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# Report

## Linking global and regional energy Strategies (LinkS)

### Executive Summary


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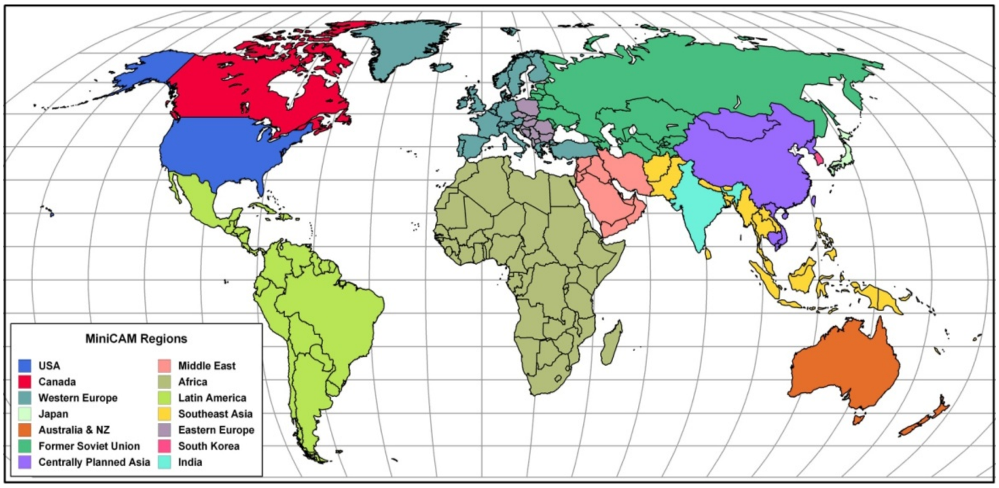


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**ABSTRACT**
*This report is the Executive Summary of the LinkS project. The full report is published as Technical Report A7352.*

LinkS was designed to analyse how global long-term strategies can be used as guidelines for the development of energy supply and technology deployment in regional energy systems. In order to produce recommendations for policy development and regional energy investment strategies, both quantitative and qualitative research were applied. Until an international climate change mitigation agreement with binding targets is established, the states and regions that implement mitigation strategies on their own initiative represent key actors for significant emissions reductions. This report therefore introduces a novel scenario "Global-20-20-20", where a hypothetical protocol based on the EU 20-20-20 policies is extended in time and space to a global scenario where an increasing number of the world's regions gradually adopt the EU approach. This hypothetical protocol illustrates the aggregated potential of "globalizing" individual regional climate policy efforts, and is a major reference for much of the work presented in this report. Furthermore, in-depth studies of the European and Chinese regions under several global policy scenarios are presented.

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# Table of contents

# 1 What we did

The project «*Linking global and regional energy Strategies (LinkS)*» was designed to analyze how global long-term strategies can be used as guidelines for the development of energy supply and technology deployment in regional energy systems. Today, regions like the EU have quite ambitious strategies for renewable energy and emission mitigation, while others have no specific strategies yet. If rapidly growing economies like Brazil, Russia, India and China delay their emission reduction efforts, the OECD countries have to do correspondingly more to keep total Greenhouse Gas (GHG) emissions within necessary limits by the end of this century. We therefore have to find correlated strategies that are both efficient and acceptable in several regions at the same time.

The term "*linking*" has multiple interpretations in this project beyond the one stated in the title:

- *Linking Global and Regional Energy Strategies*
- *Linking different energy system models (GCAM, WGM, TIMES, EMPIRE, EMPS)*
- *Linking policy analysis and energy system modeling*
- *Linking international research teams*

Figure 1-1 shows how the different research tasks and corresponding models in LinkS were connected during the analysis.

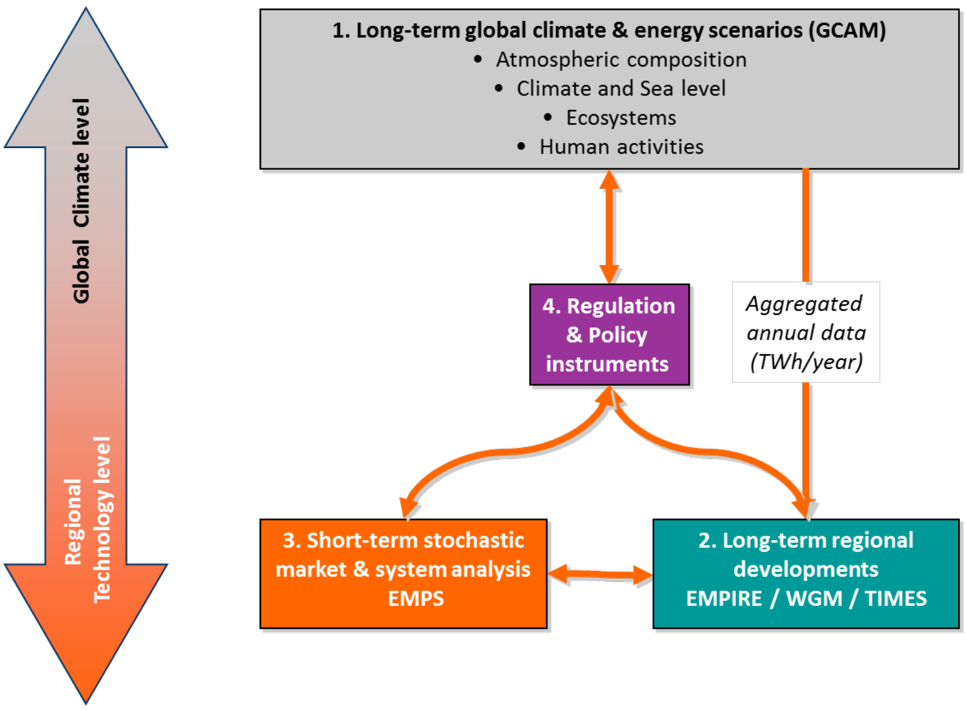


**Figure 1-1 Research tasks and models in the LinkS project**

In order to produce recommendations for policy development and regional energy investment strategies, both quantitative and qualitative research were applied. Long term global scenarios of greenhouse gas emissions were correlated with regional energy system developments with a higher geographical resolution, i.e. involving data on a regional and national level. We did this by applying two groups of models with different degrees of geographical detail and correlating selected input and output of the groups. One of the scenarios was also run through a qualitative policy analysis. The levels and elements of our analysis were:

**A) *Global and long term development model***

- US partner Joint Global Change Research Institute calculated the long term development of global economy, energy supply, land use and climate with their integrated assessment model *GCAM (Global Change Assessment Model)* which operates with 5 years increments from 2005 to 2095 for 14 regions of the world. GCAM is a community model available for further use at NTNU and SINTEF.

***B) Regional high resolution models***

- The *World Gas Model (WGM)* from the University of Maryland is a global natural gas system model that was run with 5-year time steps with 2 demand levels (seasons) to study regional gas market developments under different scenarios.
- The Chinese energy system was modelled in *TIMES* by Tsinghua University in Beijing with annual resolution and multiple demand levels to 2020.
- A new model *EMPIRE* (European Model for Power system Investment with (high shares of) Renewable Energy) was developed for the European power system. EMPIRE is an electricity system model with investments in 5-year time steps to 2060 and relatively high operational detail (666 stages per year).
- In order to study the effects of the high shares of renewable energy in Europe in more detail, SINTEF's *EMPS* model was correlated with EMPIRE. EMPS is a commercial level European electricity system model that was run with transmission investments in 5-year time steps to 2060 and very high operational detail: 19,500 stages per year based on 75 years of historical data for renewable energy sources (wind, solar and hydro).

***C) Policy Analysis on selected Regions***

- Regional knowledge and qualitative data on policy instruments related to energy system development and climate change mitigation were provided by the research partners at the University of Maryland, Tsinghua and SINTEF.

Our main findings are summarized below for each of the "linking" interpretations.

# 2 What we found

## 2.1 Linking global and regional energy strategies

As an overall approach in the project, we used the global long-term model GCAM as the "top model" that gave long-term guidelines for the development of energy and climate change mitigation in different regions of the world (see Figure 1-1). The advantage of this model is that we can quantify long-term global developments within each scenario and thus examine the links between e.g. Europe, USA and China endogenously under various policy and technology assumptions. Similar modeling exercises limited to EU level would have to assume global developments and give these as exogenous parameters to the analysis.

On the other hand, a general disadvantage in integrated assessment models like GCAM is the low spatial detail within each region. Thus, while GCAM sets the long-term general trends, regional bottom-up models with greater spatial and technology detail are necessary to give more specific recommendations within each region. We did this for EU and China; however, the Chinese 5-year planning currently does not look further than 2020 for the energy system so a longer-term correlation has not been possible.

### *2.1.1 Global energy strategies*

With GCAM, we explored the implications for human systems, in particular energy, land and economic systems, when developing effective regional and local strategies to limit human climate forcing, in three dimensions: *Policy Stringency*, *Technology Availability* and *Policy Architecture*.

**Policy Stringency**: We compared two alternative limits on $CO_2$-e (Carbon Dioxide equivalent) concentrations by the end of this century: 450 ppm $CO_2$-e and 650 ppm $CO_2$-e. Both scenarios share the same socioeconomic, technology availability and policy instrument assumptions. We found that both were technically feasible under the common assumptions we employed, but both required immediate departures from the reference pathway, and the more stringent limit implied more rapid deviation from a reference pathway. Both scenarios required greater reliance on renewable energy forms, nuclear power, Carbon Capture and Storage (CCS), and energy efficiency technologies for the global energy system as well as secession of deforestation and initiation of afforestation programs in addition to production of bioenergy and behavioural change toward lower-carbon intensity diets. The more ambitious climate goal was more expensive, engaging resources that would otherwise have gone toward other uses.

**Technology Availability:** Nuclear power and CCS are two technologies which hold the potential to reduce emissions of $CO_2$ to the atmosphere while providing energy. We crafted two scenarios to explore the implications of circumstances in which either or both of these technologies were unavailable in the context of a world that is attempting to limit $CO_2$-e concentrations to 650 ppm. In general, climate forcing can be held at or below 650 ppm $CO_2$-e throughout the 21st century regardless of whether or not these two technologies were available. However, as the non-carbon energy technology set is reduced in scope, pressure to deploy alternative renewable energy forms, energy conservation technologies, and terrestrial carbon sequestration are increased as are economic costs. The carbon price was less sensitive to technology availability than to an increase in policy stringency from 650 ppm $CO_2$-e to 450 ppm $CO_2$-e.

**Policy Architecture:** Finally, we explored the implications of broadening international participation and extending the degree of ambition over time of the European Union's 20-20-20 energy and climate policy architecture. We assumed an approach which has four policy elements: A GHG Emissions Limit, a Renewable Energy Standard, a Biofuel Standard, and an Energy Efficiency Standard. We extended the protocol in time and space, establishing a novel policy scenario called "*Global 20-20-20*" in which an increasing number of the world's regions adopt the EU approach as outlined in Table 2-1. We assumed that four groups of policies and measures are implemented, beginning in Europe and then extending to other OECD regions and China, and then to the rest of the world. The four categories of policies and measures and associated degrees of stringency are given in Table 2-2. Each protocol stage or "period" is assumed to be 15 years.

**Table 2-1 Timing of regional participation in Global 20-20-20 scenario**

| Region | First year in which climate mitigation policies and measures are introduced | Reference Year |
|---|---|---|
| Eastern Europe, Western Europe | **2020** | 1990 |
| Australia & New Zealand, Canada, China, Japan, S. Korea, USA | **2035** | 2005 |
| Former Soviet Union, India, Latin America | **2050** | 2020 |
| Africa, Middle East, Southeast Asia | **2065** | 2035 |

**Table 2-2 Policies and measures examined in the Global 20-20-20 scenario**

| Policies and Measures | Implementation | First Period Commitment | Second Period Commitment | Third Period Commitment | Beyond the Third Period |
|---|---|---|---|---|---|
| GHG Emissions Limits | *Emissions reductions are measured relative to those in the 30 years prior to the 1st commitment period. (e.g. 1990 for Europe, 2005 for the USA)* | 20% | 50% | 80% | 80% |
| Renewable Energy Portfolio Standard | *Percentage of final energy that must come from renewable energy sources* | 20% | 50% | 80% | 80% |
| Biofuels Standard | *Percentage of transportation energy from biofuels.* | 10% | 25% | 50% | 50% |
| Energy Efficiency Standard | *Reduction in final energy demand relative to the reference scenario, other things unchanged.* | 20% | 50% | 80% | 80% |

The global energy system is substantially different under the Global 20-20-20 hypothetical protocol than under the reference scenario (which describes a potential evolution in the *absence* of new policies to limit anthropogenic climate change). Reductions in primary energy use are on the order of one third; see Figure 2-1, compared with Figure 2-2. On the other hand the power sector grows by more than a factor of two by the end of the century, Figure 2-3 compared with Figure 2-4. This is driven by the twin forces of a renewable energy portfolio standard and a carbon price that shifts end-use energy demand away from fossil fuels and toward electricity. The renewable portfolio standard dramatically increases the share of wind and solar power in the mix. The largest changes in the system are observed after the year 2065 when all regions of the world are part of the emissions mitigation protocol. Substantially more renewable energy is used under the Global 20-20-20 scenario than in the reference scenario. Bioenergy production grows to 286 EJ/yr by 2095 compared with 117 EJ/yr in the reference scenario.

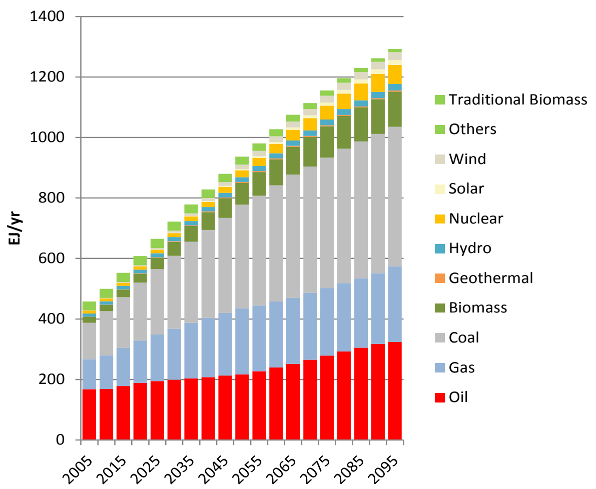


**Figure 2-1 Global Primary Energy Consumption by Fuel, Reference Scenario**

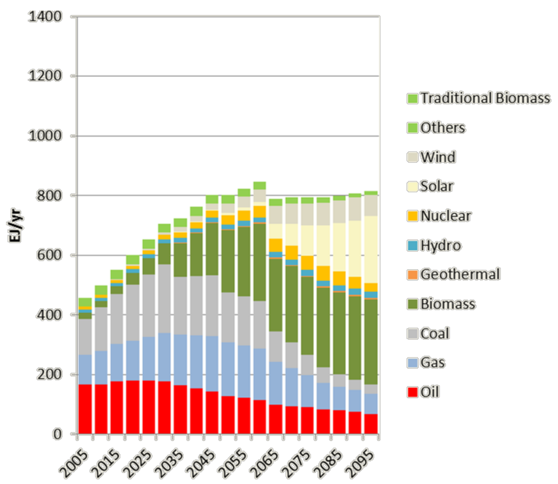


**Figure 2-2 Global Primary Energy Consumption by Fuel, Global 20-20-20**

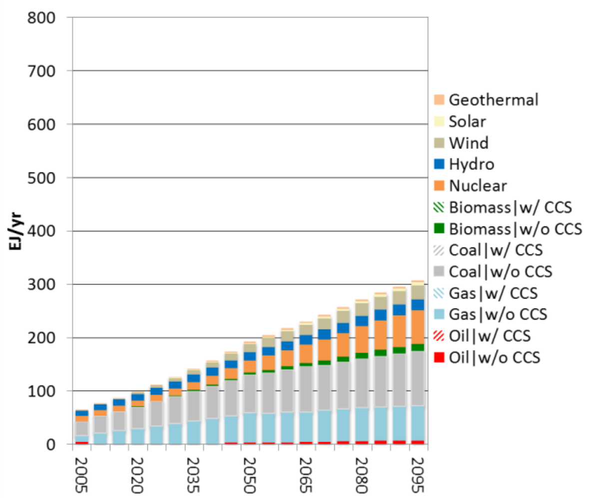


**Figure 2-3 Global Electric Power Fuel Consumption by Type, Reference Scenario**

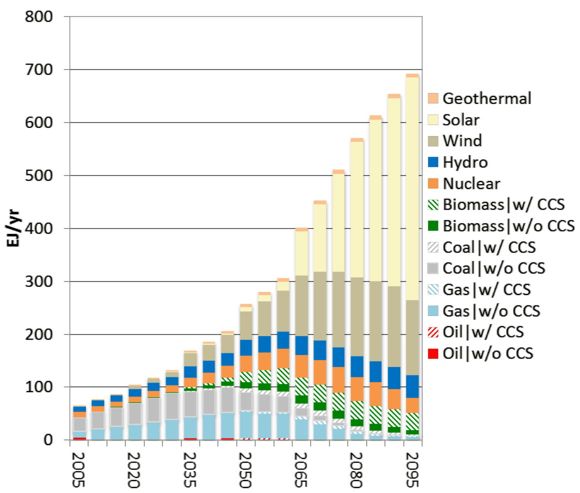


**Figure 2-4 Global Electric Power Fuel Consumption by Type, Global 20-20-20**

This policy package was effective in achieving deep reductions in the emission of anthropogenic climate forcing agents. The economic cost was between 10 and 15 per cent higher than a pure carbon tax policy, but it lowered the tax emerging from the carbon market.

The emissions mitigation strategy used in the Global 20-20-20 scenario differs fundamentally from the 450 and 650 ppm $CO_2$-e scenarios in that the latter employ a carbon price alone, which is an ideal economic policy tool, whereas the former employs a combination of policy instruments that include regulatory instruments in addition to a cap-and-trade regime. When only the cap-and-trade regime was in place under the Global 20-20-20 scenario, the carbon price rose to almost $300/t$CO_2$ by the end of the century. This price lies between carbon tax in the 450 and 650 ppm $CO_2$-e limit cases, as might be expected since the Global 20-20-20 policy package produces radiative forcing of 3.2 $Wm^{-2}$ in 2095, or approximately 505 ppm $CO_2$-e. Note that as the climate constraint tightens, the carbon price increases non-linearly. In the year 2095, carbon price for the 650 ppm $CO_2$-e is approximately $200/t$CO_2$, the carbon price for the 505 ppm $CO_2$-e limit is $300/t$CO_2$, and carbon price for the 450 ppm $CO_2$-e scenario is almost $800/t $CO_2$.

Present discounted costs in 2005 USD for the period 2005 to 2095 are given in Table 2-3 along with the fraction of present discounted global GDP that these costs represent.

**Table 2-3 Present Discounted Social Cost of Emissions Mitigation Policies**

| Scenario | Total PD Cost | % PD GDP |
|---|---|---|
| 650 Stabilization | $ 1.71 | 0.11 % |
| 650 Stabilization (NoCCS) | $ 2.00 | 0.13 % |
| 650 Stabilization (NoCCS, NoNuc) | $ 3.05 | 0.20 % |
| 450 Stabilization | $ 10.42 | 0.70 % |
| Global 202020 | $ 10.83 | 0.73 % |

(Trillions of Present Discounted 2005 USD, discount rate = 5%)

There is a substantial increase in cost moving from stabilization of $CO_2$-e concentrations at 650 ppm $CO_2$-e to stabilization at 450 ppm $CO_2$-e. The difference in social cost between 650 ppm $CO_2$-e with all of the technologies, and without either CCS or nuclear power as mitigation options is roughly a factor of two. By comparison, the Global 20-20-20 policy package is somewhat more expensive than the 450 ppm $CO_2$-e, but yields a somewhat lower environmental benefit. Since the Global 20-20-20 includes a cap-and-trade component, it suggests that costs could be lowered by de-emphasizing the non- cap-and-trade policy elements as the program expands its participation and deepens its commitments. It also allows some latitude for a tightening the mitigation while still managing the cost.

In our scenario, all world regions copied the EU 20-20-20 policies at different points in time, but in principle each region can design and introduce their own policies independently of each other. Provided these regional policies are sufficiently strong and correctly timed, a set of independent regional policies seems to give almost as large emissions reductions as a global carbon market but at a somewhat higher socio-economic cost. This may therefore be a feasible approach in the absence of a single global agreement.

## 2.1.2 *Regional energy strategies*

**China:** As the world's largest emitter of $CO_2$ China is a crucial country for introduction of efficient climate change mitigation strategies. China has enormous resources of renewable energy and has one of the highest investment rates in wind energy in the world. Furthermore, in the 12$^{th}$ Five Year Plan (FYP) (2011-2015) several policies for energy efficiency improvement and emissions reductions are introduced, but due to the continued strong growth in the Chinese economy total emissions still increase. The actual growth in China is larger than estimated in the current GCAM projections so it remains to be seen if future 5-year plans manage to overcome the growth and bring emissions down to the level they need to be to significantly limit the atmospheric concentrations of $CO_2$ by the end of the century.

The regional analysis for the electricity sector in China is made only up to year 2020, which is the main period for the 12$^{th}$ FYP. The actual electricity demand is already higher than estimated in the GCAM scenarios, which are tuned to 2005 as base year. Nuclear and renewable power generation can't fully meet the rapid growth of demand due to the constraints of available resources. Thus, coal-fired power generation will still maintain a rapid growth momentum in China during the period 2010-2020, and will maintain the position as the power generation technology with the largest total installed capacity and highest energy production. However, due to extensive modernization and use of larger-scale units, it is possible to limit the $CO_2$ emissions from the Chinese power industry to between 3 and 5 billion tonnes by 2020. The installed thermal capacity and growth rates are shown in Figure 2-5.

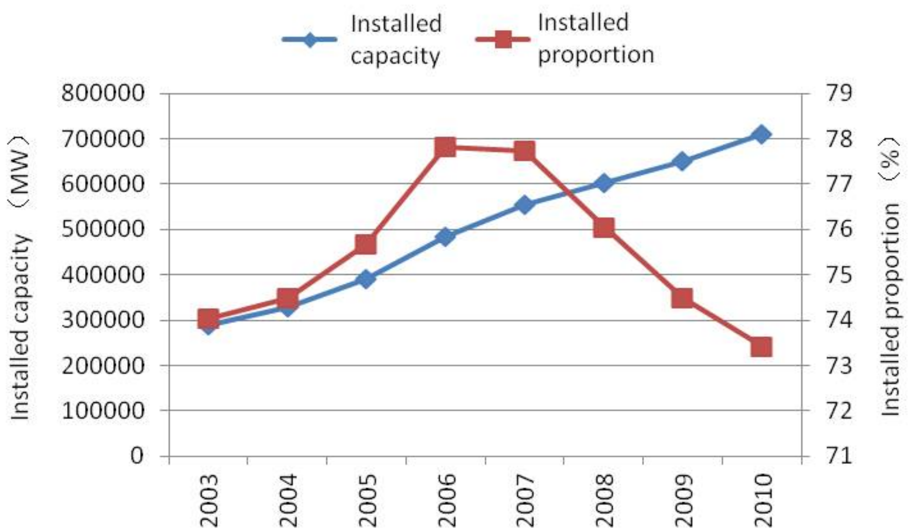


**Figure 2-5 The total installed capacity of thermal power and proportional growth in China (2003-2010)**
Source: The power industry's statistical annual reports, China Electricity Council

**Europe:** On the national level, there are also faster developments in Europe than estimated by GCAM, e.g. the growth of wind and solar energy combined with the recent decision for nuclear decommissioning in Germany. This is caused by the ambitious policies for energy efficiency, renewable energy and emissions reductions introduced in the EU and in each country the last years. Due to these targeted policies and regulations, Europe is able to develop its energy system much faster than estimated by a global model that basically follows cost-optimal algorithms.

When considering country-wise results for European generation capacity and production mix in 2050, it is clear that some investments and production profiles are quite robust across scenarios. Especially investments in new wind generation capacity in countries such as France, Great Britain, Italy, Poland and Norway, are similar in the different policy scenarios (in particular as a share of the total wind investments in Europe). In countries such as Spain and the Netherlands, on the other hand, investments in new wind capacity are substantial in the policy scenarios where there is a lot of wind, namely the 450 ppm and Global 20-20-20 scenarios, but in the 650 ppm scenario these investments do not occur to the same degree. These results give an indication to where in Europe the wind resources are most valuable, not just in terms of where one can expect the highest production per installed capacity, but also where wind production is most useful for covering demand in the system.

The optimal cumulative investments in transmission capacity by 2050, computed by the EMPIRE model, are shown in Figure 2-6. The amounts of new capacity are 60 GW, 96 GW and 108 GW for the 650 ppm, the 450 ppm and the Global 202020 scenarios, respectively. To put these numbers into perspective, the total initial transmission capacity between European countries is around 67 GW in 2010. Thus, according to the EMPIRE model, significant reinforcements in the transmission system are required for an optimal development of the European power system.

The Global 20-20-20 scenario is especially interesting with respect to generation and transmission capacities, as it is the policy scenario with the lowest demand in 2050 compared to the two others. However, in terms of generation capacity, investments are just as high as in the 650 ppm scenario, and in terms of transmission capacity the Global 20-20-20 scenario has by far the highest investments. A key feature of the Global 20-20-20 scenario is the high penetration of wind energy, which cannot be dispatched the same way as conventional power generation technologies. Balancing supply and demand everywhere in the system, at all times, requires either local back-up capacity or a strong grid which is able to support high flows of power from surplus regions to deficit regions (or a mix of the two strategies).

When considering which links are most important to reinforce a few examples stand out. In all the policy scenarios the corridors Spain – France, France – Germany, Spain – Portugal, France – Italy, Germany – Poland, Germany – Sweden, UK – Norway and Norway – Sweden see substantial investments. There is a clear indication that increasing the transfer capacity between North and South, and westwards, in continental Europe is an economical strategy. The size of investments in these corridors varies across scenarios, which is not surprising given the large differences in the generation capacity mix.

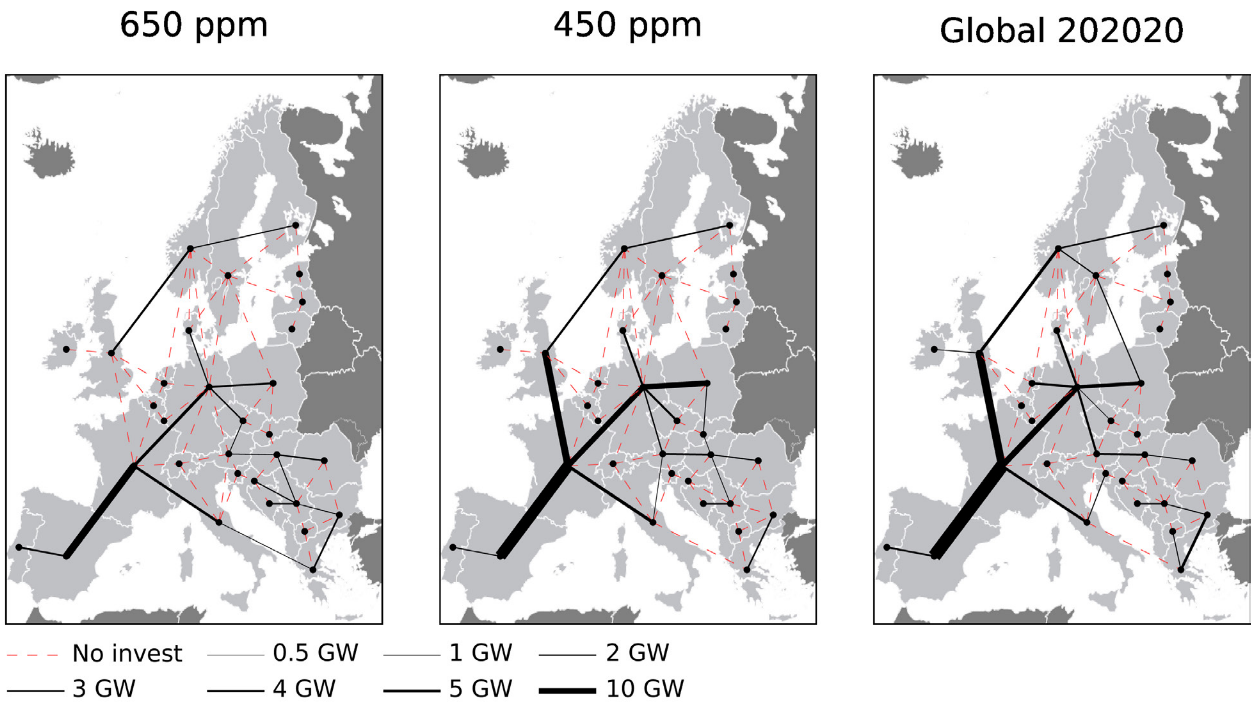


**Figure 2-6 Cumulative investments by 2050 in exchange corridors between countries in the EMPIRE model**

An interesting difference between the 650 ppm scenario and the two others is the investments in capacity for the UK – France interconnection. In the 650 ppm scenario this link is not reinforced at all, but in the 450 ppm and Global 20-20-20 scenarios between 12 and 14 GW of new transfer capacity is installed. The reason for this is likely the fact that in the 650 ppm scenario the UK has more conventional power generation capacity available, which reduces the need for connections with neighboring countries as demand can be covered locally.

**$CO_2$ taxes:** Since a $CO_2$ tax is one of the most likely instruments to use in a global emission reduction scheme, we used the World Gas Model to examine the impacts of such a tax in different regions. We used the resulting global $CO_2$ price from the 650 ppm scenario in GCAM (which is the scenario with highest shares of natural gas) and analyzed the effects in different gas markets.

In the US market, the best option of policy implementation would be if the $CO_2$ tax was imposed on consumers as this will give the lowest loss of consumer surplus. For Germany, however, the best option would be if the tax was dynamically adjusted between consumers and producers from one time period to another. The best carbon tax allocation is on the consumer side until 2030 when it is better to apply the tax to the suppliers, then again on the consumers. These results are caused by the mixed structure of the German market where some part is subject to the market power from large suppliers like Russia and Norway, and some are not. Thus, while some German players are price-takers, others set the price from an oligopolistic perspective. The decisions made by rival players that set the price consequently affect the supply decisions of price-taker players.

A final example of the benefits of linking global and regional strategies is the simplified analysis of carbon leakage in the GCAM model. Introduction of an early carbon tax in a single region will create a difference in production cost of aluminium between these and other regions without such a tax. However, as more and more regions join the climate mitigation efforts, whether by accession to a global carbon market or by introducing regionally specific policies, this apparent cost advantage will gradually disappear, as shown in Figure 2-7.

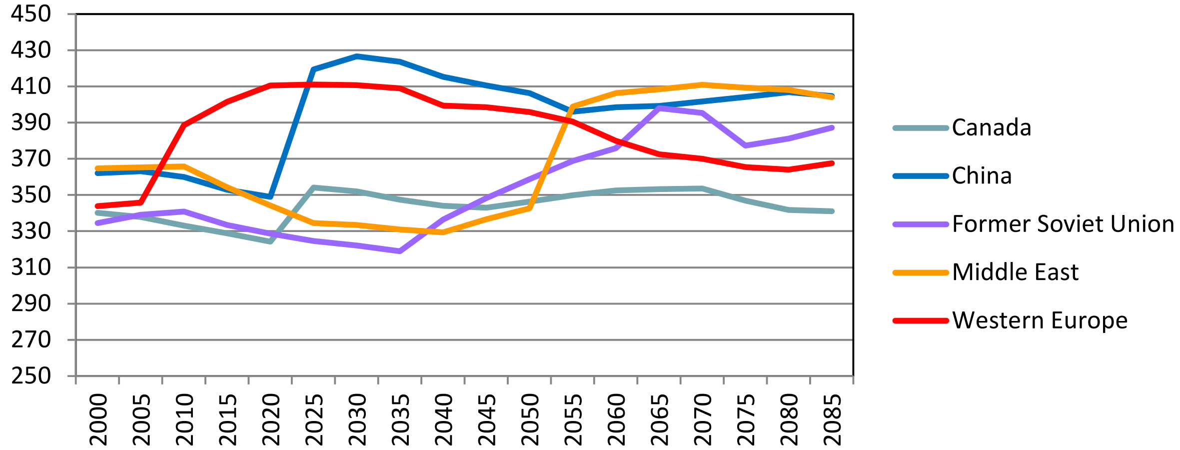


**Figure 2-7 Energy cost including carbon taxation from the Global 20-20-20 scenario in a selection of other significant aluminium producing regions [USD/tonne]**

## 2.2 Linking different energy system models

The original ambitions in the LinkS project were to soft-link multiple energy system models with different technological, spatial and temporal resolution, and iterate these into a sufficient convergence in selected regions. By running GCAM as the global "top model" it was possible to use long-term results from this model as input for the regional models and WGM, typically $CO_2$ prices, fuel prices and demand. However, iterating for convergence turned out to be a bigger challenge than anticipated. In the GCAM-WGM case, the latter has a much higher resolution in terms of gas market players and can therefore tune its results to more detailed and realistic market data than GCAM. Also, while GCAM finds a cost-minimizing result through market equilibriums, WGM is a complementarity model where each player tries to maximize its profits. Thus, it was difficult to iterate the two models into a single converged solution.

Even bigger challenges were encountered when we tried to iterate in a triangle between electricity and gas models in a single region under GCAM projections. Each model initially got the same input data from GCAM but when the two regional models (WGM-EMPIRE for Europe and WGM-TIMES for China) where iterated for convergence, the regional solution did not match the original GCAM solution anymore. We eventually abandoned the approach of convergence for a triangle of models; GCAM-WGM-EMPIRE and GCAM-WGM-TIMES, respectively, and stayed with a bilateral soft-link where each model received its input from GCAM.

In the case of Europe, however, we went one step further in comparing two different models for long-term expansion of the electricity system; the new EMPIRE model developed by an ongoing PhD task in LinkS and the existing EMPS model expanded with an investment algorithm. EMPIRE uses a perfect foresight linear investment algorithm with 666 operational situations per year, while EMPS has a single stage (myopic) investment algorithm with a much higher operational detail (19,500 situations per year). The former thus has a more mathematically stringent investment algorithm while the latter has a much better representation of variable renewable production in Europe.

In the European analyses, the setup of the EMPIRE model is in the different policy scenarios based on the following data from GCAM: demand, $CO_2$ prices, fuel prices and fixed annual O&M costs, resulting share of each generation technology within specific limits, generation capacity investment costs and economic life time for all technologies (see Figure 1-1.). Costs for transmission capacity investments are European specific figures. Hourly time series for renewable energy sources (wind and solar) are calculated for each country based on historical European data. EMPIRE identifies investments in new generation and transmission capacity in and between the countries where the profit is highest. EMPS calculates profitable investments in transmission capacities based on input data from EMPIRE.

Figure 2-8 shows the expected annual energy mix for all countries in 2050 after new transmission capacity is included, for both models EMPS and EMPIRE. The EMPIRE model has found it optimal to invest in more transmission capacity than EMPS and thus has the ability to replace more of the expensive fuel types in some countries with cheaper ones imported from other countries. Both models invest in the same channels, as shown in Figure 2-9 though with some difference in size.

From the present analysis, it is not possible to conclude that one result is more "correct" that the other since there is no systematic difference between the results from the two models. In particular, the results from the EMPIRE model are sensitive to the choice of statistical data for "free" renewable energy from wind and solar resources. The results are sufficiently similar to indicate that either model would be a feasible tool to use for electricity system expansion planning in a 50-year perspective.

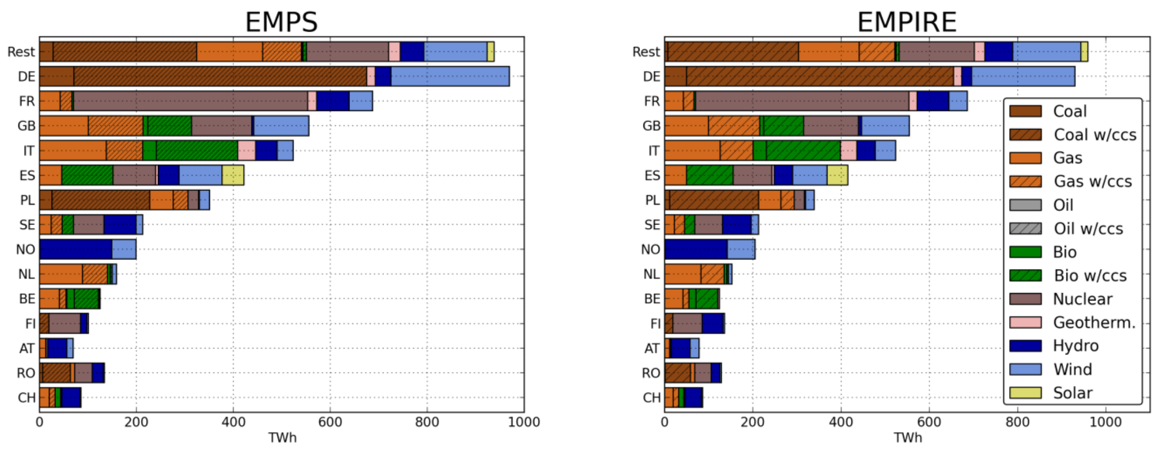


**Figure 2-8 European energy mix in 2050 in 450 ppm scenario calculated by EMPS and EMPIRE models**

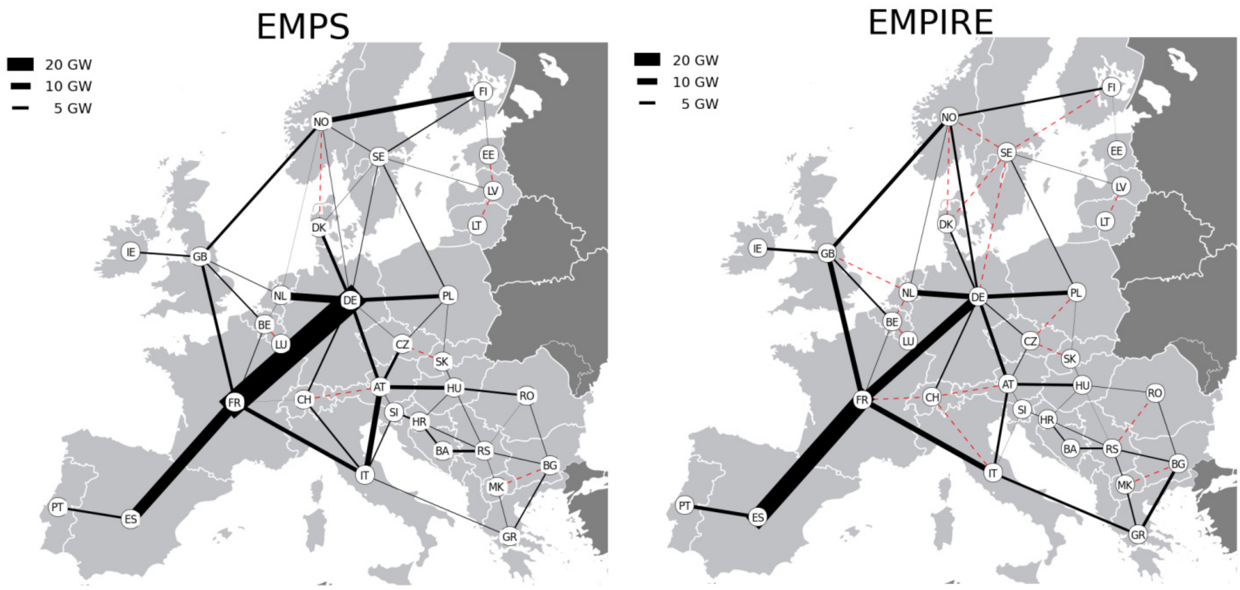


**Figure 2-9 Cumulative European transmission capacity investments in 2050 in 450 ppm scenario calculated by EMPS and EMPIRE models**

## 2.3 Linking policy analysis and energy system modelling

It was a challenging task also to link the fundamentally different areas of policy analysis and energy system modelling. The mathematical structure of GCAM allows the introduction of different policy measures as input to the analysis, but for more technology oriented models this ability is typically limited to adjustment of input parameters like $CO_2$ taxes, fuel prices, demand reductions etc. It is generally not possible to give regional energy and climate policy instruments as direct input to bottom-up energy system models. We therefore chose to perform the policy-modelling linking in several stages:

1. Specific policy measures were introduced in GCAM (global carbon market, Global 20-20-20 etc)
2. Results from the GCAM analyses were taken as input to the regional models
3. Results from the regional models where discussed in a policy context

In this way, we were able to formulate some initial policy measures, quantify these in a multi-level numerical process and then discuss the outcome on both a global and a regional level. In particular, the Global 20-20-20 scenario is an interesting example of this approach. We formulated a hypothetical global policy where the EU's 20-20-20 targets are extended in time and space to include all world regions and showed how this regional approach could yield reasonably high emissions reductions, refer Section 2.1.1. Afterwards, we discussed how feasible the specific 20-20-20 measures would be in the regions of USA, EU and China.

The main conclusion is that bottom-up, regionally independent policy measures could yield significant climate change mitigation results. Naturally, each region should be allowed to find its own appropriate measures; the EU 20-20-20 approach is just an example. In principle, three main steps can be considered when evaluating how a specific region can be included in climate change mitigation efforts:

1. ***Identify the anchorage of global and regional climate policies***
   - From which policy level do the (climate) policy initiatives in the region stem?
   - Climate policy anchorage, global and regional, might indicate political will and priority.
   - Regional political context affects both the policy anchorage and the choice of policy instruments. No single regulatory instrument or policy is "best" for all purposes.

2. ***Issue linkage and co-benefits of climate policies***
   - To what extent are climate policy initiatives linked to other relevant policy fields? Are there any potential co-benefits?
   - Systematic analysis and overview over a region's climate-specific and climate-relevant policies will not only provide insight on existing and potential issue linkage, but may also produce new suggestions of acceptable *climate-relevant* policies if *climate-specific* policies are controversial.

3. ***Interdependencies***
   - Identify patterns of economic and political interaction and mutual dependencies as a path for common solutions both within and between regions

China ratified the Kyoto Protocol in 2002, but as a developing country it has no quantified emission reduction target under the program. China is a dominant player in the Clean Development Mechanism (CDM), the only market-based mechanism in the Kyoto Protocol involving both developed and developing countries. China has also contributed actively to the global efforts through mainstreaming mitigation into its energy and environment policy. China's national goals dated year 2010 are:

i) $CO_2$ emissions reduction per unit GDP by 40-45% by 2020 compared to the 2005 level.

ii) Increased share of non-fossil fuels in primary energy consumption to around 15% by 2020.

iii) Increased forest coverage by 40 million hectares and forest stock volume by 1.3 billion cubic meters by 2020 from 2005 levels. This political statement was partly translated into a legal instrument in year 2011, a mandatory target to reduce carbon intensity by 17% by 2015 in its 12$^{th}$ Five Year Plan.

Major current policy initiatives in China are climate-relevant, but a significant shift towards a more climate-specific pattern has been made during the 12$^{th}$ FYP period. However, despite announced ambitions there are few policy efforts directly aimed at *emission reductions per se*. China has little experience with ETS-like (Emission Trading Scheme) policy measures for GHG emissions reduction and a direct cap would probably be more appropriate since Chinese authorities have a tradition for command and control policy measures. However, carbon emission market establishment is listed as one of the major targets in the work plan for GHG emission control during the 12$^{th}$ Five Year Plan period, and currently there are seven pilot emission markets, where some major cities and provinces are exploring the viability of ETS-like schemes. Given China's increasingly strong market orientation in other domains, it is not unlikely they would be able to successfully develop a nationwide Chinese ETS.

In terms of *Renewable Energy Standards*, a more direct target set by the government directly for each province (adapted to that province's technical and economic structure) is feasible. In the 12th FYP, China has set a national target of 11.4 % non-fossil share in primary energy by 2015 compared to 2010. Targets for *Energy Efficiency Standards* are already a main instrument in China and should be a feasible way to continue.

The United States signed the Kyoto protocol in its first period (1998-2012) and agreed to commit to a 7 percent emission reduction compared to 1990 levels within 2012, but the Protocol was never ratified by the U.S. Senate. At the 2009 COP-15 UNFCCC meeting in Copenhagen Obama pledged a GHG reduction target "in the range of a 17% emission reduction by 2020 compared with 2005 levels". This pledge has been reaffirmed in international settings by the State Department; however it is not a part of the 2012 Doha Amendment, where the US is no longer listed as having a quantified emission limitation. At the moment, there is no legislation at the federal level that ensures that the US achieves its international emissions reduction pledge. Furthermore, given the existing legislative guidance, any international agreement that entails binding emission reductions will likely fail to be ratified. Domestic initiatives will, however, continue at the federal, regional, state and city scale. States will continue to pursue a number of policies, most notably the California cap-and-trade. Taken as a whole, these policies have the potential to make an important contribution to limiting emissions. However, they are unlikely to attain reductions consistent with the commitments pledged by Obama at the 2009 COP-15.

A federal *Emission Trading System* could hypothetically be introduced in the US since the region is already highly market oriented. Besides, there are already experiences with ETS-like schemes at the state level. An US approach to a 'federal ETS' would likely be composed of state-based schemes and systems being linked together. Also, a federal *Renewable Energy Standard* could be politically viable in an US context. As long as RES-policy initiatives are linked to other concerns than climate-change mitigation, not least security of supply, these will be accepted by a broader range of political forces. A number of states have already employed specific RES-targets and policy measures, so a federal target where each state is allowed to find its own means of fulfilling the target could be feasible. The state level targets could also be adapted according to the state's structure, economy and industry, like in the EU and China. However, it seems less likely that federal requirements for Energy Efficiency Standards will be set for state level activities and industry, although the US federal government has a tradition of setting targets for energy efficiency in federal operations (such as buildings and vehicle fleet). Targets for energy efficiency related to cars have also been set by the US Congress.

## 2.4 Linking international research teams

Last, but not least, the 5 years of the LinkS project have given the opportunity to link several world-class research teams:

- Joint Global Change Research Institute (JGCRI), Maryland, USA
- Dept of Civil and Environmental Engineering, University of Maryland, USA
- Center for Integrative Environmental Research (CIER), University of Maryland, USA
- Energy, Environment and Economy Institute (3E), Tsinghua University, China
- Dept. of Industrial Economics and Technology Management, NTNU, Norway
- Dept. of Electrical Power Engineering, NTNU, Norway
- Market-Grid Analysis group, SINTEF Energy Research, Norway
- Policy and Governance group, SINTEF Energy Research, Norway

In addition to the scientific knowledge and modelling expertise, each of the international partners has contributed with detailed knowledge about their countries' energy system and policies. This has enabled a detailed analysis of global and regional energy strategies, linked with regional policy analyses. Tsinghua University provided valuable insights into Chinese energy and climate policies to the other teams. Similarly, the complex policy implementation of the Global 20-20-20 scenario in GCAM was enabled by detailed input from the European partners.

The main disadvantage of this large and inhomogeneous group has been the geographical distances and thus the infrequent physical meetings. Physical meetings are crucial to develop an efficient and well integrated research team. Throughout the duration of the project, we have arranged two physical workshops each year in addition to shorter periods of staff exchange. This has ensured a good atmosphere of multi-disciplinary collaboration and research, although more frequent physical meetings might have improved the work even further.

At the time of writing, the LinkS team has submitted 14 peer-reviewed international papers (of which 7 are published or accepted for publishing), published 9 books and reports (not including this TR) and given 56 presentations at various international conferences and meetings. The final conference of LinkS was arranged in Oslo 28 August 2013 with 30 participants. Two part-funded PhD dissertations are delivered at University of Maryland, while the 3rd is still on-going. Furthermore, one PhD study is on-going at NTNU and one at Tsinghua University.

# 3 Recommendations for further work

The LinkS project had very high ambitions of linking strategies, models and research teams. We are not aware of any other projects attempting to reach these objectives on such a broad scale. A lot of interesting and relevant multi-disciplinary work is performed and increased insights have been achieved during these years, but there are still unanswered questions that should be given attention in further research activities. The most relevant topics we have noted are the following:

- Closing the feedback loop from the regional bottom-up models to CGAM by adjusting input parameters and constraints according to more detailed regional analyses. In particular, the representation of variable renewable energy resources and local infrastructure challenges may introduce new or modified constraints to CGAM.
- Continue the global analyses of independent regional policies in GCAM by expanding the Global 20-20-20 scenario to encompass several regionally differentiated policies.
- Perform detailed bottom-up studies under the global scenarios in more regions than the EU and China.
- Include more nationally or regionally specific policies in the regional studies; targeted RES support schemes, certificate markets, feed-in tariffs etc .
- Continue the bottom-up energy system studies in China beyond 2020.
- Further analyses of the differences between perfect foresight and myopic investment analyses in Europe. In particular, the effect of statistical year for renewables in EMPIRE merits further analysis e.g. by re-running the comparison with a year with particularly low renewable resources and a year with average renewable resources.

With regards to the model linking, we do not recommend further attempts to converge three or more models in the same loop; bilateral iterations between two models at a time is challenging enough.

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