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Project Overview

1 Executive Summary - German

Das Klimaabkommen von Paris unterstreicht den unmittelbaren Handlungsbedarf, Maßnahmen zur Begrenzung des Klimawandels zu setzen. Die Entwicklung nationaler Klimastrategien benötigt Modelle, die langfristige Transformationspfade abbilden können. Die Motivation für das Projekt **ClimTrans2050** leitet sich aus der Verpflichtung Österreichs ab, den Ausstoß von Treibhausgasemissionen zu reduzieren, um die langfristigen THG-Minderungsziele zu erfüllen. In Übereinstimmung mit dem 7. ACRP-Call wurde im Rahmen des Projekts ein Forschungsplans für ein open source Modell für Österreich entwickelt, das geeignet ist, Emissionspfade, die eine THG-Emissionsreduktion um 80-95% bis 2050 im Vergleich zu 1990 erreichen, und mit diesen Pfaden verbundene Kosten abzuleiten.

Die Leitfrage für **ClimTrans2050** lautet: Welcher Modellierungsrahmen ist am besten geeignet, um den langfristigen Transformationsprozess abzubilden und zu analysieren, der erforderlich ist um die österreichischen Treibhausgase entscheidend zu reduzieren? Wir schlagen einen Rahmen für ein open source Modell vor, der das Verständnis für Transformationsoptionen verbessert und einen innovativen Modellierungsansatz zur Analyse dieser Optionen bietet. Der gewählte Zugang in der Entwicklung dieses Modellrahmens ist, von derzeitigen Modellparadigmen zu lernen, aber in der Konzeption des Modellierungsansatzes darüber hinaus zu gehen. Ein zentraler Aspekt ist in diesem Zusammenhang die Einführung von Funktionalitäten als Zielvariablen für ökonomische Aktivität.

Das Ziel von **ClimTrans2050** war die Entwicklung eines Forschungsplans für ein open source Modell, das i) Emissionsreduktionspfade und Kosten für Österreich skizzieren kann, und ii) eine Unterstützung für die Zielerreichung einer THG-Reduktion von 80-95% darstellt. Mit dem vorgeschlagenen Modellierungsrahmen unterstützt das Projekt österreichische Entscheidungsträger dabei, ein besseres Verständnis über die sozialen Aspekte des Klimawandels zu erlangen. Der Forschungsplan **ClimTrans2050** zeichnet sich durch zwei Aspekte aus: i) der Forschungsplan folgt dem innovativen Ansatz von wohlstandsrelevanten Funktionalitäten, und ii) der Forschungsplan stellt eine konsistente Einbettung des open source Modells für Österreich in den globalen Kontext sicher.

Das Schlüsselelement des entwickelten und vorgeschlagenen Modellrahmens ist wie erwähnt der Fokus auf wohlstandsrelevante Funktionalitäten, wie Wohnen, Mobilität (genauer gesagt dem Zugang zu Personen und Gütern) oder Ernährung, die letztlich das Ziel ökonomischer Aktivität sind. Funktionalitäten im **ClimTrans2050** Forschungsplan sind das Ergebnis der Interaktion von Bestandsgrößen (*stocks*; z.B. Gebäude, Maschinen) und Flussgrößen (*flows*; z.B. Energie, Material). Zusätzlich zu Funktionalitäten, die den Endverbrauch betreffen und relevant für den individuellen Wohlstand von Personen sind, umfasst das Konzept implizit auch intermediäre Funktionalitäten für Güter und Dienstleistungen ("reproducibles").

Transformationsprozesse erfordern ein detailliertes Verständnis der Strukturen, die die physische, ökonomische und institutionelle Ebene verbinden. Die Entwicklung eines open source Modells für die Analyse langfristiger Prozesse (insbesondere von Veränderungen in unserem komplexen sozio-ökonomischen und sozio-technologischem System) erfordert eine sehr detaillierte Darstellung der Rolle von Technologien, da diese die Qualität des Kapitalstocks bestimmen.

Der **ClimTrans2050** Forschungsplan schlägt eine alternative Perspektive auf Emissions- und ökonomische Strukturen sowie auf das begleitende institutionelle Umfeld vor und identifiziert Forschungsbedarf für die Implementierung eines funktionsfähigen open source Modells für Österreich. Ergänzend werden exemplarische Modellmodule, die der im Forschungsplan entwickelten Argumentation folgen und eine interaktive Web-Plattform entwickelt. Der Forschungsplan und die exemplarischen Modellmodule sind ein erster Schritt für die Entwicklung eines umfassenden Modells, das zu einem besseren Verständnis von Transformationsprozessen beitragen soll. In diesem Sinn enthält der Forschungsplan vielfältige Anregungen und eine breite Basis für weitere Forschungsschritte.

Die Entwicklung des konzeptuellen Rahmens basierend auf Funktionalitäten setzte die Offenheit und Diskursbereitschaft des Projektteams für eine grundlegend neue Modellperspektive voraus. Die beträchtliche Anzahl an internen Projektreffen stellte daher ein Schlüsselelement des **ClimTrans2050** Projekts dar. Um die Intuition und Akzeptanz des Konzepts für langfristige Transformationsprozesse zu überprüfen wurden drei externe Workshops veranstaltet. Zwei davon richteten sich an die wissenschaftliche Community, der dritte Workshop hatte die Einbindung von Stakeholdern zum Ziel. Der erste Expertenworkshop fand im ersten Viertel der Projektlaufzeit (April 2015), der zweite nahe am Ende der Projektlaufzeit statt. Der Stakeholder Workshop fand im September 2015 statt. Um möglichst großen Nutzen aus den Workshops zu ziehen, organisierten wir diese in einem partizipativen Rahmen, mit einem Schwerpunkt auf kleinen Tischrunden.

Der Output, der die Diskussionen und die Inputs der externen Workshops integriert, ist im Bericht **"ClimTrans2050 Research Plan"** zusammengefasst. Gemeinsam mit den begleitenden Beispielmodulen findet sich der Forschungsplan auf der Projekthomepage *climtrans2050.wifo.ac.at/.*

Das Konzept der Funktionalitäten im Rahmen eines "deepened structural model" wird entlang von drei Ebenen (**three tiers**) operationalisiert, die für die Quellen sowie für die Zusammensetzung und die Entwicklung der österreichischen Emissionen relevant sind: die physische, die ökonomische und die institutionelle Ebene. Das zugrundeliegende Konzept der Funktionalitäten und die Struktur der drei Ebenen stellen die Basis für die Analyse von Transitionsprozessen zu einer CO_2 armen Gesellschaft dar.

Zusammengefasst bietet der **ClimTrans2050** Forschungsplan:

- Kohärente, nachvollziehbare Modellierungsrichtlinien, die den Fokus auf Funktionalitäten (z.B. Wohnen, Mobilität) legen und die Wechselbeziehung von Bestands- und Flussgrößen für die Bereitstellung von Funktionalitäten betonen.
- Einen Rahmen für einen "deepened structural modelling" Ansatz für die Modellierung der österreichischen Emissionen entlang von drei Ebenen, wobei die physische, die ökonomische und die institutionelle Dimension bewusst unterschieden werden.
- Ein Modellrahmen, der für die Analyse nicht-inkrementeller Veränderungen und von Transitionsprozessen geeignet ist.
- Richtlinien für zukünftige Forschungsaktivitäten entlang des "three tier"-Ansatzes einschließlich der Wechselwirkung zwischen den Ebenen.
- Ein kohärentes Gesamtkonzept, das die schrittweise Einbindung von Forschungsaktivitäten erlaubt, um schlussendlich zu einem open source modell zu kommen, das die Österreichischen Luftschadstoffinventur vollständig im Vergleich zu den drei Ebenen abbildet

2 Executive Summary

The Paris agreement substantiates the immediate need for action to mitigate climate change. The design and development of national climate strategies calls for modelling tools that are able to address long term transformation[1] pathways. **ClimTrans2050** is motivated by the requirement of Austria to design and implement mitigation measures to meet very long term greenhouse gas (GHG) emission reduction commitments. In line with the 7th call of the ACRP, the project focuses on the preparation of a research plan to create an open source model that will allow delineation of emission reduction paths and costs for Austria that would be capable of achieving an 80-95% reduction in GHG emissions by 2050, compared to 1990 levels.

The guiding question for **ClimTrans2050** is: What kind of modelling framework is most suitable for assessing the long-term transformation processes needed to drastically reduce Austria's GHG emissions? We propose a framework for an open source model that improves understanding of transformation options and provides an innovative modelling approach for their analysis. Our approach for developing this framework was to learn from, but go beyond current modelling paradigms. One central aspect in this context is the introduction of functionalities as target variable of economic activity.

The aim of the **ClimTrans2050** project was to prepare a research plan for an open source model, that will i) outline emission reduction paths and costs for Austria; and ii) help Austria attain a 80-95% reduction in greenhouse gas (GHG) emissions by 2050. The project also supports Austrian decision makers by proposing a modelling framework for an improved understanding of the social aspects of climate change.

ClimTrans2050 is unique in two ways: the research plan for the proposed open source i) follows the innovative approach of functionalities to be satisfied from the perspective of wellbeing in a low carbon world; and ii) provides a consistent embedding of an Austria-focused open source model in a global emissions and long-term warming context.

The key element of the modelling framework developed and proposed in this research plan is its focus on wellbeing-related functionalities, ranging from shelter through to mobility (i.e. more precisely access to persons and goods), as the ultimate goals of economic activity. Functionalities (e.g. nutrition, shelter, access to goods, services and people) as understood in the context of this research plan are defined as the outcome of the interaction of stocks (e.g. buildings and machinery) and flows (e.g. energy and materials). In addition to end-use functionalities (as relevant for the wellbeing of persons) the concept implicitly also includes intermediary functionalities for reproducibles (as goods and services).

Transformation processes require a deep understanding of the structures linking the physical, economic and institutional layers. We therefore start from functionalities and highlight the role of stocks and flows for providing them. Establishing an open source model for the very long run, and especially for changes in our complex socio-technological system, thus requires a more explicit representation of the role of technologies, given that these determine the quality of an economy's capital stock.

The **ClimTrans2050** Research Plan proposes a new perspective on emissions and economic structures as well as the accompanying institutional framework and identifies next steps for research for the implementation of a fully operational open source model for Austria. This is complemented by exemplary model modules that follow the rationale as developed in the research plan. The model modules are available on an interactive web platform (*climtrans2050.wifo.ac.at*). The research plan is the first step for the development of an operational open source

[1] Throughout this report we use the terms "transition" and "transformation" as synonyms. We are aware that there is literature that discusses the difference between these two terms.

model based on the proposed new understanding of modelling transformation processes. In this sense the research plan provides manifold suggestions and broad basis for further research.

The development of the conceptual framework based on functionalities was conditional on the openness of the project team and an intense discourse in the search for a new mindset for modelling. The considerable number of internal meetings was thus one of the key elements in the **ClimTrans2050** project. In order to test the intuition and acceptance of the concept for long term transformation analysis three external project workshops were held. Two of them addressed the scientific community and one workshop focused on the engagement of stakeholders. The first expert workshop took place in the first quarter of the project (April 2015), the second one close to the end of the project. The stakeholder workshop was held in September 2015. In order to harvest the most from these workshops we organised them in participatory manner and put an emphasis on small table group discussion.

The intellectual output integrating these discussions and the input from the external workshops is captured in the report "**ClimTrans2050** Research Plan" and the accompanying exemplary model modules (ClimTrans2050 Working Paper No.2, Schleicher et al., 2016) available at the project homepage *climtrans2050.wifo.ac.at/.*

The concept of functionalities in a deepened structural model is made operational along **three tiers** that are relevant for the sources and the composition and the development of Austrian emissions: the physical, the economic and the institutional tier. Each functionality affects the three tiers and is also affected by them. This underlying mindset (functionalities) and basic structure (three tiers) for modelling builds the basis for analysing transition processes that drive the emissions and the economic system.

The **ClimTrans2050** Research Plan provides

- coherent and understandable modelling guidelines that put the focus on functionalities (relating to shelter, access to persons, services and goods, nutrition, etc.) and that stress the interrelationship of stocks and flows in order to provide the functionalities;
- a framework for a deepened structural approach to modelling the Austrian emissions system along a three tier approach that deliberately differentiates between the physical, the economic and the institutional dimensions;
- a modelling framework that allows analysing non-incremental change and transition processes;
- guidance for next steps of research activities following the three tier approach, like modelling feedbacks within the tiers and interactions between them;
- a coherent overall setting that allows integrating the research activities in a stepwise manner, ultimately arriving at an open source model that fully covers the Austrian emission inventory in relation to the three tiers.

3 Motivation and objectives

The need for advancement in modelling in the context of climate change and long-run transformation has increasingly gained attention. The limitations of current modelling has been addressed e.g. by Pindyck (2012, 2013, 2015), Stern (2016), Rosen and Guenther (2015). However, any advancement or proposal of an extended modelling framework should reflect on current modelling practices. The guiding question for **ClimTrans2050** is: What kind of modelling framework is most suitable for assessing the long-term transformation processes needed to drastically reduce Austria’s GHG emissions? We propose a framework for an open source model that improves the understanding of transformation options and provides an innovative modelling approach for their analysis. Our approach for developing this framework was to learn from, but go beyond current modelling paradigms. One central aspect in this context is the introduction of functionalities as target variables of economic activity. The modelling mindset as developed in **ClimTrans2050** results from intense discussions and stepwise clarification of the conceptual foundation. In the development of the framework the project team aimed at a coherent reasoning throughout the research plan. The research plan is to be seen as a first step that prepares the development and implementation of a fully operational open source model for Austria which requires additional time and resources. Transformation options that could be analysed with such an extended modelling instrument would be the ones that are compatible with emerging visions of human lifestyles and economic activities and, additionally, with limiting factors such as GHG emissions.

The aim of the **ClimTrans2050** project was to prepare a research plan for an open source model, that will i) outline emission reduction paths and costs for Austria; and ii) help Austria attain a 80-95% reduction in greenhouse gas (GHG) emissions by 2050. The project also supports Austrian decision makers by proposing a modelling framework for an improved understanding of the social aspects of climate change. **ClimTrans2050** is unique in two ways: the research plan for the proposed open source model i) follows the innovative approach of functionalities to be satisfied from the perspective of wellbeing in a low carbon world; and ii) provides a consistent embedding of an Austria-focused open source model in a global emissions and long-term warming context.

The key element of the modelling framework developed and proposed in this research plan is its focus on wellbeing-related functionalities, ranging from shelter through to mobility (i.e. more precisely access to persons and goods), as the ultimate goals of economic activity. Transformation processes require a deep understanding of the structures linking the physical, economic and institutional layers. We therefore start from functionalities and highlight the role of stocks and flows for providing them. Establishing an open source model for the very long run, and especially for changes in our complex socio-technological system, thus requires a more explicit representation of the role of technologies, given that these determine the quality of an economy's capital stock.

The **ClimTrans2050** Research Plan proposes a new perspective on emissions and economic structures as well as the accompanying institutional framework and identifies next steps for research for the implementation of a fully operational open source model for Austria. This is complemented by exemplary model modules that follow the rationale as developed in the research plan. The model modules are available on an interactive web platform (*climtrans2050.wifo.ac.at*). The research plan is the first step for the development of an operational open source model based on the proposed new understanding of modelling transformation processes. In this sense the research plan provides manifold suggestions and broad basis for further research.

It is in the nature of a research plan that its development differs strongly from "standard" research projects. In the case of **ClimTrans2050** the target is to advance and substantiate the conceptual basis for modelling long term transformation processes that is suited for a stepwise development of an open source model for the Austrian emission system. Two basic qualifications shape the development of the conceptual framework: First, a critical appraisal of current modelling practices, and second, the acknowledgment that Austrian GHG emissions are embedded into a global context.

4 Content and results

4.1 Assessing current modelling practices

A meta-analysis of the strengths and weaknesses of current energy modelling practices is presented in detail in **ClimTrans2050** Working Paper No.1 (Schinko et al., 2015) attached in the Appendix of the research plan (see: http://climtrans2050.wifo.ac.at/). For the most common state of the art energy modelling approaches a critical and systematic review has been conducted, giving insight into the respective strengths and weaknesses with special regard for long-term transition analyses.

Based on this meta-analysis we suggest that a methodological framework for analysing long-run transition processes has to move beyond current state of the art techniques and simultaneously fulfil the following requirements: 1) inherent dynamic analysis, describing and investigating explicitly the path between different states of system variables, 2) specification of details, in particular of the central role of functionalities that are provided by the interaction of flows and corresponding stock variables, 3) a clear distinction between structures of the energy/emission/economic systems and (economic) mechanisms and 4) ability to find feasible pathways (e.g. reflecting both the investment and the operating phase). Furthermore, a crucial early task in modelling is to specify explicitly which of the model elements are determined endogenously, and which exogenously, ideally governed by the demands of the underlying question to be answered.

4.2 National emissions requirements in a global context

One basic qualification for the development of the conceptual framework is the acknowledgment that Austrian GHG emissions are embedded into a global context. We provide a consistent framework for translating the overall ambition of limiting global warming to national carbon budgets. The functionality-based approach to modelling economic transitions as developed in the **ClimTrans2050** project is designed to help identify feasible scenarios of transition to a low carbon economy for Austria.

National consistency with a globally assumed warming target requires two steps: 1) Specifying global GHG emissions constraints corresponding to an assumed warming target; and 2) Distributing efforts of global climate action among nations. An extended version of the Emissions-Temperature-Uncertainty (ETU) framework (Jonas et al., 2014) provides the means to address both these problems.

The concept of a budget of cumulative global GHG emissions over a certain period is the key to understanding what any assumed warming target means in terms of required global GHG emissions cuts. In the work of Meinshausen et al. (2009) it has been shown that the cumulative emissions in the period 2000 – 2050, rather than emissions in any individual year within this period, are a good predictor of a stabilisation level of global warming after 2050 (with respect to pre-industrial period). The ETU framework builds on this finding. In short, it allows us to translate a global warming target (e.g. 2°C above the mean global temperature in the pre-industrial period) into cumulative global GHG emissions until 2050. Knowing this budget and the present level of emissions we are able to derive the rate of required reductions as well as the target level of global GHG emissions in 2050.

The ETU framework is based on the principle of global per capita GHG emissions equity in 2050 (meaning that in 2050 the limit of emissions required to support living and wellbeing of any individual will be equal for anyone, regardless of his/her nationality, age, etc.). The merit of this principle is that it provides targets for per capita emissions in 2050 that are easy to understand, and are universal and meaningful at any scale (from global through national to local).

How this concept could be operationalised in detail is demonstrated in the research plan document as well as on the project website (http://climtrans2050.wifo.ac.at/).

The demonstration of the general approach is the starting point for identifying the next research steps necessary in the development of a comprehensive open source model. Modelling techniques based on the functionalities approach need to be developed on a broad basis to support the identification of the most feasible solutions and policies aiming at a transformation of the current economy into a low carbon one. To this end, functionalities serve best if considered in interaction, not separately. The same is true for scenarios of GHG emissions resulting from future evolution of different functionalities: they can be assessed best if considered together, forming a complete picture of future emissions.

Being complete in assigning all national GHG emissions to functionalities, yet avoiding double-counting, is of utmost importance if a functionalities-based modelling approach is to be relevant for formulating GHG emissions reductions strategies. Therefore the development of a functionality-based analogue of sectoral emissions accounting currently in use is a key task for further research.

4.3 Modelling based on functionalities

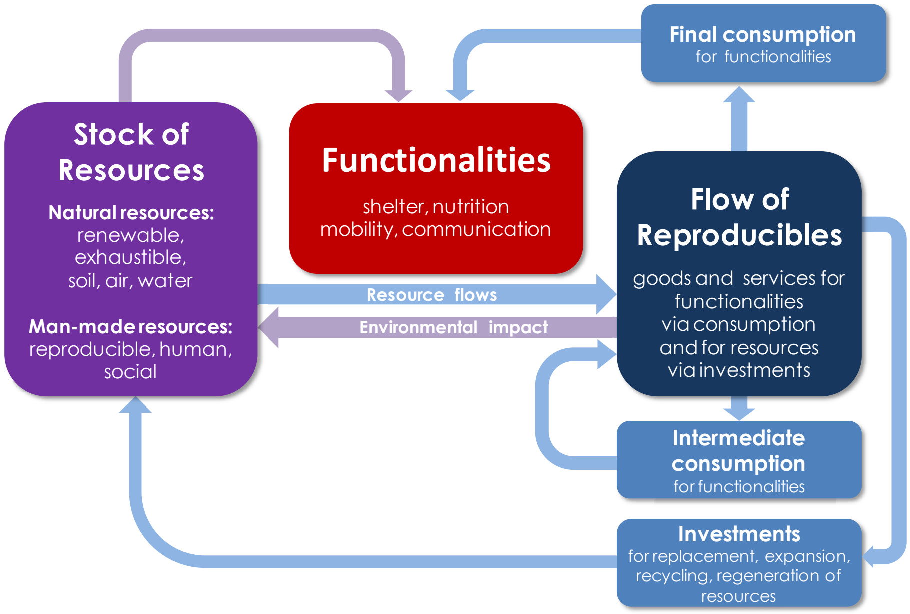
Major challenges to modelling economic, energy and emissions systems are the need to cover a time horizon over several decades and dealing with significant changes with respect to upcoming breakthrough technologies, disruptive events, social innovations and structural changes. Both issues require a new generation of models that aim at a more deepened structural analysis on the one hand and an explicit representation of the relevant stocks on the other. The longer time horizon is motivated by the implications of investments that are made today but determine flows and environmental impacts over their whole lifetime, in some cases (e.g. buildings) over several decades.

These deliberations motivate a deepened structural framework for a more comprehensive understanding of economic activities. Figure 1 visualises the central aspects and their interactions. Three distinctive categories are of importance: Functionalities, stocks of resources and flows of reproducibles. The volume and composition of functionalities needed or desired determines the volume and composition of reproducibles (goods and services). Flows of reproducibles are either used as intermediate consumption in the production of goods and services or they represent one component for providing functionalities via final consumption. Functionalities result from the interaction of the stocks of resources with the flows of reproducibles. Via investment, reproducibles (e.g. buildings, cars, machinery) flow into the stock of resources, changing either its volume or quality.

The rationale of the interdependence between the stock of resources and the flow of reproducibles is crucial since a specific functionality can be satisfied with a varying combination of stocks and flows. In the context of the functionality shelter e.g. for a specific room temperature a higher flow of energy is required in the case of a low quality of the building stock or vice versa.

In the context of transformation processes the role of breakthrough or disruptive technologies becomes evident as their diffusion would impact the flow of reproducibles in order to serve functionalities. Investments in such innovative technologies (zero energy and plus energy houses, new materials and processes in the production sector such as bio-refineries, alternative agricultural processes such as extensive agriculture, …) have the potential of fundamentally changing our energy and/or emission systems compared to conventional investment decisions. Complementary to innovative technologies social innovations and behavioural change (dietary habits, changes in mobility behaviour or in product use like the avoidance of stand by functions) may contribute significantly to a transformation of energy, emission and/or economic systems.

Figure 1 A deepened structural approach to modelling economic activities



This deepened structural approach has the following key features:

- First, the notion of functionalities as purpose of any economic activity.
- Second, the emphasis on the role of the stock of resources (not only reproducible and human resources, but also renewable and exhaustible resources) for the flow of reproducible (goods and services).
- Third, the interactions of the stocks of resources and the flow of reproducibles for providing functionalities.
- Fourth, the direct relevance of stocks for functionalities.
- Fifth, the environmental impact of economic activity on the extended stock of resources.

One major aspect of the deepened structural modelling approach is the emphasis on the proposition that functionalities result from the interaction of flows from reproducibles and stocks of an extended list of resources. Long-run considerations of economic development are highly dependent not only on the volume of resources as human and reproducible capital stocks but also on the natural capital stock like exhaustible and renewable resources (including water, soil and atmosphere).

Following different strands of research that aim at enhancing economic analysis and modelling with a focus on wellbeing, the **ClimTrans2050** Research Plan and the proposed modelling framework for an open source model focus on energy or emission relevant functionalities[2] as the ultimate goal of economic activity.

> ***Functionalities*** *(e.g. nutrition, shelter, access to goods, services and people)* as understood in the context of this research plan are defined as ***the outcome of the interaction of stocks*** *(e.g. buildings and machinery)* ***and flows*** *(e.g. energy and materials)*.
>
> *In addition to end-use functionalities (as relevant for the wellbeing of persons) the concept implicitly also includes intermediary functionalities for reproducibles (as goods and services).*

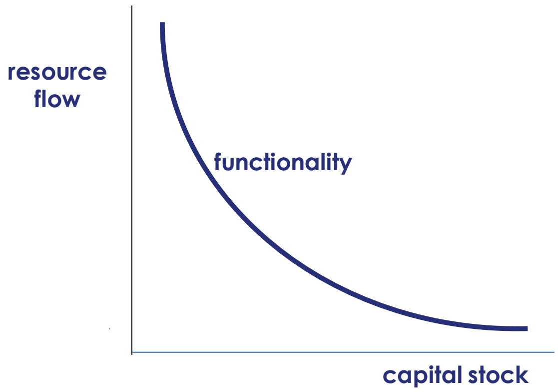
[2] Other functionalities are e.g. health, quality food or nature protection. Also for these functionalities the challenge of quantification applies.

Functionalities can cover comprehensive areas like shelter, nutrition or access to goods, services and people (mobility), or supportive energy related functionalities such as thermal, mechanical or specific electric functionalities, when the energy system is analysed in more detail.

The focus on functionalities and the interaction of stocks and flows shape the proposed basic structure of the framework for an open source model for Austria in the **ClimTrans2050** Research Plan.

In the following we summarise the relevance of the interaction of stocks and flows for providing functionalities in more detail. Figure 2 illustrates that a specific functionality is the result of resource flows and capital stocks. All points along the graph represent the same level of a specific functionality that is provided by a combination of the capital stock and resource flows. Along the curve to the right are those combinations where larger capital stock (in the case of mobility e.g. more public transport) or a capital stock of higher quality requires much less resource flows for the provision of the functionality.

Figure 2 Relevance of stocks and flows for providing functionalities



The concept of functionalities in a deepened structural model is made operational along **three tiers** that are relevant for the sources and the composition of Austrian emissions: the physical, the economic and the institutional tier. Each functionality affects the three tiers and is also affected by them. This underlying mindset (functionalities) and basic structure (three tiers) for modelling builds the basis for analysing transition processes that drive the emissions and the economic system. One of the main challenges of implementing and developing a deepened structural modelling are additional data requirements.

Tier 1: The physical layer

Tier 1 addresses the physical layer of the modelling approach. It represents the interaction of the stock of resources and the flow of goods and services providing welfare relevant functionalities. These interactions cause impacts on resources, in particular on the level of emissions in air, water and land. The insight gained from modelling the details of the physical structure will allow evaluating the impact of changes in technologies (stocks) – above all also disruptive changes – on emissions.

Tier 2: The economic layer

Tier 2 is dealing with the socio-economic and techno-economic structure by assessing stocks and flows related to specific functionalities. Tier 2 translates (changes in) the physical structure underlying the functionalities into economic activities and costs. The economic model structure needs to distinguish the effect of transformation options on different levels of the emission system, i.e. the amount of functionalities desired, flow impacts and stock impacts.

The knowledge of the quality of the existing capital stock including infrastructure and the related flows is the basis for the (macro-)economic evaluation of transformation processes towards low-emissions structures. Related investments and operating costs influence diffusion paths of innovative technologies.

The overall macro-economic impacts (changes in intermediate consumption, employment, etc.) of different transformation options need to be captured in the economic layer. Again this comprises the investment and the operating phase. The economic evaluation of the investment phase has to account for the changes in intermediate consumption due to new technologies, i.e. disruptive technologies might significantly change the input output structure of an economy. This may be true for the investment as well as the operating phase. While the economic effect resulting from investment demand is limited to the investment phase, the economic impact of the transformation option in the operating phase depends on the lifetime of the technology.

Macroeconomic model modules for the open source model that can capture the interlinkages across economic sectors and agents and which explicitly illustrate the different impact of investment and operating are needed. Input-output modelling for the macroeconomic analysis of the transition allows capturing the complex interrelations within the economic system. It can translate technological change into system-wide economic impacts via changes of the underlying production coefficients. In addition this approach can build on existing models with respect to modelling effort and data requirements and thus it is also in line with the target to build up an open source framework.

Tier 3: The institutional layer

Economic activities are embedded into an institutional framework which comprises the regulatory setting that is relevant for coordination and incentives. This includes the role of markets in the private sector and the issue of market failures, which require corrective actions by the public sector (command and control, price instruments) and institutional innovations. The model development strategies therefore need to take into account the role of non-market based regulatory instruments in addition to market based instruments. This extended embedding also includes changes in lifestyles, innovative business models and collaborations.

Framing an economic model by differentiating these tiered components for transition analysis offers a number of insights.

- First, it allows differentiating physical interactions and their economic representation in monetary units.
- Second, it separates the description of economic structures from the mechanisms which impact those structures.[3]
- Third, a variety of market and non-market based mechanisms can be considered.
- Fourth, details in technologies which might be relevant for describing and evaluating transformation processes can be captured.

4.4 The cascade of the energy system and the sources of greenhouse gas emissions (Tier 1)

4.4.1 Energy related emissions

Following the mindset for a deepened understanding of our economies as discussed above, functionalities are also at the core of a deepened structural model of the energy system. An operational approach to energy related functionalities is classifying them according to the energy services they are providing:

- energy related functionalities for providing thermal services (at low or high temperatures),

[3] The structures depict e.g. the impact of technologies on emissions but also related investments and operating expenditures. This is differentiated from mechanisms that influence e.g. the choice of or the diffusion rate of new technologies like economic instruments or command-and-control regulation.

- energy related functionalities for providing mechanical services (stationary engines and mobile engines for transport), and
- energy related functionalities for providing specific electrical services as lighting, electronics and for electro-chemical processes.

These functionalities are closely related to the energy cascade that represents the internal structure of an energy system, i.e. a sequence starting with energy related functionalities. Together with the relevant technologies, the demand for energy related functionalities determines the following energy flows:

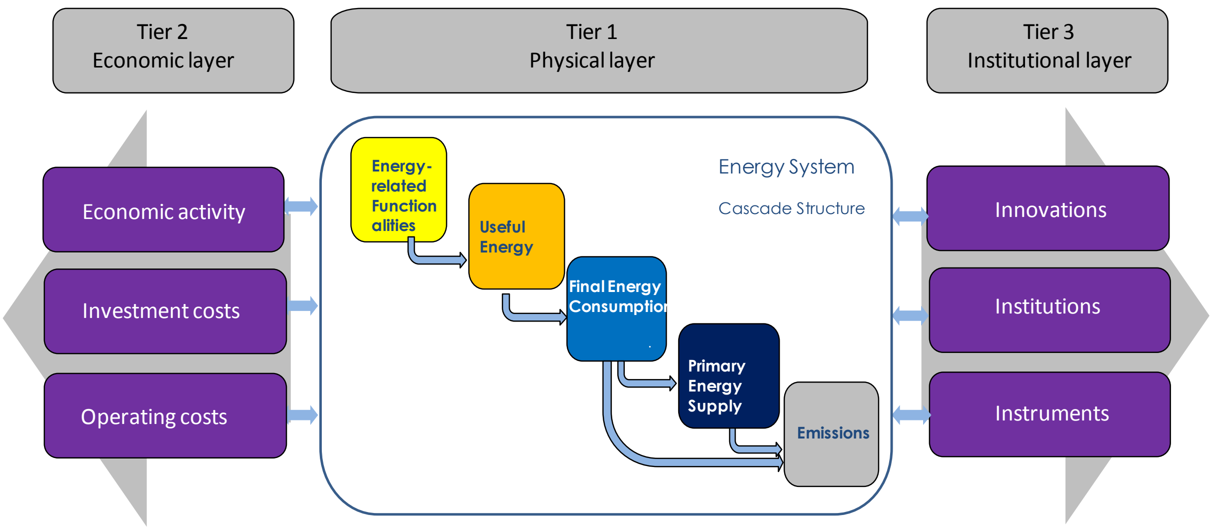
- useful energy flows,
- final energy flows, and
- primary energy flows.

In a deepened structural model of the energy system therefore on each level of the energy cascade the relevant technologies for application, transformation and primary energy supply need to be identified.

For analysing radical transformations which are necessary to achieve the goal of decarbonisation a deeper understanding of the internal structures of energy systems is needed. A constituting feature of the internal relationships in an energy system is a layer of cascades, starting from energy related functionalities which we name synonymously energy services. We move on via useful and final energy consumption to primary energy flows. We denote this view of an energy system the "Cascade Structure" approach as illustrated in Figure 3 which also shows how Tier 1 relates to Tiers 2 and 3.

This perspective of the energy system is fundamentally different from the mainstream focus on energy flows which neglects energy services (energy related functionalities) relevant for wellbeing. Another distinguishing feature for the proposed deepened understanding is the inversion of the sequence of argumentation. Starting point are the energy services and by explicitly considering relevant application and transformation technologies subsequently the energy flows are determined at the respective levels of the energy cascade.

Figure 3 The "Cascade Structure" approach



The energy system and the resulting energy related emissions are embedded into the structures of an economy with a number of links between the physical, the economic and the institutional layers. Buildings, for example, interact with energy flows which are determined by the quality of the building stock, by user behaviour and the related incentives provided by costs (in Tier 2, the economic layer) and the institutional setting like building codes or economic instruments (in Tier 3, the institutional layer) as drivers for long-run structural change.

Looking into the internal structures of energy systems we distinguish a cascade of four layers (Figure 3). The top layer represents different types of energy related functionalities which are synonyms for the term energy services:

- thermal energy services for e.g. maintaining buildings at comfortable temperatures and enabling heat-related production processes,
- mechanical energy services for providing mobile or stationary services in all kinds of machinery, and
- specific electric energy services needed for electric motors, lighting and electronics.

Energy services are provided by useful energy which is characterised by its purpose as

- thermal applications in low and high temperature processes,
- mechanical applications in stationary and mobile engines, and
- specific electric applications as in lighting and electronics.

The next layer of the energy system is composed of the energy flows that are metered in households and companies and which comprises final energy consumption for

- heating and cooling in buildings and production,
- fuels for stationary and mobile engines, and
- electricity for machinery, lighting, electronics and electro-chemical processes.

The amount of final energy is determined by the amount of energy services desired on the one hand and the quality and efficiency of the corresponding application and transformation technologies on the other. In the context of application technologies, aspects of technologies particularly relevant for the transition to low-energy and low carbon structures include the thermal quality of buildings, the efficiency of stationary and mobile engines or the efficiency of lighting and electronic devices. In the context of transformation technologies, heating and cooling systems and the conversion of primary energy into final energy as electricity and heat or the conversion of crude oil into fuels need to be considered.

The lowest layer of the energy system concerns the primary energy flows as

- fossil energy (coal, crude oil, natural gas, non-renewable waste),
- renewable energy sources (thermal solar, PV, ambient and geothermal heat, wind, hydro, biomass, renewable waste), and
- uranium for nuclear transformation processes[4].

Emissions from the energy system arise from fossil energy flows via transformation processes, including distribution losses, and final consumption of fossil energy sources. For understanding emission reduction potentials and emission reduction policies it is essential to identify these origins of emissions.

4.4.2 Non-energy related emissions

Like for energy related emissions, functionalities are also at the core of a deepened structural model of non-energy related emissions. The common approach of modelling industrial and agricultural process emissions focuses on the production process (the supply side) but does not explicitly consider the demand side (in the context of **ClimTrans2050** the functionality).

The functionalities approach starts at the other end of the food cascade (Figure 4). The intuition is that a transformation process starting at the demand side discloses more options for emission reductions than one

[4] For Austria relevant in the form of imported electricity.

starting at the supply side. Therefore this approach explores the demand side and its drivers. Better knowledge on the demand drivers allows more targeted policies to induce a demand shift. Nutrition might change over time in terms of amount and composition. For example, the amount of calories taken in per day and capita may change over time. More importantly, the composition of consumed calories (e.g. the shares of meat, vegetables etc.) and the shares of proteins, fat and carbohydrates will change (e.g. as a result of habits, lifestyles).

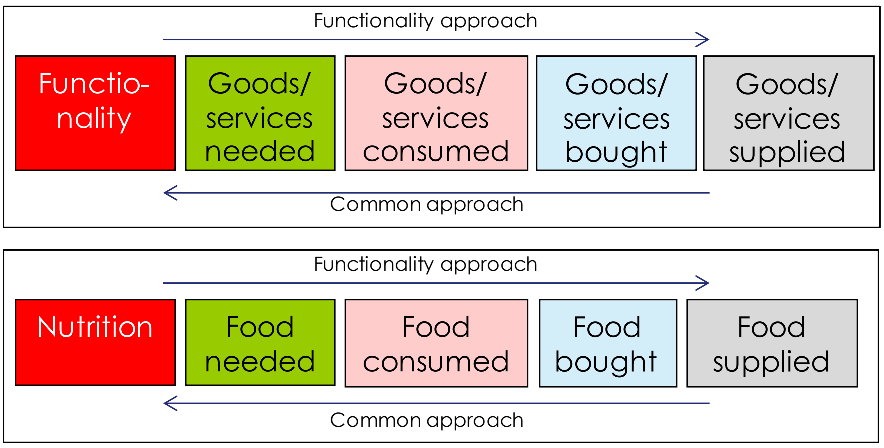
Thus the primary goal of the functionality approach is to analyse the demand and its driving factors and how these can be influenced to achieve a targeted reduction of emissions. The next step is to assess which types of food are most relevant for consumption and to assess how the food can be produced with as few emissions as possible (Figure 4). "Food needed" denotes the amount of calories humans require for everyday activities. Optionally the amount of food required for pets can also be included in this category. The amount of "food needed"[5] may be used as quality control for the model output, since it provides a lower boundary (otherwise people would starve). "Food consumed" is usually a higher amount than "food needed" because of preferences, sports activities, intolerances, malnutrition, bulimia or overweight, etc. Likewise, the amount of "food bought" is higher than the amount of "food consumed", due to losses in cooking and waste (intentionally and unintentionally[6]). Finally, not all food is sold but is disposed to waste in wholesale and retail (shops and markets) or food service (restaurants, hotels, takeaways). Furthermore there are losses in food production (agriculture) and processing (food industry). "Food supplied" will hence be larger than "food bought".

A Swedish study (IVL, 2016) reports that total food waste in the EU-28 amounted to 87.6 million tons in the year 2012, which corresponds to 173 kg per person and year or roughly half a kilogram per day and capita.

Figure 4 is an analogy to the energy cascade. It shows the common modelling approach starting from the supply side and the functionality approach, starting from the demand side. Food, represented by calories, can be considered as a special form of energy. However, food also provides micronutrients such as vitamins, minerals and trace metals.

Starting from food as consumed good a generalised cascade structure can be deduced for each good (reproducible) or service (e.g. health, administration). While emissions are modelled in Tier 1, it is important to understand the economic implications (Tier 2) and the institutional setting (Tier 3) shaping the physical layer (Tier 1).

Figure 4 Food cascade and goods/ services cascade in analogy to the energy cascade[1])



[1]) Imports and exports have to be considered in "goods/ services bought" or specifically "food bought"

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[5] This could e.g. be based on recommendations of the WHO.

[6] Intentional losses in cooking arise e.g. from peelings or bones; intentional waste are leftovers (including food that is not eaten, because it does not taste well); unintentional losses are e.g. mishaps in cooking and rotten food.

For describing the functionality nutrition in Austria (as the main driver for food production), the following information is relevant:

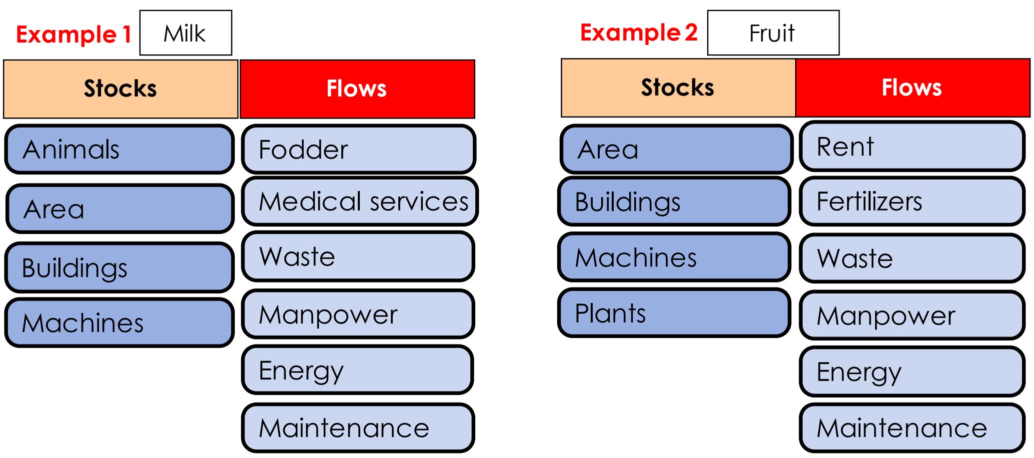
- population in Austria (including specific demographic parameters like age, sex and work),
- amount of consumption of selected types of food per capita,
- shares of domestic production, import and exports of the food types, and
- lifestyles and social factors.

A model suitable for analysing transformation processes has to represent the food cascade and the economic and institutional interdependencies. One step is to select representative types of food for modelling nutrition purposes. The modelling structure needs to capture what amount of which products is needed to cover the functionality, as well as the energy input and the corresponding emissions for the individual production processes of each food type. Total emissions allocated to the functionality nutrition then result from the sum of all these production processes, depending on the system boundaries applied (e.g. distribution or cooling chain may also be assigned to this functionality[7]). A categorisation of food types could divide food into animal based products like meat (including fish and insects), milk and others (e.g. eggs, gelatine, honey), and plant based products like fruit, corn (i.e. all sorts of grains), vegetables and algae and others (e.g. mushrooms). In all categories the derivatives of the main source are included, e.g. milk products (yogurt) in milk, fruit juice in fruit, bread in corn and sugar in vegetables.

Figure 5 depicts two examples (example 1: milk; example 2: fruit) to illustrate relevant stocks and flows that have to be taken into account for modelling the functionality nutrition. For the production of milk (and subsequent products like cheese) the most important stock is the number of dairy cows, sheep and goat providing milk. Pasture land for the animals is needed as well as building infrastructure (e.g. stables, fences). Furthermore milking machines and vehicles are part of the technical infrastructure. Important flows connected to milk production are fodder for the animals, provision of a healthy environment which includes medical services and dealing with manure generated by the animals, energy for machinery and buildings[8] as well as workforce for maintenance.

The production of fruit (example 2) has similarities to example 1 with respect to stocks except for the fruit growing plants (trees and bushes). Naturally the use of the area and buildings (e.g. silos) and the type of machines differ significantly from example 1. The most important additional flow is the use of fertilizers.

Figure 5 Examples for material stocks and flows related to the functionality nutrition



[7] In any case double counting of emissions needs to be avoided.
[8] Again double counting of emissions needs to be avoided.

4.5 The economic layer (Tier 2)

For a techno- and socio-economic evaluation of transition based on functionalities, proxies are needed for measurement and evaluation. The extent of the provision of a functionality is driven by demand which in turn is driven by demographics (population) and lifestyles.

A functionality can be served by a multitude of different technologies (characterised by different degrees of resource productivity), which determines economic activities. The economic analysis allows comparing the resources required to serve functionalities, and thus identify the most resource-efficient pathways. In economic terms this translates into different investment and operating costs as well as different sectoral demand structures.

For the economic evaluation of functionalities the interaction of stocks and flows is crucial (see above for a broader discussion on the importance of stock and flow interaction). We thus suggest applying the concept of user costs, since it captures both stock related costs (i.e. capital costs) as well as costs attributed to flows (i.e. operating costs). Annual user costs are the sum of annualised capital costs and annual operating costs and are (or at least should be) an important determinant for individual decision making. While the differentiation between those two subcategories of costs is crucial, usually they are interdependent, e.g. since in most cases the quality of the capital stock determines the level of operating costs. Hence, users face a situation where they can choose between either having low capital costs (in that respect a thus measured lower quality of the stock) and a high resource flow with high operating costs or vice versa (i.e. a high quality capital stock with low operating costs). These cost considerations build upon the physical relationship as depicted in Tier 1 (the physical layer) which here serves as the connecting point to the economic analysis.

Since often GHG or CO_2 emissions are connected stronger to annual flows than to the creation of the stock itself, a transition to a low carbon economy could be achieved by increasing the quality of the stock, to decrease the necessary annual flows and thus emissions.

For an economic evaluation we require the respective annualised costs of improving the stock (new technology) and the resulting resource and cost savings. Both should be given normalised to the unit applied. Thus, for the transition analysis to a low carbon economy not only the description of the current state of technologies is necessary, but also cost profiles of new technologies, including potential breakthrough technologies which may substitute dominant current technologies. Note that the functionalities per se do not change within this transition, but technologies to serve them and lifestyles to draw on them do. Hence for each functionality new (high-potential) technologies or fundamental behavioural change need to be identified and respective cost information needs to be gathered. The possible shifts from the set of currently used technologies (and the associated costs) to a set of new (breakthrough) technologies or behavioural patterns describe available transition processes. Both technologies and behavioural patterns affect economic structures.

While the perspective of the user is crucial for incentives (Tier 3) to actually achieve transition, implications of such a transition have aggregate effects beyond those on the respective individual user. This aggregate level thus is the second crucial one to be in the focus of analysis and consideration. In economic terms it is the macroeconomic perspective (i.e. capturing the macroeconomic effects of the transition) that is at the core of our interest at this level. Macroeconomic effects emerge via the interlinkages across different economic sectors and agents. For example, if there is increased demand for construction activities for the thermal improvement of the building stock, this generates increased demand for labour and other intermediate inputs in sectors that provide products which are needed for construction activities (e.g. insulation material, transport etc…). Also foreign trade may be affected by the transition if import intensities of products and technologies for transition options differ from those of conventional technology options. For example, if insulation material for buildings is over(under)proportionally imported, the foreign trade balance worsens (improves). Any acceleration of the diffusion of transition technologies is reflected in stronger macroeconomic effects. To reveal these overall economic effects input-output based analysis may be applied, since this method captures the interrelationships between all economic sectors within a macroeconomic consistent framework.

Note that for each functionality this explorative approach might have to be adjusted for some functionality-specific characteristics, yet the overall approach is the same and can be summarised as follows:

1) Define functionalities and respective proxies
2) Identify technologies serving these functionalities in the current state
3) Identify new technologies with potential for substituting current technologies (including the extent of possible substitution)
4) Derive cost of changing to new technologies
5) Compare resource, emission and economic effects across technologies at both the user and aggregate socio-economic level.

The outlined approach for the economic evaluation of transformation options is demonstrated in more detail in the **ClimTrans2050** Research Plan for the functionality "shelter".

4.6 The institutional layer of a deepened structural modelling approach (Tier 3)

Compared to traditional modelling approaches **ClimTrans2050** proposes an extended mindset for modelling that integrates the institutional layer more explicitly into the overall framework. Different institutional elements are also integrated in mainstream modelling, however, they typically show a strong focus on market mechanisms. To overcome this shortcoming of mainstream modelling, the **ClimTrans2050** Research Plan adopts a broad perspective on institutions and especially emphasises the role of lifestyles and consumption patterns.

The institutional layer in its comprehensive understanding determines the framing in which socio-economic activities take place, and thus shapes what form they take as well as it determines their GHG emissions. In the context of the functionality approach it ultimately co-determines the level of functionalities and which combinations of stocks and flows are chosen for satisfying them. The institutional layer is an enabling factor for functionalities and for transformation processes. In order to highlight the relevance of the different aspects of the institutional layer and particularly emphasising the role of non-price mechanisms **ClimTrans2050** proposes a separate tier to address the institutional setting. The rationale for this is to augment transparency with respect to instruments and mechanisms in modelling.

The institutions modelled in Tier 3 transmit to Tier 2 and Tier 1. In order to illustrate this transmission process one can use efficiency standards as an example. For a certain functionality more stringent regulation would translate into an investment demand, changing (the quality of) stocks. The functionality then would be provided by a new combination of stocks and flows. The respective effects of the economic activities in Tier 2 translate into changes in emissions in Tier 1.

The institutional layer is not to be considered as a separate module, but as a different yet integrated modelling step. The aim is not to strive for a "supermodel" that encompasses all thinkable aspects of institutions. A series of modules would be more feasible to capture the role of institutions for transition processes and emissions. However interactions between model modules need to be considered, i.e. one has to assess whether a linkage of model modules is advisable or necessary.

Giving special emphasis to the role and potentials of different institutions by deliberately distinguishing between the three tiers is one of the cornerstones of the **ClimTrans2050** Research Plan. In a nutshell this approach has the following merits:

- It encourages broadening the scope of institutional elements and new practices in modelling.
- It puts special emphasis on non-market mechanisms.

- It increases the transparency of the impact of different institutional elements on the transition process towards a low carbon economy.
- The **ClimTrans2050** modelling framework links the physical layer (Tier 1) and the economic layer (Tier 2) to the institutional layer (Tier 3).

How the institutional layer (Tier 3) can be understood as building block of the deepened structural modelling approach as developed above is illustrated in Figure 6. The main interest as expressed here is the transmission process of the mechanisms from the institutional layer to the economic and physical layer. The **ClimTrans2050** Research Plan aims at a series of model modules along the three tier structure that supports the development of an open source model suited to capture transformation processes.

The institutional setting is given at Tier 3, including aspects such as which allocations are organised via markets, where and what norms or standards are set (social, environmental, technological, labour), or which specific policy instruments are implemented.

Tier 2 as well as Tier 1 in contrast is a representation of the result of any such setting given at Tier 3, from a socio-economic and emissions perspective. It is a socio-economic and physical depiction of what is defined and modelled at Tier 3. Tier 2 thus e.g. can inform about the impacts of the settings defined at Tier 3 (such as specific policies) on induced economic activity and in turn about employment and output effects both in the investment and operating phase. Obviously this also brings about feedback effects, e.g. disposable income or tax revenues. Policy model modules implemented at Tier 3 can draw from this information.

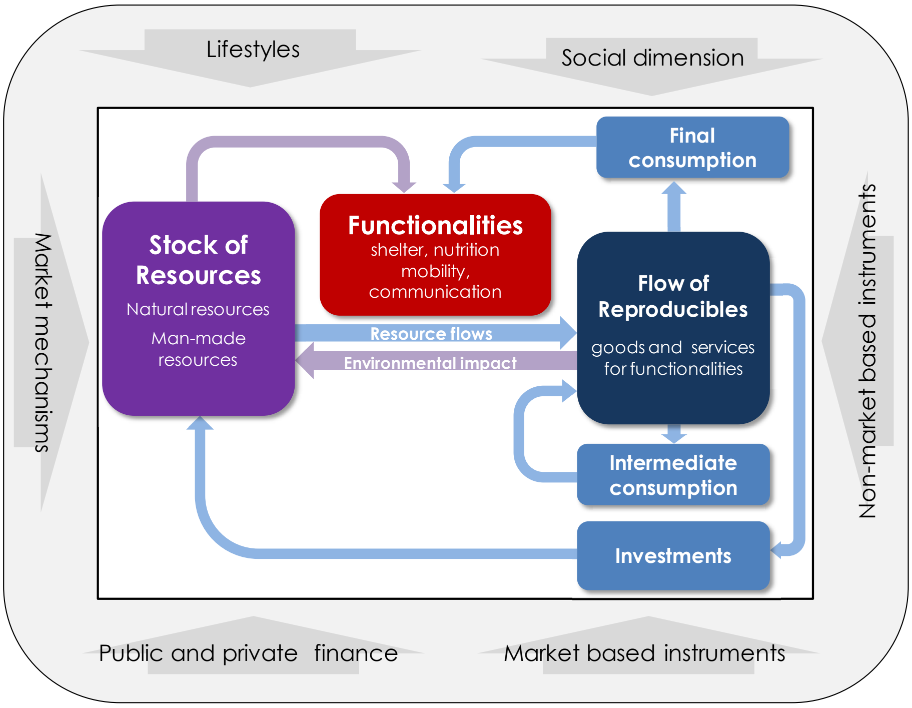
In the following we reflect on institutional elements that are of high relevance in the context of long run decarbonisation processes. This comprises heterogeneous elements that encompass both market based and non-market based instruments and mechanisms:

- Lifestyles: Lifestyles are reflected in consumption patterns that relate to certain production structures and ultimately greenhouse gas emissions. Although research (e.g. IPCC, 2014) points at the crucial role of lifestyles for climate change mitigation, they are often not explicitly addressed in modelling.
- Social dimension: The social dimension includes e.g. the labour market design, distributional aspects, or education. These aspects are already taken up in different level of detail and different way in existing models. Knowledge already available can serve as input for model modules in the deepened structural modelling approach.
- Non-market based instruments: This group of instruments comprises command-and-control instruments like standards. Usually these instruments are not the main focus in traditional economic modelling approaches that typically put a stronger emphasis on changes in relative prices. This category of instruments, however, may exert considerable changes in economic activity and economic structures.
- Market based instruments: They are represented broadly in existing economic models and are e.g. modelled as taxes, permits, or subsidies. Typically the effect of market based instruments is modelled as causality between price changes and changes in production and consumption patterns. Interlinkages with other regulations e.g. standards is in this context frequently concealed. Explicitly addressing the institutional layer facilitates to focus on these aspects.
- Public and private finance: The public sector is of high relevance and has a large potential with respect to changing capital stocks and infrastructure. Hence, for low carbon transition modelling it needs to be addressed in sufficient detail; e.g. with respect to the tax structure or public investment. For user costs, as emphasised in the **ClimTrans2050** Research Plan, aspects of private finance like amortisation periods need to gain in importance in modelling. This concept is standard for investment decisions, but not firmly integrated in macroeconomic models.

- Market mechanisms: They represent the role of markets for economic activities.

This list above makes clear that the institutional layer as part of the deepened structural modelling framework covers a broad range of issues including the role of markets in the private sector and the issue of market failures which require corrective actions by the public sector (command and control, price instruments), institutional innovations and lifestyles. Modelling behavioural change, though of key importance for assessing long term transformation processes, is challenging and may require novel approaches. Consumption patterns e.g. can often not be explained solely by economic considerations but are also driven by status, habits and customs. To integrate (existing) research on these aspects into a comprehensive open source model will be one main step in model development.

Figure 6 The institutional layer of a deepened structural approach



The above described elements cannot be interpreted as being independent from each other. From a modelling perspective it seems more feasible to tackle the aspects in a series of separate model modules due to e.g. the high level of complexity or high data requirements. However not only feedback effects between the different tiers of the model need to be accounted for but also the interlinkages between separate elements of the institutional layer.

The model modules in Tier 3 are not an end in itself but a means to define the setting triggering the transmission process to Tier 1 and Tier 2 and the prevailing respective economic and emission structure. Storylines for long run transition options need to be translated into a specific model setting and model inputs on all three tiers. Through the transmission process Tier 1 gives then the interpretation on the effect on emissions incorporating also the changes in Tier 2. Transformation options that aim at a specific emission target very likely will require an iteration process, i.e. after providing an institutional setting (Tier 3) and deriving the effects in Tier 1 and Tier 2 the parameters in Tier 3 will have to be adjusted (e.g. new instruments, change in scale of instruments).

4.7 Exemplary model modules

One of the goals of the ClimTrans2050 project was to supplement the developed methodological concept with exemplary empirical model modules directed both at the modelling community and decision makers. The two model modules presented at the interactive web platform (***climtrans2050****.wifo.ac.at/)* are illustrations of the energy cascade and Austrian reduction paths in a global context. Details on the model structure for the energy system are described in the ClimTrans2050 Working Paper No.2 (Schleicher et al., 2016). The methodological background for the Austrian emission pathways is laid out in chapter 3 in the **ClimTrans2050** Research Plan.

The interactive section of the web platform is the first step for the development of an operational open source model based on the proposed new understanding of modelling transformation processes. In this sense the research plan provides manifold suggestions and broad basis for further research.

With respect to the energy system, the implementation as a web tool offers the cascade structure of the energy system in an easily accessible way. The low access barriers allow especially stakeholders, and other non-modelers, visualisation and modification possibilities of all relevant information. For the modelling community it provides a rich database and the demonstration of the translation of the concept of the energy cascade into an empirical structure. Users can create visions of the future of the Austrian energy system. All decisions are reflected in the composition of energy use, energy supply and induced CO_2 emissions. The findings are visualised and can be compared with past development. We are able to partition CO_2 emissions fully to energy related functionalities. This is done by adding to the CO_2 emissions from the fossil energy flows needed for a particular functionality also the indirect emissions via the consumption of electricity and heat and the related distribution losses.

Visualisations of the global and Austrian historical GHG emissions as well as of the reduction targets presented in sections 3.2 and 3.3 of the **ClimTrans2050** Research Plan are also available on the project's web platform offering a broader overview of the emissions and reductions leading towards different warming targets.

4.8 Knowledge gaps and next research steps for a fully operational open source model

4.8.1 Research gaps and next research steps for the energy module

Deepening the functionality approach to energy modelling

- Developing operational indicators for energy related functionalities: Supporting information for obtaining a better understanding of thermal, mechanical and specific electric services.
- Identifying gaps in currently available databases and developing proposals for improving data collection activities: Currently available databases are not adequate for deepened structural modelling and need to be extended with respect to the concept of functionalities.
- Designing model modules for specific energy related functionalities: Tackling the complexities of specific functionalities, as in the case of shelter the role of temperature, lighting, and communication facilities.
- Collecting a knowledge base about technologies which are in particular relevant for the transition to low-energy and low carbon structures: Whenever new technologies emerge, they can be evaluated with respect to energy productivity, energy sources and emissions along the cascade structure of the modelling approach. It is expected that energy systems will experience not before long a number of breakthrough technologies, ranging from a new generation of batteries to new options for distributed generation technologies.

Modelling the linkage between Tier 1 and 2

- Providing the details on technologies and investments.
- Modelling the impacts of these investments on energy productivity and energy demand and operating costs.
- Modelling the impact of these investments on other sectors of the economy including energy demand and related emissions.

Modelling the impact of Tier 3 on Tier 1

- Evaluating the relevance of the institutional layer e.g. economic instruments (taxes, subsidies), prices and income and income distribution, command and control regulations (standards, zoning regulations) for energy related decisions.
- Capture the transmission process from drivers for innovative technologies and business models that impact the energy system.

4.8.2 Research gaps and next research steps for modelling non-energy related emissions

Deepening the functionality approach for non-energy greenhouse gas emissions

- The open source model should aim at providing the structure of the status quo starting from functionalities; the amount of total emissions should be in coherence with national inventory (at least for Austria overall).
- The availability, utility and quality of relevant data such as population growth, dietary habits (amount of consumed milk products, different types of meat, vegetables, …) has to be assessed.
- Gaps in currently available databases need to be identified and suggestions for improving data availability with respect to functionalities need to be made.
- Scenarios for future nutrition and how this consumption can be influenced (behavioural changes -> Tier 3) have to be developed. Factors of health and wellbeing should also be considered, e.g. the calorie demand should not be covered only by a single source of food.
- The model module should be capable of analysing changes of technical parameters such as
  - production of calories per animal,
  - yield of grain with a certain content of calories/proteins/carbohydrates per hectare of land,
  - amount of fertiliser needed per hectare of land,
  - emission factors (e.g. race of cattle).
- An assessment of uncertainties concerning data and model results needs to be made; the focus should be on the most relevant and sensitive parameters.

Modelling the linkage between Tier 1 and 2

- Interlinking most important economic parameters for nutrition and related emissions.
- Accounting the structure of the agricultural sector (size of farms, percentage of organic farming,…).
- Interlinking technical parameters (e.g. learning curves, but also complete switches of technologies) and emissions.
- Allowing for and integrate breakthrough technologies.
- Changing technological coefficients over time.
- Dealing with boundaries and restrictions (e.g. area, water, human resources).
- Avoid double counting of activities (reproducibles, infrastructure).

4.8.3 Research gaps and next research steps for modelling the economic layer (Tier 2)

In order to be able to evaluate transition options, a better understanding of both the current state and potential new ways to serve functionalities is required. Concrete tasks to this end include:

- Definition of functionalities

  Give a clear and precise definition of all core functionalities

- Definition of respective proxies to measure functionalities.

  Define carefully how to measure each functionality using proxies. This allows comparability for substitution[9].

  Examples for proxies:

  - Shelter: keeping 1 m^2 residential area at 21°C
  - Mobility: As the actual objective is "Access to persons, goods and services", traditional proxies, e.g. person-km, are misleading. What if we investigate the technology 3D-teleconferencing? This technology makes passenger transport obsolete in some cases. A proper proxy may be "talk to a visible person for 1 hour".

- Development of an adequate analytical system

  The deepened understanding of the structure of (economic/energy/emissions) systems requires a corresponding analytical framework that is able to simultaneously capture stock and flow elements.

- Identification of high-potential breakthrough technologies and respective costs

  The availability of technologies, in particular breakthrough types, needs to be analysed, leading to data requirements for breakthrough technologies

- Identify at which levels transitions can occur

  Taking the functionalities as given, transition can happen at different points in the spectrum of transition from marginal changes to radical changes:

  - Efficiency improvements within a technology (e.g. more efficient diesel engines reduces losses between final energy and useful energy)
  - Change of the technology itself (e.g. use electric vehicles instead of conventional cars)
  - Change of the proxy to serve a functionality (e.g. physical transport may become obsolete by introducing 3D teleconferencing)

- Identify the extent of possible substitution

  The quantitative relevance to substitute other resources with break-through technologies, in particular energy, needs to be analysed (also reflected in the diffusion rate).

  By how much can new technologies substitute current technologies? What are the limits of substitutability?

- Identification of cost profiles for current and future technologies

  User costs: For an economic assessment user costs are relevant. For the evaluation of transition options user cost profiles are desirable for comparability. Operating costs relate to final

[9] Note: If the unit of measurement changes, this may be an indicator for systemic changes. For further insights trace back energy and resource demand as well as emissions with respect to the proxy, i.e. follow the steps of the cascade structure of the energy and emission system backwards: that is from functionality to emissions; for energy related functionalities this means to trace back the energy cascade: functionality – energy service – useful energy – final energy consumption – primary energy.

resource/energy consumption in physical terms determined in Tier 1. Investment costs relate to costs occurring with changes in capital stocks. Sensitive parameters are prices used for the long run transition analysis.

- Quantification of macroeconomic implications of transition options

  For a macroeconomic assessment of transition options indirect effects (sectoral interdependencies, factor market feedbacks) need to be acknowledged, for both environmental (GHG emissions) and socioeconomic (economic activity, employment level, inflation, ...) impact analysis. For the evaluation of transition options these sectorally detailed effects, as well as their net aggregate implications are crucial in comparing different options for society. Applying an input-output model as core element can well serve this objective.

- Reveal all necessary inputs needed (energy, non-energy, capital, labour)

Modelling the linkage between Tier 2 and 3

- The institutional framework (Tier 3) may induce changes in economic structures, such that
  - User costs implemented at Tier 2 relate differently to physical parameters of Tier 1 (when e.g. incentive systems are changed by new financing options of building insulation). This may affect both investment and operating costs.
  - Macroeconomic feedback mechanisms change (when e.g. a basic income changes labour supply – Tier 3) which need to be adequately depicted (mutually consistent) at Tier 2.

  Identification of how institutions can foster transition processes making use of economic incentives

- Data base screening

  In order to integrate the suggested methodologies into an open source model a thorough screening of existing databases is necessary as well as the identification of additional data requirements.

4.8.4 Research gaps and next research steps for modelling the institutional layer (Tier 3)

The explicit distinction between the economic structure and the institutional setting is one of the innovative aspects of the modelling framework for an open source model proposed in the **ClimTrans2050** project. In this respect the following research gaps should stimulate efforts to widen the perspective in transition modelling.

- Specify detailed modules for the institutional elements of Tier 3.
- Define module interfaces that capture the interlinkages between instruments, behavioural or social changes (Tier 3) and that enable the quantifications of the impact on emissions via economic or technical parameters.
- Allow for and integrate disruptive events (e.g. BSE, bird or swine flu).
- Allow for and integrate social innovations and structural changes.

4.8.5 Research gaps for the empirical implementation

- Specify and compile detailed modelling and data for the economic and institutional layer.
- Modeling the interfaces that capture the interlinkages between different instruments and the physical layer.
- Quantifications of the economic impacts.
- Modeling of disruptive events and compilation of necessary data and parameters to capture them.

- Extend the empirical basis to model modules of other functionalities.

4.8.6 Research gaps and next research steps for embedding the open source model into a global context

The development of a functionality-based analogue of sectoral emissions accounting currently in use is a key task for further research. Among other issues, it will require:

- Finding a one-to-one mapping (i.e. complete and avoiding double-counting) of sectoral inventories into a set of relevant functionalities covering all national GHG emissions (cf. sections 5.1 and 5.2)
- Addressing the issue of emissions embodied in international trade and consumption of goods produced outside of the Austrian territory and vice versa (net balance of imported and exported products and services)
- Development of data collection methods which will support the construction of the functionality-based emissions inventories in the future (e.g. collecting data on lifecycle emissions of stocks)

Principles guiding the assignment of fractions of the global GHG emissions budget to specific nations are a matter not only of science, but also of international politics. The principle of equity of per capita emissions in 2050 used currently by the ETU framework has its scientific merits. However, it also has disadvantages of a practical and political nature. There is a need for other criteria for the distribution of the global GHG emissions budget among nations which address the abovementioned issues.

5 Conclusions

The **ClimTrans2050** Research Plan provides a framework and research guidelines for the development of a fully operational open source model along the conceptual structure presented above. The open source approach as outlined in **ClimTrans2050** has two objectives:

- An interface for the research community in order to provide a platform and transparent information for a stepwise extension of the open source model; and
- a visualisation tool for users such as policy decision makers.

The underlying mindset for such an innovative modelling approach defines a wide range of research efforts as addressed in this research plan. An example for these new research tasks is the need for a coherent modelling of the three tiers and the interactions and feedbacks between them. These research tasks need to be embedded in a simultaneously conducted extension and improvement of existing databases.

We identified in particular the following key features for the next generation of models:

- The focus on functionalities as indicator for wellbeing and economic performance.

  The key element of the modelling framework developed and proposed in this research plan is its focus on wellbeing-related functionalities, ranging from shelter through to mobility (i.e. more precisely access to persons and goods), as the ultimate goals of economic activity. Analysis of transformation processes requires a deep understanding of the structures linking the physical, economic and institutional layers. We therefore start from functionalities and highlight the role of stocks and flows for providing them.

- A deepened specification of the structure of the system, such as the cascade structure in the context of energy and non-energy systems.

  Establishing an open source model for the very long run, and especially for changes in our complex socio-technological system, requires a more explicit representation of the role of technologies, given that these determine the quality of an economy's capital stock.

  Major challenges to modelling economic systems are the need to cover a time horizon over several decades and dealing with significant changes with respect to upcoming breakthrough technologies, disruptive events, social innovations and structural changes. Both issues require a new generation of models that aim at a more deepened structural analysis on the one hand and an explicit representation of the relevant stocks on the other.

  The longer time horizon is motivated by the implications of investments that are made today but determine flows and environmental impacts over their whole lifetime, in some cases over several decades. Such investments relate e.g. to buildings where the building quality determines the amount of energy flows for heating and cooling, or to mobility where the main influential factors to reduce person kilometres are spatial planning including land use change and infrastructure investments.

  Illustrating this approach we look at the energy system: For transformations which are necessary to achieve the goal of decarbonising the energy system a deeper understanding of the internal structures of systems is needed. A constituting feature of the internal relationships in an energy system is a layer of cascades, starting from energy related functionalities which we name synonymously energy services. We move on via useful and final energy consumption to primary energy flows. We denote this view of an energy system the “Cascade Structure” approach (see also above).

  This perspective of the energy system is fundamentally different from the mainstream focus on energy flows which neglects energy services relevant for wellbeing. Another distinguishing feature for the proposed deepened understanding is the inversion of the sequence of argumentation. Starting point are the energy services and by explicitly considering relevant application and transformation technologies subsequently the energy flows are determined at the respective levels of the energy cascade. A similar example concerns the functionality nutrition for non-energy emissions and is presented in the research plan.

- The separation of the specification of structures from the mechanisms that are generating these structures, in particular non-market based mechanisms.

  Economic activities are embedded into an institutional framework which comprises the regulatory setting that is relevant for coordination and incentives. This includes the role of markets in the private sector and the issue of market failures, which require corrective actions by the public sector (command and control, price instruments) and institutional innovations. The model development strategies therefore need to take into account the role of non-market based regulatory instruments in addition to market based instruments. This extended embedding also includes changes in lifestyles, innovative business models and collaborations.

The concept of functionalities in a deepened structural model is made operational along **three tiers** that are relevant for the sources and the composition of Austrian emissions: the physical, the economic and the institutional tier. Each functionality affects the three tiers and is also affected by them. This underlying mindset (functionalities) and basic structure (three tiers) for modelling builds the basis for analysing transition processes that drive the emissions and the economic system.

The **ClimTrans2050** Research Plan aims at providing

- coherent and understandable modelling guidelines that put the focus on functionalities (relating to shelter, access to persons, services and goods, nutrition, etc.) and that stress the interrelationship of stocks and flows in order to provide the functionalities;
- a framework for a deepened structural approach to modelling the Austrian emissions system along a three tier approach that deliberately differentiates between the physical, the economic and the institutional dimensions;
- a modelling framework that allows analysing non-incremental change and transition processes;
- guidance for next steps of research activities following the three tier approach, like modelling feedbacks within the tiers and interactions between them;
- a coherent overall setting that allows to integrate the research activities in a stepwise manner, ultimately arriving at an open source model that fully covers the Austrian emission inventory in relation to the three tiers.

In line with the open source approach we provide

- the structure for a web-based platform for exchanging and disseminating information and first model modules to stakeholders and the research community;
- pilot modelling modules based on functionalities and the three tier approach as first milestones of the research steps needed for the open source model;
- a framework for integrating the Austrian emissions inventory into a global context.

The project team feels that the innovative modelling approach as developed within the project **ClimTrans2050** is suitable to be carried on in future research of the project team. The framework for the deepened structural modelling approach is well suited to stimulate discussions in the scientific community on a national and international level as well as with decision makers (policy, administration, social partners, etc.).

The summary of the identified knowledge gaps above indicates, that the development of a comprehensive modelling infrastructure depends on the "cooperation" between researchers and funding institutions in the sense that researchers need to be open minded and funding institutions need to give commitment for midterm funding. The research plan and the proposed modelling framework can be seen as input for the formulation of funding programs and as basis for improved policy advice on long term transition processes.

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B) Project details

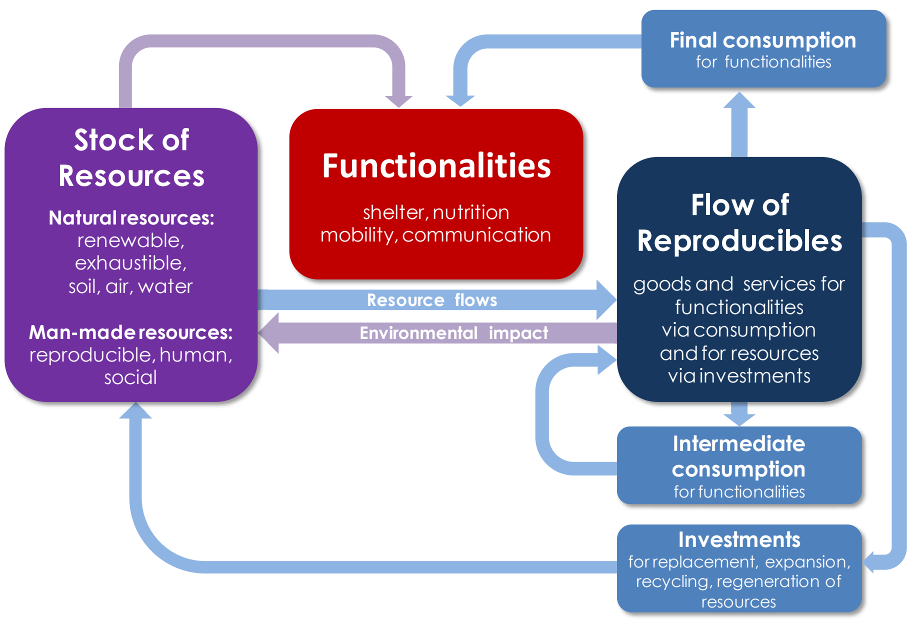
6 Method

The **ClimTrans2050** research plan proposes a new mindset and a stepwise development of a fully operational open source model based on a deepened structural approach. To this end a suitable model structure is explored that ultimately will be able to capture the entire greenhouse gas inventory on the one hand and to explore the economic implications on the other hand.

The present research plan seeks to promote the concept of functionalities as ultimate purpose of economic activity. Functionalities are defined as the result of the interaction between stocks and flows to serve (basic) human needs such as shelter or access to goods, services and persons, e.g. the thermal experience in a building results from the quality of the building stock and the related energy flows.

Figure 7 visualises the core elements and their interactions. Three distinctive categories are of importance: Functionalities, stock of resources and flow of reproducibles. The volume of functionalities needed and desired, determine the volume of reproducibles, as goods and services. Flows of reproducibles are either used as intermediate consumption in the production of goods and services or they represent via final consumption one component for providing functionalities. The intuition and rationale of the crucial role of the interdependence between the stock of resources and the flow of reproducibles is that a specific functionality can be satisfied with a varying combination of stocks and flows, e.g. in the case of shelter the thermal functionality needs a higher flow of energy in the case of a low quality of the building stock or vice versa.

Figure 7 A deepened structural approach to modelling economic activities



Via investment, reproducibles (e.g. buildings, cars, machinery) flow into the stock of resources, changing either the volume or the quality of the stock of resources.

The role of breakthrough or disruptive technologies is evident as their diffusion would impact the flow of reproducibles in order to serve functionalities. Investments in such innovative technologies (plus energy houses, alternative agricultural processes, …) have the potential of fundamentally changing our energy and/or emission systems. Complementary to innovative technologies social innovations and behavioral change (dietary habits, mobility behavior, product use like the avoidance of stand by functions) may contribute significantly to a transformation of energy, emission and/ or economic systems.

The concept of functionalities in a deepened structural model is made operational along three tiers that are relevant for the sources and the composition of Austrian emissions:

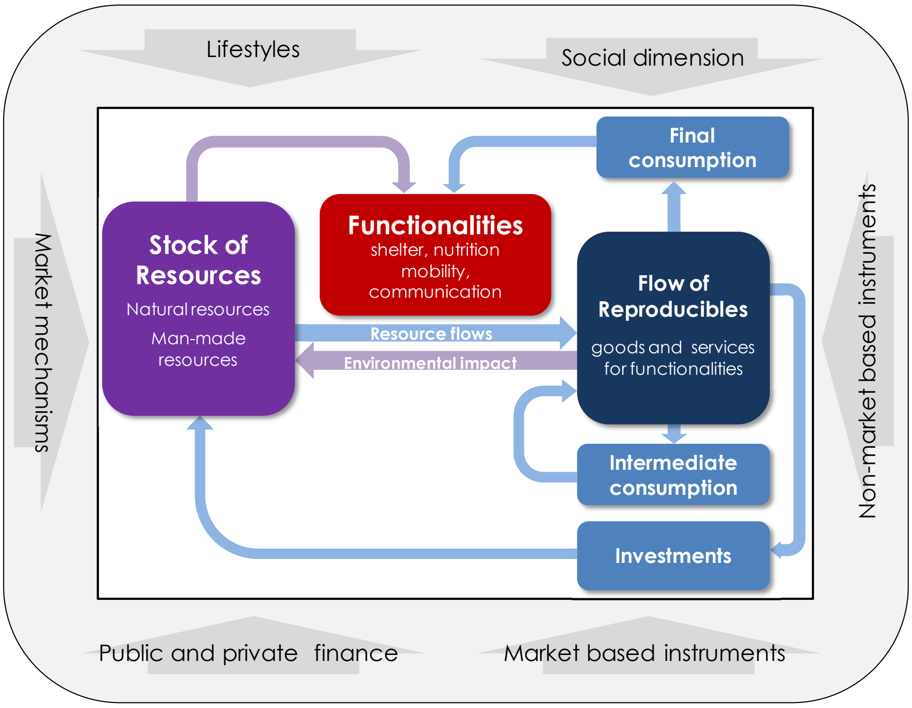
Tier 1: The physical layer

Tier 2: The economic layer

Tier 3: The institutional layer

A distinguishing feature of **ClimTrans2050** is the emphasis of the institutional layer that is a crucial element for transition processes. Figure 8 illustrates that the physical and economic layer are embedded into the institutional layer.

Figure 8 The institutional layer of a deepened structural approach



The development of the conceptual framework based on functionalities was conditional on the openness of the project team and an intense discourse in the search for a new mindset for modelling. The considerable number of internal meetings was thus one of the key elements in the **ClimTrans2050** project. In order to test the intuition and acceptance of the concept for long term transformation analysis three external project workshops were held. Two of them addressed the scientific community and one workshop focused on the engagement of stakeholders. The first expert workshop took place in the first quarter of the project (April 2015), the second one close to the end of the project. The stakeholder workshop was held in September 2015. In order to harvest the most from these workshops we organised them in participatory manner and put an emphasis on small table group discussion.

The intellectual output integrating these discussions and the input from the external workshops is captured in the report **ClimTrans2050** Research Plan (attached in the appendix) and the accompanying exemplary model modules are available at the project homepage ***climtrans2050****.wifo.ac.at/*.

In the ClimTrans2050 project we provide an internet platform http://climtrans2050.wifo.ac.at/. This homepage serves three purposes:

- Background information on the project and project team
- Access to project outputs
- Exemplary model modules with interactive elements

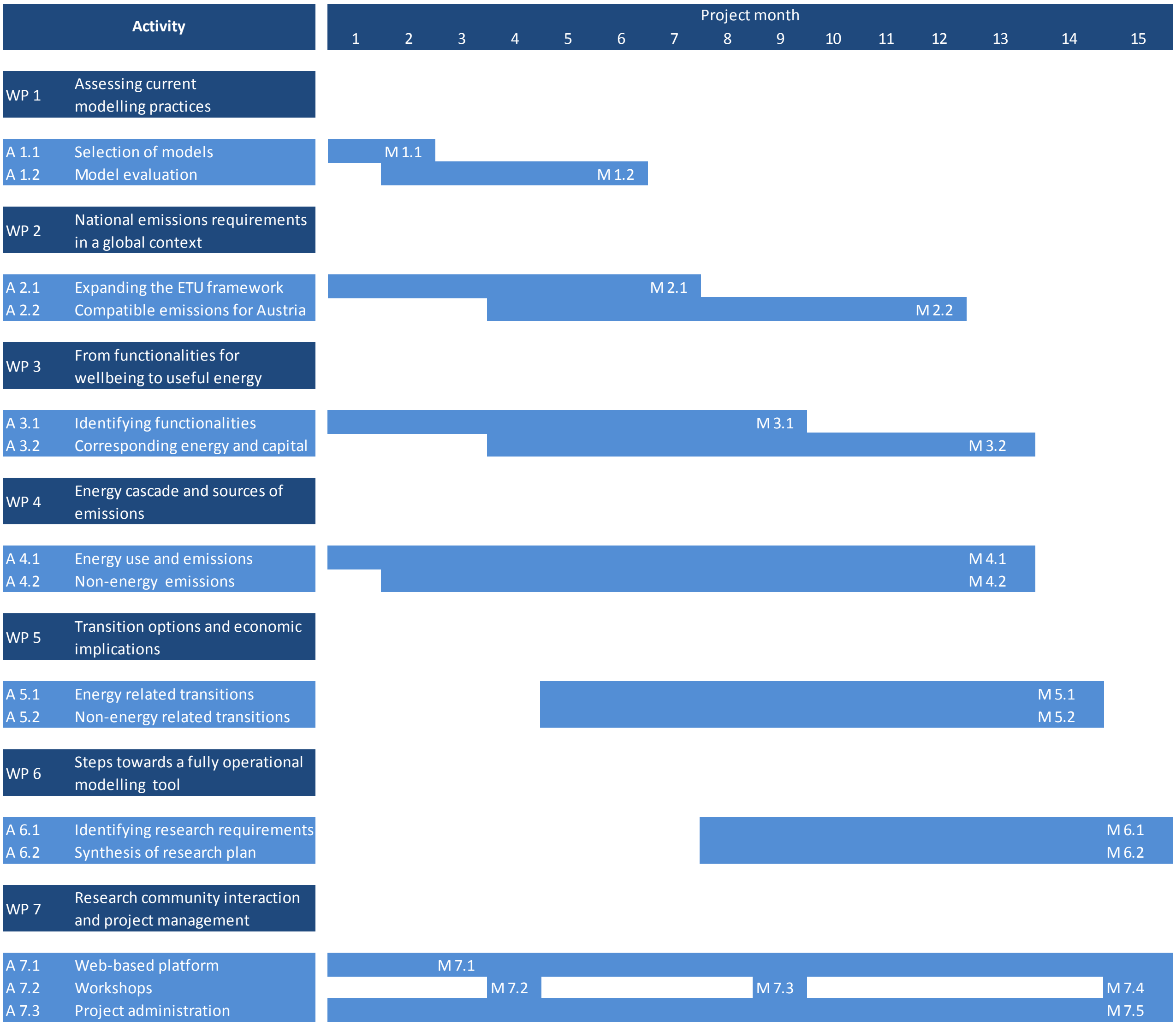
The interactive section of the web platform is the first step for the development of an operational open source model based on the proposed new understanding of modelling transformation processes. In this sense the research plan provides manifold suggestions and broad basis for further research.

With respect to the energy system, the implementation as a web tool offers the cascade structure of the energy system in an easily accessible way. The low access barriers allow especially stakeholders, and other non-modelers, visualisation and modification possibilities of all relevant information. For the modelling community it provides a rich database and the demonstration of the translation of the concept of the energy cascade into an empirical structure. Users can create visions of the future of the Austrian energy system. All decisions are reflected in the composition of energy use, energy supply and induced CO2 emissions. The findings are visualized and can be compared with past development.

A second exemplary model module allows the visualisation of Austrian reduction paths in a global context as conceptualised in chapter 3 of the ClimTrans2050 Research Plan.

The web tool is implemented as a responsive web application, which can be used on every contemporary computer, tablet and smartphone. All the chosen options are locally persisted and remembered over multiple sessions.

7 Work and time schedule



8 Publications and dissemination activities

Publications	
	Köppl, A., Schleicher, S., Kettner, C., Hofer, C., Köberl, K., Bachner, G., Schinko, T., Steininger, K., Schneider, J., Schindler, I., Krutzler, T., Gallauner, T., Jonas, M., Zebrowski, P., (2016). *Modelling low energy and low carbon transformations: The ClimTrans2050 Research Plan*, Vienna.
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	Jonas, M., Zebrowski, P., (2016). *Uncertainty in an Emissions Constrained World: Method Overview and Data Revision*. IIASA Interrim Report. http://climtrans2050.wifo.ac.at/tiki-index.php?page=Project+Output
Workshops	
	Expert workshop, April 24th 2015, WIFO Vienna
	Stakeholder workshop, September 30th 2015, UBA Vienna
	Expert workshop, April 3rd 2016, WIFO Vienna
Presentations on Conferences	
	Growth in Transition, February 23rd 2016, Vienna
	Klimatag, April 8th 2016, Graz