EUCALC

Explore sustainable European futures

Lessons learnt from EUCalc: further research and innovation needs

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Main authors	Juergen Kropp
Partner in charge	PIK
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1 Executive Summary

This report summarises the main achievements, lessons learnt and still open research gaps the European calculator project has identified during the course of its project work. The following text provides an overarching view on the main findings of the project, how decisions have been made and which problems persist. All partners provided first-hand information on their particular challenges they were facing. Several point have been identified which could be improved and can create directions for further research.

2 Introduction

The mission of the European Calculator (EUCalc) Project is to develop a new model for an assessment of climate protection solutions for Europe as a whole and for European Member states plus Switzerland. Given the complexity of the interrelations between energy demanding/supplying sectors it is currently difficult for stakeholders to maintain a sound overview of potential pathways. Consequently, EUCalc developed a new approach which covers all GHG emitting sectors and many related resources, but simplified the interrelationships between sectors by cutting some of the most complex feedback loops in the least impactful links. All users can have access to the model and play with contrasted assumptions about future developments in Europe as a whole and for each member country. The model is rooted between pure complex and dynamic society-energy system and integrated impact assessment tools. It introduces an intermediate level of complexity and a multi-sector approach that is based on co-design with scientific and societal actors. The model relates emission reduction with human lifestyles, the exploitation and/or conservation of natural resources, job creation, energy production, agriculture, costs, etc. in one highly integrative approach and tool which enables decision makers to get real-time policy support underpinned by comprehensive trade-off analyses (cf. Figure 1). The approach therefore is pragmatic as it addresses the need of politicians and experts. This deliverable sums up the experiences made during the course of the model development. It shows that it was a tremendous endeavour to develop a completely new approach from scratch within a time horizon of three years. To some extent, the time required, the complexity and interdependencies between the sectors, the necessary and very specific coordination amongst the partners, the very intensive stakeholder dialogues, the underlying programming challenges as well as the necessary quality checks, were underestimated. This caused delays and ended up in the request for a four-month project extension. However, despite of these shortcomings the project could be steered to a good end, i.e. the promised tools and model are developed. Nevertheless, some shortcomings remain and it is the purpose of this deliverable to discuss the lessons learnt and where the EUCalc consortium still sees research gaps and therefore the need for further developments.

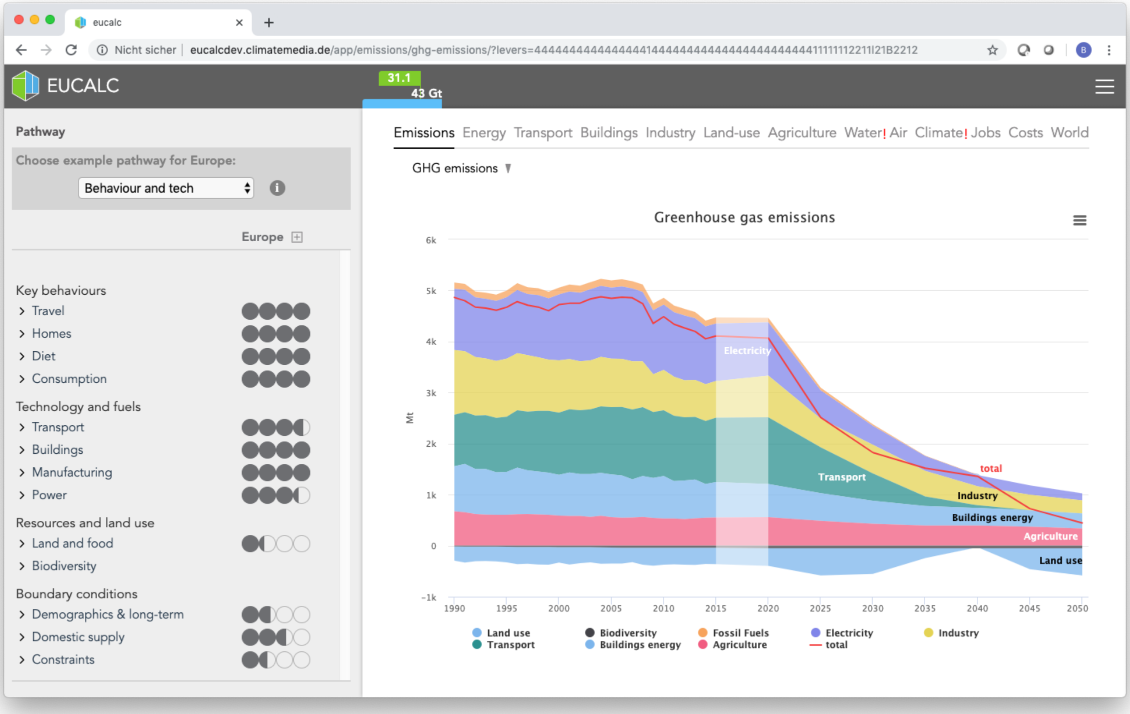

Figure 1 – The EUCalc Transition Pathways Explorer web application showing greenhouse gas emissions from 1990 to 2050 set to the "Middle of the road" example pathway.

2.1 Core elements of the European Calculator model

The European Calculator idea was motivated by an idea of Sir David MacKay (Mackay, 2009), the former chief advisor for energy policy of the former UK Dept. Energy and Climate Change. He motivated also the so-called "Global Calculator (GC)", approach, a zero-dimensional supply and demand model for the earth as a whole and for trade-off and co-benefit analyses of society-energy systems. As in the GC, the EUCalc model core is based on a directed graph model comprising different intersection nodes representing information exchange and interrelationships between sectors. In comparison to its origin, the EUCalc approach covers much more complexity, i.e. as it considers many more interrelationships and has as standard resolution the European Member states plus Switzerland. The graph models and calculates energy supply and demand and the conversion of fossil fuels into carbon dioxide emissions. As such this part is not time explicit. The time development is introduced by time series data for each sector, which is needed for the forcing of the model. In terms of scenario calculations the sectors are important. For each of these, so-called levers have been defined on the basis of a sound scientific reasoning process. The ambition level settings of the levers represent scenarios for potential sector developments, i.e. whether a sector and consequently a country or Europe proceeds along a more business usual pathway or is "Apollo"-ambitious in terms of achieving carbon neutrality. As main outcome the European Calculator estimates emission and energy pathways, but also calculates impacts, i.e. on health or job creation Similar to the GC approach stakeholders have played an important role in the

European Calculator project - in two ways. Firstly, stakeholder workshops were organised to estimate and concretize the user demand. Secondly, expert workshops have been organised together with the sector responsible partners. The idea was to gain their views about technological sector developments and societal achievements for countries and for Europe as a whole when it comes to climate protection targets.

This deliverable is mainly organised into three parts. In the subsequent section the main conclusions drawn from the three years of project work will be discussed. This is followed by a description how the stakeholder process in EUCalc was organised and what has been learnt from this exercise. This is followed by a more detailed description of the project as a whole and of sector issues.

3 Thoughts on stakeholder engagements

As climate protection and sustainable futures are socially important tasks which need to be solved in a dialogue and cooperative concerted action EUCalc involved hundreds of stakeholder from the beginning of the project. For all partners these intensive stakeholder dialogues were an experiment creating important insights for the consortium, but also for the form and organisation of such dialogues.

3.1 Problems during stakeholder dialogues

The nature of the EUCalc was accompanied with a strict schedule of the stakeholder dialogues. In general the project had planned three kinds, namely demand concretization workshop, sector expert meetings, and outreach dialogues. While the two previous had been organised the outreach dialogues are still pending. The sector expert meetings were by far the most time demanding, as for each sector experts needed to be identified and the meeting to be prepared from different points of sector views. In terms of a coherent process, it was difficult to find the right timing between the expert workshops and the model development work. The reasons were various a briefly explained in the following:

- Overall, several efforts for the model development were underestimated, which impacted on the stakeholder involvement.
- The whole process was time consuming and resource demanding, also in terms of maintaining continued engagement throughout the development of model to maintain interest and involvement.
- Geographic scope requires a pragmatic approach to stakeholder engagement in terms of capturing knowledge from certain contexts and particular groups rather through representative bodies.
- Would have been greatly assisted if a beta version of the model - even for one country - had been available as planned for stakeholder workshops.
- Extension and delay in delivering the TPE had a significant impact on planned outreach to members of the European Parliament.
- The launching of the call for evidence before the model and the TPE were properly usable was in retrospect a significant factor for a limited of feedback.

- Of the groups identified as critical stakeholder segments, the outreach to EU Parliamentarians was fractured due to internal deliverable issues. As the parliament was newly elected some efforts need to be replicated.

3.2 Achievements and Benefits from stakeholder dialogues

- Having expert stakeholders in a face to face discussion revealed much richer information on the levers and assumptions and improves the evidence base for the model development.
- It created new collaborations as a result of demands arising from the process of co-design and stakeholder engagement (JRC, IIASA etc.).
- A systematic methodology - including a high level of transparency and clarity in input management - produced more consistent and verifiable results.
- A systematic approach to stakeholder mapping broadened thinking about the range and profile of stakeholders and ensures that all major types of stakeholders are given the opportunity to provide input.
- Helps to build a database of potential future supporters and promoters in the dissemination phase.

In general the stakeholder involvement was a very important aspect of the project. It allowed to precise the scope of some modules (e.g., lifestyles and socio-economic impacts) and to gather feedback, for example, on the ambition levels or methods used. However, gathering an exhaustive and balanced "map of stakeholders" was sometimes challenging while the presence of all stakeholders' groups may not be necessary at each stage of the project (for example feedback on the methods used require experts and not policy makers).

3.3 Lessons learnt for future projects

During the early phases of the project it is essential to realistically plan with sufficient time for the team building (experts). This holds for the time planning, but also for preparatory documents. In the EUCalc this was underestimated. Enough time and a sound briefing is a major precondition for a successful stakeholder event. In particular to the EUCalc project some further points were essential:

- to have a strict deadline for recruitment of - and agreed with - consortium member teams to be in place which occurs early in project,
- to ensure that future projects front load deadlines for crucial products so that the products are ready when required,
- to ensure that future budgets have a research contingency so that new data which surfaces as part of stakeholder engagement can comfortably be built into the modelling process,
- a good phasing of stakeholder engagement is critical in order to maintain interest (e.g. workshops, Call for Evidence),
- project extensions could have unintended consequences (cf. above),
- considering the weighted importance of stakeholder engagement in this type of model and in this project, it would be desirable to have a more advanced academic partner with more deep and theoretical expertise on

stakeholder dialogues to document the research component of these activities,
- during the stakeholder dialogues many topics were brought into the discussions which could not discussed and integrated completely.

4 Main Achievements and Research Gaps

The EUCalc model goes clearly beyond the GC and other country derivatives in terms of model depth and spatial resolution. This is due to its design outlined in the DoA, although all partners were aware of the fact the idea to develop a European Calculator with a country resolution describing interdependencies and between EU and countries and the rest of the world was an endeavour.

4.1 Overarching Achievements

The EUCalc project has reached the following key achievements:

1. The models represents an increased sectoral complexity, e.g., better representation of lifestyles choices, more food groups and production options in agriculture, detailed modelling of land use dynamics, closer link between the demand and supply of electricity (i.e., not only a warning, but production capacity adjusted to satisfy balancing), to mention a few.
2. Increased inter-sectoral complexity: the model is one of the most advanced in terms of its coverage of the key value chains. The demand for products (e.g., cars in transport, new houses or fertilizers in agriculture) is connected to material demand (e.g., steel for cars, cement for buildings, and ammonia for fertilizers), which provides clear hints that circular economy could create important impacts.
3. Increased spatial complexity, i.e. it has a resolution of 29 countries plus the European Union and the rest of the world as the whole, which for instance, allowed to implement regional (inter-country) electricity balancing (i.e. import-export) or sub-country water scarcity calculations.
4. Implementation of new features and additional types of impacts, e.g., impacts on water (consumption, withdrawal, water stress), health, biodiversity, employment, trade, etc..

4.2 Remaining research gaps

Although EUCalc made great achievements, the team also partly underestimated the necessary work load and made too enthusiastic assumptions about the time necessary for sector developments. However, it is a great achievement to have implemented a country resolution and even an extended spatial resolution below the country level for some sectors. This indeed can be improved even further, for example for land use, health, economics and climate. Despite of the achievements the team identified many additional research gaps, namely:

1. It was tried to introduce a more economic rationale into the engineering-based calculator approach. It seems rewarding to investigate, how to better integrate general insights gained from economic models - or an advanced economic rationale - into the calculator model. Some economic constraints, for instance, could be directly included in the lifestyle module, partially driving individuals' behaviours and firms' choices in industry or freight transport.
2. In terms of the previous it is also necessary to investigate further the potential feedback loops. In the current version, loops (feedbacks) have been simplified wherever possible in order to keep the complexity manageable and, in particular, to keep the model reasonably fast. However, this puts some severe constraints on several modules. Such a simplified approach was sometimes not optimal given the integrated nature of some problems at hand (see below, more details regarding CCUS, water and employment).
3. Some key connections between sectors are also missing in terms of the impact of demand side sectors on electricity balancing alternatives. Demand-side options have been covered with limited details so far.
4. The calculator model together with the TPE provides a road forward for policy makers. While EU/country objectives or targets are well represented in the model, the impacts of monetary instruments (e.g., tax and subventions) are more difficult to assess. To provide this information, a policy calculator/interface would be required to translate the "engineering-based" levers into policy levers, or vice versa. A kind on a more advanced "economic module" discussed above could help achieve this goal.
5. Due to the underestimated development load the scientific exploitation of the project results is still pending.

4.3 Lessons Learnt

Compared to existing models, EUCalc offers a wider scope by combining modules such as lifestyles, buildings, transport, agriculture, industry, energy supply, water, employment, etc. It is thus, a unique approach thanks to its detailed representation of society and of the interactions between sectors. As a drawback, the model and TEP are not yet as mature as existing models and it cannot go into the same level of details as models focusing mainly on only one sector. The following conclusions can be drawn from the project work:

1. There is a high demand and interest for tools such as the EUCalc Transition Pathways Explorer. In particular, the multi-disciplinary nature of the project and its objectives (transparency; open source regarding assumptions, data, model) received plenty of positive feedback from the research community during conferences and seminar, and from stakeholders during workshops.
2. Taking into account the complexity, the time, and the coordination need of the EUCalc endeavour a critical partner selection is needed, as several partners were on very different levels in terms of necessary skills.
3. The user-friendly online interface, as well as the emphasis on dissemination and communication (MOOC, policy briefs, educational tool, etc.), is a highlight of the project and is critical to reach the public/stakeholders. One can only regret the limited time available for these tasks, given the delays in the model design. Nonetheless, these

kinds of efforts to bring science to the public/policy makers should be a must for any project.
4. Opening the simulation space to the users, thanks to levers and an intelligible exploration interface (the Transition Pathways Explorer, TPE, cf. Fig. 1), allows to simulate a full spectrum of pathways instead of a set of predefined (subjective/narrow) scenarios. This idea, coming from engineering-based calculators, could actually inspire modelling in other fields, as e.g. economics (see research gaps).
5. Exchange with stakeholders and input received from the call for evidence provided the impression the TPE web application was highly welcomed. However, many people either think that the tool is too limited to model the very specific sensitivities they want to test, or many others find it too complex. Therefore, it was decided to widen the target group for the simpler my2050 version of the web application.
6. The EUCalc model is a data-rich model, i.e. it requires a lot of data to properly calibrate the model and thus appropriately simulate decarbonization pathways. The sectoral and/or spatial granularity needed for this purpose was sometimes not available, or of low quality. Improving/developing such a database would be of great help for research projects similar to EUCalc.
7. The use of the KNIME software for sectoral modelling purposes was a novel idea and a strength in accommodating the complexity of the EUCALC model. In particular it supported also partners with less expertise in modelling and programming. This was also geared towards enabling the real time effect for the tool with an increased level of transparency. Indeed, transparency was a feature not just proposed by the consortium, but one element that was demanded by policy makers during the first co-design workshop held in Brussels in March 2017.
8. Indeed, KNIME was suggested as one solution in the DoA and it came with a price. The increasing model complexity had the cost, that the "real time" target is still extremely difficult to achieve, because of the fact the KNIME codes needed to be translated to Python. Therefore, it is desired to have a second version programmed in C/C++ and parallelised. Tests have shown that the response time of the system on requests could be increased by at least a factor ten.
9. As constructed, the EUCalc model, allows the user to near-freely explore the option space for decarbonization that would otherwise be narrowed down to the constraint of optimum economic feasibility. This is, at the same time, an advantage and a disadvantage. The latter because the EUCalc model cannot contribute in equal terms to the mainstream narrative and provide a range of least costly mitigation paths. The advantage is that it frees users to detect combinations of levers that break long established trade-offs in other modelling exercises. A concrete example of this is the competition between land available for food production and bio-fuels
10. A comparison of the EUCalc output with other output from existing models (scenario comparison) is still a task to do. In this context also a formal framework for an uncertainty assessment should be introduced. While some uncertainties are managed with a lever choice, others are possibly not obvious as hidden in interrelationships between sectors. Another point to be crosschecked relates to the potential impact of simplification of

feedback mechanisms. It might be that this could lead to an under-/overestimation of emissions.

11. The EUCalc model is a multidimensional model that was transdisciplinarily built. The team had to grapple with the multiple methodological and technical challenges, such as coupling CGE models with I/O models, and speaking a common language.
12. On the methodological challenges, each sector has its own needs. For example, multiple spatial resolutions (e.g. from local water basins to European electricity networks); multiple time scales (intra-day to seasonal for power balance, seasons for water, etc.) and multiple databases with heterogeneous level of details.
13. Regarding the technical issues, the multi-disciplinary nature of the team provided all the richness that such a team can bring, but also presented as a challenge for achieving scientific robustness. In terms of the latter it is desired to evaluate robustness and consistency (cf. also point 10).
14. The number of deliverables (approx 70) was too high and not always necessary in terms of content partitioning, e.g. some could have been merged easily. Moreover, a lot of deliverables relied on the model output which did generate multiple delays in their delivery. Last but not least the internal review process was also very time demanding
15. As the project brought together a number of people with different programming experience putting together their contributions following their own logic created some problems. Hence, the quality of the code and programming may not be coherent across modules that could also affect the long execution time of the runs.
16. The EUCalc model allows the user to sequentially trace, from demand to supply to emissions, the main leverage points to reduce GHG in particular sector and at an aggregate level. That said, it will remain challenging for non-experts to fully exploit these leverage points given the amount of lever combinations available to reduce emissions. This situation has not improved from previous calculators (see more on research gaps in the respective sector descriptions, point 5 and comments below).

Summing up, EUCalc made many progress and could fulfil promises. However, in some terms the consortium was too enthusiastic in its assumptions. First and foremost this holds for the time. Given the workload 3 yrs was too short.

While the KNIME for developing the code was appropriate, given the complexity of the model, the high number of interfaces between modules, the transparency (as an added value) is questionable. Nonetheless, the code is open source, as well as the documents are available, but considering the time and coding constraints to read and understand it, it could be doubtful that politicians, as the main target group of the tool, will make a deep dive to understand the calculations. For a full understanding scientific competence is still needed (cf. also point 5 above). However, although there is additional complexity inherent in the new EUCalc modelling framework, the EUCalc approach provides a clear step forward, namely in particular:

- An integrative platform that encompasses EU28+1 member states,
- A first take on transboundary issues, and further sector representations,
- A research tool (the online transitions pathways explorer TPE).

In particular, the complexity of necessary team exchange as well the one related to model has been managed while ensuring at the same time:

- Openness – the model and its data are will be fully published and freely available online
- Collaboration – the model was built by an European team with input from hundreds of experts
- Simplicity – the modelling strived to be as simply as possible, while still including all energy, emissions and a full range of future scenarios, and properly covering the key sector interlinkages
- Transparency – using the principles of 'co-design' and public calls for evidence ensured significant engagement from all relevant sectors of society

This has led to discontinuities in the user-led, co-design and sector modelling activities. An additional 12 months would have been needed for a final iterative cycle of model development, stakeholder engagement and co-design.

5 Sector Specific Issues

5.1 Carbon Capturing, Utilization, and Sequestration (CCUS)

5.1.1 Achievements

The CCUS module provides a detailed analysis of the CCUS process by breaking down the carbon flow from capture (CC), sequestration (CCS) and utilization (CCU). The carbon is captured in industry and power subsectors (including biogenic carbon capture) by CC technologies in a process-specific granularity in agreement with technological and economic feasibilities. The CCUS module provides the data as well as the decision support for carbon capture in the other two subsectors. Once captured, the carbon can be either sequestrated or utilized depending on a lever position and on the potential left for sequestration. This CCS potential for EU28 and Switzerland is analysed country-specific according to the geological and geographical limitations, taking into account on-shore and off-shore carbon storage potential and including analysis of carbon transportation from sources to sinks (e.g. existing pipelines). This allows to analyse the bottlenecks in carbon transport and sequestration on the European map. If not sequestrated, the carbon is used and transformed into synthetic natural gas, providing a "carbon-neutral" alternative to natural gas since the electricity used for the transformation process (to produce hydrogen) comes from excess renewable electricity.

5.1.2 Further Research/Going Beyond

Currently, the carbon utilization (CCU) route modelled in the CCUS module is production of synthetic natural gas which is then transferred to the minerals module. Four alternatives (including different fuels and chemicals) were originally considered and aborted due to calculation chain issues. The sequential resolution approach of the calculator does not allow to create "loops" which would send products of the CCUS module to modules upstream of the calculation chain (e.g. the transport, industry, power). This limits the flexibility of the CCUS modelling approach, which could only partially be overcome by demand-driven modelling, as is explained in the following paragraph.

The current logic of the CCUS is that the carbon available from the industry and power sectors for capture drives the use and sequestration processes. As an alternative, CCS and CCUS could be modelled independently. While CCS could still be computed thanks to a CC lever (controlling the amount of carbon captured in industry and power), CCU could be determined by the demand of synthetic fuels (also called "e-fuels"). This would allow to deepen the policy narratives for instance in the transport sector where e-fuels could be an alternative to electrification. However, this improvement requires several adjustments of the model. First, direct air capture technologies – currently left out due to their prohibitive cost and heavy energy penalty, which creates a computational loop issue with the power supply module – should be introduced in the model. Second, the conversion road "renewable electricity to hydrogen to e-fuels" must be better represented in the power supply sector, which also entails a better integration of the CCUS and energy production modules, thereby moving the CCUS module upstream of the calculation chain and making it a "core" module. Indeed, the focus of the CCUS module would move from a mean to limit/decrease the GHG emissions towards a way to produce alternative e-fuels in the context of an increasing penetration of renewables.

5.2 Water issues

5.2.1 Achievements

In the water module, an enhanced space and time granularity has been implemented to better represent water issues. This holds also for sub-national entities in Spain, Italy, Greece, France, UK and Germany. In the approach two seasons, namely winter and summer are distinguished.

Thanks to the links with sectoral modules (e.g., lifestyle, agriculture, industry, energy), the water module provides a detailed analysis of the sectoral water consumption and withdrawal. In addition, the European map of the water stress (ratio between water consumption and availability for each region) provides information on which regions are at risk and when, and thus on the potential competition for water use, which could jeopardize the food production or the cooling of power plants.

5.2.2 Further Research/Going Beyond

Hence, the proposal focused on the most intensive sector in terms of energy consumption and GHG emissions. Water issues, although mentioned, were incorporated as an addition. This rationale is reflected in the model since the water module is at the end of the chain, thus limiting the scope of the module. For instance, the impacts of water shortage on the agriculture and energy production system were included directly in the agriculture and power modules using inputs from the climate module. To better represent water issues in a calculator, a more integrated view of the water-energy-food nexus is necessary. This would allow to introduce different water supply options (e.g. desalination, rainwater collection, water treatment and reuse) in the model and thus to better analyse the impacts of water management policies.

In addition, while the calculator adopts a country resolution, water issues should generally be addressed using a water basin granularity. This was partially tackled in EUCalc by splitting large countries into smaller regions. The resolution adopted represents a trade-off between precision, available information and computation time. Still, it could be adjusted to better fit with water basin borders.

Finally, the calculator country perspective also hides the detailed location of activities. However, this information is crucial since the quantity and quality of water flows are affected by the upstream activities. Hence, the water module presents regional water stress map but could not dive into more details. In particular, water quality issues (e.g. chemical and heat pollution) were left out of the model. One possibility to tackle these issues would be to enrich the calculator with Geographical Information System. Nonetheless, given the complexity of this task, limiting the scope to one country is preferable.

5.3 Employment

5.3.1 Achievements

The employment module computes the employment impacts (labour participation and wage evolution) for each decarbonisation pathway using a macroeconomic model specifically designed for EUCalc. The detailed representation of the economy allows for a close interface with the sectoral modules (e.g. lifestyle, building, transport, agriculture, industry and power) and to better understand which economic sectors are more affected by a transition toward a low-carbon economy. The inclusion of skill heterogeneity (i.e. educational attainment) provides information on which population groups are more vulnerable, and thus on the needs for education and training. The scope and questions addressed by the module were defined thanks to stakeholders' consultation workshop.

Compared to the existing model and studies looking at the impacts on employment of decarbonization, the employment module offers a larger flexibility and scope. For instance, the model can compute the impacts on employment of lifestyles changes, while those are often overlooked in the literature. Moreover, the Employment module has accessed to detailed sectoral information thanks to the coupling with the sectoral modules. On the other hand, a standard macroeconomic model cannot have the in-depth sectoral representation achieved by the EUCalc modular approach.

5.3.2 Further Research/Going Beyond

The employment module offers an important methodological contribution for future calculators by trying to reconcile macroeconomic theory with the engineering-based calculator approach. Although successful, the module is just a first step towards integrating more economics rationales in future calculators.

First, in EUCalc, the idea was to derive socio-economic impacts using inputs from the sectoral modules (e.g. industry, agriculture, power, etc.), which model decarbonization pathways. Hence, the employment module is at the end of the chain. This constrained the scope of the module. For instance, the population evolution being given by a lifestyle lever, the impacts of labour mobility (due to differences in wages and skills across countries) could not be assessed. Similarly, because the consumption and production of several commodities (e.g. food, materials, transport) were already fully computed in the sectoral modules, reconciliating the sectoral modules outputs with general equilibrium analysis was at times quite a challenging task. Introducing more economic rationale in all the modules would greatly help to better integrate economic constraints.

Second, the employment module could be enriched to provide a deeper analysis of employment issues. For instance, while the model does introduce skill heterogeneity in workers, it makes the rather unrealistic assumption of perfect workers mobility between sectors. Adjusting this feature would require analysing in details each country labour market and labour policies to understand the drivers of unemployment and the potential issue of skills matching (i.e. workers cannot find firms matching their skills, and reciprocally). This analysis would also allow to better apprehending education and training issues, by letting the workers get education/training in response of skills demand, while the workers skills are currently exogenously given by a scenario.

Finally, while the employment module was designed to assess the impacts on employment of decarbonization pathways, it would be possible to analyse broader questions related to employment using a calculator. For instance, policies such as labour taxation, minimum wage, or legal working hours could be assessed by introducing in the framework labour policy levers.

5.4 Economics, Relations to the RoW

5.4.1 Achievements

Reaching carbon neutrality in the EU contributes to global emission reductions, but it is only part of the efforts to tackle climate change, due to the presence of carbon leakage and because the EU’s share in global emissions (and GDP) has been and is decreasing over time. In order to describe the relationship between countries and to the rest of the world GTAP was exploited and particular scenarios calculated.

- Combination of engineering type and CGE type modelling approaches: In order to quantify the transboundary effects of decarbonization pathways, that are set by the user of the EUCalc Transition Pathways Explorer, data and results from “core” modules (demand and supply sectors) of the EUCalc model are converted to exogenous shocks for the GTAP-EUCalc computable general equilibrium model to simulate perturbations to a projected baseline of the world economy in 2050. Results of these calculations are then provided to the TPE.
- “Closeness measure”: Since the trade module (GTAP-EUCalc CGE) simulates the transboundary effects of only a small subset of the pathways that can be set by the user of the TPE, a measure has been designed to find the “closest” pathway for which there are GTAP-EUCalc results to the one set by the user. The measure is based on the differences in sectoral energy consumption shares of a given pathway with respect to the ones of a baseline.

5.4.2 Further Research/Going Beyond

- The need to fully characterize/model the de-carbonization pathways of the other major economies and emitters in the rest of the world; after all, most current projections point to a “smaller” rather than “larger” EU by 2050, as compared to the EU of today, as measured in terms of total GDP and emission.

- Modify GTAP-EUCalc structure to include the investments needed to achieve technological changes (e.g. create parallel industrial sectors with a different intermediate consumption structure and different/higher costs)
- Analyze how different policy instruments may achieve typical/important de-carbonization pathways envisioned in the core modules, rather than simply assuming cost-free technological changes on the supply side and preference shifts in the consumption side.
- It is of interest to design a more advanced economic module, which would rely more on economic theory/assumptions, but in parallel would let the users simulate their own scenario (via economic levers). Opening the space of scenarios to the users would be a great value added with respect to standard economic models, which are sometimes described as “black-box”.
- The calculator provides a road forward for policy makers. While EU/country objectives or targets are well represented, the impacts of monetary instruments (e.g., tax and subventions) are more difficult to assess. To provide this information, a policy interface would be required to translate the “engineering-based” levers into policy levers.
- Several new features were implemented into EUCalc (cf. text). Additional environmental and socio-economic indicators could be implemented. For example, poverty analysis and distributional effects (inequalities) could be obtained by refining the macroeconomic model, e.g. used in the employment module.
- Analyse how generalized findings from economic models (such as inter-national elasticities, parametrized leakage measures) could enrich the calculator approach without the need for genuinely marrying the two modelling worlds (which might lead to prompt divorce anyway).
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5.5 Technology module

5.5.1 Achievements

In dynamically changing environment like energy systems, a high level of technological disaggregation and the appropriate representation of technology options and dynamics need to be adequately captured by the model. The technology module serves as a repository including all relevant information on technology development. It is a hub to provide information on

- technology efficiency,
- specific energy consumption factors (incl. feedstock),
- product material composition,
- lifespan or lifetime,
- specific emission factors (CO_2, CH_4, N_2O),
- costs (CAPEX and OPEX),
- learning rates,
- energy self-consumption,
- and fuel prices,

until 2050 and each ambition level. Currently, the technology matrix includes:

- 59 transport technologies,
- 38 buildings technologies (appliances, heating and cooling, renovation),
- 21 manufacturing and production technologies,
- 12 carbon capture storage and use technologies,
- 12 power generation technologies,
- 5 storage and balancing technologies,
- and 21 domestic products in agriculture (livestock and afw).

5.5.2 Further Research/Going Beyond

Within the project, there has been an attempt to consolidate assumptions and data sources with other modelling initiatives (cf. Fig. 2):

EUCALC Current technology matrix initiatives

Organisation	Comment	Person
PBL Wuppertal	• Linked to ReInvent, focus on meat, paper, plastics, and steel • Data is used in IMAGE model • MIDDEN not opensource and NL specific	• Mariesse van Sluisveld (PBL) • Clemens Schneider (Wuppertal) • https://www.pbl.nl/en/middenweb
Institute for European Studies	• Structured per technology (~150 technologies) • It is not clear for which model this data is used	• Tom Wyns (Matilda Axelson as focal point) • https://www.ies.be/files/Addenda_0.pdf
IDDRI	• Structured per technology (~80 technologies) • Source for the DDP	• Chris Bataille
Fraunhofer	• Currently developing a technology matrix	• Dr. Tobias Fleiter • https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/industrial_innovation_part_1_en.pdf
Simon Fraser University	• CIMS model	• Mark Jaccard
Climact, Oegut	• Structured per technology (~100 technologies, ~25 in industry, wider quantitative scope (water, particles,…) • Linked to EUCalc	• mc@climact.com
IEA	• credible but difficult and expensive to share data (e.g. GlobalCalc, CWF) • Relies on underlying suppliers • CEA (does some data compilations)	• Davide d'Ambrosio
EU JRC	• IDEES database (through Potentia model) • BREF (Bat REFerence document, encyclopaedic, but refreshed every 10 years and not user friendly format)	
Various universities	• TIMES/MARKALtechnology matrix? • Appears to plug on other sources	• University College London should be interested • VITO will have a DB in 2021
DNV GL	• open data base, only energy forecast data?	• energy.transition@dnvgl.com • Link

More effort should be directed towards consolidating these initiatives.

5.6 Manufacturing and production module

5.6.1 Achievements

In the manufacturing and production module, an enhanced coverage of industrial sectors compared to previous approaches has been implemented. These comprise:

- Iron and steel
- Cement
- Basic chemicals
- Ammonia

- Paper
- Aluminium
- Copper
- Glass
- Lime
- Wood and wood products
- Textiles and leather
- Food, beverage and tobacco
- Machinery equipment
- Transport equipment
- Other industries

Through a product-to-material link based on activities on the demand side (transport, buildings, and lifestyles) a clear understanding of linkages between demand and supply is represented and can be communicated by the TPE. The direct outcomes are energy as well as emissions, which are calculated within the module workflow. The following sub-modules water, power supply, storage, employment, air pollution, carbon capture storage and use as well as agriculture depend on inputs from the manufacturing module.

The mining sector ought to have been modelled within the industry sector. This would have enabled everything associated with industry sector being handled in one sector.

The EU development and progress have considerable impact on economic reserves and raise the question of fairness in mineral resource attribution. Quarrying in Europe has little impact on GHG emissions hence the absence of emissions in the mineral model.

5.6.2 Further Research/Going Beyond

- Further research should put an emphasis on the development of innovative production technologies and process innovations, which enable a large-scale deployment.
- Industrial roadmaps and pathways developed in recent years at sectoral and/or national levels give some insights into the CAPEX (capital expenditures) and OPEX (operational expenditures) needs for industrial low-CO_2 transformation. However, there is currently no estimate of aggregate additional CAPEX needs across EIIs in the EU towards 2050 reduction pathways.
- For most energy intensive industries, the current production location has significant strategic value (e.g. connections to infrastructure and logistics, proximity to raw materials supply chains and/or customers). A higher spatial granularity therefore would be necessary.
- The role of EU and national financing instruments in the transition to low-carbon production technologies and processes as well as removing barriers and other additional constraints should be investigated.
- Sectors like the steel, non-ferrous metals, ferro- alloys, chemicals and fertilizers heavily rely on raw material imports into the EU. For most basic materials therefore, enhanced circularity will become even more critical over the next decades as a strategy to reduce emissions, reduce energy use, maintain supply security, and enhance production and growth while reducing costs.

5.7 Electricity

5.7.1 Achievements

The European Calculator approach is the first version which goes beyond the annual time resolution and calculates the needs for the electricity grid in hourly steps (i.e. 8760 data points for a year). This is an improvement in order to consider the intermittent nature of growing share of PV and wind, as well as maturing battery technologies able to balance the load. Through the balancing strategies lever the user can set the portfolio of technologies responsible to shift the load and provide the needed flexibility, from the least to the most ambitious level the share of natural gas decreases as flexibility option while share and role of zero carbon flexibility technologies (including batteries, flywheel, compressed air storage, power to gas, etc., and pumped hydro storage) are growing. Another lever helps the user to consider the impact and patterns of electric car charging on the grid flexibility.

Levers in electricity generation allow the user to exploit different trajectories for renewable based generation, coal and nuclear power. Scenarios for renewables in the most ambitious lever are approaching the technical potential, while the creation of coal and nuclear power pathways follow a different approach. Hereby, a bottom-up method assessing the situation of each coal and nuclear power plant is applied with considering their lifetimes, licences and the policy of the country. This way, the user can access the impact of different phase-out timings or capacity expansions.

The EUCalc does not consider a sole country in its modelling environment, but rather 28 countries that are interacting with each other and together with the rest of the world. Therefore, with regards to electricity, interconnectors and they role in balancing are included in the model as a new feature. Additionally, aligned with the policy aims of the EU, trading zones are (following the grouping of countries by the ENTSO-E (European Network of Transmission System Operators for Electricity)) used to calculate the electricity flows between countries with assuming no bottleneck inside the trading zones but only between them.

5.7.2 Research Gaps/Going Beyond

Nevertheless, the electricity module has still some deficits, which could be improved.

- Unlike an equilibrium model that seeks the optima of certain conditions, the calculator allows the user to play freely with the input data (i.e. lever settings). While this allows the user to test any combinations, even very ambitious ones, it does not allow to investigate the impact of primary economic factors that influence the equilibrium (and this way they would overwrite the user set scenarios). For example, price elasticities, such as impact of gas prices on demand and impact of carbon prices on coal phase-out, cannot be investigated.
- Due to the aforementioned flexible nature and user-oriented scenario setting of the model, in order to match electricity supply and demand, a technology option needs to be left open (i.e. not governed by a lever but controlled by the gap between supply and demand). If all the available electricity production technologies would be bound by the lever setting, then gaps between supply and demand cannot be filled without

overwriting the lever setting by the user. Currently, in the EUCalc natural gas-based power generation fills the gap between supply and demand, therefore natural gas based electricity generation is not controlled by a lever directly.
- While the model is integrated with the GTAP modelling framework to access the interactions between the EU and the rest of the world, this integration does not allow to investigate the import dependency of the EU in energy carriers which is though an important aspect of the EU energy policy. This is due to the distinct features of the GTAP modelling framework.
- While hourly granularity modelling is a novelty, this feature can be further fine-tuned by considering system adequacy and grid congestion, as well as with enhancing the interaction with modules providing the demand for electricity in order to consider better demand side measures.
- Oil refinery modelling though only 3% of the emissions can be improved. The oil refinery supply-demand matching is a more complex and driven by economic conditions (oil price, demand for oil production with considering price elasticity, export-import balances of oil products, and performance of oil refineries abroad) that could not be considered in the current complexity. Additional routes for decarbonization of the sector may be assessed as well.

5.8 Buildings Sector

5.8.1 Main achievements

- A comparable approach to decarbonizing the building stocks of all countries is implemented taking into account the different starting positions regarding the age of the stocks, the different fuel mixes, as well as the different climates.
- The decarbonization of the building stock can be analyzed completely (once the power sector can separate the GHG emissions for electricity and combined heat and power).
- This allows an in-depth analysis of the contributions and potential combination of district heating, local renewables (fossil fuel phase out in heating) and electrification.

5.8.2 Research Gaps/Going Beyond

- Building debris was not part of the EUCalc project implying that the full life cycle of buildings could not be included. Further, for the buildings sector energy and emissions related to building insulation waste and their treatment are not covered by EUCalc.
- The potentials for renewable energy may differ in each country and may create a competition for land, if the natural formations do not exclude or favor single uses. This competition and the potentials can only be reflected roughly in the EUCalc.
- Tracking of renovation activity and the current energetic state of the building stock is impossible with the current recording system. Problems on the legal GDPR issues remain unsolved.
- The climate impact on heating and cooling in the different climates and building types of Europe is not sufficiently examined and can be improved.

- The information on biomass (gas, liquid, solid) type of wood and recyclability are not detailed enough to enable an analysis of cascade use of renewable material.
- The topic of uneven distribution of renewable energy availability in different countries and energy demand is not addressed.
- With the currently available data in buildings the sort of biomass cannot be detailed which weakens the link to agriculture and the ability to come up with specific solutions.

In a high-level aggregated tool such as the EUCalc the potential linked to re-use of material cannot be analyzed in detail as part of the analysis of circular economy. The products need to be designed for re-use and potentially for later combustion is prerequisite of a cascade use of materials. For example, for wood as a biomaterial this means the wood is used first for multiple material purposes (full material, then for example chipboard) and finally for energy use. The allowed additions like glues and colors need to be defined to enable a later use and clean combustion. This may reintroduce older manufacturing techniques that require specific training.

5.9 Social Aspects/Health & Air pollution

5.9.1 Main conclusions

- Social impacts are increasingly important considerations in policy strategies (see latest discussions on air pollution for health impacts and NO_x impacts on environments and social consequences for farmers, buildings, etc.). Based on the achievements an air pollution module was included, which enables a powerful analysis of how air pollution and climate policies are linked and can in some cases lead to tradeoffs.
- Showing social impacts can provide insight on tensions between solutions for climate change mitigation which are counterproductive for social issues. It has proven possible to identify important and relevant social impacts which can be reliably quantified and incorporated in the mode and the European Pathway Explorer

5.9.2 Lessons learnt

- A careful process with experts and stakeholders to decide on social impacts which can be incorporated in the pathway explorer is important to create a reliable and trustworthy module. This indeed needs more time. As we have learned in the process other social impacts were chosen than originally anticipated (health instead of food- and energy security)
- The methodological approach with a follow-up expert workshop to validate the module approach for the chosen social impact (health) was crucial to verify reliable datasets, potential indicators, and units, and led to collaboration with institutions which could provide those (IIASA)
- Since, most of the social impacts are quantitative, it became clear that decision-makers require a new approach to overcomes analytical limits to existing practice, which could better integrates qualitative narratives with quantitative analysis.

- Stakeholder engagement at the proposal stage could have highlighted air pollution as a key area of concern for policy makers (as was later found in the social impacts engagement workshops), and this would have allowed allocation of appropriate time resource to the air pollution module. As it was, this module has been developed relatively late in the whole project and was not resourced adequately (in terms of time and capacities of the responsible partner), meaning that methodological advances were not possible as the project was reliant on a collaboration with IIASA.
- The methodological approach to first identify the social impacts to be incorporated with experts (first workshop) concluded on other social impacts than originally anticipated (health instead of gender, food- and energy security, based on the results of the stakeholders survey). These were not the prime expertise of the partner responsible. This was planned to be solved with the hiring of expertise, but delays in finding adequate people led to unexpected delays in making the module. This was solved through collaboration with other partners (cf. previous point).
- There are limitations to the social impacts which can meaningfully be shown in scenario models as it is difficult to define social impacts which can reliably be quantified and for which datasets are available which can be used in model configurations
- Often people hold deeply convinced assumptions on social impacts, results that show other outcomes may be perceived as wrong which can result in more debate on the scientific quality of the model as a whole

5.9.3 Research Gaps/Going Beyond

- More research into the identification of social issues related to different sectors and lifestyles could significantly enhance our insights in political tensions. However, how to integrate this into the formal framework remains open so far. This should be followed by identifying and building reliable dataset which can be used in the pathway explorer.
- Further, more detailed research on the causal relations between sector and lifestyle paths is desirable, so that verifiable calculations to quantify social impacts can be made.
- Including more social impacts would enhance the political choices for decarbonisation pathways
- More effort should be put to integrate more qualitative social impacts into decarbonization modelling process, although this was not in the main focus of EUCalc
- The air pollution module operates at the national scale. It is therefore not possible to be downscaled to cities, where most air pollution problems occur. This would require a spatial dimension to the calculator so that emissions from various sectors could be associated with different areas and population densities. Adding a spatial dimension (intra-state) to the calculator approach would not be a straightforward task and would require innovation across the different modules. However, advantages would include higher resolution of air pollution impacts, greater heterogeneity of policy impacts within states, and perhaps more targeted climate policies.

5.10 Lifestyles/Climate

5.10.1 Main Achievements

As the implemented lifestyle modules shows at the EU-level, opting for very ambitious lifestyles or technological changes in the transport sector, points towards a similar magnitude of GHG savings by 2050, i.e. 54% to 65% respectively, if compared with 2015 levels. In a sector (lifestyles) that is remarkably hard to decarbonize, future policies need to go beyond efficiency standards and subsidizing technologies and provide comparable attention to the delineation of structural incentives for lowering traveling distances and increasing occupancies of private transport.

For the agricultural sector, a shift in lifestyles towards healthy diets and less food waste also allows for important GHG reductions that could be used as leeway in case that other sectors may fail to achieve their 2020 and 2030 targets; as for example, in Austria, Belgium, Cyprus, Finland, Germany, Ireland, Luxembourg and Malta (cf. European Environmental Agency (EEA): existing measures will not be enough to meet their 2020 under the Effort Sharing Decision (ESD)).

Lifestyle levers and levels in the EUCalc model are more granular and ambitious than the changes in lifestyles proposed under the 1.5-LIFE scenario of the European long-term strategy for achieving climate neutrality by 2050 (published in 2018). Two examples of the lack of granularity in the 1.5-LIFE scenario are: i) a non-consideration in the 1.5-LIFE of the mitigation potential of GHG emissions entailed with a reduction of the overall residential area per person; ii) a non-consideration of the mitigation potential of lifestyles aiming at reducing obesity levels of the population to half. An example of the differences in ambition between the EUCalc model and the 1.5-LIFE scenario can be found in the consideration of dietary shifts. The type of diet assumed under the 1.5-LIFE scenario matches at best ambition to the ambition level 2 in the EUCalc model.

Unlike the Global Calculator, the EUCalc model takes the projected future climate as an input for the calculation in the water, land use, agriculture, forestry, electricity supply and buildings sectors. The leading climate data used as an input is a value of global temperature rise expected in 2100, reflecting a decision taken by the user about the level of mitigation ambition taken by the rest of the world (RoW). This can be done by means of setting the "Global mitigation effort" lever.

The agriculture, land use and forestry module, for example, is provided with a crop production change factor based on the selected level of RoW mitigation ambition / global warming.

As a second example, water availability values for calculating water stress are based on which RoW mitigation ambition level is selected and are derived from a spatially explicit water model.

5.10.2 Lessons learnt

Dealing with the climate module it was found that the KNIME approach was not optimal, therefore it was programmed in Python directly (in regard of KNIME, cf. also comments above).

5.10.3 Research Gaps/Going Beyond

The aspect of individual involvement in the adoption of particular lifestyle options was raised in the stakeholder's consultation, but has not been addressed in the EUCalc model as it was out of the modelling scope. The drivers and limitations of human activities remain a subject of debate and so does their integration in energy models. On the other hand, the EUCalc has taken the first steps into this direction by modelling explicitly lifestyle changes based on existing literature. The opportunity is now there to integrate in the EUCalc framework socially-motivated determinants of individual activities, such as norms, institutions or inequalities.

In terms of the spatial resolution several modules could be improved, e.g. for the climate component, while other, e.g. as the lifestyle definitions will remain more coarse.

The integration of the climate module implies a more detailed consideration of feedbacks (cf. also above), as the actual simplification could imply an underestimation of emissions.

Although climate change is considered in the biodiversity and agriculture components sink/source conversions were not yet taken into account.

5.11 Minerals, Land, Water, and Biodiversity

5.11.1 Achievements

- Regarding the mineral modelling work, there is a significant statistical data and literature on mineral resources available that was used. There appears to be a great deal of interest on the impact of digital and energy transitions on mineral resources from policy makers and the research community respectively. The results from the EUCALC mineral module follow similar trends as JRC papers and other reports/scientific papers reviewed.
- Land-use, land-use change, and forestry dynamics formerly considered net-use changes. The EUCALC now considers the highest level of detail given in the UNFCCC inventory data and accounts for the heterogeneity of each country's inventory. Going further would require using a more advanced approach to account for land associated emissions that would not be aligned with the UNFCCC inventories.
- The former agriculture, land-use, land-use change, and forestry modules were limited and highly aggregated. In the European Calculator, we were inspired by the state-of-the-art models and we now offer a similar level of detail, including features that enables one to explore from agro-ecology to highly intensified pathways for agriculture, as well as to explore the synergies and trade-offs that can occur through bio-energy and biomaterial demand as well as diet shifts. Additional features have also been added, such as insect farming and microalgae bio-refinery, agro-forestry, no-tillage practices, and so on.
- Although the model acknowledged some minor technical concessions, the approach enables multi-dimensional outputs to be included (combined), which also adds value to the agriculture and land-use, land-use change, and forestry modules. For example, the approach allows the employment

impact for all the settings that include a wide range of diets and agricultural practices, from highly intensive to 100% agroecological, in a unique module. This is also the case for biodiversity, air pollution, water impacts, and mineral demand impacts (phosphate scarcity).

5.11.2 Research Gaps/Going Beyond

- There is a need to explore the possibility of setting up proper levers for resource recycling to show resource availability following certain circular economy policies (impossible at the moment due to model speed issues). It may be useful in future to address the indirect emissions from quarrying resources outside Europe with respect to Europe lifestyle choices.
- Land-use, land-use change, and forestry dynamics formerly considered net-use changes. The EUCALC now considers the highest level of detail given in the UNFCCC inventory data and accounts for the heterogeneity of each country’s inventory. Going further would require using a more advanced approach to account for land associated emissions that would not be aligned with the UNFCCC inventories.
- Although the module now considers land as agriculture, forest, or grassland the land use types need to be further resolved, as in Europe, large extents of land are mixed, and grassland may be fertilized or not. All of this will change the sink potentials. In the moment these are treated as LULUCF ag/not ag as this is how EUSTAT provides the data. For a better representation of emissions it is needed to shift to a broader range of carbon sink potentials.

5.12 Programming Demand and Tool Development

5.12.1 Achievements

- A completely new modelling framework was built from scratch and built in parallel by more than 10 organizations across Europe. This was enabled by using programming tools such as GITHUB to ensure that all partners could work on their own sectoral parts and then recombined.
- KNIME was used to allow transparent model design and make the programming somewhat simpler to learn, but it was also fully converted to PYTHON based on a KNIME-to-PYTHON converter developed in-house. This allows to speed-up running time and provide a clear interface (or API) to the online tool
- The use of the KNIME software for sectoral modelling purposes was a novel idea and a strength in accommodating the complexity of the EUCalc model. In particular it supported also partners with less expertise in modelling. However, retrospectively choosing KNIME sacrificed the "real-time" goal (response-time for request between 30-60 seconds in the moment). But the decision was necessary in order to ensure a permanent flow of work amongst the very different partners.
- The programming has advanced intersectoral connections which allow to reflect their dependencies effectively. Feedback loops were analysed and cut at the weakest link (i.e. the link which has the least impact on overall cross-sectoral results)
- The Transition Pathways Explorer web application provides a clear and simple interface to the EUCalc model and enables the user to explore the

vast solution space for the European decarbonisation challenge, which is spanned by the model. This is a major achievement since advancements with respect to earlier interfaces have been accomplished in spite of the considerable increase in the amount of detail of both model input and model output.

- The Transition Pathways Explorer introduces the notion of international fairness by asking the user to decide about the European share of the global greenhouse gas budget, http://tool.european-calculator.eu/budget. The layout of the web application then focusses the users' attention to finding a pathway that complies with the resulting European budget.
- The budget approach combines two things that are frequently incompatible: The concept is scientifically sound and easy to understand. It is superior to the timely net-zero approach that neglects the fact that different decarbonisation speeds would lead to different cumulative emissions and, hence, to different amounts of warming, even if net-zero is reached at the same time.

5.12.2 Research Gaps/Going Beyond

- While running speed is under a minute it is still not at the level we were hoping, even after converting the code to python it doesn't run close to "real time" (what we defined as under ~20 seconds). Therefore, further alternatives should be explored, the most extreme of them being to reprogramme the model in C/C++ to allow for parallelisation. Tests have shown that the response time of the system on requests could be increased by at least a factor ten. Simpler alternatives at the sector levels may well exist to optimize the code to run faster.
- More generally, in the future it may be explored to move the programming from a dual KIME-PYTHON approach (which includes a conversion step between the 2) to a single programming language. This would allow to program directly based on the strengths of that language (be it PYTHON or C/C++).
- Feedback loops could be explored further to clarify if they are bringing serious limitations and whether some of the links that have been avoided should and could be reinstated with faster running times. However, all the current choices have been studied and motivated.
- A specific focus should be set on the idea of "Complexity-on-demand", i.e. users should have the opportunity to work at the granularity that they find relevant for their own use, defining their ambition levels either at the sectoral level (transport, buildings, etc.), or sub-sector level (passenger vs freight), for example. This level of granularity is present in the model and the key here would be to ensure that the user interface can be adapted by the user to reflect it.

6 Conclusions

This deliverable describes how far the EUCalc consortium came, which difficulties were underestimated, and were needs for further improvements are seen. Despite of many progress bringing EUCalc to a sound mode, the tool needs still efforts and investments which are lying partly beyond the scope of the actual project. In these terms the work on EUCalc is still ongoing. However, the project made visible progress. The actual approach is unique in terms of sector coverage, resolution and defines benchmark scenarios rather than optimal pathways. However, the model and TPE still follows a pragmatic approach, which has advantages and disadvantages. In order to mention a few:

- allows to think out of the box (in formal terms beyond the state space defined in fixed in fully dynamic models),
- can create storylines,
- allows to evaluate trade-offs for many different choices,
- Increased number of implemented sub-modules,
- includes a clear and transparent link of product-material-energy-emissions nexus,
- is not a macro-economic general equilibrium model (PRIMES, etc.) implying that an economic improvement is desirable,
- implementation and relations to the rest of the world need still to be improved. The same holds also for the number of interactions.
- Similar holds also for the relations between member countries and the EU.

Summing up, the project has fulfilled its promises, albeit with some concessions.

7 References

Mackay D (2009) Sustainable energy - without the hot air. Available under: https://withouthotair.com