innovation that take place within domestic borders. For an effective growth in green technologies, it is important that both the climate and technology policies are predictable, stable and long-lasting. Ideally, policies promoting Research and Development (R&D) should be coordinated and funding pooled and competed for internationally. Facilitating the spread of technologies and international funding of technological transfer to less developed, growing economies will also accelerate the green technological transformation. For some technological development, learning by deploying would be a crucial element.

Potential obstacles to a rapid green technological change are protectionist trends in world trade or other political priorities in national and geopolitics, novel sources or technologies for cheap extraction of fossil resources and/or limited technological steps resulting from green R&D.

Certainty assessment: The driver #2 Clean technology development can range from *weak* to *strong*.

3.3. #3 Power storage technology development

This driver embraces all new technologies offering inexpensive possibilities to level out fluctuations in the European (and global) electricity supply. Batteries, as

[2] Bio-Energy with Carbon Capture and Storage technologies

well as solutions involving storage and electricity supply by prosumers[3], will enable economies to rely more heavily on renewable electricity generation and can help the electrification of energy services hitherto based on fossil fuels, like transportation. Since the Norwegian power generation is already clean, a battery revolution would, first of all, alter the Norwegian economy by dampening the role of Norwegian hydropower and Norwegian fossil fuels in European energy mix.

Strengthening and weakening factors: The accelerators and obstacles for the development of power storage technologies will largely be similar to those of clean technology development, in general (see driver #2). A characteristic of the storage technologies is their reliance on advanced infrastructure investments and market designs (intelligent net and smart grids). Here, the governments will have to play a role in coordinating/facilitating and/or funding investments. For example, existing regulations can hamper novel solutions and will have to be altered. The transformation can be blocked by incumbent power companies afraid of losing market positions; these can include Norwegian market players within hydropower and fossil fuels. Improved energy efficiency and active demand management can reduce the need for storage along with the need for renewable power.

Certainty assessment: The driver #3 Power storage technology development can range from *weak* to *strong*.

3.4. #4 Extreme weather events

The driver includes weather events expected to become more frequent because of climate change, like water deficiency, draught, flooding and sliding. Episodes of regional food shortage, migration and conflicts will become more frequent. The need for emergency aid and adaptation investments from richer parts of the world will escalate, and so will the migration pressure to areas of the globe that are richer, more adapted or less exposed to natural disasters due to climate change like Europe and Norway.

Strengthening and weakening factors: The frequency of extreme weather events will also rise within Norway and Europe, diverting policies and resources towards repairs, maintenance and adaptation. However, the focus on mitigation and global cooperation can also be strengthened along with more evident impacts of climate change. The Norwegian economy can see some gains from a wetter climate in terms of hydropower and food production.

If climate change implies a melting of permafrost and/or the Pole ice, extreme weather events can be expected to accelerate further. The consequences of climate change can be dampened if societies are prepared and adapted to natural events and emergency situations, if the events strengthen global mitigation efforts and cooperation, if affordable technologies and the capacity to make use of them are readily available both for mitigation and adaptation.

Certainty assessment: The increased occurrence of the driver #4 Extreme weather events is regarded as certain.

3.5. #5 Strong EU policy

This driver involves Europe being a leading region for mitigation policy and a proactive power in international negotiations and central funder of technological transfer and adaptation efforts in less developed regions. For the Norwegian

[3] Prosumers refer to individuals and households that are not only consuming electricity, but are also producing and selling excess power to the network for example originating from solar sources and/or stored in electric car batteries.

climate strategies, EU policies are decisive for lowering the costs, increasing the effects and keeping up the ambitions. The EU emission trading system (ETS) relieves the pressure on national industries and facilitates CO_2 pricing. If the EU succeed to establish similar arrangements for emissions outside the ETS, Norwegian ambitions will be easier to meet.

Strengthening and weakening factors: The stringency of EU policy will be stimulated if cheaper abatement options develop, if Europe succeeds to establish fair and acceptable distributional mechanisms and/or if economic prosperity grows in the region. On the other hand, the EU climate ambitions are at risk if the political and economic conditions worsen and contribute to disintegrate the union. Conflicts and crises will lend less priority to the climate issue. Disintegration can make each country more self-centred and concerned with being self-sufficient in energy and food supply. Their national actions can easily render short-sighted, cost-driving and reduce welfare levels.

Certainty assessment: We regard the driver #5 Strong EU policy as reasonably certain.

3.6. #6 Lower oil demand

Lower oil demand will be the result to the extent that alternative energy supply flourishes, fuel efficiency improves and fuel subsidies are phased out in the world. The most direct result for the Norwegian economy will be relatively lower oil prices and, hence, lower profitability of the petroleum sector.

Strengthening and weakening factors: The decline in oil demand will be accelerated if effective renewable technologies, storage solutions and market designs evolve rapidly. One precondition will be active and focussed governments, which again depend on how severe climate change is regarded relative to other societal challenges. Rapid economic growth in 3rd world countries will tend to increase oil demand, particularly if combined with sluggish renewable energy development and lack of international cooperation and low or no carbon pricing.

Certainty assessment: The prospect of #6 Lower oil demand is uncertain. We can face a future with continued high fossil fuel reliance where renewables come on top of fossils or a future where the energy system is based on renewables and energy-efficiency that replace oil demand globally.

3.7. #7 Increased electricity demand

The demand for electricity increases as a consequence of the electrification of transportation and heating services in Europe. In Norway, the rise will mainly take place in transportation. The results will be higher European (and Norwegian) electricity prices, loss of competitiveness for power-intensive industries and potentially more reliance on imports and cross-border grid structures. The issue of energy security, high energy prices and distribution will be on the political agenda.

Strengthening and weakening factors: Electricity demand will be strengthened by governmental involvement in the electrification shift, e.g., by continuing the Norwegian electric vehicle policies. The pressure on the electricity price pressure will be enhanced if Europe simultaneously faces a rapid population growth through immigration or increased economic wealth of the inhabitants. On the other hand, electrifications will be slowed down if costs of clean power technologies and/or battery technology do not come down and/or if consumers/voters are reluctant to take on the high costs. Rapidly improving energy-efficiency in the buildings sector may reduce electricity demand significantly. There might also evolve other alternatives to electrification that turn out to be less costly/more acceptable, like fuel efficiency, biofuels and hydrogen/fuel cells in transportation.

Certainty assessment: #7 Increased electricity demand seems to be unavoidable towards 2050 both in light of the electrification process already evolving and because of a general growth in the European income and population.

3.8. #8 Green norms and preferences

This driver is defined as consumers (particularly in Europe) changing what they want, how and when they want it in a green direction. Consumption *sufficiency* replaces consumption *growth* as a driving force and leisure is more emphasised at the expense of consuming (more) resource-intensive goods and services. For instance, people demand increased flexibility in energy and transport use and focus on the longevity of products. The demand will fall for energy, particularly fossil fuels, and also for goods that rely on energy in their provision. Demand for sharing services etc. will increase. People are highly aware of the climate change issue. This also implies a broader social support for strong public policy.

Strengthening and weakening factors: Green norms and preferences will be strengthened if social structures and societal solutions arise to preserve and reinforce them. Examples would be the evolvement of institutions for sharing economy, infrastructures supportive of new city life styles and the facilitation for people who seek simpler lifestyles in rural areas. Europe encompasses a large variety of norms, attitudes and values today. For green norms and preferences to strengthen, current trends most noticeably found in Germany and France need to be reinforced and diffused to more of the region, including Norway.

Transformation of attitudes can be inhibited if individual habits are persistent by nature, if they depend on rigid structures and/or if policies – or lack of policies – favour the choices that continue to make use of existing technologies and infrastructures.

Certainty assessment: The cultural transformation towards #8 Green norms and preferences can be *rapid* or *slow*.

3.9. #9 Cities as political agents

Cities will take on the role as important agents for change in Europe and Norway. Political actors at city level or regional level actively develop their own policies, gain more power (e.g. through covenants among mayors, spillover effects to other cities, and also nudging policies at the national level). The impacts in a Norwegian context will be that novel technological and structural solutions evolve at local levels, leading to potentially large shifts in the modes of living in cities. The changes will be most marked for consumers (as opposed to firms).

Strengthening and weakening factors: The transformation of cities will be accelerated if consumers actively take part and demand coordinated action from their communities. The triggers can be high local pollution levels, congestion problems or other local environmental challenges related to greenhouse gas emissions. The cities' action can also accelerate if there are conflicts between the state and local level interests or if the national government is weak. Green norms and preferences will interplay with and residually reinforce the local level policy actions (see driver #8).

Certainty assessment: #9 Cities as political agents will expectedly be a significant feature of international climate and energy policy development and implementation.

3.10. #10 Technological success of CCS

CCS can become a commercial success if there are sufficiently high carbon prices, rapid technological progress and public acceptance. The direct impact on the Norwegian climate strategy will be that mitigating emissions from Norwegian manufacturing and petroleum activities becomes relatively inexpensive. Globally, CCS will be most important for fossil-fuelled power plants. CCS will increase the feasibility of ambitious targets both at a national and global level, including ambitions for gross, and even net, negative emissions in some countries within a few decades.

Strengthening and weakening factors: The probability of rapid development and wide-spread deployment of CCS will increase only if the world makes use of high carbon prices, if the technology is publicly accepted and legalised in terms of pipeline and storage safety and storage capacity, and if the costs of capturing, transportation and storage are driven down. Otherwise, CCS will not be a significant part of the climate change response.

Certainty assessment: Both #10 Technological success of CCS, as well as its failure, are likely future outcomes.

3.11. #11 Evolvement of the digital economy

The digital economy is generic, including development of internet (fiber), big data, robotisation, internet of things, and with massive and cheap data collection and analysis. It will benefit all parts of the society, also the greening of the economy. An obvious benefit is better monitoring, which will allow efficient energy consumption (smart grids, prosumer patterns, easier transition to high renewable energy share). It will also be part of a large range of new, greener business models (sharing economy, robotisation, skype meetings, etc.). The digital possibilities represent an economic game changer. In all sectors of the economy the ultimatum will be “go digital or die”.

There are large potentials for making use of the general digitalisation of the society to reinforce the greening potential. For instance, internet (fiber), big data and computation capacity can be used to establish new, and better informed, value chains. Digitalisation may offer large network and scale economies.

Strengthening and weakening factors: The speed of the digital revolution can be deterred by rules of data security, privacy protection and other law issues. There are risks of cyber attacks, cyber terrorism and break-down of key societal systems. Power groups in the established value chains can work against the new businesses. There is also the risk of cheaper and more attractive options having counterproductive rebound effects in terms of emissions. Economic growth, more available goods and services via interne, attractive innovations in gadgets and technical equipment, etc., can increase the volume of consumption.

Certainty assessment: There is little uncertainty about the driver #11 Evolvement of the digital economy –it will continue.

3.12. Other drivers revisited

At the workshop participants discussed, though less systematically, drivers that were not independently mentioned and analysed in the list above. These were:

- New, sudden technological breakthroughs (black swans),
- General economic and financial growth versus long-term crisis (the *relative* growth of green versus other economic sectors is important, not green growth per se),
- Social norms and structures in addition to the more individually reliant #8 Green norms and preferences above,
- The development in other regions than Europe,
- Large geopolitical issues, such as a long-lasting conflict between China and USA.

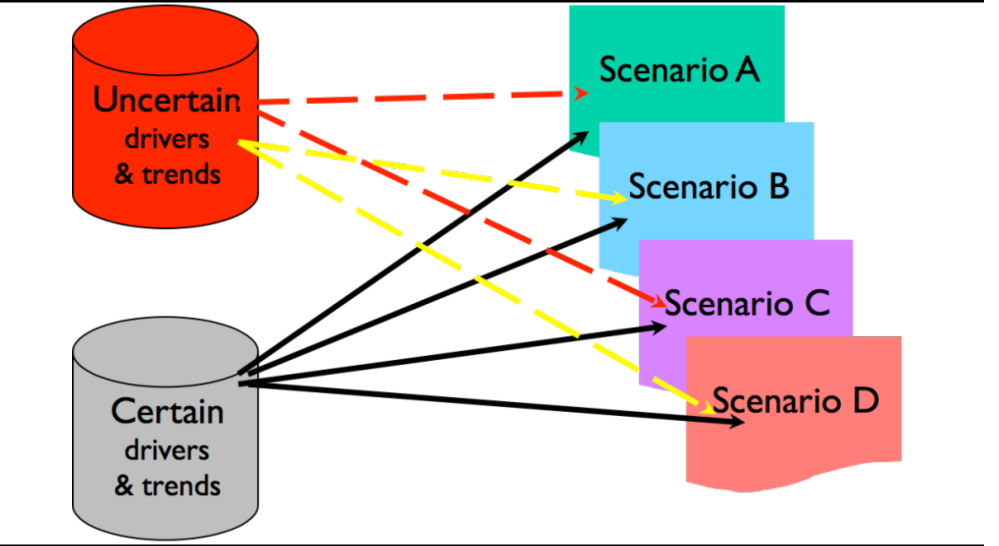
4. Defining scenarios

4.1. Choosing the axes and scenarios

The driving forces described in chapter 3 are the building blocks of scenarios. Each driver has a certain impact on the scenario question: *"the design and performance of national climate strategies in the period of 2020-2050?"* Each driver also has inherent uncertainty as it plays out towards 2050. The scenarios are constructed from a set of driving forces, in which the driving forces are combined in a consistent manner:

Drivers with a low uncertainty (i.e. fairly certain), are used as a common foundation for all the scenarios. That is because their impacts are expected to play out in any future. The drivers with a high uncertainty and high impact, however, are considered critical or key drivers. The highly uncertain impacts of these drivers can take the future in very different directions. In this scenario method, we construct scenarios by using the certain drivers in all scenarios, while using the uncertain drivers as one particular impact in one scenario, and the opposite impact in another scenario. See Figure 4.1 below:

Figure 4.1 Building of scenarios based on drivers



After the drivers were defined at the workshop, they were ranked according to impact and uncertainty. This was done in an iterative process, first at sub-group level, then plenary level, and refined in a second discussion.

This driver ranking work resulted in the selection of the following drivers as "certain" (or "low uncertainty"):

- #4 Extreme weather events (see Section 3.4)
- #5 Strong EU policy (see Section 3.5)
- #7 Increased electricity demand (see Section 3.7)
- #9 Cities as political agents (see Section 3.9)
- #11 Evolvement of the digital economy (see Section 3.11)

These five drivers (high impact, low uncertainty) become the common foundation of all scenarios.

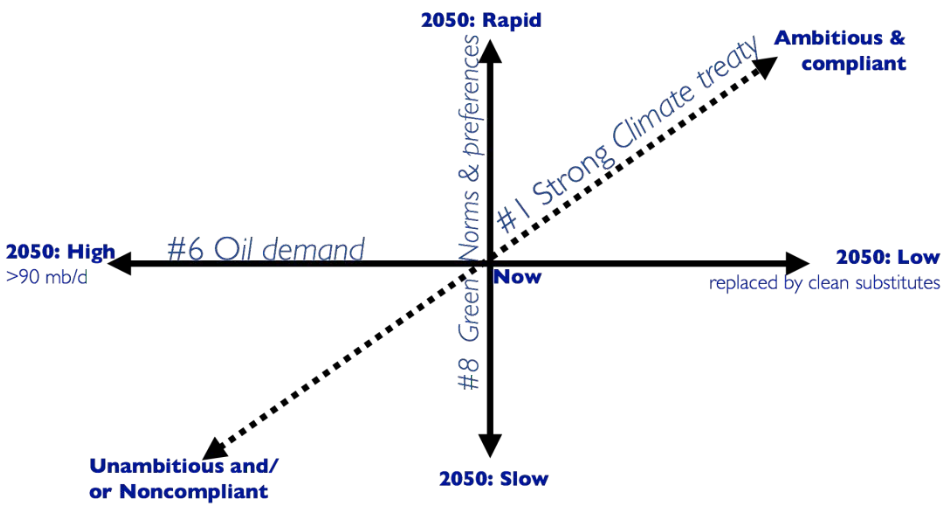
The ranking also resulted in picking these three drivers as key drivers with equally high impact and high uncertainty:

#1 Strong Climate Treaty (see Section 3.1)
#6 Lower oil demand (see Section 3.6)
#8 Green norms and preferences (see Section 3.8)

In the workshop discussion, we concluded that there are correlations between these drivers. First, #8 Green norms and preferences will lead to #1 Strong climate treaties, and the more rapid shift of norms and preferences the more compliant and ambitious treaties will result, and vice versa. Second, #6 Lower oil demand would make #1 Strong climate treaties more likely, as well as the opposite causal direction; the more compliant and ambitious the climate treaties, the more will oil demand go down.

Therefore, we decided to use #6 Lower oil demand and #8 Green norms and preferences as main axes in the scenario uncertainty space as illustrated in Figure 4.2, while #1 Strong climate treaty is inserted as a third, diagonal axis impacting only two of the main quadrants in Figure 4.2.

Figure 4.2 Axes of the scenarios

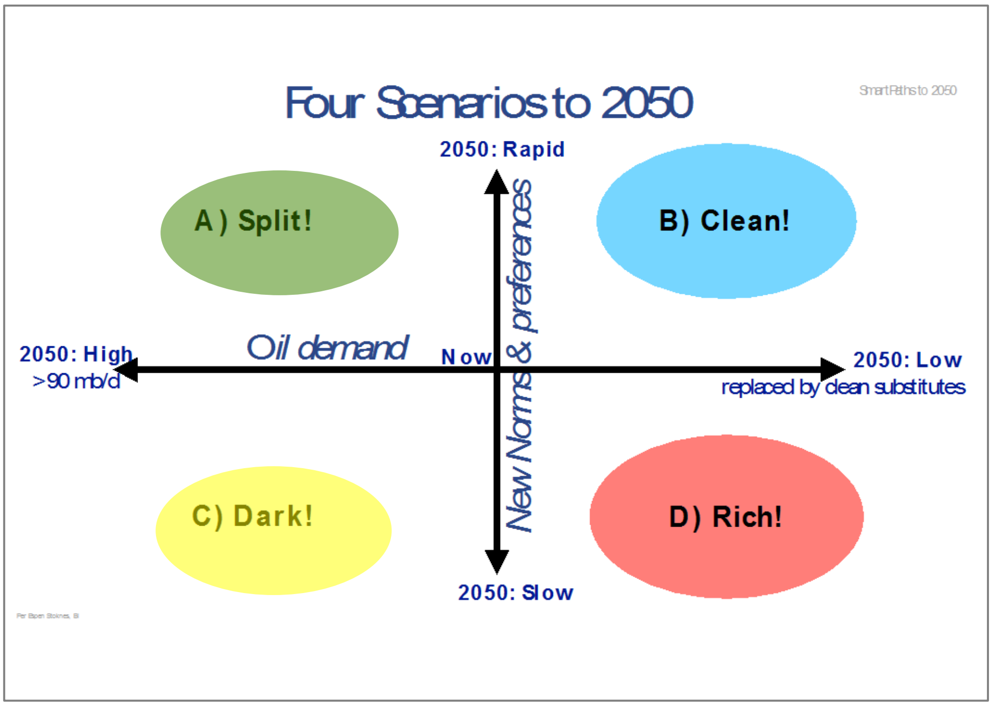


Based on this structure, we get four scenarios; one in each quadrant formed by the main axes. The final step of the workshop was to “visit” these four quadrants, and describe the scenarios that can emerge towards 2050, if the future heads in this direction. In Figure 4.3 below, the diagonal axis, #8 Strong climate treaties, is not explicitly shown in the figure with the names of the scenario. This is just to make the figure design visually simpler, i.e., less cluttered.

4.2. Description of the scenarios

Given the axes as depicted in Figure 4.2., the workshop participants were split in four groups, each given the task of describing one of the scenarios. The scenarios were coined SPLIT!, CLEAN!, DARK! and RICH!. Figure 4.3 illustrates the scenario logic and the subsequent sections sum up the scenario characteristics. We structure their descriptions into three chronological periods, one covering each decade of the period 2020-2050. (The scenario text is organised in variables/trends rather than in chronological periods, as variable-wise is how the exogenous assumptions will be fed into the model in subsequent work packages.)

Figure 4.3 The four scenarios



4.2.1. SPLIT!

In this future world, we get a split development with two simultaneous and opposing tracks on energy and climate. Despite a public shift to #8 Green norms and preferences, the global #6 oil demand remains high, particularly in emerging economies. The most prosperous countries see a rapid shift to green norms and keep a quick pace towards low emission societies. This is mutually reinforced by climate treaties among the richer countries and cities. However, the less wealthy part of the world is mostly passively associated with the international climate efforts. Their primary focus is on rapid economic growth, and they allow themselves lax, if any, emission targets. Climate policies are virtually absent in these countries and their considerable need for energy relies heavily on cheap fossil fuels.

The split leads to increasing tensions between the relatively rich and poor people and regions, making mitigation efforts regionally concentrated. Continued fossil-fuel reliance and successful lobbying in other regions undermine the efforts to get strong global climate treaties in place. By 2050, the world faces severe climate disruptions, economic contraction and frequent political conflicts.

Population, growth and climate change

The first ten years of this scenario, from 2020 to 2030, is mostly prosperous. Both in the Western hemisphere and in developing countries there is large economic optimism, which is reflected differently: In the richer part of the world, the climate change awareness is high and businesses see opportunities for profitable green entrepreneurship. The labour force is well-educated and innovative. The optimism in lower-income countries is based on high growth rates and large consumption demand. Population growth also remains high in many of the latter regions, like Nigeria and India.

Gradually, the growth is hampered by climate change such as droughts, food scarcity, natural disasters and substantial public expenses in emergency aid, infrastructure maintenance and adaptation efforts. The crises also reduce population growth rates in the suffering regions. Towards 2050, living standards stop increasing and start falling in more and more parts of the world.

We see conflicts due to migration and cultural clashes and struggles over access and control over water, food and energy resources, that eventually also limit growth in the relatively wealthier parts of the world. The Western hemisphere has an economy increasingly based on green norms and values. However, the ideas of international cooperation start to fade, and along with conflicts over trade and migration control, the Western countries become more self-supported and isolated. Even local communities start isolating themselves and fighting for regional power with the national authorities and with each other.

Climate change is severe by the end of the period. By 2050 the temperature has a clearly increasing trend and on track for a global warming increase of 3˚C.

International cooperation and geopolitics

In the second decade – from 2030 to 2040 – the world's most prosperous countries continue their quick pace towards digitally advanced, low-emission societies. Their ambitions rely on international cooperation and agreements. Europe is integrating closer and has fruitful cooperation with China and several smaller, proactive economies, like Canada and Australia. Also, the most ambitious US' states and cities cooperate. However, the US federal government, along with the lion-share of the emerging and developing countries takes little or no part in the international efforts. Their political focus is elsewhere, on growth, conflicts and instability. Propaganda and fake news continue to link climate concerns to conspiracies.

There is tension between the green innovative economies and the others because of counteracting development paths. In the last decade to 2050, as global warming and extreme weather events get increasingly urgent and far-reaching, this deepens the conflicts over poverty and inequality. The border policies of the European and other Western countries reinforce political and cultural polarisation of the world. Also, within borders conflicts arise because the materialist lifestyles in the South and the environmental-friendly lifestyle of the North are challenged by lack of financial and natural resources.

This SPLIT! scenario, which started out rather happily, turns difficult for a majority of people during the 2040-2050 period because of declining average living standards, strong inequality and large climate change consequences.

Technology development

Overall, in the SPLIT! world, there is fast development in green technology in Europe and their climate mitigation allies, including China, but slower in US and developing countries. During 2020-2030, development and deployment of solar and wind energy will rise substantially. Several pilot CCS projects will be launched. Technological growth in the climate-policy-lax countries will, primarily, be driven by adoption of solutions that increase labour productivity. Technologies that facilitate climate adaptation will also be in demand, particularly in the Southern hemisphere. Thus, advanced technologies and expertise in adaptation strategies will also form part of the green growth in Europe and China. Since global oil demand is considerable, high-tech exploration and extraction technologies will also find their way to the boiling market.

The diffusion of renewable technologies will continue in the 2030-2050 period to the extent that solutions are available and perceived privately competitive. Already by 2030, European abatement innovations, and in particular their advancements in CCS – to some extent also in bio-CCS, face market limitations as the rest of the world is not following up the mitigation efforts. However, the market-pull in adaptation technologies strengthens.

Energy mix

In SPLIT! the energy-mix is by 2050 markedly divided in two: In Europe and the other climate-concerned countries, the share of renewables is high and increasing along the period, driving out fossils. In much of rest of the world including the US, the growth in renewables comes on top of a still a high fossil fuel reliance. This is held up by exploiting novel, unconventional sources and policy support for fields with relatively costly extraction.

4.2.2. CLEAN!

In the CLEAN! future, we see the convergence of a rapid global shift to #8 Green norms and preferences with significantly #6 Lower oil demand and #1 strong climate treaties. The latter drivers are reinforced by rapid development of cheap, low-carbon technologies. The result is that fossil fuels become ever less competitive, leaving the global demand for oil and other fossil fuels at very low levels by 2050. This #1 Strong climate treaties are ambitious, compliant and encompass almost all of the globes' nations.

Population, growth and climate change

Economic growth is moderately high worldwide, though somewhat lessened by the costs of high mitigation ambitions, maintenance and repairs, investments in resilient infrastructure, renewables and abatement technologies and a fast restructuring of the economy.

Renewables gradually crowd out fossil energy, which leads to growth becoming increasingly decoupled from fossil fuels. Along with growth, employment and welfare improve and the world population gradually becomes healthier and more educated. This causes the population growth rate to decline over time.

Climate change has a dampening effect on economic growth, because of damaging weather events and the costs of infrastructure maintenance and migration. Even if there are severe conflicts in parts of the world around the strictness of environmental regulations and who should bear the costs, the awareness and acceptance among people of the severe negative impacts of climate change strengthen green norms and preferences in the population. This leads to higher political mitigation ambitions and international commitments are gradually strengthened. The world seems to be on a pathway where warming will be limited to less than 2˚C and the most dangerous effects of climate change avoided. However, frequent extreme events and non-linear climate change processes still wreak havoc from time to time.

International cooperation and geopolitics

The ambitious global climate treaty becomes a reality: After the first COP stocktake in 2023 decided in the Paris Agreement, new and stronger pledges (NDCs) are taken on by virtually all the countries. The ambitions are made much easier and attractive by the rapidly growing access to cheap clean technologies. Carbon pricing and other regulatory measures are gradually introduced in most countries, though not equally strict in all sectors and regions.

The EU strengthens the emissions control by several decisions: The reserve of allowances in the *Emissions Trading System* (ETS), which has been held back during 2020s, is deleted. The ETS cap is reduced markedly from 2031 to 2040, and then further restrained from 2041 to 2050. Negative emissions are included in the

ETS. Further, the EU launches a moratorium on new fossil fuel power, unless abated with CCS. Emissions standards and road pricing are extensively used in the transport sector, and under the EU's leadership, international air and shipping become regulated by comprehensive international agreements. The ambitious EU policies are supported by an accepting and trustful population.

Regulation of *Greenhouse Gas* (GHG) emissions are gradually strengthened in most countries across the world. Also, marginal abatement costs converge, partly facilitated by extending ETS markets and linking of markets across borders. International efforts are made to ensure the development and transfer of renewable technologies. By the end of the period, both sinks and sources are linked in a global trading system, and loss-and-damage-mechanisms[4] are in place and working, making adaptation more feasible for the most affected regions.

Technology development
Rapid growth in clean technology is a main prerequisite for the successful mitigation and cooperation efforts. Along with cost decreases for the low-emission technologies we know today due to learning-curves, there is a willingness to fund the introduction and testing of novel solutions. One novel area of R&D and large-scale testing is that of negative emission technologies. R&D support to dirty technologies is weakened or totally phased out. Smart grids with decentralized production and prosumers become a prevalent feature of the energy systems. The need for heating and cooling in buildings and industry is to large extent delivered by heat-pumps that run on new renewable powers and replace fossils.

In the first part of the period, the technological change relies on green incentive structures in many countries for clean technology R&D and diffusion. Besides support schemes, the development is a response to high demand for low-emission technologies. Also among consumers, final goods and services with low-carbon/GHG footprints are preferred. These shifts in demand result both from high carbon prices and the significant transition of preferences and norms. General productivity gains increase leisure (as opposed to consumption) more than has historically been the case.

Energy mix
In CLEAN! we see unprecedented investments in renewable energy technologies, batteries and other storage solutions. But despite the rapid growth in renewables, however, transition still takes time because phasing-out of existing coal plants is slow in some areas.

4.2.3. DARK!
In this future, neither #6 Lower oil demand nor #8 Green norms and preferences occur. On the contrary, there are plenty of cheap fossil energy resources and high reliance on old energy technologies and mindsets. As a consequence, no #1 Strong climate treaties are pushed and the Paris Agreement turns out to be a failure with no abatement impact. By the first stocktaking in 2023 it becomes clear that few nations reinforce their targets. USA has completely withdrawn and several countries follow the US' abandoning. The EU and a few wealthy, small countries keep mitigation ambitions high and try to rescue the Paris Agreement, however, in the second decade no coordinated efforts are made to mitigate climate change.

Alongside the abundance of cheap fossil fuels, investments in renewable technologies are too slow and, subsequently, abatement costs are higher than expected. Security of supply is perceived by many policymakers as more important

[4] Loss-and-damage-mechanisms are designed to address, fund and compensate loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to the adverse effects of climate change.

than accelerating the shift from fossils to what they perceive to be intermittent and unreliable renewables. These facts hamper the transformation to green attitudes and lifestyles and the progress of international climate negotiations.

Worse, in the DARK! scenario there is an escalating conflict between China and the US over economic, political and military power. Other parts of the world, including EU is drawn in. It starts in the wake of the fruitless negotiations on climate change, and as the years go by, the large economic burdens of frequent natural disasters, social unrest and pessimism reinforce the tensions. A regional pacific war breaks out (non-nuclear) and lasts well into the 2040s and the last years of the decade are devoted to a rebuilding of the societies.

Population, growth and climate change
During the first decade, economic growth is relatively high, *inter alia*, due to large supply of cheap fossil energy. Population grows at a moderate rate. Signs of climate change are not obvious and climate change has low priority. Only the EU and a few wealthy, small countries keep mitigation ambitions high and try to rescue the Paris Agreement.

As the years go by, hurricanes, floods, heatwaves and drought incidents become ever more frequent. In USA, there is increasing unrest and dissatisfaction with the government; the US. government blames China for the steadily more apparent changes of the global climate. Chinese money pulls out of Europe and USA as a response and this severely reinforces the economic recession.

When military clashes break out from around 2030, also the EU gives up its long-term climate policy ambitions. Between 2040 and 2050, all the nations that have been involved in the global conflict need full focus on rebuilding of their economies. In addition, there are frequent natural disasters in all parts of the world. EU resumes climate policy efforts towards the very end of the period.

International cooperation and geopolitics
The Paris climate agreement starts falling apart already during the 2020's, and only the EU and a few wealthy, small countries keep mitigation ambitions high in an attempt to rescue the agreement. They only succeed to continue a shallow and limited international cooperation in climate policies, and only for the first decade.

Technology development
During the 2020s there are moderate levels of R&D activity, but no further significant breakthroughs occur in batteries or low-carbon technologies other than for military applications. There is also less focus on R&D in large-scale renewables, as the prospects for being able to compete with the cheap fossil fuel supply appear small. Along with increasing global tensions, the large economies redirect all R&D resources to military research and all progress within mitigation technologies halts.

The reliance on and development of the digital economy with smart-grid and internet of things, is fragmented due to the risk for hostile hacking and digital terror. The development of smart cities, electrification and energy infrastructure is also of less relevance in this scenario, and viewed as a potential vulnerability. The political emphasis is on national security and near-term interests.

Energy mix
Russia continues to be a stable gas supplier. During the 2020s there is a slow increase in the share of renewables, and some switching from coal to gas, however,

fossil fuels continue to be dominant. Due to the uncertain geopolitical situation (military clashes and war), there are virtually no resources devoted to renewable energy infrastructures. Military R&D leads to lower costs of nuclear technologies and a resulting higher reliance on nuclear power plants. However, shortage of nuclear fuel after the wars increases the share of fossil fuels again.

4.2.4. RICH!

The RICH! future is characterised by massive investment growth in renewables, causing a drop to much #6 Lower oil demand. The success of renewable technologies is not the result of #8 Green norms and preferences or #1 Strong climate treaties, but a sudden realisation that renewables have become economically competitive and commercially very attractive. Technological breakthroughs and rapid innovations make renewables so cheap that fossil fuel resources struggle to compete purely on price. The technological transition starts in the China and EU, as this is where the green investment and R&D takes off first. This renewable revolution inhibits the most overwhelming threats of climate change, but further global climate negotiations struggle with increasing social inequality and discussions over allocation of burdens. This weakens the compliance and ambitions of climate treaties.

Population, growth and climate change

EU growth is based on affordable (renewable) energy and on the economy being a global market leader on innovative energy technologies. Cities are key political agents. Even if rapid technological progress and robotization drive growth, labour resources are highly educated and effectively exploited, particularly within R&D and services. People still work as much as today for instance with R&D and a lot of new service activities. Along with the economic growth, inequality increases. The European population is growing.

The renewable industries grow so quickly in all countries that clean technologies increasingly replace fossil fuel use and thus limit the emissions. The greening of norms and environmental consciousness is not pronounced, however, and we see continued, growing damages to nature and loss of species in vast areas in the wake of renewable energy generation. And due to the lack of ambitious and compliant climate treaties, global abatement of GHGs is slower than required for keeping below 2˚C. Climate change materialises along this scenario as moderately frequent, and slowly escalating, incidents of drought, hurricanes, floods etc. However, within the period until 2050 they do not get as severe as to draw the nations into another large-scale, ambitious effort of global climate negotiations.

International cooperation and geopolitics

The globalization trend continues. The global community collaborates on trade liberalisation, technological transfer and national and international institutional development. A fine-tuned weapon balance between strong, equal military alliances is crucial for world peace. Military spending is particularly sizeable by the large nations. The US continues its tradition of the protective role for the European countries. Trump is not re-elected; the US foreign affairs and trade policy in the 2020s fall back on the track from the Obama era. Despite Brexit, Britain is still closely linked to the EU economically and politically.

The world becomes culturally more homogenous and thus travelling from city to city gets more routine and less exotic. Business collaboration rather exploits digital virtual-reality solutions. Air travelling is still growing, but not as rapidly as in the 2010's.

Technology development
EU’s position as a clean technology forerunner is gained not least due to the heavy subsidy programmes in the years before and well into the 2020s within renewables, electrified transport and emission-free industry processes. Wind and solar energy, together with energy storage, becomes rapidly cheaper. Circular economy makes effective use of raw materials. Nuclear power becomes more secure and efficient and is revitalised, but struggle with competitiveness relative to renewables. Battery-electric and zero-emission hydrogen dominate all new transport completely from the 2040s. Robots and digital solutions are emerging within all fields. Hydrogen reduction is widely used in manufacturing, increasingly replacing coal in the industry sector.

Energy mix
By 2030, EU renewable generation acquires a higher share than the target (i.e., 27% of final energy consumption). Nuclear is competitive and upholds its share both in the EU and globally. In the second decade, the share of nuclear starts increasing. Coal power is completely out of the European energy mix, and is also declining in the rest of the world. Energy storage problems are mostly solved, including hydrogen production and an extensive grid distributing the energy according to demand. Energy production is a smart mix of both centralised and decentralised. The energy supply in the 2040’s is fully based on power from renewables and nuclear. Electricity demand is high.

5. From qualitative to quantitative scenarios

The ambition of the subsequent work of *SMART PATHS* is to provide two distinct contributions based on the scenarios. First, the four explorative, qualitative scenarios above will serve as the starting point for *quantitative* global scenarios. The main research question to be studied by this approach is: *What likely future external impulses are particularly decisive for the performance of national climate strategies?* Obviously, the quantifications will have to be less detailed and colourful than the sketches of the scenarios resulting from the qualitative exercise. The main drivers in each global scenario will be translated into relevant parameters and exogenous variables and quantified within two different global models. The first, ETSAP-TIAM, is an energy system model, which has its strength in capturing energy technological aspects of the scenarios. The other model, SNOW, is a computational general equilibrium (CGE) model which is more focussed on how regional economic resources, trade relations and factor movements among countries affect the economies involved. The two model traditions will be iterated to complement each other in the quantitative descriptions of the scenarios.

Second, we concentrate on particularly decisive factors for the *Norwegian* climate strategies because the global scenarios eventually will be used to answer the following research question: *How robust are Norwegian climate strategies to external impulses?* The approach to answer this question will be simulations of a Norwegian CGE model – SNOW-NO – which can be linked to the global SNOW model. The response of the Norwegian economy and policymakers to changes in external drivers is an important robustness check of the domestic climate strategies.

Similar scenario studies play an important role in research on global climate change. There is a large literature on global scenarios, to which the contributions of *SMART PATHS* will contribute. One branch of this literature consists of energy system analysis, among which the annual Energy Technology Perspectives (ETP), led by IEA has a particularly strong impact. In IEA (2017) three scenarios towards 2060 are developed: The Reference Technology Scenario assuming existing international commitments are met, the Two Degree Scenario, assumed to keep long-run global warming below 2°C, and the Beyond Two Degree Scenario which tests how far the world can get with large-scale exploitation by 2060 of all technologies either available or in the pipeline today. The report assesses their challenges in terms of climate goals, economic development and energy security.

As the analysis is partial, the scenarios rely on exogenous input on the economic development from IMF's World Economic Outlook Database[5] and the economic development is assumed identical for the three scenarios. In comparison, *SMART PATHS* aims to scrutinise the dependence between the technological and economic development. The interdependences are in both directions: Technological breakthroughs and dispersion change the economic performance and comparative advantage of regions and economic activities like trade, R&D, investments and use of capital are determinants of technological change. Economic policies in general, and abatement policies in particular, affect both economic performance and technological change.

Another large and dominant scenario project our analysis will relate to is the so-called Shared Socioeconomic Pathways (SSP) project (O'Neill et al., 2017), developed by a large international research collaboration. The purpose is to establish a common set of benchmarks for studies of policy options for the globe. The SSPs include five consistent narratives for the world and is quantified by

[5] https://www.imf.org/external/pubs/ft/weo/2017/01/weodata/index.aspx

means of six large models, including energy system models and CGE/IAM[6] models. The approach of *SMART PATHS* is closely related. It includes and aims to quantify four narratives (and a business-as-usual scenario can also become topical). We will use two complementary models in tandem to quantify them.

An important distinction between the projects is that the SSPs pre-define the *results* of the scenarios and go backwards by asking whether there is a reasonable combination of drivers that can produce these results. This is called back-casting within the foresight methodologies. Specifically, the results that the SSPs target are distinct scenarios in terms of what challenges they will face in terms of mitigation and/or adaptation policies. On the contrary, the scenarios of *SMART PATHS* start with the causes and derive the outcomes. The causes, or driving forces, are systematically picked and assessed before they are combined in coherent narratives.

SMART PATHS has several ambitions that fit in with those of the SSP project. First, it also aims to study policy options, however, by taking a *national* perspective rather than the global perspective of the SSPs. According to the decided outline of the forthcoming 6th assessment report of the IPCC, national perspectives and national policy choices are anticipated to be emphasised in the report (IPCC, 2017). In that respect, *SMART PATHS* can hopefully fit into the background literature of the assessment. The plan is to treat the global scenarios as alternative exogenous surroundings in which the Norwegian climate policy strategy is to be designed. To prepare the global scenarios for a robustness study for the small, open Norwegian economy, part of SMART PATHS' task is to link the outcomes of the socioeconomic drivers to plausible global policy actions. Abatement policies (and adaptation policies) are explicitly left out of the SSPs, because they are benchmarks for global policies. In this respect, our global scenarios add to the ambition of the SSPs.

Furthermore, most published quantitative scenarios are long-term projections that lack medium-term descriptions. Also, few scenarios take into consideration imperfect and diverse policy choices and unfavourable collaboration environments. *SMART PATHS* aims to fill these gaps. Van Ruijven (2016) points to a serious knowledge gap of *quantitative* medium-term implications when real-world restrictions are accounted for. In this respect, we find two of the four scenarios particularly interesting. First, the DARK! scenario describes a world where cheap fossil fuel resources and reliance on old technologies and mindsets slowly deteriorate international collaboration on climate change, and where the economic implications over the long term are destructive and reinforce national and international inequality. The other is SPLIT!, where the developed world assumes a proactive role in mitigating climate change, while large abundance of fossil fuels combined with inertia and lobbyism hamper the actions of the less developed and emerging countries. The world thus simultaneously follows two opposing tracks on energy and climate, causing an inherent conflict and evolving divergence.

As a small, open economy, decisions by Norwegian agents in general, and the cost, design and performance of alternative national climate strategies, in particular, will expectedly not affect the world's climate and energy situation in any significant ways. If anything, it can influence early stages of learning curves and R&D for new innovations, by being an early adopter with capacity for government stimulus in periods when commercial risks are high.

[6] Integrated Assessment Models (IAMs) are extensions of CGE models by including impacts of climate change on the economies.

On the other hand, Norway relies heavily on the global surroundings. Also, despite that the goal of becoming a low-emission society by 2050 has been established as Norwegian law (Stortinget, 2017), external factors will affect exactly what this society will look like. The scenario work in *SMART PATHS* aims at shedding light on these futures, and the ‘smartest’ way to get there.

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Vedlegg A: *SMART PATHS* project description

Smart paths and costly detours towards a sustainable low-emission society short: "*SMART PATHS*"

A.1 Relevance relative to the call for proposals

KLIMAFORSK works to build up knowledge that can be used to achieve a low-emission society by 2050. The overarching objective of this proposal is **to craft medium-term national climate strategies that will take us on a smart path to the low-emission society**. We see 'climate strategies' as the combined choices of national emission targets, climate policy instruments and monitoring procedures underway to watch the transformation path. 'Smart' refers to climate strategies that are 'persistent', 'cost-effective' and 'robust'. By 'persistent' we mean that emission abatement along the path should involve measures with longer-term transformation potential. We hypothesise that picking only low-hanging fruits in the nearer term would easily lead the society on a costly detour to the low-emission society, because sluggish investments and other behavioural responses can imply fossil-fuel lock-in. The 'cost-effectiveness' criterion will call for well-targeted policies to transcend the lock-in challenge – policies that most likely will divert from the usual economic recommendation of uniform emission pricing. Finally, a 'robust' path is characterised by being smart even if external circumstances are changing.

The call is particularly concerned with how domestic mitigation is affected by societal drivers, many of which are partly out of the control of national policies. In our first Work-package (WP1), we ask the following main research question ***RQ1:*** *What likely future external impulses are particularly decisive for the performance of national climate strategies?* We will analyse technological, demographical and international economic and political drivers, with particular attention to the consequences of EU's climate and energy policy, which is especially mentioned in the call. In a separate task, we will also address how trends in norms and attitudes can affect the society's response to climate policies.

The main exploration of smart paths and detours will take place in WP2. We decompose the study of choices of national emission targets and climate policy instruments into three tasks: Task 2a addresses the 'persistence' criterion by posing ***RQ2a:*** *Are medium-term targets smart or costly devices to achieve persistent emission cuts?* Task 2b follows up the 'cost-effectiveness' issue by asking ***RQ2b:*** *How to design cost-effective climate policies that avoid lock-in?* In Task 2c the focus is on 'robustness' with respect to the impulses mapped in WP1: ***RQ2c:*** *How robust are Norwegian climate strategies to external impulses?* Finally, in WP3 we hypothesise that monitoring the pathway should be part of a climate strategy: ***RQ3:*** *What transformation indicators should be used for monitoring and facilitating adjustments on the way towards the low-emission society?*

KLIMAFORSK calls for development of new tools, specified by, e.g., models. Besides novel theoretical modelling, explorative scenario analysis and literature reviews, we will in our research rely heavily on innovative numerical modelling of Norwegian low-emission pathways. We expect our main methodological contributions in this respect to be the modelling of

(I) *a rich mixture of response dynamics* to domestic climate strategies and external shifts, including: technological deployment, changed industry and consumption patterns, and behavioural adaptation to norms and attitudes. The latter involves social and psychological dimensions of behaviour so far almost unexamined in the context of large-scale, macro-economic models,

(II) *the intertemporal dynamics of sluggishness and lock-in* between the low-emission steady state and the transitional climate strategy pathway, and

(III) *consistent sets of assumptions about uncertain external drivers* of particular significance to the Norwegian climate strategies, with the aim to investigate the strategies' robustness to external changes.

As pointed out in the call, there is a need for studying impact of public policies' on various time horizons, in relation to various objectives and in all sectors; our dynamic, large-scale model approach will respond to all these requests. Sectors of particular interest for the call are industry, transport and agriculture; all central in our proposal. An example of a detour within the transport sector could be to massively phase in first-generation biofuels that crowds out resources and demand for public transportation infrastructure. In energy-intensive manufacturing a detour could be to seize the immediate, low-cost option of relocating businesses, even if staying close to the clean energy supply in Norway could well render competitive in a global low-emission future.

It is clear from our ambitions that interdisciplinary research is necessary; economists, behavioural psychologists and technologists will collaborate closely in all WPs. In addition to our communication and dissemination activities with users, user involvement will be actively pursued by linking to the project a Transdisciplinary Science-Policy Forum with a variety of backgrounds from the business, government and research sector. The team includes 60% women, including the project manager, and female applicants for our recruit positions will be encouraged. One task (2b) is headed by a young economist.

A.2 Aspects relating to the project

A.2.1 Background and status of knowledge

The Norwegian Government has endorsed the target of becoming a low-emission society by 2050. The indicated interpretation is an 80 per cent cut or more in greenhouse gas (GHG) emissions from the 1990 emissions (MDIR, 2014). In the medium term, Norway commits to an at least 40 percent reduction by 2030 in the Paris agreement. The Norwegian strategy is to link the policy to the climate and energy policy of the EU and get access to flexible mechanisms (Meld. St. 13 (2014-2015)). Moreover, in a recent announcement the Parliament decided climate emissions *neutrality* by 2030, meaning that remaining domestic emissions will be neutralised by, e.g., carbon offsets. Our proposed analysis will take all these commitments as premises. Even so, there exist many seemingly viable routes to the low-emission society.

Expected novel findings compared to the status of knowledge

All the findings from the five ***RQ***s presented above will contribute to the knowledge about transitional routes a nation can take. The Norwegian low-emission transformation will be our example, but many of its challenges will be recognisable by other small, developed and climate-ambitious countries.

The main exploration of smart paths and detours will take place in WP2. ***RQ2a*** in WP2 questions the 'persistence' of attained medium-term abatement, because the medium-term focus easily diverts attention and resources away from the long-run, low-emission target. However, against this hypothesis stands the argument that medium-term targets ensure monitoring and commitment on the way. The intertemporal dynamics of markets and politicians can inherently cause long-term ambitions to be lowered as the date of implementation approaches (Kydland and Prescott, 1977; Karp and Tsur, 2011). When authorities are unable to credibly and convincingly commit to the future low-emission target, one suggested device is to set binding medium-term targets (Ismer and Neuhoff, 2009).

Our reason for revisiting the role of medium-term targets is that their myopic bias can bring about costly detours without radical technological or behavioural transformation: When investment costs are sunk and activity locked in for a long time, further transformation towards the low-emission society can be seriously hampered (Arthur, 1989; Narain and van't Veld, 2008). Lock-in problems in transition were early recognised. The most obvious is that investments in infrastructure and other capital take long time to carry out and are long-lived. The putty-clay model of investments was introduced already in Johansen (1959). Transitional costs may also occur as a consequence of bounded rationality phenomena, such as habits (Kallbekken and Sælen, 2013), myopia (Gabaix, 2016) and hyperbolic discounting (Laibson 1997). Moreover, behavioural responses can be hampered by social motivations and group dynamics (Schultz et al., 2007). Pointing out this principal trade-off between commitment and transformation might not be new. However, van Ruijven (2016) points to a serious gap of *quantitative* knowledge about medium-term implications when real-world restrictions are accounted for. Our project will contribute to fill this gap. In particular, we will model numerically realistic mechanisms that explain sluggish investment as well as consumer behavioural responses.

RQ2b calls for conclusions about 'cost-effective' policies in presence of sluggish responses. It should be emphasised that the policy implication is not that action should be deferred. Our hypothesis rather implies the contrary: The risk of lock-in needs to be met by immediate well-targeted policy instruments. Depending on the particular mechanism at play, investment and consumer behaviour can be incentivised by well-framed, tailored information (Hurlstone,et al., 2014; Jessou and Rapson, 2015), default rules/nudging (Kallbekken and Sælen, 2013), network-building (Currarini et al., 2014; Greaker and Midttømme, 2016).

RQ2c on 'robustness' will be addressed by systematically exposing the suggested climate strategies to alternative external scenarios. That is, first the ***RQ1*** from WP1 needs to be answered: What likely future external impulses are particularly decisive? There exist numerous decarbonisation scenario studies providing a variety of world futures, some recent and influential being IPCC (2014), EIA (2016), IEA (2016). They span out outcomes from serious climate change on the one hand and optimistic mitigation scenarios that achieve the 1.5 °C target on the other (as in recent Rogelj et al., 2015 and Aldy et al., 2016). Making use of existing global pathways in a country study is not straightforward, as crucial drivers and smart response strategies are highly country-specific (Sachs et al., 2014). This calls for constructing well-selected scenarios for our specific case that centre around the most relevant factors for the Norwegian low-emission pathways. In that exercise we will also account for alternative future trends in norms and attitudes. The results from this exercise in WP1 can then be exploited to bring about findings on whether climate strategies are 'robust' to consistent changes in the surroundings. A few examples can illustrate the relevance of such analysis: Extreme weather events can affect attitudes and bring about new behavioural patterns. Immigration will affect levels of consumption and production and tend to accentuate the need for technological solutions. On the other hand, a strategy heavily based on technological transformation will inevitably become more onerous the slower the global technological progress turns out to be.

Finally, the main finding expected from ***RQ3*** is a new set of indicators intended for monitoring the transformation and facilitating adjustments towards the low-emission society. From the discussion above it is clear that measuring how emission targets are met along a transformation path can be insufficient; a wider set of *transformation indicators* would more precisely guide policy-makers and stakeholders to the smart path. Our point of departure will be existing sustainability indicators in a wider sense; see Arrow et al. (2012); World Bank (2006); UN (2016). Our challenge departs from global climate change indicator initiatives like UNECE (2016) by focussing on single nations' performance, while at the same time acknowledging that climate change is a global phenomenon. This will call for a complementary set of emission metrics that embraces territorial as well as global effects; see, e.g., Greaker et al. (2013). In addition, technological, behavioural and political/institutional transformation that is not immediately visible as emission cuts must be captured. The robustness of the transformation strategies of the government and other actors to external changes is another important aspect.

Expected methodological contributions
We will employ advanced numerical model tools in order to generate the findings above. The research will rely on several novel methodological features, where the most important are expected to be:

(I) *A rich mixture of response dynamics* that interplay simultaneously will be represented in the models. As a result of the work in WP1 and WP2 we will be able to combine three qualitatively different response mechanisms:
(a) Technological investments and deployment
(b) Reallocation of production and consumption in response to price and income changes
(c) Behavioural responses to changes in social norms, preferences and habits

In the present scenario literature, type (a)-responses tend to be studied in technology-based, energy-system (bottom-up) models; see, e.g., EIA (2003), Loulou and Labriet (2008), IEA (2016) and IIASA (2016), while type (b)-responses are built into macro-economic (top-down) CGE models (Böhringer, Rutherford, Tol, 2009; Dixit and Jorgenson, 2013). Bottom-up models typically do not provide a microeconomic framework and neglect interactions between the energy system and the rest of the economy. On the other hand, top-down models lack detailed technology information. However, by combining the approaches into a hybrid modelling framework it is possible to embrace both technological and reallocative responses to policy and external conditions. Hybrids of the two types have emerged (e.g., The Energy Journal, 2006, Böhringer and Rutherford, 2008; Fæhn and Isaksen, 2016). However, in dynamic settings they are extremely rare. Van Ruijven (2016) has surveyed the extensive literature on pathways to a global low-emission future and concludes that a serious gap is the lack of models accounting for both types of responses. The CGE models of Statistics Norway (SSB) are hybrids with (a) and (b)-responses (Fæhn and Isaksen, 2016; Bye et al., 2015). We will develop the hybrid features of these models further; see Task 2a.

Most notably, we will supplement the (a) and (b)-type responses in SSB's models with (c)-type responses in order to capture more realistic behavioural responses. Whether bottom-up, top-down or hybrid, models typically assume economic agents with fully-informed, rational utilitarian behaviour and cost-effective solutions. Recent multidisciplinary experimental research provides evidence of bounded rationality with impact on macroeconomics in several ways (e.g., Akerlof, 2002; Shafir, 2013, Sunstein, 2015). In order to persistently and effectively transform behaviour these features must be accounted for in a climate strategy. Based on review of the vast theoretical and empirical/experimental literature we will pick a few among the most relevant and quantifiable phenomena to be included into our numerical model framework; see Task 1a and 2b.

(II) *the intertemporal dynamics of sluggishness and lock-in* between the low-emission steady state and the transitional climate strategy pathway will be modelled. This is a prerequisite for properly addressing the ***RQ***s in WP2. Nevertheless, most numerical models and existing scenarios implicitly assume that capital can be smoothly and instantaneously employed where desired and that consumer behaviour is rational. We will model technological inertia by the so-called 'putty clay' model (Johansen, 1959; Lau, Pahlke and Rutherford, 2002), and a particular challenge in our project will be to model abatement technology inertia. Behavioural inertia is virtually not explored in a numerical framework, and we will build on the behavioural modelling in WP1.

(III) *Consistent sets of assumptions about uncertain external drivers* will be developed in WP1.Our approach will deviate from and add to the scope of commonly used sensitivity test devices (Arndt, 1996) and more selective robustness tests (as in Greaker and Rosnes, 2015) by picking a few consistent sets of assumptions to form distinct storylines, into which we will systematically introduce the climate strategies. Our main tools for global projections will be the global bottom-up model ***ETSAP-TIAM*** (TIMES Integrated Assessment Model; see Loulou and Labriet, 2008; Loulou, 2008) along with ***SNoW*** (Statistics Norway's world CGE model; see Böhringer et al., 2015; Böhringer et al., 2012). A particular quality of the SNoW model is that it can be consistently linked to the CGE model for Norway that we will use for the robustness analysis of climate strategies, ***SNoW-No*** (Greaker and Rosnes, 2015; Bye et al., 2015).

A.2.2 Approaches, hypotheses and choice of method

The project consists of three closely interlinked WPs:

> ***WP1: External surroundings for choice of national climate strategies***
> Head: Arne Lind, Institute for Energy Technology, IFE.

WP1poses the main ***RQ1***: *What likely future external impulses are particularly decisive for the performance of national climate strategies?* It will identify what are the crucial external factors that the Norwegian climate strategies will have to relate to and assess their likely developments. External in this context does not mean that they are completely beyond control or independent of Norwegian decisions, but that they are exogenous to the domestic agents and mechanisms we model. Task 1a will consider how social norms and attitudes might develop and their potential effects on consumer behaviour, while Task 1b will map global technological progress, demographical changes and international, particularly European, economic and political drivers.

Task 1a: The role of social norms and attitudes for behavioural response – headed by Per Espen Stoknes, BI. We will explore how alternative choices of behavioural models matter for the conclusions on consumption patterns and energy use along the transition path, where transport choices is a key issue. The ambition is to generate a partial equilibrium, analytical framework, which will be operationalised and developed further in WP2. Many observed and studied behavioural phenomena that question the traditional rational agent models are found to be relevant to climate behaviour and low-emission transformation (Hurlstone, 2014; Sunstein, 2015). Based on the most recent literature we will select behavioural models based on their relevance and significance to Norwegian climate strategies, compatibility with our framework and data availability. Our current reading is that these three are among the candidates: **A)** myopia, where we can exploit models retrieved from monetary and fiscal market behaviour (Gabaix, 2016), **B)** habits, which have analogies with other models of transitional costs (Abel and Eberly, 1994) and **C)** network externalities that imply lock-in (Currarini et al., 2014).

Task 1b: Technological, economic and demographic drivers – headed by Arne Lind, IFE. The purpose of this task is to define and simulate a limited set of distinct scenarios where we vary the developments of external factors to form consistent storylines. Most importantly, we will put effort into selecting the main, relevant external driving forces for the performance of Norwegian climate strategies. We will base our selection on a literature survey of existing global scenarios combined with explorative scenario experiments (Schwartz, 1999, Stoknes and Hermansen, 2004; van der Heijden, 2005). The exercise is intended to provide us with a set of conceptual storylines that are distinguished in interesting and policy-relevant ways for the Norwegian low-emission future. Particularly important to explore are alternative outcomes of the ongoing negotiations, involving Norway, on EU's effort-sharing and flexibility arrangements, as well as outcomes of actions in the wake of Paris. These processes will be pivotal for Norway not least through their impacts on the global technological progress and cost development and on demand, competitiveness and input prices in international markets. Growth in population, workforce and migration are other influential factors for the low-emission transition.

We will use two global models in team to construct consistent developments based on these storylines. The first is the ETSAP-TIAM, which IFE uses for global and multinational analysis (e.g., García-Gusano et al., 2016). It is a technology-rich, partial-equilibrium, bottom-up model with a detailed description of different energy forms, resources, processing technologies and end-uses. Also fossil fuel extraction, trade and prices are determined endogenously, a special advantage of the ETSAP-TIAM model, as these markets are particularly significant for the Norwegian future pathways. In addition, mechanisms for endogenous learning by doing are accounted for, which will provide us with important information on how international prices of technologies evolve in various global settings.

Projections for the rest of the economy are taken as exogenous in ETSAP-TIAM. However, TIMES models are predesigned to be easily linked up to various types of scenarios. Besides being compatible with explorative scenarios of the types described above, ETSAP-TIAM is suited for joint simulations and iterations with global CGE models. This implies we can use it in team with the SNoW model, an MPSGE-programmed CGE model based on the GTAP database (Rutherford, 1999; Narayanan et al., 2012) that is particularly designed for projecting the global market situations under different climate assumptions. Norway can be treated as a separate region in SNoW (Böhringer et al., 2015), thereby linking our model of Norway, SNoW-No, to Europe and the rest of the world. We will build on already established procedures for modelling the links between the European climate and energy policies and Norwegian climate strategies in Aune and Fæhn (2016). The joint simulations will provide us with a set of distinct reference settings for the study of Norwegian climate strategies in WP2. More details on present SNoW-No and further development plans is provided in the description of WP2 below.

WP2: Climate targets and policies that lead us on a smart path and avoid detours

Head: Taran Fæhn, SSB

WP2 responds to the overarching objective of our proposal, which is to craft medium-term national climate strategies that will take us on a smart path to the low-emission society. It is addressed by exploring the ***RQ***s in the three tasks below.

Task 2a: Are medium-term targets smart or costly devices to achieve persistent emission cuts? – headed by Taran Fæhn, SSB. We will study whether targeting medium-term (2030) emission goals in the most cost-effective manner will lead us on the smartest long-term pathway, defined as attaining and sustaining the low-emission society from 2050 onwards at the lowest possible social cost. If the abatement by 2030 relies on technologies and behaviour that lock the society in fossil fuel-based patterns for the next decades, the low-emission society will be unnecessarily costly. In this analysis, we will take the Norwegian 2030 and 2050 commitments as given, but allow for utilising more or less of the various flexibility mechanisms intended in the EU proposal and the Paris Agreement up to 2030. The lock-in costs can be explored by comparing scenarios where domestic emissions are exogenous (mid-term targets) and endogenous (only long-term, low-emission target).

Our main work horse for studying the dynamic climate strategies both in task 2a, 2b and 2c will be the recently developed hybrid CGE model SNoW-No, which can be simulated as a dynamic Ramsey-type model (See, e.g., Bye and Nyborg, 2003; Lau et al., 2012). SNoW-No is the most recent of the hybrid model versions developed in SSB. It will give a detailed and technology-rich description of the Norwegian economy and low-emission pathways. We need to develop SNoW-No in order to be able to address the lock-in issues, the behavioural model alternatives that will be part of the transformation pathways, cost-effective policy options as well as the robustness of climate strategies. Compared with previous model versions, we will:

- Update technological input relevant for 2030 and 2050; currently, old information from Klimakur 2020 (2010) is the main basis for future costs and abatement potentials. Besides, we will increase the scope for sectoral responses to climate policy by including abatement information for a larger set of sectors (e.g., public infrastructure and LULUCF). We will survey the extensive literature, including global bottom-up scenario studies. A particularly valuable source will be the database developed by the Norwegian Environment Agency, MDIR (MDIR, 2014). Key experts at MDIR will work closely with the project team and are also represented in the Transdisciplinary Forum. Furthermore, IFE's model ***TIMES Norway*** (Rosenberg et al., 2013) has built in knowledge on end-user energy technologies. Our team already has experience with combining knowledge of TIMES Norway with that of SNoW-No (Bye et al., 2016).
- Model alternative preferential structures that account for realistic social and psychological behavioural drivers. We will build on the experience and choices from Task 1a. Besides modelling the dynamic and economy-wide interplays, policy instruments need to be represented to address policy issues in Task 2b (see also methodological contribution **(I)** above).
- Model putty-clay features along the lines of Lau, Pahlke, Rutherford (2002) to represent realistic technological transition costs of both abatement investments and other investments (see contribution (**II)** above).
- Integrate the updated and improved SNoW-No model into the global context of the global SNoW model and simulate it under the different external assumption sets in the robustness study of tsk 2c (see contribution **(III)** above).

<u>*Task 2b: How to design cost-effective climate policies that avoid lock-in? – headed by Halvor Storrøsten, SSB.*</u> The purpose of this task is to characterise and operationalise cost-effective policy instruments in the presence of lock-in and transition costs. We will start with analytical explorations of welfare-maximising social and private partial equilibria when behavioural transformation is sluggish. Specifically, we intend to build intertemporal analytical models that build on the considerations and theoretical modelling of alternative consumer behaviour in Task 1a. The models will be used to draw conclusions about appropriate policy interventions, including improved information, setting defaults choice rules or building networks.

Operationalised policy instruments will then be modelled within the numerical setting described in Task 2a. A numerical CGE analysis will add quantitative information and insight into the instruments' important interplays with other existing policies, with the rich variety of responses and agents and with the rest of the world (footprints, trade, allowance trading). We will also address policy implications of simultaneous technological inertia caused by putty-clay investments.

Task 2c: How robust are Norwegian climate strategies to external impulses? – headed by Orvika Rosnes, SSB. The set of reference paths defined in Task 1b will be the starting point for investigating the robustness of alternative Norwegian transformation pathways. We will – in accordance with our intended methodological contribution **(III)** – carry out a systematic robustness analysis of how the main pathways developed in Task 2a and Task 2b perform in terms of persistence and social costs under a predefined set of storylines (from WP1). The robustness analysis will also assess how flexible and adjustable the strategies are. Some instruments can, for instance, be too tailored or too reliant on predictability to be effective under shifting circumstances.

WP3: Indicators for monitoring the transformation towards a low emission society

Head: Mads Greaker, SSB

The **RQ3** on what transformation indicators should be used underway for monitoring and facilitating adjustments of the directions towards the low-emission society is motivated by the hypotheses that monitoring should be an integrated part of a climate strategy and that emission statistics is not a sufficient indicator of the status of the transformation process. Based on the analysis of emission targets in WP2, this WP aims to complement with a wider set of indicators. Task 3a will survey the existing related indicators to map their relevance for a national transformation indicator set. Task 3b aims at forming a conceptual framework that embrace the main aspects an indicator set should capture and suggest some main, operationalised indicator metrics.

Task 3a: From sustainability indicators to national transformation indicators – headed by Iulie Aslaksen, SSB.

The purpose of this task is to survey existing related indicators in order to seek inspiration from or directly use components that can reflect low-emission transformation. Among these, existing sustainability indicators are particularly relevant. They are designed to monitor a number of societal processes, also climate-relevant changes as the development of GHG emissions, energy availability and global warming. Their many-faceted content will also guide us to important trade-offs and synergies, in particular between climate change and other sustainability criteria. We will survey the published climate-related indicators, in particular. While some are oriented towards global climate-change signals like GHG concentration, temperature and extreme weather events, others will be more relevant to learn from from a national climate strategy perspective, including policy indicators and emission metrics. A particular criterion for a transformation indicator set is a forward-looking perspective; an aspect that we have already scrutinised in relation to sustainability indicators (Garnåsjordet et al., 2011).

Task 3b: A set of national transformation indicators – headed by Mads Greaker, SSB. Our national focus calls for a discussion of relevant emissions concepts and metrics. This will build further on Greaker et al. (2013), who suggested the relevant measure to be the accumulated emissions relative to a nationally defined carbon budget. Also, the relevance and measuring of national versus global emission contributions (carbon leakage, carbon footprints, carbon offsets) will be discussed.

A particular challenge for a transformation indicator is the forward-looking monitoring purpose. Besides emission metrics, we will need to find indices of particularly three main facets of the transformation speed: **(A)** Technological transformation, which can be monitored by observing dispersion and deployment of climate-friendly technologies and production methods, R&D activity and impact within green technologies, patenting, and technology policy. Relevant to consider here is that energy savings need not indicate emission savings in the highly renewable-based Norwegian case. **(B)** Behavioural transformation, where indicators should reflect aspects like changes in attitudes, action, participation, consumption trends and green entrepreneurship. **(C)** Political, regulatory and institutional transformation. Indicators here can, in principle, embrace all governmental decisions and operations with direct or indirect effects on the low-emission realisation.
We will take advantage of the analysis of the ‘persistency’, ‘cost-effectiveness’ and ‘robustness’ criteria and consider what can be learned from the pathways analysed in WP2.Measuring transformation in a quantitative way is challenging, let alone deciding what is too little or even too much. Our numerical analyses can guide us to some extent. We will pay attention to methodological soundness and data availability when defining a functional indicator set. Transferability of knowledge is another concern: Even if our focus is the transformation of the Norwegian society, the learning from WP3 should be readily exportable.

A.3. The project plan, project management, organisation and cooperation

This project will be hosted by the Research Department in SSB. Project leader is Head of Research, Senior Researcher (SR) Taran Fæhn, who also heads WP2. SR PhD Arne Lind (IFE) heads WP1 and SR PhD Mads Greaker (SSB) WP3. Rest of the team will be: Dir. Per Espen Stoknes (BI), PhD Pernille Seljom (IFE), Prof. Karen Turner (Univ. of Strathclyde, UK), Prof. Chris Böhringer (Univ. of Oldenburg, Germany) and researchers from SSB (PhD Halvor Storrøsten, PhD Orvika Rosnes, SR PhD Iulie Aslaksen, SR PhD Brita Bye, Head of Research PhD Cathrine Hagem). Their allocation, which is specified in a separate attachment, is organised to let all WPs take advantage of several methodological approaches and the interdisciplinary competence in the project (economics, psychology and technology). The proposal aims to develop further the network built in the FME-S *CREE*, where IFE and Prof. Böhringer have been key associates. Prof. Turner is brought in for her particular experience in the economics-technology nexus, and Stoknes for his insight into behavioural economics and psychology.

In addition, a Transdisciplinary Science-Policy Forum will be actively involved throughout the project period. By now, 8 carefully picked experts from the business, government and research sectors with complementary competence to the project team have confirmed willingness to participate; see attachments: Knut.Sunde@norskindustri.no; Janne.Stene@stortinget.no; Kjetil.Lund@statkraft.com; Are.Lindegaard@miljodir.no; Marte.Sollie@fin.dep.no; Jon.B.Skjaerseth@fni.no; Caroline.D.Ditlev-Simonsen@bi.no; Helena.Cabal@ciemat.es. It will meet at least once a year with the whole project group and regularly be consulted when relevant to discuss approaches, progress and societal relevance. See also Section 5 and form for their role. We will also engage 2-3 recruits at master level by offering stipends and supervision.

A.4. Key perspectives and compliance with strategic documents

A.4.1Compliance with strategic documents

Our proposal responds to challenges addressed in a variety of key policy papers and official committee reports (NoUs) related to the climate change and Norwegian responsibility; see, e.g., the overview in footnote 1 of the KLIMAFORSK Programme Plan. It also forms an integrated part of the strategies and the specialised competence of the research institutions in the project team; for the strategy of the project owner, SSB, see www.ssb.no. We intend to involve stakeholders and policy-makers in all phases of the research. This is crucial, as virtually all industries, organisations and policy institutions have built strategies for low-emission pathways into their strategies – this particularly applies to the users represented in our Transdisciplinary Forum.

A.4.2. Relevance and benefit to society

The key to fulfilling the Paris commitments and low-emission goals of the world's nations lies to a large extent in the complex interface between scientific approaches. Our proposal aims to fill some of the knowledge gaps by combining psychology, technology and economics when describing scenarios and barriers and suggest strategies. Our results and communication strategy will particularly benefit Norwegian policy-makers, business and stakeholders, but also add insight into other nations' climate strategies.

A.4.3. Environmental impact

The implementation of the project will not harm the environment. On the contrary, the knowledge from the project has the potential of contributing to find low-emission, sustainable pathways. We will contribute to the ambition of KLIMAFORSK to reduce climate footprints. We will mostly interact electronically with the partners abroad, choose climate-friendly travel modes when available and strive to attend conferences for our dissemination that are concerned about minimising and neutralising own carbon footprints, buying offsets and offering green options to participants.

A.4.4. Ethical perspectives

Our research project, as such, will be ethically sound. It will hopefully bring relevant knowledge on challenges of societal transformation, a process that in itself has a number of intra- and intergenerational ethical aspects.

A.4.5. Gender issues (recruitment of women, gender balance, and gender perspectives)

The research team as well as the Transdisciplinary Forum are both well gender-balanced, with 60 and 50% women shares, respectively. The project leader is female and we will encourage female applicants for our recruit stipends. The project could produce gender-relevant results, e.g., on climate behaviour, but this is not, *ex ante*, part of our hypotheses.

A.5. Dissemination and communication of results

Key messages and results from this project will be relevant to several target groups and audiences: government at different levels, businesses and industry, national and international research community, environmental organisations, industry organisations, media and the general public. We organise the project with attention to reaching all these groups: (i) The Transdisciplinary Forum will be involved from the outset and throughout the project to give input to research questions, approaches and communication of results. It consists of expertise complementary to the project team on low-emission strategies and societal transition; see Section 3. (ii) In particular, we will at an early stage arrange a scenario workshop that will form premises for our project, where we aim to engage a wide range of transdisciplinary and scientific expertise. (iii) The issues of climate strategies for reaching the low-emission society are high on the political, public and business agendas. SSB and the other national project partners already have well-established contact with governmental and private relevant actors, as well as environmental and industrial organisations, which we will draw upon in our outreach activities to bring policy-relevant results to policy and decision-makers. (iv) SSB has an experienced and well-staffed communication department that will be actively involved in project dissemination and communication activities. We will maintain an active Web page for the project. We will actively promote our findings and experiences in social media (Twitter, Facebook) and also write 2-4 popular articles for newspapers and magazines. We will also approach the general public and stakeholders to be engaged in the climate strategies and low-emission transformation in Norway by arranging a meeting led by the Communication Department in SSB or the Green Growth Centre of BI Norwegian Business School. (v) We will bring novel insight from our research to the research frontier through 9 planned articles in top peer-reviewed field journals. All preliminary papers will be presented in both scientific and broader forums, where we will invite the Forum and other users. They will also be openly and widely dispersed as discussion papers. (vi) We will make sure that novelties in approach and results from our model tools will be documented and easily accessed by other researchers and analysts. Both the MPSGE programming platform of the SNoW models and the ETSAP-TIMES models have well-functioning communities for sharing and learning; see http://www.gamsworld.org/mpsge/index.htm and http://iea-etsap.org/forum/index.php. For more details on communication and dissemination, see application form.

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