Using a hybrid hard-linked model to analyze reduced climate gas emissions from transport

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Abstract

In this paper we have hard-linked a bottom-up energy system model (TIMES) and a top-down computable general equilibrium (CGE) model (REMES) in order to analyse both the energy system impacts and the economic impacts of reducing greenhouse gas emissions from transport. We study a limitation of CO_2 emissions from transport in Norway in 2030 to 50% of CO_2 emissions in 1990. The linked approach gives new insight both in terms of the technology mix and the emissions from different transport segments, ripple effects through the economy and regional welfare effects. Furthermore, the convergence of our full-link full-form hybrid model is relevant for comparison with soft-linked approaches.

Keywords: Energy system analysis, Economic modeling, Hard-linking, Top-down and bottom-up, Energy-climate policy, Greenhouse gas emission reduction

1 Introduction

The transition towards a sustainable energy system affect a number of other sectors in the economy. This has created a need to better integrate energy system models with economic modelling. We have hard-linked a bottom-up energy system model, TIMES, and a top-down computable general equilibrium (CGE) model, REMES, in order to analyse both the energy system impacts and the regional economic impacts of reducing greenhouse gas emissions from transport. In our case study from Norway, future CO_2 emissions from transport in 2030 are limited to 50% of CO_2 emissions in 1990. The first contribution of the paper is related to the policy insight which suggests how ambitious emission reductions can be achieved in the transport sector. The second contribution is on the linking methodology building a hybrid approach. Before going in detail on that, we review existing literature.

Top-down CGE models describe the whole economy, and emphasize the possibilities to substitute different production factors in order to maximize the profits of firms and satisfy market clearance conditions. The proof of existence of a general equilibrium was established in [1]. The first successful implementation of an applied general equilibrium model without the assumption of fixed input-output coefficients was made in 1960 by Leif Johansen [2, 3]. A survey of well-known CGE models for sustainability impact assessments is presented in [4]. The substitution possibilities between energy and other production factors are captured in production functions, which describe the changes in fuel mixes as the result of price changes under certain substitution elasticities. The smooth CGE production functions can result in violation of basic energy conservation principles. The widely used constant elasticity of substitution (CES) production function aggregates economic quantities in a nonlinear fashion, conserving value but not physical energy flows [5]. Top-down representations of technologies can also produce fuel substitution patterns that are inconsistent with bottom-up cost data [6].

Bottom-up engineering models describe energy supply from primary energy sources, via conversion and distribution processes to final energy use as well as interactions between these. In contrast to CGE models, they neglect the macroeconomic impact of energy policies, since they are partial equilibrium models and look only at the energy market. Another weakness is that bottom-up models are unable to capture the full economy-wide rebound effects. They can easily capture substitution of energy carriers or technologies, but cannot anticipate demand increase due to income effects [7]. For a further discussion see [8-11].

Hybrid models aim to combine the technological explicitness of bottom-up models with the economic richness of top-down models [11]. Classifications of hybrid modeling are provided by [8] and [11, 12]. We use the terms *soft-linking* versus *hard-linking* as defined by [8], where soft-linking is information transfer controlled by the user and hard-linking is formal links where information is transferred without any user judgment (usually by computer programs). One further step is to *integrate* the models as one, instead of exchanging information between separate model runs.

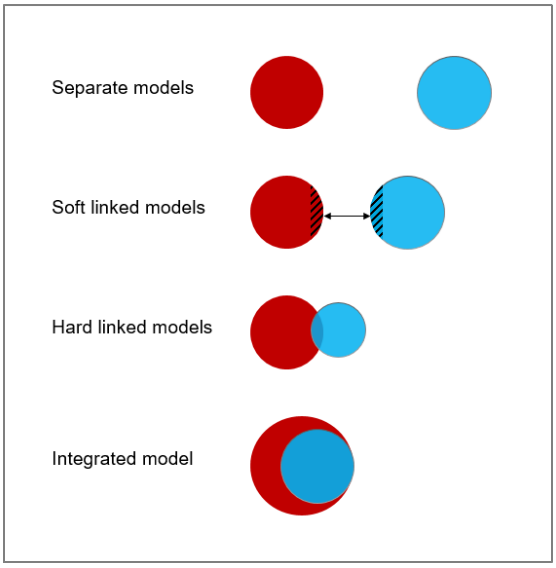

Figure 1 Hybrid model variants

Early examples of typically soft-linking full models are found in [13-15]. Some notable contributions include soft-linking between ETEM and GEMINI-E3 focusing on residentials [16] and MARKAL and EPPA focusing on transport [17], while recent examples attempt to link all economic sectors between TIMES and EMEC [18] and between TIMES and GEM-

E3 [19]. Many earlier linking experiments have simplified one of the models or narrowed the focus to defined parts of the economy, and been able to hard-link the models. Some well-known examples of this type are the ETA-Macro model [20], MARKAL-Macro [21-23], MESSAGE-Macro [24] and WITCH [25]. Fortes et al. [19] use the terms "full-link" and "full-form" to characterize hybrid models. Full-link hybrid models cover all economic sectors, while full-form hybrid models combine detailed and extensive technology data with disaggregated economic structure.

Böhringer, Rutherford and Löschel have been proponents for the integrated approach, and have shown that bottom-up formulations of activity analysis can be integrated by formulating the general equilibrium problem as a complementarity problem [11, 12, 26, 27]. This type of approach was presented by [28] and further demonstrated by [29]. The integrated approach focuses on a selected sector in order to maintain tractability. Most contributions in this category focus on electricity [5, 6, 30-34].

One reason for keeping the models intact instead of integrated is that top-down and bottom-up data are collected from different data sources and often with different product granulation and time resolutions. Bottom-up models focuses on quantities and builds on national energy balances, while top-down models deals with economic values and builds on national accounts. In order to integrate models, data must be reconciled across models - which is highly advisable, but engineering and economic data are rarely consistent with each other [30]. By linking the models, we retain the consistency of each database.

Our top-down model builds on regional accounts data. As far as the authors are aware, our article represents the first hard-linking of large-scale stand-alone models employing a full-link with regional resolution and full-form bottom-up and top-down approach. We keep the two models intact and exchange relative information affecting demand, energy mix and capital growth.

Our two models and their hard-linking is described in section 2. Section 3 introduces the case study and presents results. We conclude in Section 4, where we also summarize the advantages of hard-linking.

2 The models and the linking

TIMES (**T**he **I**ntegrated **M**arkal **E**fom **S**ystem) gives a detailed description of the entire energy system including all resources, energy production technologies, energy carriers, demand devices, and sectorial demand for energy services [35]. The model assumes perfect competition and perfect foresight and is demand driven. The model aims to supply energy services at minimum global cost by making equipment decisions, as well as operating, primary energy supply and energy trade decisions. A version of TIMES-Norway [36, 37] is used. The base year of the model is 2010 and the model horizon is to 2050. The time resolution covers all weeks during each year with five time slices per week, giving 260 time slices annually. Geographically the model covers Norway, and is divided into 5 model regions based on the pricing areas in the Nordic spot market for electricity [38]. There is exchange of electricity between regions and neighbouring countries, and the transmission capacity within and outside the model regions is given exogenously and is based on the current capacity.

Generally, the projected energy demand has to be given exogenously to the model [39], but due to the hard-linking of the two model approaches, the energy demand is now determined endogenously by REMES. The energy service demands of residential, service, industry and transportation are used as input to the TIMES-Norway model. The top-down model REMES is a **R**egional **E**quilibrium **M**odel with focus on the **E**nergy **S**ystem. REMES is a spatial CGE model. Consumers are demanding goods in order to maximize utility, and producers are supplying goods in order to maximize profits. A social accounting matrix (SAM) defines a benchmark equilibrium for the model. All the economic agents and goods are represented with accounts for all the economic transactions in a base year. Knowing this reference equilibrium, the model is able to adapt to shocks or policy changes like taxes, subsidies or endowment changes.

REMES focuses on the multiregional aspects, and works on the basis of fully balanced interregional SAMs with detailed interregional trade flows and transport margins. The model implementation allows for a flexible nesting structure. The nesting structure and substitution elasticities used in this study are presented in appendix 7.2. We refer to the REMES model description in [40] for further details. The work has been inspired from several spatial CGE models such as PINGO [41], RAEM [42] and RHOMOLO [43-45]. Each agent in REMES is represented on the regional level, and comprise a representative household, a representative producer in each sector, a trader for each good acting according to the Armington assumption [46], a local government and a local investment sector.

2.1 Design of the hard linking

Both the top-down and the bottom-up models have their own detailed databases. We keep both models intact, but have expanded them by accepting input from the other model (see Figure 2).The exception is the adjustment of capital growth, which mandates homogenizing the absolute levels between model.

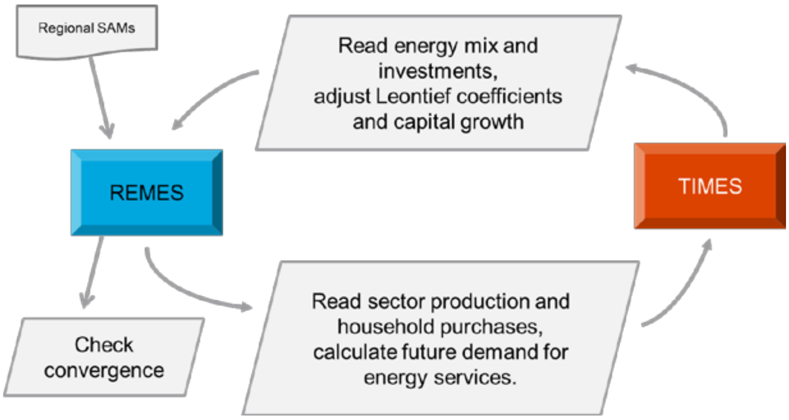

Figure 2 Hardlinked models and mappings

We do not attempt to define or restrict prices in REMES based on TIMES results, as done in [18, 19]. TIMES results should adjust technical aspects of REMES only.

One challenge is to define a data granulation that preserves the individual model strengths but allows an overlap enabling the linking between the models. The TIMES model gains from highly granulated data. In contrast, REMES is designed to work with aggregated data. The SAM describes an economic equilibrium where the use of production factors and available technologies are optimized simultaneously by different agents.

Preparations to accommodate hard-linking are:

1) Define data granularity for regions, sectors and commodities suitable for linking the top-down and the bottom-up model.
2) Define mappings between the model data structures (depending on step 1).

3) Describe nesting structure and substitution elasticities in top-down model (depending on step 1).
4) Preprocess top-down national accounts data to the data granularity defined in step 1.
5) Preprocess bottom-up national energy balance data to the data granularity defined in step 1.

The preparation process for the top-down model is illustrated in Figure 3.

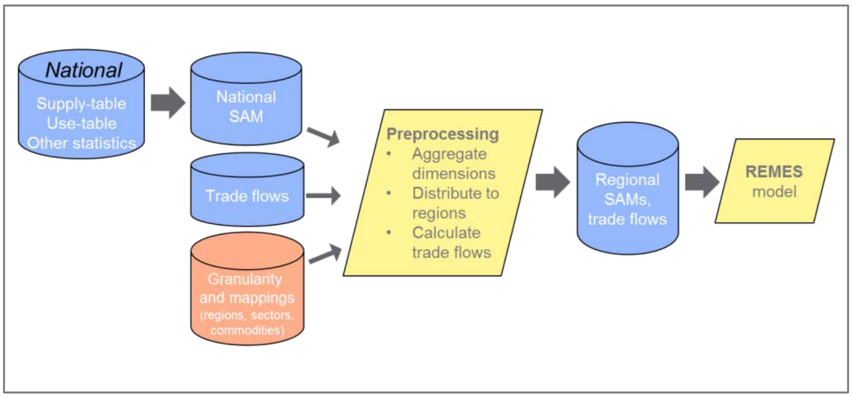

Figure 3 Illustration of data input and preprocessing for the top-down model

We have defined four mappings, in order to couple the data dimensions: commodity (1 mapping), sector (2 mappings) and geographic region (1 mapping). Sector mappings are directional, see Figure 4.

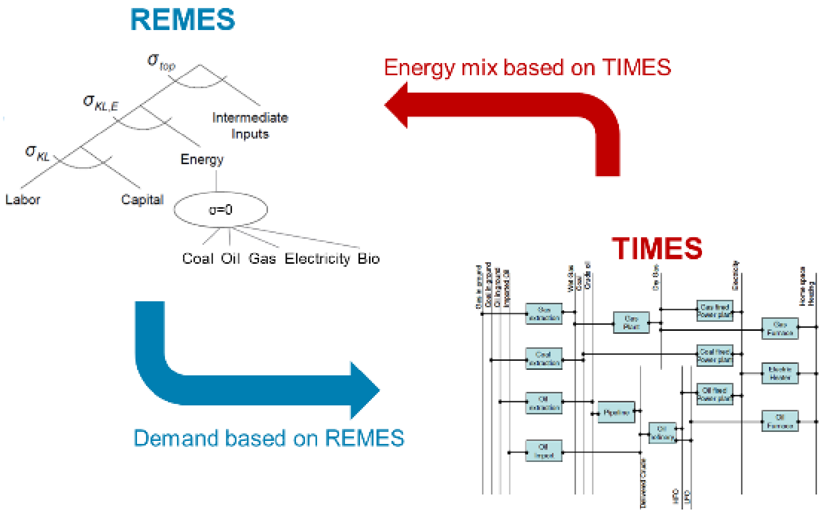

Figure 4 Directional sector mappings

In order to achieve a full-link, full-form and hard-linked approach, we have simplified the time dimension. We run a static version of the REMES model and assume a linear development of demand for energy services from base year to horizon year. We harmonize time assumptions in the setup of the models, such that growth assumptions in REMES match the planning horizon in TIMES.

Sets

R regions in top-down model, indexed by *r*, mapped by subsets $R_{r'}$

R'	regions in bottom-up model, indexed by r', mapped by subsets R'_r
C	energy commodities in top-down model, indexed by c, mapped by subsets $C_{c'}$
C'	energy commodities in bottom-up model, indexed by c', mapped by subsets C'_c
S	sectors in top-down model, indexed by s, mapped by subsets $S_{s'}$
S'	energy service demand sectors in bottom-up model, indexed by s', enumerates relevant energy services[1]
P'	processes in bottom-up model providing energy service, indexed by p', mapped by subsets P'_s
T'	time periods in bottom-up model, indexed by t'
TS'	timeslices in bottom-up model, indexed by τ'

Mapping parameters

$k_{s,s'}$	demand factor mapping top-down sector activity to bottom-up energy service demand
$\mu_{p',s}$	distribution of bottom-up energy use in process p' towards top-down sector s

Examples of the four mappings are provided in section 7.6 in the appendix.

2.2 From REMES to TIMES: Energy service demand

REMES provides input about total energy demand to TIMES. We assume there are specific energy intensities for each industry in each region, measuring input of energy service per production quantity. Energy services consists of heating, cooling, electricity specific, transport and energy in the form of raw materials.

When a sector produces more, we assume that demand for energy services increase proportionally, keeping the same energy intensity. Assumptions about decreasing or increasing energy intensities can easily be implemented as well.

<u>We define the following notation:</u>

$TDem_{r',t^{base},s'}$	base year demand for energy service in bottom-up model for sector s' and region r'
$XD_{r,s}$	sector production from top-down model in region r and sector s
$HOUS\_EXP_r$	household expenditure from top-down model in region r
$\alpha_{r',s'}$	demand growth factor based on top-down model
$TDem_{r',t',s'}$	calculated demand in bottom-up model region r', period t', energy service demand sector s'

The demand in TIMES is calculated as:

$$TDem_{r',t',s'} = TDem_{r',t^{base},s'} + TDem_{r',t^{base},s'} \cdot \alpha_{r',s'} \cdot \frac{(t' - t^{base})}{(t^{future} - t^{base})}$$

The demand growth factor is based on REMES:

$$\alpha_{r',s'} = \sum_{r \in R_{r'}, s \in S_{s'}} \frac{\left(XD_{r,s}^{future} - XD_{r,s}^{base}\right)}{XD_{r,s}^{base}} k_{s,s'}$$

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[1] H=heat, E=electricity specific, M=materials, C=cooling, T=transport

Most TIMES demands are mapped from one relevant REMES sector acting as demand driver, and a natural default value for the mapping factor $k_{s,s'}$ is 1, retaining the same energy intensity in the future as in the base year.

In the tertiary sector we assume that new buildings in education, health and social services, hotel and restaurant, offices, wholesale and retail are expected to have lower energy demands, and these growth factors are scaled down based on regulations on technical requirements for building works. We assume that new requirements will lead to lower energy services demand, but that some buildings will also lag behind due to lack of refurbishment.

The factor $k_{s,s'}$ allows to make demand growth dependant of more than one REMES sector, and pooling these together. Values of $k_{s,s'}$ must then be scaled accordingly.

Households

For households we assume specific energy service intensities for each region, measuring input of energy service per household expenditure. Energy services consists of heating and electricity specific energy demand.

Household expenditure from REMES is used as driver for energy services demand in TIMES. We calculate alpha coefficients for single-family houses, multi-family houses and cottages:

$$\alpha_{r',s'} = \sum_{r \in R_{r'}} \frac{\left(HOUS\_EXP_r^{future} - HOUS\_EXP_r^{base}\right)}{HOUS\_EXP_r^{base}} k_{HOUS,s'}$$

The factor $k_{HOUS,s'}$ acts as an income elasticity. We assume heating to be a normal and necessity good with income elasticity between 0 and 1, while electricity is assumed to be a luxury good with income elasticity above 1. In this study we have assumed income elasticities of 0.99 for heating and 1.01 for electricity in existing single-family and multi-family houses.

Energy demand for heating is expected to decrease more sharply in new buildings, due to strengthened regulations and improved building techniques. We assume that heating demand decrease by 23% in new single family houses and by 25% in new multi-family houses, captured by the two factors $\varphi_{single\ family} = 0.77$, and $\varphi_{multi\ family} = 0.75$.

Furthermore, we assume certain shares $\psi_{t,s'}$ of new single-family and multi-family houses per year during the planning period, see Figure 5.

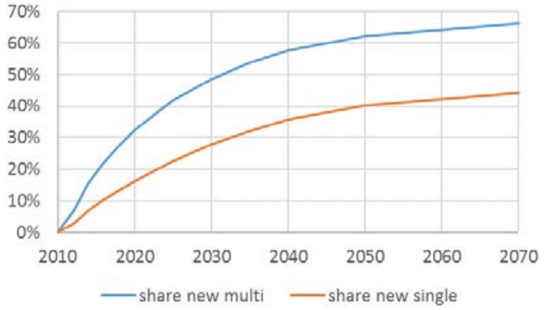

Figure 5 Share of new buildings in building stock

For new houses[2], we calculate demand for heating as

$$TDem_{r',t',s'} = \left(TDem_{r',t^{base},s'} + TDem_{r',t^{base},s'} \cdot \alpha_{r',s'} \cdot \frac{(t' - t^{base})}{(t^{future} - t^{base})} \right) \psi_{t,s'} \varphi_{s'} , \quad s' \in S'^{household\ heating}$$

For existing houses[3], we calculate demand for heating as

$$TDem_{r',t',s'} = \left(TDem_{r',t^{base},s'} + TDem_{r',t^{base},s'} \cdot \alpha_{r',s'} \cdot \frac{(t' - t^{base})}{(t^{future} - t^{base})} \right) (1 - \psi_t) , \quad s' \in S'^{household\ heating}$$

Electricity-specific demand in households is calculated accordingly, only without the use of the heat specific factor φ.

Transport

TIMES focuses on transport demand groups with exogenous demand, and associated transport technologies. Demand for transport services in REMES is determined by the amount of inter-regional trade multiplied with inter-regional transport and trade margins and direct consumption of transport services by households and firms.

Demand growth factor $\alpha_{r',s'}$ is based on REMES:

$$\alpha_{r',s'} = \sum\nolimits_{r \in R_{r'}, s \in S_{s'}} \frac{\left(XD_{r,s}^{future} - XD_{r,s}^{base} \right)}{XD_{r,s}^{base}} k_{s,s'} + \sum\nolimits_{r \in R_{r'}} \frac{\left(HOUS\_EXP_r^{future} - HOUS\_EXP_r^{base} \right)}{HOUS\_EXP_r^{base}} k_{HOUS,s'} , \quad s' \in S'^{transport}$$

For a detailed overview over linking parameters for transport see Appendix 10.1.

2.3 From TIMES to REMES: Energy mix

We assume Leontief production technology with fixed input factors for energy inputs in the spatial CGE model. Leontief coefficients of the production functions are calibrated on the data from inter-regional SAMs.

We adjust Leontief coefficients in REMES based on TIMES quantities. This adjustment constitutes a second shock to REMES, in addition to growth in labour and capital. Factors for relative development of energy carriers as input to REMES sectors per region are calculated by comparing TIMES's flows of energy carriers in the future year against the base year.

We define the following notation:

$Flo_{r',t',p',c',\tau'}$	flow of energy in bottom-up model of energy commodity *c'* in process *p'* in region *r'* during time period *t'* and timeslice *τ'*
$\lambda_{r,c,s}$	Leontief adjustment factor changing use of energy commodity *c* in sector *s* in region *r* based on bottom-up model

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[2] The s'index used in TIMES enumerates both energy service (heating versus electricity specific) and household type (single-family versus mult-family).

$cost\_adj_{r,s}$	cost adjustment factor in top-down model, rescaling Leontief factor in order to isolate substitution effect from energy commodities
Leontief$_{r,c,s}$	calculated Leontief factor in top-down model in region *r* of energy commodity *c* in sector *s*

Leontief adjustment factors for top-down sectors are calculated as:

$$\lambda_{r,c,s} = \frac{\sum_{r' \in R'_r, p' \in P'_s, c' \in C'_c, \tau' \in T} \left(Flo_{r', t_{future}, p', c', \tau'} \cdot \mu_{p',s} \right)}{\sum_{r' \in R'_r, p' \in P'_s, c' \in C'_c, \tau' \in T} \left(Flo_{r', t_{base}, p', c', \tau'} \cdot \mu_{p',s} \right)} \cdot \frac{XD_{r,s}^{base}}{XD_{r,s}^{future}}$$

The last fraction adjusts for growth in the sector as a whole. If the use of oil in the construction sector increase by 10%, but the construction sector also grows by 10%, then the relative use of oil remains unchanged. The corresponding formula for households is shown below.

$$\lambda_{r,c,\mathrm{HOUS}} = \frac{\sum_{r' \in R_r, p' \in P'_{HOUS}, c' \in C'_c, \tau' \in T} \left(Flo_{r', t_{future}, p', c', \tau'} \cdot \mu_{p',s} \right)}{\sum_{r' \in R_r, p' \in P'_{HOUS}, c' \in C'_c, \tau' \in T} \left(Flo_{r', t_{base}, p', c', \tau'} \cdot \mu_{p',s} \right)} \cdot \frac{HOUS\_EXP_r^{base}}{HOUS\_EXP_r^{future}}$$

As we prefer to keep each model with data intact, we do not attempt to harmonize the data. If TIMES has zero energy flow in the base year, we still calculate a growth factor from the first intermediate year where TIMES calculates a flow. If TIMES does have energy flow in the base year but zero energy flow in the horizon year, we calculate a zero factor as input to REMES – as opposed to the situation where TIMES does not use the energy carrier and we do not use an adjustment factor in REMES (a zero value operates differently from no value.) If TIMES does not have a flow in either the base year or the future/horizon year, we do not consider flows in intermediate years and avoid any adjustment on the corresponding Leontief-factor that might exist in REMES[3]. If TIMES utilizes an energy flow in the horizon year only, we assume a λ growth factor value of 2.

Energy flows in TIMES may evolve from a marginal level, and produce high λ growth factor values, which may cause problems in REMES. If the shock is too severe, REMES may fail to find a solution. We limit the λ growth factor to a value of 400.

The calculations described thus far will adjust the regional energy mix for each sector, and produce both substitution effects and income effects. Our primary aim is to capture the changed energy mixtures. We rescale the costs of the adjusted energy mix to become equal to the costs of the original energy mix, in order to isolate the substitution effects.

$$cost\_adj_{r,s} = \frac{\sum_{c \in C} \left(leontief_{r,c,s}^{base} \right)}{\sum_{c \in C} \left(leontief_{r,c,s}^{base} \cdot \lambda_{r,c,s} \right)}$$

$$Leontief_{r,c,s} = cost\_adj_{r,s} \cdot \lambda_{r,c,s} \cdot leontief_{r,c,s}^{base}$$

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[3] We have experienced cycling behavior during iterations when we adjust Leontief factors in such situations.

Regarding autonomous energy efficiency improvements (AEEI), REMES rely on TIMES data input on expected new future technologies and exploit TIMES results to capture future relative use of energy carriers. In this study we focus on substitution effects, and employing income effects from the adjusted energy mix is left for future research.

Transport in REMES is modelled differently from TIMES. REMES focuses on commercial transport, while household own production of transport is not captured by any other value transfer than fuel demand. Some energy flows in TIMES serves processes (for example transport technologies) which naturally belong to multiple sectors in REMES. We assume for example that most long-distance car transport (99% of the kilometres) in TIMES are demanded by households in REMES, while 15% of short distance car kilometres are driven as part of land-based commercial transport in REMES. See Appendix 10.1 for an aggregated overview of mappings of transport related energy flows from TIMES processes to REMES sectors.

2.4 Linking capital from TIMES to REMES

Changes in Leontief coefficients are typically favourable, meaning that less energy input is required to achieve the same production as before due to expected technological progress. These improvements require investments into capital stocks of the production sectors. Linking TIMES investments and REMES capital stocks requires absolute instead of relative levels. We must establish a harmonized baseline of capital stocks between the models, and we make the assumption that the scale of investments in a business as usual (bau) scenario is compatible with the capital stocks growth of REMES.

In this study we put the policy goal[4] into TIMES as a restriction, which triggers higher investments. We assume that the investment increase reduces capital growth in REMES accordingly.

We define the following notation:

$KS_{r,s}^{base}$	capital income in top-down model in region *r* and sector *s* in base year
$leontief_{r,c,s}^{base}$	Leontief factor in top-down model base year SAM
$ncapcost_{r',t',p'}$	capacity investment cost in bottom-up model for process *p'* in time period *t'* and region *r'*
$CapitalRemes_r$	estimated capital value in bottom-up model in region *r*
$NCAP_{r',t',p'}$	capacity investments in bottom-up model region *r'* time period *t'* process *p'*
$shockadj_r^{CO2K}$	calculated capital growth adjustment factor in top-down model for region *r*

Our social accounting matrix (SAM) holds capital income by region and sector in the base year ($KS_{r,s}^{base}$). The perpetuity value of the capital income would overestimate the capital value, and we add a factor κ to adjust for capital depreciation:

$$CapitalRemes_r = \frac{\sum_s KS_{r,s}^{base}}{df \cdot \kappa}$$

where df is the real discount factor used in TIMES. We assume df=4% and κ=2, these values produce a coarse capital estimate which corresponds with national estimates of real

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[4] Reducing CO_2 emissions from transport.

capital and net national wealth per capita[5]. For a discussion of discount rates in energy system models, see Garcia et al. [47].

We calculate adjustment factors for capital shocks in REMES based on TIMES investments like this[6]:

$$shockadj_r^{CO2K} = \frac{CapitalRemes_r - \sum_{r' \in R'_r, t' \in T', p' \in P'} ncapcost_{r',t',p'} \left(NCAP_{r',t',p'}^{CO2K} - NCAP_{r',t',p'}^{BAU} \right)}{CapitalRemes_r}$$

2.5 Convergence

We calculate the relative change of variable values between iterations, and compares it against a chosen tolerance. If all changes are below the tolerance, the iterations have converged. Examples for commodity prices and sectoral output are shown below (where index *i* indicates iteration number).

Commodity prices: $$\max_{r,c} \left(\frac{|P_{r,c}^{i} - P_{r,c}^{i-1}|}{(P_{r,c}^{i-1})} \right) \leq \text{tolerance}$$

Sectoral output: $$\max_{r,s} \left(\frac{|XD_{r,s}^{i} - XD_{r,s}^{i-1}|}{(XD_{r,s}^{i-1})} \right) \leq \text{tolerance}$$

We calculate the relative change of the following variables, to assess whether iterations have converged with tolerance 10^{-5} (see Figure 13): Commodity prices, sectoral output, household consumption, sectoral labour use, price of labour, price of capital, total energy system cost, consumer welfare, public welfare, investor welfare as well as hicksian prices of of consumer welfare, public welfare and investor welfare.

3 Analysis and results

3.1 Scenarios and data

In our analysis we restrict emissions of CO_2 from transport in 2030 to 50 per cent of CO_2 emissions in 1990, corresponding to suggestions by National transport agencies [48]. The CO_2-restriction is imposed in TIMES, and mandates the use of new technologies and energy carriers. We run a business-as-usual scenario (*bau*) without the CO_2-restriction, and a CO_2-reduction scenario (*co2*) with the naïve assumption that TIMES investments do not affect available capital growth in REMES. We run a third scenario (*co2k*) where we restrict CO_2 emissions and make the assumption that TIMES investments exceeding those in the *bau* scenario will reduce available capital growth in REMES.

The *co2k* scenario resembles a techno-optimistic policy where national authorities finance technological shifts to reach the common target of the society, while societal actors can

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[5] Long-term Perspectives on the Norwegian Economy 2013, white paper from Norwegian Ministry of Finance.

[6] For simplicity, we have not displayed currency indexes in the formula, as we only use one currency in this study.

behave as before. These technological investments demands capital, which could have served society better if used alternatively. In the *co2k* scenario we calculate Hicksian compensating variation per region, to quantify the amount of additional income households would mandate to compensate for their utility loss compared to the *bau* scenario.

The current policy for zero emission vehicles in Norway shares important characteristics of the *co2k* scenario. Government has provided powerful financial incentives: Battery electric vehicles and fuel cell electric vehicles are exempt from registration tax, value added tax and road tolls, pay a lower annual fee, are allowed to drive in the bus lane, enjoy free parking in municipal car parks and run free on ferries [49, 50].

We also compare stand-alone TIMES solutions based on exogenous demand with the hard-linked iterative TIMES solutions. Exogenous demand for energy services are taken from the CenSES national energy demand projection (see [51]).

Growth assumptions

We have used expected yearly growth rates for capital and labour from the government white paper “Long-term Perspectives on the Norwegian Economy 2013”, and regionalized these according to Statistics Norway’s official population projection (MMMM).

Table 1 Regional growth rates for labour and captial

Region	2010 population	2030 projection	Labour growth 2010-2030	Capital growth 2010-2030
East	2 000 176	2 560 530	18 %	53 %
South	1 181 781	1 489 341	16 %	50 %
Middle	670 073	814 900	12 %	45 %
West	530 408	658 994	15 %	48 %
North	445 333	486 861	1 %	30 %
Total	**4 827 771**	**6 010 626**	**15 %**	**49 %**

The continental shelf

Norway has an extensive production of oil and gas from the continental shelf, with high production, no households and highly specialized transportation needs. We have chosen to attach the continental shelf to the northern region of Norway, as this is the outermost region with the lowest population. Our results are presented without this combined region, but full results are available in a downloadable appendix.

3.2 Results

Figure 6 shows that changes in energy mix from scenario *bau* to *co2* has a small impact in the REMES model, and that few iterations are needed to reach convergence. Linking capital investments in scenario *co2k* has larger impacts, and more iterations (18 compared to 6) are required to achieve convergence. REMES calculates a significant growth in total yearly production from the base year (represented by iteration 0) to iteration 1, reflecting the changes between year 2010 and 2030. The production growth in our scenarios *bau* and *co2* are quite similar. The only difference in REMES between these scenarios is the energy mix feedback from TIMES. In scenario *co2k* investments in TIMES reduce available capital growth in REMES. Having less available resources reduces production potential, household income and demand for goods and services, and the value of total production decreases by 2.8 per cent compared to *bau*. This reduction influence the demand for energy services in TIMES and the total energy system costs, which Figure 6 and Figure 7 show.

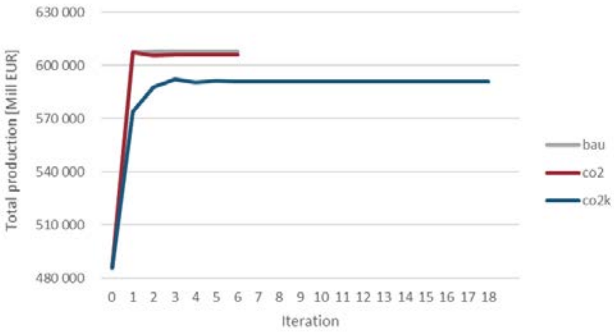

Figure 6 Value of total production in 2030 in REMES by scenario per iteration (iteration 0 shows production in base year 2010 for comparison)

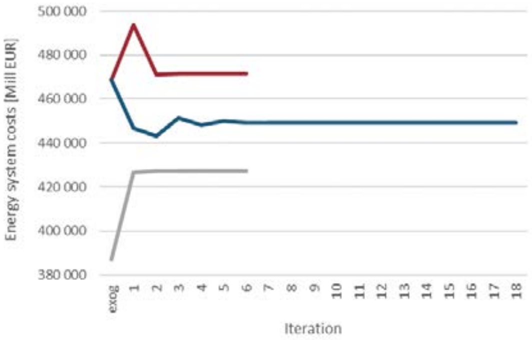

Figure 7 Total aggregated energy system costs in TIMES by scenario per iteration (the first iteration is based on exogenously given demand)

Figure 7 shows total system costs in TIMES, which grows considerably from the *bau* to the *co2* scenario while the *co2k* scenario ends somewhere in between. The constraint on CO_2 emissions from transport leads to higher investments in new technologies in TIMES. In scenario *co2k* these investments reduce production in REMES. Then demand for energy services decreases, and energy system costs in scenario *co2k* decrease compared to *co2*.

The capital linking provides important feedback and causes oscillations between the models. Total production in REMES (Figure 6) and energy system costs in TIMES (Figure 7) appear to be inversely correlated in scenario *co2k*, because increased costs in TIMES limit the growth in REMES.

In the first iteration (exog), energy service demand is given exogenously to TIMES from a national projection. We see that energy system costs increase significantly in iteration 1 in both *bau* and *co2.* The reason is that demands derived from REMES are higher than the exogenous demand in these scenarios, as we will see in Figure 8.

System costs in the *co2* scenario bounce back in iteration 2, due to changes in energy mix that REMES recognizes at this point. Further iterations appear to produce small movements after iteration 2 in scenarios *bau* and *co2*. This shows that energy mix feedback from TIMES to REMES has effects, but they are minor compared to the effects from the capital linkage. Keep in mind that we rescale Leontief coefficients to avoid income effects from the revised energy mix. We have seen that introducing such income effects have greater impacts than the isolated substitution effects of energy carriers.

Energy service demand

Figure 8 illustrates the demand in 2030 for the three main scenarios as well as the exogenous projection, divided into transport, residential and commercial (consisting of primary sector, manufacturing and services). In the *bau* scenario, the demand is higher than the exogenous projection in all sectors and all regions. In the *co2* scenario, the transport demand is reduced compared to *bau*, and the demand is reduced even further in the *co2k* scenario. For the residential sector, the demand in the converged solution is more or less identical in the *bau* and *co2* scenarios, which is higher than the exogenous projection. The *co2k* scenario experiences a slight increase in all regions for the residential sector compared to the exogenous projection.

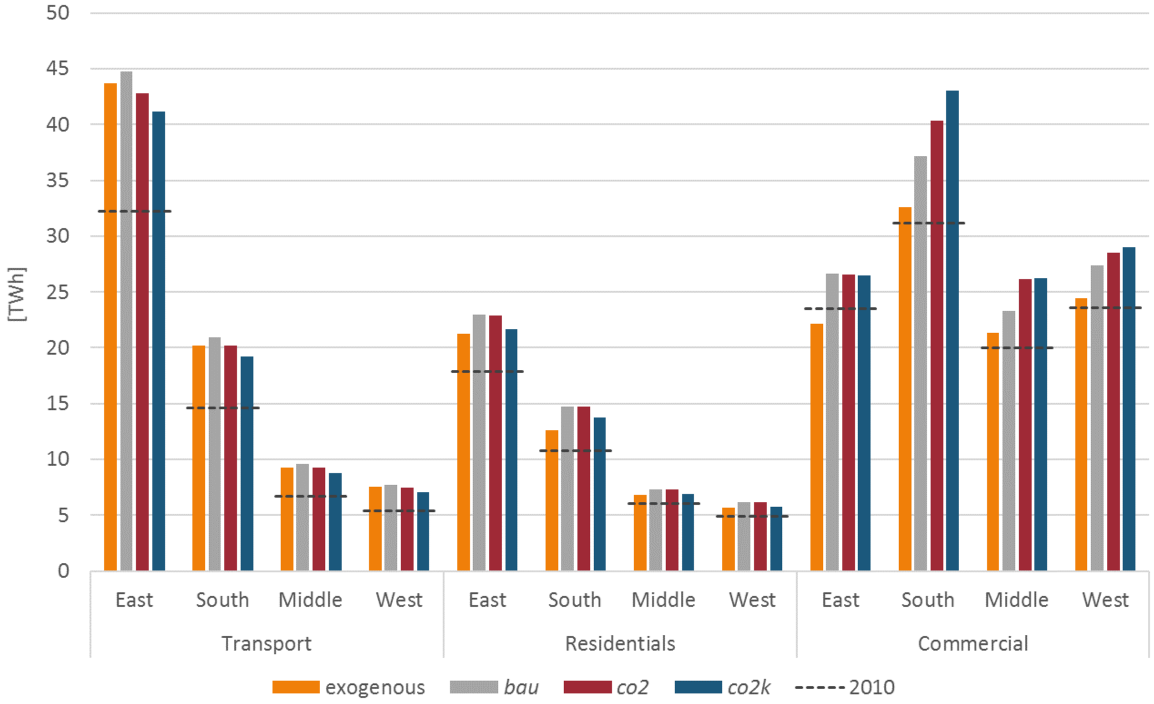

Figure 8 Projected demand for energy services in 2030 per scenario, region and aggregated sector, compared to 2010 (TWh)

For the primary sector, manufacturing and services (labelled “commercial” in Figure 8), the demand increases in all the scenarios compared to the exogenous projection. This can especially be seen in region South, but the increase is also significant in the other regions.

CO_2 emissions

Figure 9 shows the CO_2 emissions in 2030 from the transport sector in the three scenarios. Emissions based on exogenous demand and the converged solution as well as the first three iterations are included. As seen, the emissions in 2030 are restricted in both of the CO_2 reduction scenarios. The total national emissions related to transport are reduced to 6.6 Mt in 2030.

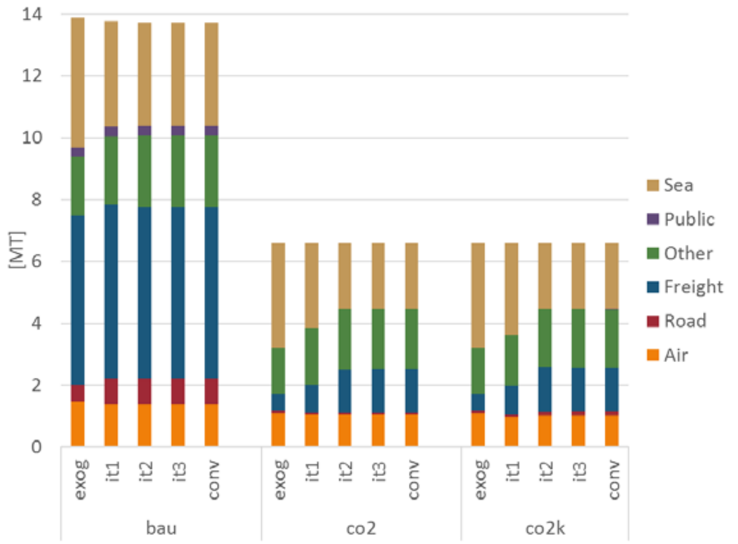

Figure 9 CO_2 emissions from transport in 2030

For both of the CO_2 reduction scenarios, the same trend is observed during the iterations. In the exogenous demand solution, emissions from sea transport account for approximately 50% of the total emissions. In the linked approach, emissions from other transport modes are highest, followed by sea transport. As seen, CO_2 emissions from freight transport increase during the iterations. There are relatively small differences between the *co2* and the *co2k* scenario. The former has slightly higher emissions from air and other, whereas the *co2k* scenario has higher emissions from road transport (i.e. cars).

In the *bau* scenario, the total national emissions decrease slowly from 15.6 Mt to 13.7 Mt in 2030. The reason for this reduction is that several new transport technologies are being used in the *bau* scenario, reducing the use of e.g. conventional diesel and gasoline engines.

Regional CO_2 emissions in 2030 from the transport sector are illustrated in Figure 10. 55% of the emissions in the *bau* scenario are related to transport activity in the east region, followed by 22% in region south. The solution based on exogenous demand allows region East to emit more CO_2 than the two hard-linked solutions, while the other regions show an opposite pattern.

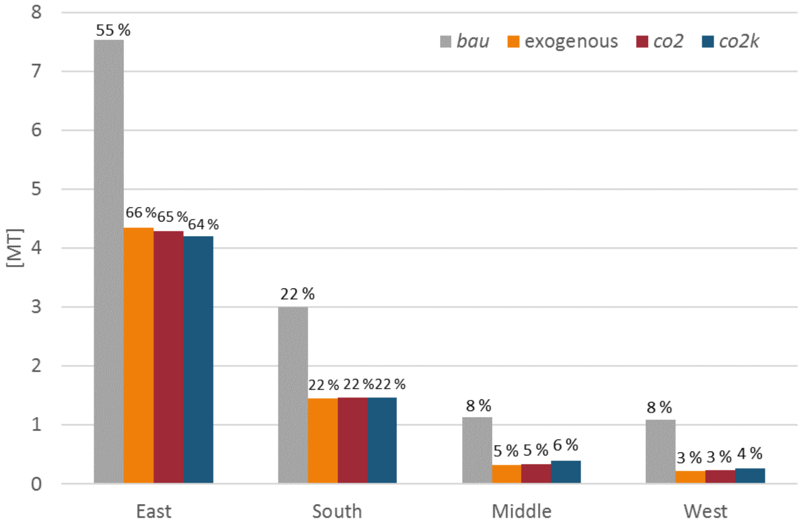

Figure 10 CO_2 emissions from transport in 2030 by region (converged solution). Relative figures (above bars) indicate regional contribution for the respective scenario.

Energy system investments

Figure 11 illustrates energy system investments in transport technologies in the planning period. The upper part shows investments that only occur in the CO_2-constrained scenarios, while the lower part shows the largest investments in *bau* as well. It is evident that the CO_2-constraint triggers large investments.

In the CO_2-constrained scenarios, a massive increase in the use of hydrogen based light (LD) and heavy duty (HD) trucks are experienced. At the same time, the use of conventional diesel trucks is reduced. For heavy duty freight transport, massive investments in hydrogen vehicles occur in 2030, whereas for light duty trucks, the investments include a combination of gasoline, diesel and hydrogen vehicles. Another main difference between *bau* and the CO_2 constrained scenarios is the reduced use of diesel for long distance car travels. The majority of the traditional diesel cars are replaced by investing in either plug-in hybrid diesel cars or hydrogen fuel cell cars. As seen in Figure 11, increased investments are also experienced in various hydrogen production technologies like electrolysis (mostly) and steam reformation of natural gas. In the *co2k* scenario, all hydrogen investments are made in 2030, whereas *co2* and *exog* starts in 2020 with hydrogen long distance cars and reformation of natural gas. A reduction in investments in electric vehicles for short distance travels is seen in the CO_2 constrained scenarios. This is due to reduced demand for short distance travels, and not because other technologies are being used.

Figure 11 shows that in the CO_2-constrained solution based on exogenous demand (*exog*), hydrogen based light duty trucks are used heavily. Transport investments in *exog* are 65 000 million Euro higher than in *co2k*. This is an indication that estimated investment costs based on inflexible exogenously given demand projections could vary greatly.

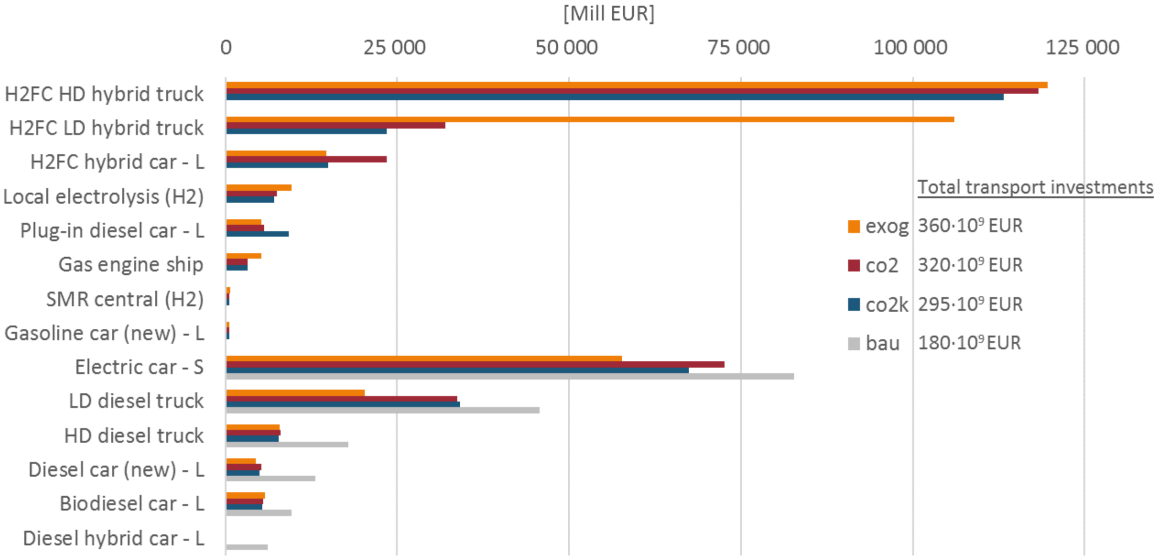

Figure 11 Total transport investments comparing the CO_2 constrained scenarios with the bau scenario (H2FC = hydrogen fuel cell, HD = heavy duty, LD = light duty, L = long distance and S = short distance)

Regional welfare analysis

Our models do not directly calculate environmental benefits from reaching the policy goal of reduced CO_2 emissions, they only assess economic costs of such policies. This means that we would need to compare the economic costs with the environmental benefits for full societal cost-benefit analysis of the policy scenarios. Here we use the Hicksian compensating variation (CV) [52] as a monetary measure of welfare loss. The CV takes the *co2k* equilibrium incomes and prices, and calculates how much income must be added in order to keep households at their *bau* utility level. Because our utility function is linear homogenous, the Hicksian compensating variation is computed as

$$CV_r = \frac{(U_r^{bau} - U_r^{co2k})}{U_r^{co2k}} I_r^{co2k}$$

Table 2 shows that the East region has the highest compensating variation, but its welfare loss as a percent of income is lowest of all. Regions South and West experience the highest welfare losses, compared to the *bau* scenario. Interestingly, the Middle region that loses the highest share of its capital growth still suffers less than the South and West regions.

Table 2 Hicksian compensating variation (CV) per region

	East	South	Middle	West	Total
Household utility					
bau	1.514	1.629	1.434	1.490	
co2k	1.421	1.507	1.341	1.380	
Price of utility					
bau	1.032	1.037	1.020	1.025	
co2k	1.023	1.027	1.010	1.015	
Income *[mill EUR]*					
bau	94 295	27 892	22 450	21 290	165 928
co2k	87 739	25 544	20 788	19 523	153 594
Hicksian compensating variation *[mill EUR]*	5 750	2 066	1 442	1 569	10 826
CV as share of bau income	6.1 %	7.4 %	6.4 %	7.4 %	6.5 %

We are able to track the CV during iterations, as shown in Figure 12.

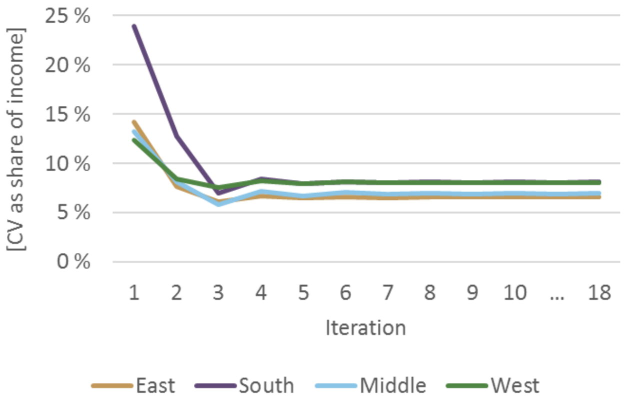

Figure 12 Compensating variation per region and iteration

Welfare losses are substantially higher during the first iterations. Eventually the hard-linked models converge to an equilibrium, where region South in particular has reduced its welfare loss compared to the initial iterations.

Welfare losses in the *co2k* scenario are corresponding to 6.5 per cent of the household income in the *bau* scenario. These figures may seem high. One reason is our conservative choice regarding the costs of the adjusted energy mix. In this study we rescaled the costs of the adjusted energy mix to become equal to the costs of the original energy mix, in order to isolate the substitution effects and neglect uncertain income effects from autonomous energy efficiency improvements (AEEI).

Comparing scenarios *co2* and *co2k* suggests however that income effects provide greater impacts than substitution effects. We suggest that AEEI improvements in the top-down model could be assessed based on results from the technologically more detailed bottom-up model. Preliminary experiments have indicated that income effects from energy efficiency improvements in the bottom-up model are significant, but these results require further investigations which fall outside the scope of this study and is left for future research.

Convergence

Figure 13 shows convergence results from the three scenarios. Each scenario run reaches the chosen tolerance set at 10^{-5} for the largest relative variable deviation between iterations.

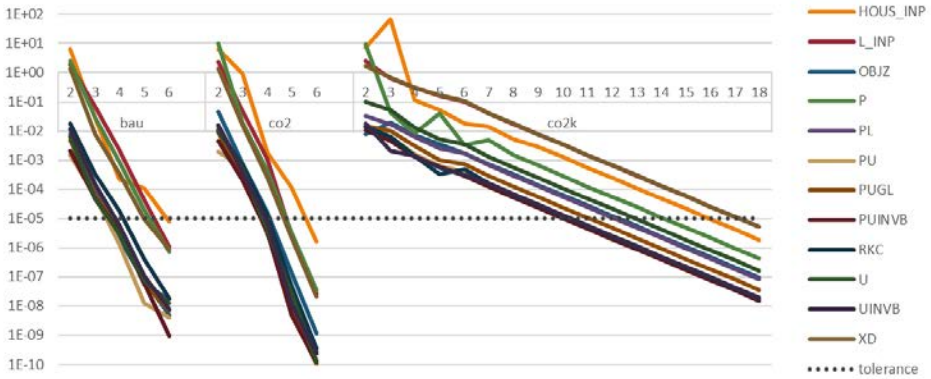

Figure 13 Largest relative variable deviations per scenario until convergence

The *bau* and *co2* scenarios reach convergence faster than the *co2k* scenario, which also links capital growth. The first two scenarios reach convergence after 6 iterations, whereas *co2k* needs 18 iterations. Computer running times are provided in appendix 7.5.

4 Conclusions

We have implemented hard-linking between a computable general equilibrium complementarity model (REMES) and an energy systems model (TIMES). This enables us to define sectoral energy policy measures and investigate ripple effects through the economy and regional welfare effects. The methodology developed in this paper represents a general and robust linking between top-down and bottom-up models using a full-link full-form approach.

Soft-linking will often lead to lower data granularity, and manual procedures will typically limit the number of iterations, resulting in less rigid convergence criteria. In this study using hard-linking, we were able to achieve stable convergence with a low tolerance of 10^{-5}. Earlier soft-linked full-link contributions have reported partial lack of convergence, see [18] pages 14, 15 and 20 and [19] page 722, footnote 4. Our hard-linking approach also exposed many convergence challenges. Initially we observed situations with multiple equilibria in the REMES model. These situations exposed model errors, which could otherwise easily go undetected. We have observed different kinds of cycling behavior during iterations, which we have been able to avoid by adjusting the linking calculations. Our full-link full-form hard-linking avoids human judgment and error, ensures replicability and speeds up scenario testing tremendously. It also exposes iterative challenges like cycling behavior, permits stringent convergence requirements, and increases the likelihood of detecting any multiple equilibria.

We have demonstrated this methodology on a study of the relations between the transport sector, the energy system and the regional economy using the models REMES and TIMES, with a target of decreasing climate gas emissions by 50% from the Norwegian transport sector compared to 1990. The target is reached by making technology investments in hydrogen vehicles. The considerable technology investments consume capital and limit the capital stock growth, decreasing the value of total production in 2030 by 2.8 per cent. The decrease in household welfare corresponds to a 6.5 per cent salary reduction.

The linking provides model harmonization, producing results that are consistent across both the bottom-up and top-down model[7]. The linking is also essential for levelling out regional welfare reductions. There are large regional welfare differences during the first iterations, and it takes several linking iterations before the regional effects stabilize.

The energy system costs from technology investments depend heavily on the demand differences in the various scenarios. This observation indicates that it would be relevant to extend the analysis with alternative policy options directly affecting demand, for example transport taxes or fuel taxes.

A promising area for further research is to assess autonomous energy efficiency improvements in the top-down model based on results from the technology rich bottom-up model in the linking procedures. Changes in the energy mix may then lead to important income effects as well as substitution effects in the top-down model. Integration of these effects provide an interesting area for future research, and availability of hard-linked models will greatly improve our ability to do so.

5 Acknowledgements

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7 Appendix

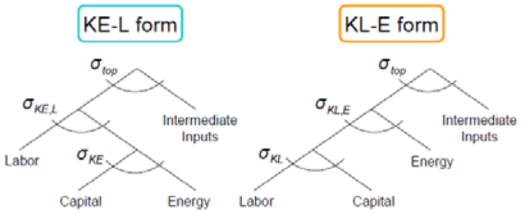
7.1 E3 and integrated assessment models

Top-down and bottom-up models in general belong to the broader class of energy-economy-environment (E3) models [19, 53], together with integrated assessment models (IAM) [54] which also should be mentioned here as a hybrid model approach. A broad definition is that IAMs integrate knowledge from two or more domains into a single framework [55], but the typical aim is to combine the scientific and economic aspects of climate change in order to assess policy options for climate change [56]. IAMs usually consists of many hard-linked modules [57], not only bottom-up and top-down.

7.2 Nesting structure

Nesting structures are commonly grouped into KLEM branches, where KLEM stands for Capital, Labour, Energy and Materials [58]. The two major forms of substitution structures are the ((KE)L)M and the ((KL)E)M forms [59].

Figure 2: Two major forms of substitution structures



The nesting variants (KE)L, (KL)E and (EL)K are compared for the German industry in [60] and [61]. The (KE)L nesting is chosen for the entire German industry, while (KL)E nesting is more realistic for most individual industrial sectors. All nesting structures are also systematically compared in [58], who concludes that the (KL)E nesting structure fits the data best. The same (KL)E nesting structure is used in [62]. Data from the World-Input-Output-Database (WIOD) is utilized to estimate a consistent dataset of substitution elasticities for the three-level nested KLEM production structure covering 35 industries. The elasticities are estimated by nonlinear estimation techniques. Relevant elasticities are compared with elasticities from [58-60].

We use elasticities reported in [62], but we let the bottom-up model decide the energy mix so we assume a Leontief nesting of energy goods (substitution elasticities are assumed to be zero). Both the top-down and the bottom-up model assume a region- and sector specific Leontief production structure. The Leontief assumption enables us to adjust Leontief coefficients for energy goods in the top-down model on the basis of energy quantities calculated by the bottom-up model TIMES.

7.3 Transport linking between REMES and TIMES

Table 3 Transport linking demand factors from REMES to TIMES

REMES (s)	TIMES (s')	$k_{s,s'}$ coefficient	TIMES unit
Air transport (TAIR)	Air transport (TAIRT)	1	GWh
Railway transport (TRAI)	Train transport (TPUTT)	1	GWh
Sea transport (TSEA)	Sea transport (TSEAT)	1	GWh
Agriculture (AAGR) Construction (CCON)	Other transport (TOTHT)	1 1	GWh GWh
Land transport (TLND)	Bus transport (TPUBT)	0.5	Mv-km [8]
Households (HOUS)	Long distance cars (TCART-L)	1.416	Mv-km
Households (HOUS) Land transport (TLND)	Short distance cars (TCART-S)	1.231 0.05	Mv-km Mv-km
Land transport (TLND)	Heavy duty freight (TFRET-H)	2	Mv-km
Land transport (TLND)	Light duty freight (TFRET-L)	2	Mv-km

Table 4 Mapping energy use from transport processees in TIMES to REMES sectors ($\mu_{p',s}$)

TIMES process	REMES sectors			
Bus transport (TPUB*)	100 %	Land transport (TLND)	-	(n.a.)
Train transport (TPUT*)	100 %	Land transport (TLND)	-	(n.a.)
Sea transport (TSEA*)	100 %	Sea transport (TSEA)	-	(n.a.)
Other mobile combustion (TOTH*)	67 %	Agriculture (AAGR)	33 %	Construction (CCON)
Air transport (TAIRT*)	99 %	Air transport (TAIR)	1 %	Households (HOUS)
Heavy freight (TFRET*-H)	100 %	Land transport (TLND)	0 %	Households (HOUS)
Light freight (TFRET*-L)	99 %	Land transport (TLND)	1 %	Households (HOUS)
Short distance cars (TCART*-S)	15 %	Land transport (TLND)	85 %	Households (HOUS)
Long distance cars (TCART*-L)	1 %	Land transport (TLND)	99 %	Households (HOUS)

7.4 Effect of capital linking in *co2k*

Energy system investments in TIMES are significantly higher in the CO$_2$ reduction scenarios than the *bau* scenario, as shown in Table 5. Total investment costs are EUR 177 million in the *bau* scenario, while investments increase to EUR 296 million in the *co2* scenario. This bottom-up increase in investments affects capital growth in the top-down model. REMES decreases demand and investments revert to EUR 275 million in the *co2k* scenario.

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[8] Million-vehicle-kilometers

Table 5 Regional investment costs in bottom-up model [million Euro]

Region	bau	co2	co2k	Increase bau->co2k
East	76.6	127.4	121.1	58 %
South	50.5	79.4	73.3	45 %
Middle	25.0	47.2	40.4	62 %
West	25.2	41.9	40.3	60 %
Grand Total	**177.3**	**296.0**	**275.1**	**55 %**

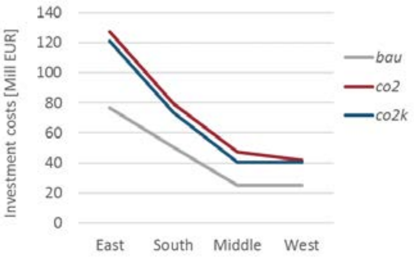

Figure 14 Regional bottom-up investment costs per region by scenario

The regions have different base year levels of capital, and the investment needs from the bottom-up model have different regional damping effects on capital growth.

Figure 15 shows regional capital growth adjustments in REMES due to investments in TIMES:

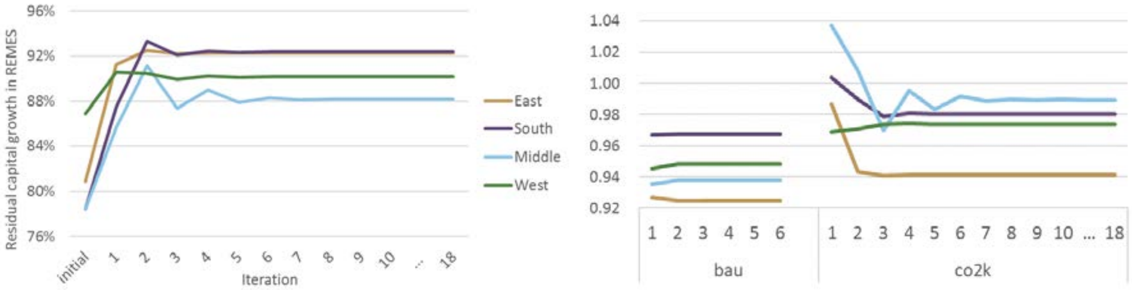

Figure 15 Regional capital growth adjustments in REMES due to investments in TIMES (*co2k* scenario)

Figure 16 Cost of capital per region for *bau* and *co2k* scenario

The East region has the largest capital base, and region South has the lowest growth of TIMES investments. Both regions have smaller decreases in capital growth than the other regions, as Figure 15 shows. Regions Middle and West have similar capital bases, but TIMES investments are larger in the Middle region. This region has the largest drop in capital growth. We also see in Figure 15 shows that this region has the largest fluctuations during the model linking iterations. Figure 16 shows how the cost of capital depends on the capital stock growth adjustments. The cost of capital is low during the *bau* iterations, since the full capital stock growth is available in REMES. When capital is consumed for technical investments in TIMES, the cost of capital is affected inversely. In the next section we look at the regional welfare consequences.

7.5 Computer runtime

Computer runtime on a Dell Precision T7600 with two Intel Xeon CPU E5-2650 2GHz processors are shown in Table 6.

Table 6 Computer running times

Scenario	Total run time	Top-down run time	Bottom-up run time	Top-down share	Bottom-up share	Itera-tions	Minutes per iteration
bau	2h 52m	0h 06m	2h 46m	3.5 %	96.5 %	6	29
co2	3h 05m	0h 06m	2h 59m	3.2 %	96.8 %	6	31
co2k	8h 53m	0h 19m	8h 34m	3.6 %	96.4 %	18	30

7.6 Data mappings

Table 7 shows instructive examples of the data mappings.

Table 7 Mapping of data structures

id	Mapping	TIMES bottom-up (example)	REMES top-down (example)	Coef-ficient
a)	Regions $R_{r'}$ and R'_{r} TIMES regions towards REMES regions (5 mappings in total)	NO1 NO2 …	R1 R2 …	n/a n/a
b)	Energy commodities $C_{c'}$ and C'_{c} TIMES energy commodities mapped towards energy commodities in REMES. (50 mappings)	NG-L NG-LPG … BIO-PEL	c_NG c_NG … c_BIO	n/a n/a n/a
c)	Sectors TIMES→REMES $\mu_{p',s}$ TIMES processes (demand devices) mapped towards REMES sectors. (519 mappings)	CEDUH001 (oil boiler, education) CEDUH002 (natural gas boiler, education) … TCART401-S (Gasoline car short distance) ″ … TOTHT400 (Fuels for transport use - other mobile combustion) ″	i-CEDU ″ HOUS i-TLND i-AAGR i-CCON	100% 100% 85% 15% 67% 33%
d)	Sectors REMES→TIMES $k_{s,s'}$ TIMES energy services in demand sectors mapped towards REMES sectors (83 mappings)	COFFE (electricity demand in commercial offices) COFFH (heating demand in commercial offices) … TCART-S (Personal Cars Short Distance) ″ … TOTHT (Other mobile combustion) ″	i-COFF ″ HOUS i-TLND i-AAGR i-CCON	0.703 0.535 1.231 0.05 1.0 1.0

Table 8 show complete mapping between regions.

Table 8 Mapping of geographical regions

BOTTOM-UP model (TIMES)	TOP-DOWN model REMES	Description
NO1	R1	East Norway
NO2	R2	South Norway
NO3	R3	Middle Norway
NO4	R4	North Norway
NO5	R5	West Norway

Table 9 show complete mapping between energy commodities in TIMES and REMES.

Table 9 Mapping of energy commodities

TIMES commodity	TIMES description	REMES commodity
ELC-HP	Electricity High Voltage: From unregulated hydro	c_POW
ELC-HV	Electricty High Voltage	c_POW
ELC-LV	Electricty Low Voltage	c_POW
ELC-LV-LOSS	Electricity Low Voltage: Losses in grid	c_POW
ELC-LV-LOSS-DEMAND	Demand for LV-losses in grid (dummy)	c_POW
ELC-WP	Electricity High Voltage: From wind power	c_POW
BIO-BAR	Bark	c_BIO
BIO-BLI	Black liqour	c_BIO
BIO-COAL	Bio-Coal	c_BIO
BIO-COKE	Bio-Coke	c_BIO
BIO-DSL	Biodiesel (2. gen)	c_BIO
BIO-ETN	Ethanol (E85)	c_BIO
BIO-FOR	Biomass from forrestry	c_BIO
BIO-MWS	Municipal waste	c_BIO
BIO-OILI	Syntetic biomass oil, industrial use	c_BIO
BIO-OILS	Syntetic biomass oil, stationary use	c_BIO
BIO-PEL	Pellets	c_BIO
BIO-SAW	Biomass saw	c_BIO
BIO-WDO	Wood	c_BIO
COAL	Coal (COAL-HC & BIO-COAL)	c_COAL
COAL-COKE	Coke	c_COAL
COAL-HC	Hard coal	c_COAL
OIL-CRUDE	Crude oil	c_COIL_
LTH	District heating	c_LTH
LTH1	District heating to grid	c_LTH
LTH-ALA	LTH Aluminium A	c_LTH
LTH-ALR	LTH Aluminium R	c_LTH
LTH-EDU	LTH Education	
LTH-HEA	LTH Health and social services	
LTH-HOT	LTH Hotel and restaurant	
LTH-MEA	LTH Metal industry A	c_LTH
LTH-MER	LTH Metal industry Rest	c_LTH
LTH-MUN	LTH Multi-family houses, new	
LTH-MUO	LTH Multi-family houses, old	
LTH-OFF	LTH Office buildings	
LTH-OTH	LTH Service sector other	
LTH-PPA	LTH Pulp and paper A	c_LTH

LTH-PPR	LTH Pulp and paper R	c_LTH
LTH-RES	LTH Rest industry	c_LTH
LTH-SIN	LTH Single family houses, new	
LTH-SIO	LTH Single family houses- old	
LTH-ST-RES	LTH Steam Turbine Rest industry	c_LTH
LTH-WSR	LTH Wholesale and Retail	
LTH-ALB	LTH Aluminium B	c_LTH
LTH-ALC	LTH Aluminium C	c_LTH
NG-CNG	Compressed Natural Gas (CNG)	c_NG
NG-L	Natural gas before pipeline distribution (for indu	c_NG
NG-LPG	Liquid Petroleum Gas	c_NG
NG-PL	Natural gas after pipeline distribution (local)	c_NG
OIL-DSL	Diesel	c_OIL-DSL
OIL-GSL	Gasoline	c_OIL-GSL
OIL-HDI	Heavy distillate for industry	c_OIL-HD
OIL-HDT	Heavy distillate for transport	c_OIL-HD
OIL-JET	Jet fuel	c_OIL-JET
OIL-KER	Kersoene	c_OIL-KER
OIL-LDI	Light distillate, industrial use	c_OIL-LD
OIL-LDIF	Light distillate, industrial use (fossil)	c_OIL-LD
OIL-LDS	Light distillate, stationary use	c_OIL-LD
OIL-LDSF	Light distillate, stationary use (fossil)	c_OIL-LD
OIL-LDT	Light distillate for transport (marine diesel)	c_OIL-LD