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ÖSTERREICHISCHES INSTITUT FÜR WIRTSCHAFTSFORSCHUNG

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Centre of Economic Scenario Analysis and Research

Energy Scenarios 2050 for Austria

Ina Meyer, Mark Sommer, Kurt Kratena

Research assistance: Katharina Köberl,
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Abstract

This study develops and analyses new energy scenarios for Austria, taking into account the international climate policy after the COP21 in Paris (2015). In two energy-economic scenarios, potential effects of climate and energy policy measures on energy consumption and value added in Austria are modelled up to the year 2050. According to the UNFCCC definition, a WEM scenario ("with existing measures") is developed which describes energy-economic trends and includes the climate and energy-economic measures implemented until the end of May 2016. In addition, a WAM plus scenario ("with additional measures") is developed and modelled, which is based on the medium- and long-term objectives of the European climate and energy policy, i.e., a greenhouse gas emissions reduction of 80 to 95 percent by 2050 (compared to 1990) and a representation of the 2030 target (greenhouse gas emissions –40 percent) detailed for Austria. The WAM plus scenario includes a large number of additional measures in the area of energy efficiency, renewable energy and technological change. Next to technological innovations and cost improvements in energy efficiency and renewable energy technologies, this includes behavioural and lifestyle changes in energy-related demand patterns and targeted infrastructure investments. The WAM plus scenario is a global climate change scenario that reflects a global commitment to achieving the goals of the Paris Climate Agreement. The modelling of the scenarios takes the form of a model coupling of a number of technology-oriented sectoral bottom-up models of the project partners (AEA, TU Vienna, TU Graz, UBA) with a top-down model – the WIFO.DYNK model (Dynamic New-Keynesian model). As a result, there is a slight absolute decoupling of economic performance and energy consumption in the WEM scenario, with an average annual GDP growth rate of 1.5 percent. Considerable investments in a low-carbon economy set significant growth impulses for the Austrian economy in the WAM plus scenario. Cost-saving effects through lower energy bills are responsible for income effects that generate a positive stimulous to the economy. Ultimately, this increases the average annual GDP growth rate to 1.7 percent (at constant prices), with a significant fall in energy demand in the main aggregated sectors. Detailed sector results can be found in the report.

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Zusammenfassung

Die vorliegende Studie analysiert und entwickelt neue Energieszenarien für Österreich bis zum Jahr 2050 unter Berücksichtigung der internationalen Klimapolitik nach der COP21 in Paris (2015). Diese Szenarien werden als Eingangsdaten für die Berechnung zukünftiger Treibhausgasemissionen (GHG) verwendet und dienen als Quelle für die Erfüllung der Berichtsanforderungen im Rahmen des Monitoring-Mechanismus nach dem Rahmenübereinkommen der Vereinten Nationen über den Klimawandel (UNFCCC). Nach UNFCCC-Definitionen wird ein WEM Szenario ("mit vorhandenen Maßnahmen") entwickelt. Darüber hinaus wird ein WAM plus Szenario ("mit zusätzlichen Maßnahmen") modelliert, das die Erreichung der langfristigen Energie- und Klimaziele der Europäischen Union für Österreich darstellt. Das ambitionierte WAM plus Szenario strebt eine Verringerung des Energieverbrauchs sowie eine Reduktion der Treibhausgasemissionen bis 2030 um 40% und bis 2050 um mindestens 80% an (UBA, 2017).

Modellbasierte Analyse

Die Ergebnisse der Szenarien für ökonomische Variablen und Variablen des österreichischen Energiesystems werden mit einem DYNK-Modell ("Dynamic New Keynesian") der österreichischen Wirtschaft berechnet. Die wichtigsten relevanten Merkmale für die Anwendung des Modells bei der Analyse von Energieszenarien sind:

1) Der hohe Detailgrad einer konsistenten Darstellung von Produktion (62 Branchen/Waren) und Nachfrage (47 Kategorien des privaten Konsums), sowie insbesondere die konsistente Integration der österreichischen Energiebilanz in das ökonomische Modell durch Verknüpfung von physischen und monetären Strömen. Das bedeutet einerseits, dass die wirtschaftlichen Treiber des Energieverbrauchs (BIP, Fahrzeugbestand, Wohnungsbestand, Effizienz der Bestände usw.) nicht auf Annahmen beruhen, sondern im Modell endogen bestimmt werden; andererseits bewirken diese Links automatische Rückkoppelungen von Veränderungen im Energiesystem auf das ökonomische System etwa durch Rebound-Effekte.
2) Die Koppelung des DYNK-Modells mit mehreren im Szenario-Projekt verwendeten Bottom-up-Modellen in den wesentlichen energieverbrauchenden Sektoren:
    (I) Elektrizitäts- und Wärmeerzeugung: Für Szenarien von Strom-/Wärmebedarf und -erzeugung wird ein Bottom-up-Modell (TIMES) der Austrian Energy Agency (AEA) verwendet, das eine große Bandbreite an Erzeugungs- und Umwandlungstechnologien abbildet. Das DYNK-Modell und das TIMES-Modell sind über nachfrageseitige Treiber (von DYNK zu TIMES) und technologischen Wandel (von TIMES zu DYNK) miteinander verknüpft.
    (II) Eisen- und Stahlerzeugung: Der Stahlsektor wird vom Umweltbundesamt (UBA) in mehrere Bottom-up-Technologien disaggregiert, die die IO-Struktur des DYNK-Modells ändern und ökonomische Auswirkungen nach sich ziehen (von UBA zu DYNK).

(III) Verkehr: Im Transportsektor erfolgt eine Verknüpfung des privaten Transportbedarfs aus DYNK, insbesondere Höhe und Struktur des Fuhrparks, mit den Bottom-up-Transportmodellen und den Datensätzen von TU Wien und TU Graz (von DYNK zu TU Modellen). Technologische Veränderungen in den Bottom-up Modellen induzieren Nachfrage-Effekte und ziehen damit wirtschaftliche Änderungen nach sich (von TU Modellen zu DYNK).

(IV) Gebäude: Im Gebäudesektor erfolgt eine Verknüpfung der privaten Wohnungsnachfrage aus DYNK (Bestand an Gebäuden, Mieten) mit dem disaggregierten Datensatz und dem Modell des Wohnungssektors der TU Wien (von DYNK zu TU Modell). Wie im Fall des Transports induzieren Bottom-up-Änderungen wirtschaftliche Effekte durch Nachfrageänderungen (von TU Modell zu DYNK).

Für Modellstrukturgleichungen sowie weitere modelltechnische Details wird auf Kapitel 2 des Berichts verwiesen.

Aus der Perspektive des DYNK-Modells gibt es zwei verschiedene exogene Datensätze:

(I) Annahmen/Datensätze aus internationalen Quellen, die für alle Teilmodelle des integrierten Modellkonsortiums gleichermaßen gelten und die Ergebnisse sowohl des DYNK-Modells als auch der Bottom-up-Modelle gleichgerichtet beeinflussen.

(II) Annahmen/Datensätze, die Ergebnisse der Bottom-up-Modelle sind und als Eingangsdaten in das DYNK-Modell integriert werden.

Das WEM Szenario

Das WEM Szenario beschreibt energie-ökonomische Trends und bereits ergriffene Maßnahmen der Energie- und Klimapolitik. Die Annahmen für dieses Szenario wurden aus einschlägigen internationalen Publikationen sowie aus Quellen österreichischer Stakeholder entnommen. Eine wichtige Quelle sind beispielsweise die Positionen für Subventionen und Steuern entsprechend dem österreichischen Stabilitätsprogramm.

Die wichtigsten exogenen Daten umfassen die Bevölkerungs- und die Haushaltsentwicklung sowie die Energiepreise und den Euro/Dollar-Wechselkurs. Energiepreisannahmen werden aus den jüngsten globalen (IEA, 2016) oder europäischen (PRIMES-Modell) Energieszenarien entnommen. Demnach steigen die realen Preise für Rohöl kontinuierlich (Rohöl: 2015 49 € je Barrel, 2020 77 €, 2030 96 €, 2050 111 €). Der Rohölpreis steigt relativ zu Kohle und Erdgas am stärksten. Die Bildung eines europäischen Gasmarktes mit verschiedenen Hubs und neuen, flexiblen Transportmöglichkeiten (Pipelines, LNG) sorgt für eine Entkoppelung des Gaspreises von den Preisen für Rohöl und Kohle (Erdgas: 2015 6 €/MMBtu, 2020 8 €, 2030 10 €, 2050 11 €). Energiepreise beeinflussen die Preise für energiehaltige Güter und sind damit Einflussfaktoren der Konsumnachfrage.

Die Bevölkerungsentwicklung für Österreich – als Determinante für die Anzahl der Haushalte und die Haushaltsenergienachfrage – weist ein nichtlineares Wachstum mit abnehmendem Zuwachs auf (2050 ca. 9,6 Mio. Einwohner).

Weitere Annahmenkategorien der Modellierung beziehen sich auf die gesetzten Maßnahmen der österreichischen Energie- und Klimapolitik, wobei Entwicklungen in der Energieeffizienz und Energieträgersubstitutionen im Bereich von langlebigen Konsumgütern wie Kraftfahrzeugen oder von Heizsystemen eine entscheidende Rolle spielen:

(I) Die Autoflotte erzielt in 2050 einen Autobestand in Höhe von 660 Pkw pro 1.000 Einwohner mit einem Anteil an Elektrofahrzeugen in Höhe von 60%. Die Energieeffizienz von Verbrennungsmotoren wird nicht wesentlich gesteigert.

(II) Im Raumwärmeberich verringern sich vor allem mit Heizöl betriebene Systeme deutlich, während Solar- und Umgebungswärme zum bevorzugten Versorgungstyp avancieren.

(III) In der Stromproduktion setzt sich der Trend zu Photovoltaik und Windkraftwerken fort. In Summe decken beide Technologien 2050 25% des heimischen Stromverbrauches ab.

Ökonomische Ergebnisse im WEM Szenario

Neben den oben beschriebenen Einflussgrößen stellen die wesentlichen Treiber der wirtschaftlichen Dynamik die Entwicklung der Faktorproduktivität sowie die Integration Österreichs in den Weltmarkt (Nachfrage nach österreichischen Exportprodukten) dar. Letztere Variable wurden so adjustiert, dass ein durchschnittliches Wachstum p.a. des Bruttoinlandsproduktes (BIP) von ca. 1,5%[1] erzielt wird. Die Wachstumsdynamik einzelner Sektoren ist dabei unterschiedlich ausgeprägt. Der produzierende Bereich entwickelt sich am dynamischsten (2015 = 100, 2050 = 170), gefolgt von Handel und Dienstleistungen (2050 = 160), Verkehrsleistungen (2050 = 155) und der Landwirtschaft inklusive Bergbau (2050 = 130). Detaillierte Branchenergebnisse sind dem Bericht zu entnehmen.

Ergebnisse für den Endenergieverbrauch im WEM Szenario

Die Ergebnisse für den Transportsektor insgesamt zeigen einen leicht abnehmenden Energieverbrauch. Für den privaten Verkehr zeigt sich ein Rückgang von ca. 165 PJ (2017) auf ca. 115 PJ (2050), trotz leicht steigender Transportleistung (Anzahl gefahrene Kilometer), der im Wesentlichen eine Elektrifizierung des Verkehrssektors widerspiegelt. Insgesamt bleibt Dieselkraftstoff jedoch die Hauptenergiequelle des Verkehrssektors.

Die Haushaltsenergienachfrage einschließlich der privaten Verkehrsleistungen weist ebenfalls eine deutlich abnehmende Entwicklung auf, die zusätzlich zur Elektrifizierung des Verkehrs (Abnahme der Nachfrage nach Benzin- und Dieselkraftstoffen) durch einen Nachfragerückgang im Raumwärmebereich durch eine höhere Effizienz der Gebäudehülle sowie sinkende Heizgradtage zu erklären ist.

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[1] Das langfristige 1,5% Wachstum p.a. garantiert die Vergleichbarkeit mit den zum Zeitpunkt der Erstellung der Szenarien aktuellsten PRIMES Szenarien, die ebenfalls eine langfristige BIP Wachstumsrate in dieser Höhe annehmen.

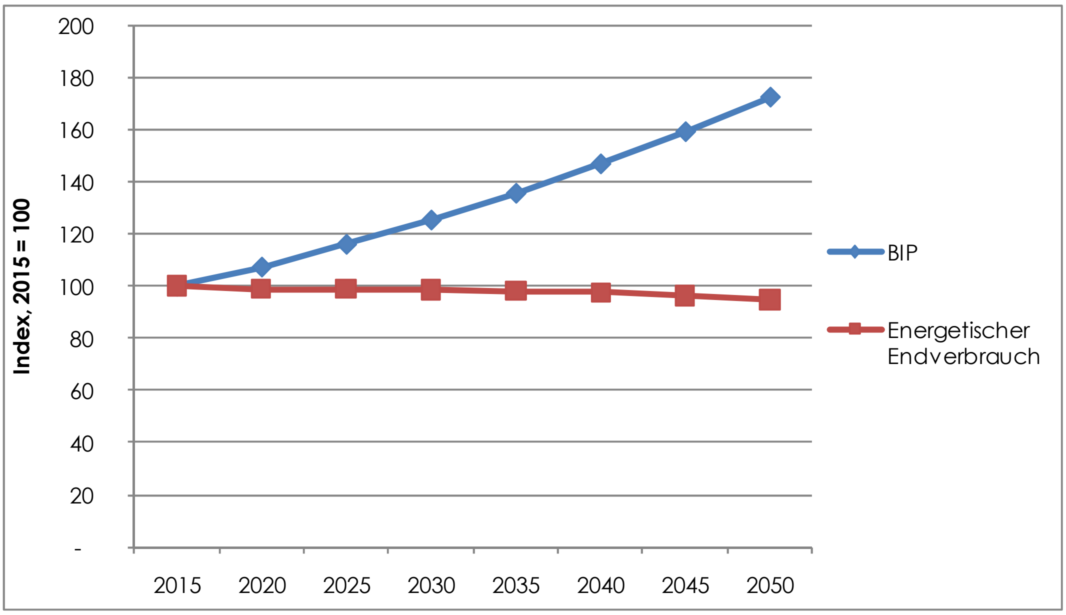
Die hinterlegten Energieeffizienzzuwächse, die auf den historischen Entwicklungen basieren, reichen in den Industriesektoren kurz- und mittelfristig nicht aus, um die aus dem Wirtschaftswachstum generierte Energienachfrage zu kompensieren. Langfristig allerdings kommt es zur Stabilisierung, die in den Dienstleistungssektoren über den gesamten Zeitraum anhält.

In Summe über alle Sektoren stagniert der Endenergieverbrauch im WEM Szenario. Der steigende Endenergieverbrauch im produzierenden Sektor wird durch die rückläufige Energienachfrage im Haushaltsbereich ausgeglichen.

Entkoppelung von Wirtschaftsleistung und Energieverbrauch

Insgesamt kommt es im WEM Szenario zu einer geringfügigen absoluten Entkoppelung von Wirtschaftsleistung und Energieverbrauch, bei einer durchschnittlichen jährlichen Wachstumsrate des BIP in Höhe von 1,5% und einem leicht fallenden absoluten Endenergieverbrauch.

Abbildung 1: BIP (real) und energetischer Endverbrauch im WEM Szenario



Q: Eigene Berechnungen.

Das WAM plus Szenario

Das WAM plus Szenario orientiert sich an den mittel- und langfristigen Vorgaben der europäischen Klimapolitik mit dem Ziel einer 80 bis 95%igen Reduktion der Treibhausgasemissionen bis 2050 im Vergleich zum Basisjahr 1990. Da spezifische Politiken der Dekarbonisierung (Carbon Capture and Sequestration, CCS) nicht von dieser Studie abgedeckt oder für Österreich (Kernkraft) nicht relevant sind, muss das WAM plus Szenario eine signifikante Reduktion des Energieverbrauchs in allen Sektoren und auf allen Ebenen (Endenergie, Transformation, Verluste) erzielen sowie die Nutzung aller erneuerbaren Potenziale (unter Berücksichtigung von Umweltbelastungen) ausschöpfen. Neben technologischen Innovationen und Kostenverbesserungen bei der Energieeffizienz und erneuerbaren Energietechnologien umfassen diese Verhaltens- und Lebensstiländerungen bezüglich energierelevanter Bedarfsmuster.

Für die Zielerreichung ist ein gemeinsames Verständnis darüber, wie man das Energiesystem erfolgreich umwandeln, die Wirtschaft dekarbonisieren und soziale und politische Hindernisse im Übergangsprozess überwinden kann, von zentraler Bedeutung. Die Konzeption des WAM plus Szenarios, die eine breite Beteiligung von österreichischen Stakeholdern einschloss, gilt als ein wichtiger Baustein eines solchen Verständigungs- und Kommunikationsprozesses.

Der strukturelle Wandel stellt einen zentralen Treiber in diesem Szenario dar, vor allem in Bezug auf zielgerichtete Infrastrukturinvestitionen, denn die Infrastruktur bestimmt langfristig den Energieverbrauch (Pfadabhängigkeit) und spielt eine wichtige Rolle für die Stabilität und Funktionsfähigkeit von Energienetzen (Strom, Gas, Fernwärme), Gebäuden und Transportsystemen und damit für die Wirtschaftsleistung.

Das WAM plus Szenario ist ein globales Klimaschutzszenario, das ein globales Engagement für die Erreichung der Ziele des Pariser Klimaabkommens abbildet, um die globale Erwärmung deutlich unterhalb einer durchschnittlichen Temperaturerhöhung von +2°C (bzw. +1,5°C) gegenüber dem vorindustriellen Niveau zu begrenzen. Weltweite Maßnahmen zum Klimaschutz implizieren die Notwendigkeit eines steilen und deutlichen Anstiegs der Energie- und CO_2-Preise, die nach dem Kohlenstoffgehalt der einzelnen Energieträger differenziert werden.

Das WAM plus Szenario Narrativ beinhaltet wesentliche Veränderungen in Bezug auf das Verhalten von Wirtschaftsakteuren und die ökonomischen Strukturen (Technologien und Produktionsprozesse). Die Verbesserung der Energieeffizienz (pro Produktionseinheit oder Einheit einer Energiedienstleistung) spielt eine strategisch wichtige Rolle. Sie wird durch den strukturellen Wandel zu neuen Produkten, Dienstleistungen und Materialien, neuen Produktionsprozessen und Verbesserungen in allgemeinen Technologien (Dampferzeugung, Motoren usw.) getragen. Es werden Maßnahmen berücksichtigt, die auf weniger Ressourcennutzung abzielen, wie etwa die Verlängerung der Lebensdauer und die Reparatur von Produkten, das Recycling von Altstoffen und Abfällen (Meyer et al., 2018) sowie das Teilen von langlebigen Gütern (Sharing Economy). Die Sanierung von Gebäuden stellt einen zentralen Bestandteil der Energieeffizienzstrategie dar ebenso wie organisatorische Reformen des Verkehrs durch eine Reorganisation und Neu-Kombination von verschiedenen Verkehrsträgern (Modi) und alternativen Antrieben und Technologien (Digitalisierung).

Ein weiterer wichtiger Sektor in diesem Szenario ist die Stromerzeugung. Aufgrund von Investitionen in das Netz, kann die inländische Stromproduktion gesteigert und das Netzmanagement optimiert werden. Diese Entwicklung hilft, die Energieerzeugung aus fossilen Brennstoffen einzudämmen und das Potenzial verschiedener erneuerbarer Energien zu nutzbar zu machen.

Annahmen für das WAM plus Szenario

Im WAM plus Szenario übersteigen die Energiepreise für Rohöl, Erdgas und Kohle aufgrund von politisch gesetzten CO_2-Preisen ab 2025 die Energiepreise des WEM Szenarios. Der Preis für Kohle, der kohlenstoffintensivste der drei fossilen Brennstoffe, übersteigt den Rohölpreis in 2031 (2015 = 100, 2050 = 800). Der Ölpreis zeigt eine etwa 600%ige Steigerung bis 2050 und der Preis für Erdgas weist aufgrund seines relativ niedrigen Kohlenstoffgehalts die niedrigste Preisentwicklungstrajektorie auf (2050 = 500).

Im WAM plus Szenario wird der bestehende Kapitalstock in einen deutlich energieeffizienteren und weniger fossile Brennstoffe verbrauchenden Kapitalstock transformiert. Das bezieht sich auf energieeffiziente Investitionen in der Industrie, im Bausektor und im Verkehr (Einsatz von elektrischen Antrieben und neuen Verkehrsträgerkombinationen). Der Gebäudebereich im WAM plus Szenario (Wohngebäude und gewerbliche Gebäude) zeichnet sich durch erhebliche Investitionen in Sanierungen, Neubau und neue Heizungsanlagen aus. Die zugrundeliegenden Maßnahmen sind überwiegend regulatorischer Natur, was zu einem "Sanierungsplan" für Gebäude und einem '"Austauschplan" für Heizungsanlagen führt. Zur Erreichung dieser Vorgaben werden substanzielle Investitionen getätigt (durchschnittlich 400 Mio. € p.a.).

Entsprechend den Bottom-up-Modellen für den Verkehrssektor liegen im WAM plus Szenario der Fahrzeugbestand je Kraftstoffart (Benzin, Diesel) unter und der Bestand an Elektroautos (erreicht 2045 100% Anteil am Bestand) über denjenigen des WEM Szenarios. Dies ist das Ergebnis eines Portfolios von Maßnahmen zur Reduzierung individueller motorisierter Mobilität, vor allem in Städten. Der Schwerpunkt der energiebezogenen Verkehrspolitik richtet sich auf die Nutzung von öffentlichen Verkehrsmitteln sowie auf das Radfahren und zu Fuß gehen. Eine weitere wichtige Maßnahme ist die Substitution der bestehenden Flatrate-Autobahnvignette durch ein allgemeines System, das Mobilitätsdienstleistungen auf allen Straßen erfasst. Die Erlöse aus dieser Abgabe kompensieren reduzierte Einnahmen im Staatshaushalt, die aus der erhöhten Kohlenstoff-Besteuerung und der damit einhergehenden reduzierten Nachfrage nach Benzin und Diesel entstehen. Als Konsequenz reduziert sich die Transportleistung erheblich. Für den Güterverkehr führen die Maßnahmen im WAM plus Szenario ebenfalls zu einer Elektrifizierung des Verkehrs (Verschiebung des Modalsplits zu höherem Anteil des Schienenverkehrs, Zunahme von Elektroantrieben auf der Straße). Die Maßnahmen im Güterverkehr umfassen beträchtliche Investitionssummen und werden aus dem Investitionsbudget des öffentlichen Sektors und der Eisenbahnunternehmen finanziert. Im Bereich der Luftfahrt wird eine Begrenzung von besonders ineffizienten Kurzstreckenflügen umgesetzt, die eine Verlagerung von 33% des Luftverkehrs (in Personenkilometern) auf die Bahn bewirken.

Eine Elektrifizierung der Verkehrswirtschaft erzielt nur durch strukturelle Veränderungen in der Strom- und Wärmeerzeugung erhebliche Rückgänge bei den Treibhausgasemissionen. Für gegebene Energiepreise und Unterstützungsmaßnahmen wird das Potenzial von erneuerbaren Energien im WAM plus Szenario daher weitestgehend ausgeschöpft. Das betrifft insbesondere den Ausbau von Wind- und PV-Kapazitäten sowie teilweise den Ausbau von Wasserkraft. Die Nettoeinfuhren von Elektrizität können in diesem Szenario – basierend auf den Berechnungen des UBA – ausgeglichen werden.

Das WAM plus Szenario umfasst die Nutzung von unterschiedlichen Energieeinsparpotenzialen in verschiedenen Industriebranchen. Diese werden vor allem durch einen intra-industriellen strukturellen Wandel hin zu neuen Produktionsprozessen getragen, was zu einem geänderten Energiebedarf und einem neuen Energieträger-Mix führt.

Ökonomische Ergebnisse im WAM plus Szenario

Beträchtliche Investitionen in die Gebäudesanierung, die erneuerbare Stromerzeugung und Verkehrsinfrastruktur stellen einen bedeutenden Wachstumsimpuls für die österreichische Wirtschaft dar. Gleiches gilt für die Investitionen in energiesparende Technologien und Prozesse in der Fertigung. Die Finanzierung dieser Investitionen erfolgt durch eine Verlagerung von Finanzmitteln aus anderen Investitionen (im Falle des Transports) bzw. durch die Bereitstellung von Mitteln aus bereits geplanten Investitionsplänen (Stromnetz) sowie zum Teil durch Fördermaßnahmen, die partiell auch bremsende Effekte auf die österreichische Wirtschaft ausüben.

Insgesamt sorgen der energiesparende technologische Fortschritt kombiniert mit den Energieträgersubstitutionen weg von fossiler hin zu erneuerbaren Energieträgern für zusätzliche makroökonomische Impulse, die im DYNK-Modell direkte, indirekte und induzierte Effekte in der Volkswirtschaft auslösen. So erzielen die kostensparenden Effekte (niedrigerer Heizbedarf, geringerer Energieaufwand durch Elektroautos usw.) Einkommenseffekte, die positiv auf die Wirtschaft zurück wirken (Rebound-Effekt). Im Endeffekt beobachten wir im WAM plus Szenario eine geringfügige zusätzliche positive makroökonomische Wirkung als Summe aller Branchen- und Rohstoffeffekte im DYNK-Modell: Die durchschnittliche jährliche Wachstumsrate des BIP steigt von 1,5% im WEM Szenario auf 1,7% im WAM plus Szenario (in konstanten Preisen). Detaillierte Branchenergebnisse können dem Bericht entnommen werden.

Ergebnisse für den Endenergieverbrauch im WAM plus Szenario

Die Maßnahmen im WAM plus Szenario sind eine Kombination aus energiesparendem technologischem Fortschritt und Energieträger-Shifts, getrieben durch Investitionen. Die wichtigste Energieträgerverschiebung findet im Transportsektor statt – von fossilen Brennstoffen hin zu Elektrizität. Parallel dazu verändert sich auch die anteilige Nutzung der einzelnen Verkehrsträger bei einer Reduktion der Mobilitätsnachfrage. Dies führt zusammen mit einem Rückgang im Endenergieverbrauch für Raumwärme und -kühlung und anderen haushaltsbezogenen Anwendungen insgesamt zu einer reduzierten Endenergienachfrage der Haushalte. Dennoch steigt der Strombedarf der Haushalte erheblich an, obwohl die Nachfrage für andere Zwecke (Geräte und Heizung) und auch die PKW-Fahrleistung (nach Inputdaten des

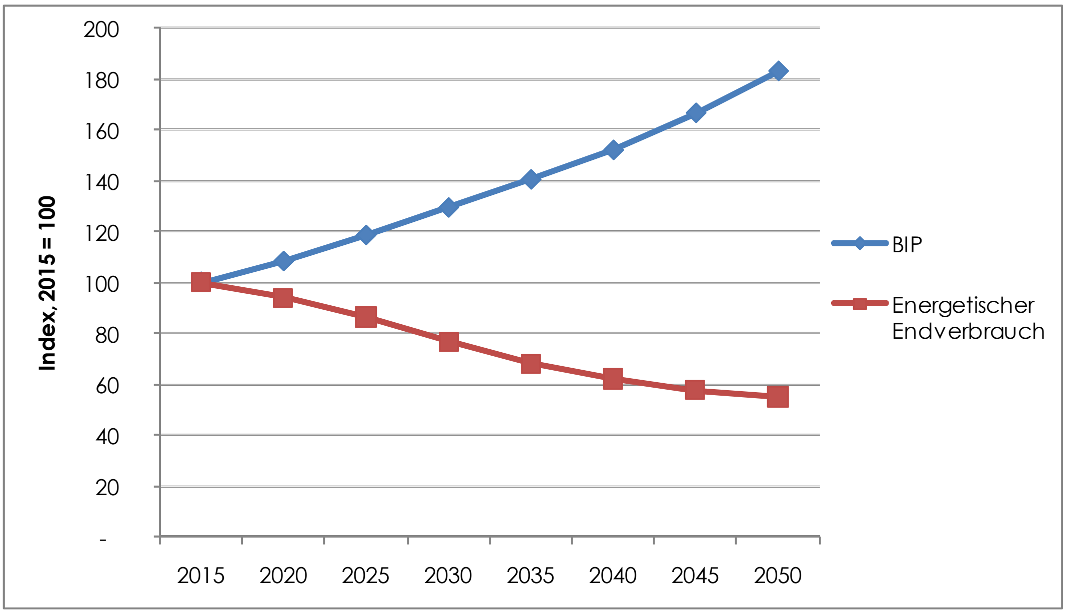
UBA) sinkt. Durch den Anstieg des Anteils erneuerbarer Energieträger an der Stromerzeugung wird ein wichtiger Teil dieses zusätzlichen Strombedarfs durch nichtfossile Energieerzeugung bereitgestellt.

Im WEM Szenario stagniert der Energiebedarf der wichtigsten aggregierten Sektoren. Im WAM plus Szenario zeigt der Energiebedarf dieser Sektoren hingegen einen deutlichen Rückgang, der im Verkehrssektor am stärksten ausfällt. Für alle verarbeitenden Sektoren ist das Produktionswachstum höher als im WEM Szenario, während der Energiebedarf deutlich reduziert wird.

Entkoppelung der Wirtschaftsleistung vom Energieverbrauch

Absolute Entkopplung von Energie und Wirtschaftsleistung wird zu einem allgemeinen und weitverbreiteten Merkmal im WAM plus Szenario. Die Reduktion der Energieintensität beträgt 3,4% p.a. (bei einem durchschnittlichen jährlichen BIP-Wachstum in Höhe von 1,7%). Diese Reduktion liegt außerhalb der in der Vergangenheit beobachtbaren Intensitätsreduktionen, auch nach massiven Energiepreisschocks, wie in den 1970er Jahren. Aus dieser historischen Erfahrung können Energieintensitätsreduktionen pro BIP-Einheit von mehr als 2% p.a. nur durch eine Kombination vielfältiger energiepolitischer Maßnahmen (wie sie eben im WAM plus Szenario angenommen wird) erreicht werden.

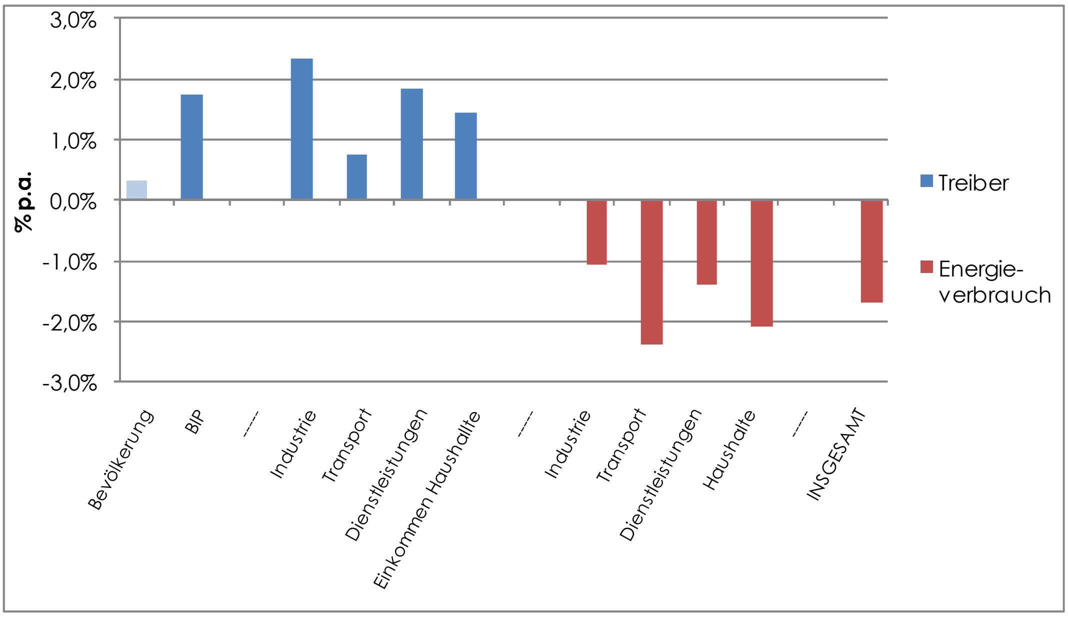
Abbildung 2: BIP (real) und energetischer Endverbrauch im WAM plus Szenario



Q: Eigene Berechnungen.

Eine absolute Entkopplung des Energieverbrauchs (rot in Abbildung 3) im WAM plus Szenario wird bei gleichzeitig wachstumstreibenden Faktoren in allen Bereichen der Wirtschaft (blau in Abbildung 3) erreicht.

Abbildung 3: Wachstum der Treiber (Bevölkerung, reale Produktion und Einkommen) und der Energieverbräuche im WAM plus Szenario



Q: Eigene Berechnungen.

1 Introduction

This study analyses and develops new energy scenarios for Austria until 2050, taking into account the international setting of climate policy after COP21 in Paris (2015). These scenarios will be used as input data for calculating projected future greenhouse gas (GHG) emissions, and serve as a source for fulfilling the reporting requirements under the Monitoring Mechanism, according to the United Nations Framework Convention on Climate Change (UNFCCC), as well. According to UNFCCC definitions, a WEM ("with existing measures") scenario is developed. Furthermore a WAM plus ("with additional measures") scenario is developed, where the targets of European energy and climate policy are achieved for Austria. That comprises a reduction in energy consumption and in the carbon content of energy, which leads to 40% reduction in Austrian GHG emissions until 2030 and to 80% reduction in emissions until 2050 (UBA, 2017).

The results of the scenarios for economic variables and variables of the Austrian energy system are calculated applying a DYNK ("Dynamic New Keynesian") model of the Austrian economy. A similar model has been developed for the European economy (EU 27), both as an inter-regional IO model (Kratena et al., 2013), as well as a 'one economy model' of the EU 27 (Kratena and Sommer, 2014) and has been applied for environmental policy analysis (Arto et al., 2015). The main relevant characteristics for applying the model in analyzing energy scenarios are:

(i) Disaggregation into 62 industries/goods and 47 categories of private consumption.

(ii) Consistent integration of the Austrian energy balance into the model by linking physical and monetary flows. On the one hand, this means that economic drivers of energy use (GDP, vehicle stock, housing stock, efficiency of stocks, etc.) are not based on assumptions, but model results. On the other hand, these links automatically yield economic impacts of changes in the energy system.

The DYNK model is further linked to several bottom-up models used in the scenario project simultaneously. That mainly refers to:

- Electricity and heat generation: a bottom-up model (TIMES), operated by the Austrian Energy Agency (AEA), which comprises a large set of generation and appliance technologies is used for scenarios of electricity/heat demand and generation. The DYNK model and the TIMES model are linked via drivers of the demand side ('from DYNK to TIMES') and technological change ('from TIMES to DYNK').

- Basic metal (steel) production: disaggregation of the steel sector in several bottom-up technologies, as laid down in Schumacher and Sands (2007) for Germany and as prepared by the Environmental Agency (UBA) for Austria, is carried out. Bottom-up changes alter the IO structure of the DYNK model and have economic impacts.

- Transport: Linking the private transport demand part of DYNK, especially the level and structure of the vehicle fleet with the bottom-up transport model and dataset of TU Wien and TU Graz. Bottom-up changes induce demand effects and therefore economic impacts.
- Buildings: Linking of private housing demand in DYNK (stock of buildings, rents) with the disaggregated data stock and model of the building sector of TU Wien. As in the case of transport, bottom-up changes induce economic effects via demand changes.

2 Methodological Approach

The DYNK model approach applied in this study is a hybrid between an econometric IO and a CGE model and is characterized by the integration of rigidities and institutional frictions. In the long-run the model works similar to a CGE model, and explicitly describes an adjustment path towards a long-run equilibrium. The term 'New Keynesian' refers to the existence of a long-run full employment equilibrium, which will not be reached in the short run, due to institutional rigidities. These rigidities include liquidity constraints for consumers (deviation from the permanent income hypothesis), and wage bargaining (deviation from the competitive labour market). The model describes the inter-linkages between 62 industries as well as the consumption of five household income groups by these 62 commodities (NACE 2008).

The model of households' demand comprises three nests, where in the first nest the demand for durables (houses, vehicles) and total nondurables is derived. The second nest links energy demand (in monetary and physical units) to the durable stock (houses, vehicles, appliances), taking into account the energy efficiency embodied in the stocks. In the third nest eight categories of non-energy nondurable demand are determined in a flexible demand system (AIDS model) and then further split up into the 62 commodities of the IO model. The model of production links the input-output structures (Leontief technologies) of 62 domestic and imported inputs to a Translog model with K, L, E, M^m (imports) and M^d (domestic) factors. The factor energy (E) is further split up into 26 types of energy. The labour market is specified via wage curves, where wage increases by industry depend on productivity, the consumer price and the distance to full employment. The model is closed by endogenizing parts of public expenditure in order to meet the mid-term stability program for public finances.

2.1 The economic model

The IO core of the model is based on Supply-Use tables for Europe (EUROSTAT) and intermediate demand is split into domestic and imported commodities. Instead of deriving a technical coefficient matrix (inputs of intermediate commodities per unit of industry output) from the use matrix, this modelling step is split into two parts in the DYNK model. First, vectors of total input coefficients per unit of industry output for domestic and imported commodities ($\mathbf{v}_D$ and $\mathbf{v}_M$) are defined. The commodity structure below this level is then in a second step defined by use structure matrices $\mathbf{S}^{m}$ and $\mathbf{S}^{d}$ with column sum equal to unity. A further distinction within the use matrix is between non-energy and energy commodities. The commodity balance for non-energy commodities is then defined by applying the use structure matrices $\mathbf{S}^{m}_{NE}$ and $\mathbf{S}^{d}_{NE}$ as well as the diagonal matrices of the factor shares defined above, $\hat{\mathbf{V}}_{D}$ and $\hat{\mathbf{V}}_{M}$. Multiplying the use structure matrix with the corresponding factor share matrix and with the column vector of output in current prices gives the sum of intermediate demand by commodity. The procedure for energy commodities is the same, with use structure matrices $\mathbf{S}^{m}_{E}$ and $\mathbf{S}^{d}_{E}$ (where the column sum over both matrices yields one), and diagonal matrix $\hat{\mathbf{V}}_{E}$. These matrices are determined together with the physical flows of energy in the energy balance (see the next section).

The full commodity balance is given by adding the column vectors of domestic consumption ($\mathbf{c}^{d}$), capital formation ($\mathbf{cf}^{d}$) and public consumption ($\mathbf{cg}^{d}$). Capital formation is endogenous as well and derived from capital demand by industry in the Translog model, applying the capital formation matrix. The (column vector) of the domestic output of commodities in current prices, $\mathbf{p}^{D}\mathbf{q}^{D}$, is transformed into the (column vector) of output in current prices, $\mathbf{p}_{Q}\mathbf{q}$, by applying the market shares matrix, $\mathbf{C}$ (industries * commodities) with column sum equal to one:

$$\mathbf{p}^{D}\mathbf{q}^{D} = \left[\hat{\mathbf{V}}_{D}\mathbf{S}^{\mathbf{d}}_{\mathbf{NE}}\right]\mathbf{p}_{Q}\mathbf{q} + \left[\hat{\mathbf{V}}_{E}\mathbf{S}^{\mathbf{d}}_{\mathbf{E}}\right]\mathbf{p}_{Q}\mathbf{q} + \mathbf{c}^{d} + \mathbf{cf}^{d} + \mathbf{ex}^{d} + \mathbf{st}^{d} + \mathbf{cg}^{d} \tag{1}$$

$$\mathbf{p}_{Q}\mathbf{q} = \mathbf{C}\,\mathbf{p}_{D}\mathbf{q}_{D} \tag{2}$$

These two equations describe the core IO model of the system and can be solved in a loop for equilibrium values of output ($p_Q q$ and $p_D q_D$), once final demand categories ($\mathbf{c}^{d}$, $\mathbf{cf}^{d}$, $\mathbf{ex}^{d}$, $\mathbf{st}^{d}$ and $\mathbf{cg}^{d}$) and matrices ($\hat{\mathbf{V}}_{D}$, $\hat{\mathbf{V}}_{E}$, $\mathbf{S}^{d}_{NE}$ and $\mathbf{S}^{d}_{E}$) are given.

The final demand categories ($\mathbf{c}^{d}$, $\mathbf{cf}^{d}$, $\mathbf{ex}^{d}$, $\mathbf{st}^{d}$ and $\mathbf{cg}^{d}$) comprise energy and non-energy commodities, are all in current prices and are all – except stock changes ($\mathbf{st}^{d}$) – endogenous. The export vector $\mathbf{ex}^{d}$ is calibrated with price elasticity of unity for all commodities and therefore is constant in current prices.

2.1.1 Household demand

The consumption block differentiates between different stages and separability is assumed between these stages. The separability assumption in that context also implies that the dynamic decision process is disentangled. At the first stage, the demand for durables (real estate property and vehicles) is modeled in a way consistent with the version of the buffer stock model described in Luengo-Prado (2006). Further, total nondurable demand is also specified in a way consistent with the main properties of the buffer stock model (excessive smoothing, excess sensitivity). All model parameters are based on dynamic estimation of panel data for Europe (1995-2011).

At the second stage, energy consumption, disaggregated into: heating, electricity and fuels for transport, is modeled as a service demand in terms of utilization of the capital (durable) stock. Therefore, it links energy demand (in monetary and physical units) to the durable stock (houses, vehicles, appliances). An important variable is the average energy efficiency of the corresponding durable stocks (dwelling for heating, vehicles for fuels for transport, and appliances for electricity). The transport part allows for substitution between public transport services and private car transport. For this second stage, the model parameters are based on estimations with an EU 27 country panel (1995-2011). The energy expenditure of households is based on EUROSTAT, the Energy Accounts from the WIOD database, as well as IEA Energy Prices. Energy efficiency for electricity and for heating is inserted from the corresponding values of the bottom-up models (EEG/TU Wien and TU Graz). These parameters therefore constitute the link between the bottom-up models applied for the scenarios and the top-down approach of DYNK. It is also possible to overwrite certain functions in the DYNK model by solutions from the bottom-up model. That refers in the first place to purchases and therefore – in a dynamic perspective - to stocks of durables. It also refers to service demand for heating ad transport, but in that case the direct (price) rebound effect in DYNK is left out.

Finally, the third stage contains the model of non-energy nondurable consumption, modeled in a flexible demand system (AIDS model). This third step is again split into two nests: (i) an aggregate level of eight categories, described in an AIDS model, and (ii) a detailed model of 47 COICOP categories, explained by sub-shares of the aggregate categories that change over time and can be changed exogenously for model simulation purposes. The econometric estimation has been carried out for an EU 27 country panel (1995-2009) from EUROSTAT National Accounts, as well as for data from the household survey 2004/2005 for six EU countries: Austria, France, Italy, Slovakia, Spain and UK (Salotti, et al., 2015).

The first stage yields (column) vectors of total nondurable consumption $(\mathbf{c}_{\mathrm{nondur}})$ and of investment in owned houses $(\mathbf{c}_{\mathrm{hous}})$ and in vehicles $(\mathbf{c}_{\mathrm{veh}})$. From the second stage one derives (column) vectors of fuel, heat, and electricity consumption: $\mathbf{c}_{\mathrm{fuel}}$, $\mathbf{c}_{\mathrm{heat}}$, and $\mathbf{c}_{\mathrm{el}}$.
Nondurable non-energy consumption is then given by:

$$\mathbf{c}_{\mathrm{NE}} = \mathbf{c}_{\mathrm{nondur}} - \mathbf{c}_{\mathrm{fuel}} - \mathbf{c}_{\mathrm{heat}} - \mathbf{c}_{\mathrm{el}} \qquad (3)$$

The vector of commodities of non-energy consumption (cj) is in a next step derived from multiplying the matrix of budget shares, **W**, with the vector of nondurable non-energy consumption (converted into a diagonal matrix):

$$\mathbf{c}_{\mathrm{j}} = \mathbf{W}[\hat{\mathbf{c}}_{\mathrm{NE}}] \tag{4}$$

where j = 1...8 are the eight non-energy consumption commodities. The final result of this procedure is a vector of durable, energy and non-energy consumption. This vector is then transformed into a consumption vector by commodities of the input-output core in the DYNK model in purchaser prices, $\mathbf{c}_{\mathrm{pp}}$, by applying the bridge matrix, $\mathbf{B}_{\mathrm{C}}$:

$$\mathbf{c}_{\mathrm{pp}} = \mathbf{B}_{\mathrm{C}}\,\mathbf{c}_{\mathrm{j}} \tag{5}$$

The bridge matrix links the classification of consumption commodities (COICOP) to the industry classification of the DYNK model. The vector is then further split up into a domestic and imported part for each commodity and converted into producer prices by reallocating trade and transport margins to the corresponding industries and subtracting taxes less subsidies. That yields the vectors of total domestic ($\mathbf{c}^{\mathrm{d}}$) and imported ($\mathbf{c}^{\mathrm{m}}$) consumption, with $\mathbf{c} = \mathbf{c}^{\mathrm{d}} + \mathbf{c}^{\mathrm{m}}$, all valued at producer prices. For this converting a matrix of net tax rates (with identical tax rates on domestic and imported commodities) is applied.

The two energy categories (fuel and heating) of the model of energy consumption need to be directly linked to the energy accounts by user (62 industries plus households) and detailed fuel category (26) in physical units. This is done in two several steps. First, the vector $\begin{bmatrix} c_{fuel} \\ c_{heat} \end{bmatrix}$ is deflated by aggregate prices of fuels and heating, where these energy prices are not specified as deflators, but as monetary values per physical energy unit (TJ). Then the deflated categories, in energy units, are allocated to the 26 energy types (e) of the model by applying fixed sub-shares, s_{ef}. The aggregate prices used for the first step (for fuel and heating, p_f) are defined by the exogenous prices by energy type (p_e) and the corresponding sub-shares:

$$p_f = \sum_e s_{ef}\, p_e \tag{6}$$

This gives a matrix of direct energy consumption of households by type of energy (e).

2.1.2 Production and trade

The model of production links the above described commodity balances of the IO core model (Leontief technologies) of 62 domestic and imported inputs to a Translog model with K, L, E, M^m (imports) and M^d (domestic) factors. The factor energy (E) is further split up into 26 types of energy, from which energy demand of production is derived (see the next section).

The Translog specification assumes constant returns to scale and perfect competition and incorporates autonomous technical change for all input factors (i.e. the factor biases) as well as TFP (total factor productivity). All data for the production system are derived from the WIOD (World Input Output Database) dataset that contains World Input Output Tables (WIOT) in current and previous year's prices, Environmental Accounts (EA), and Socioeconomic Accounts (SEA). For energy inputs the data in physical units (TJ) by energy type and user are used. Energy prices by energy type are exogenous, like in the household block of the model. The systems of output price and factor demand equation by industry across the EU 27 have been estimated applying the Seemingly Unrelated Regression (SUR) estimator for the balanced panel under cross section fixed effects. The estimation results yield values for the own and cross price elasticity for capital, labour, energy, and imported intermediates respectively. The average (un-weighted) own price elasticity of labour as well as of energy is about –0.5, while the own price elasticity of imported intermediates (–0.75) and capital (–0.95) is considerably higher. For energy-intensive industries the own price elasticity of energy is lower, but the substitution elasticity between energy and capital is slightly higher than on average. Though, also on average, capital and energy are substitutes (though in several sectors complementary). The rate of factor bias in general is very low, and technical progress slightly energy using and labour saving.

The labour market is characterized by wage bargaining, formalized in wage curves by industry. These wage curves are specified as the employees' gross wage rate per hour by industry. The labour price (index) of the Translog model is then defined by adding the employers' social security contribution to that. Wage data including hours worked are taken from WIOD Sectoral Accounts and are complemented by labour force data from EUROSTAT. The wage equations have been estimated for the full EU 27 panel. Combining the meta-analysis of Folmer (2009) on the empirical wage curve literature with a basic wage bargaining model from Boeters and Savard (2013) gives a specification for the sectoral hourly wages. The un-weighted average of the long-run unemployment elasticity of wages across industries is 0.06. The long-run productivity elasticity of wages is only about 0.3, whereas the consumer price elasticity is close to unity (0.8).

The set of five energy categories of the model of inter-fuel substitution needs to be directly linked to two parts of the model: (i) the energy accounts by industry and detailed fuel category (26) in physical units (TJ) and (ii) the energy commodities and industries of the use table (NACE/CPA 10, 11, 23, 40) in monetary units. The first link is carried out in the same way as described above for households, i.e. by deflating with a price per unit of physical input (TJ) and applying sub-shares in physical terms. The second link is carried out by applying changes in the structure of the five energy inputs to the use structure matrix of the factor E (see next section).

Imports by commodity are in this model determined by the sum of final and intermediate demand by commodity. For this purpose, an import shares matrix for final demand, $\mathbf{M^f}$ is introduced and applied to the total final demand matrix, $\mathbf{F}$ (consisting of the columns of final demand, c, cf, ex, st, cg). The elements of matrix $\mathbf{F}$ are treated as constant and could alternatively be modeled via the Armington elasticity. Note that the major part of imports (i.e. intermediate goods) is variable and reacts upon prices. Total imports by commodities IM are in this framework given by imports of final demand, both energy and non-energy commodities imports and of intermediate inputs (energy), as well as non-energy (the symbol $\otimes$ represents element by element multiplication of two matrices):

$$\mathbf{IM} = \mathbf{M^f} \otimes \mathbf{F} + \left[\hat{\mathbf{V}}_{\mathrm{M}} \mathbf{S}^{\mathbf{m}}_{\mathbf{NE}}\right] \mathbf{p}_{\mathrm{Q}} \mathbf{Q} + \left[\hat{\mathbf{V}}_{\mathrm{E}} \mathbf{S}^{\mathbf{m}}_{\mathbf{E}}\right] \mathbf{p}_{\mathrm{Q}} \mathbf{Q} \tag{7}$$

2.2 Integration of physical and monetary energy demand

The full integration of the Austrian energy balance (according to the IEA concept and methodology) into the DYNK model can be seen as a prerequisite for using the model in the analysis of energy scenarios. The energy balance is organized as a system of commodity balances in physical units. The IO core of the DYNK model is based on Supply/Use tables (SUT) in monetary units. Several steps of transformation of the two datasets are necessary in order to integrate both datasets in the model.

The Austrian energy balance comprises production (primary), transformation output, and imports as sources of supply of energy and exports, final energy use (including transport losses, non-energetic use, and use of the energy sector), and transformation input as sources of use (demand). All aggregates are measured in physical units (TJ) and are available for 26 categories of energy (from hard coal to electricity). Final energy is disaggregated into 20 production and service sectors and one household sector, transformation input and output are classified by six processes (coke oven, blast furnace, refinery, charcoal production, electricity/heat sector, and electricity/heat auto-producers).

The first step in linking the energy balance to the SUT in monetary units consists of constructing a SUT system from the energy balance, following Fleissner, et al. (1993) and Stadler (2008). The make matrix $\mathbf{V}_{\mathrm{E}}$ of this system is the sum of a matrix of primary energy production (e.g. crude oil) $\mathbf{V}_{\mathrm{P,E}}$ and a matrix of transformation output, $\mathbf{V}_{\mathrm{T,E}}$: $\mathbf{V}_{\mathrm{E}} = \mathbf{V}_{\mathrm{P,E}} + \mathbf{V}_{\mathrm{T,E}}$. The use matrix $\mathbf{U}_{\mathrm{E}}$ of this system is the sum of a matrix of final energy consumption $\mathbf{U}_{\mathrm{F,E}}$ and a matrix of transformation input, $\mathbf{U}_{\mathrm{T,E}}$: $\mathbf{U}_{\mathrm{E}} = \mathbf{U}_{\mathrm{F,E}} + \mathbf{U}_{\mathrm{T,E}}$. Both matrices have the dimension of *m* sectors (comprising 21 sectors of final energy use and six processes of transformation) and *k* categories of energy (from hard coal to electricity). We further define row vectors of: imports ($\mathbf{im}$), stock changes and recycling ($\mathbf{st}$), exports ($\mathbf{ex}$), and other final demand ($\mathbf{f^*}$, including energy use of the energy sector, transport losses, non-energetic use of energy). All these vectors have the dimension of *k* categories of energy. Total supply and total demand $\mathbf{Q}_{\mathrm{E}}$ according to the concept of economic IO models can be written as:

$$\mathbf{i'V}_{\mathrm{E}} + \mathbf{im} + \mathbf{st} = \mathbf{Q}_{\mathrm{E}} = \mathbf{i'U}_{\mathrm{E}} + \mathbf{f}^* + \mathbf{ex} \tag{8}$$

where $\mathbf{i}$ is the unity vector.

The relevant aggregate in the energy balance is gross inland consumption $\mathbf{G}_{\mathrm{E}}$, which is not identical with total supply and demand, $\mathbf{Q}_{\mathrm{E}}$. Gross inland consumption can be derived in the supply/use system presented here by

$$\mathbf{G}_{\mathrm{E}} = \mathbf{Q}_{\mathrm{E}} - \mathbf{i}'\mathbf{U}_{\mathrm{T,E}} - \mathbf{ex} \tag{9}$$

Gross inland consumption is defined according to a concept of domestic primary energy use, therefore non-domestic use (exports) and energy that is only transformed are subtracted from the total commodity balance.

The system laid down in equation (7) and (8) is converted into an IO model that can be solved for total supply and gross inland consumption, given final energy demand. This solution of the model in physical units is used to check the consistency of the solution of the integrated model. The philosophy of the integrated model is consistently linking the SUT model in DYNK in monetary units to the SUT model in physical units from the energy balance and therefore taking into account energy transformation and production directly in the SUT of the DYNK model.

The second step consists of linking the model described above to the energy part (in monetary units) of the DYNK model. This is done by introducing "implicit energy prices" by dividing a monetary data set from the SUT in the DYNK model by a physical data set from the energy balance, which is consistent with each other. First of all, the physical energy data need to be transformed into the classifications of the DYNK model. The sectors in the monetary SUT are the 64 industries of NACE 2008 (*j* sectors) and the *f* energy goods that can be derived from this classification are: (i) Biomass, Fire Wood, (ii) Coal, Oil, Gas (from primary production), (iii) Coke and Oil Products, and (iv) Electricity, Steam, Heat and Gas (from gas distribution). The building parts of the link that can be directly derived from the data are:

- The transposed use matrix $\mathbf{U}_{\mathrm{E}}(f,m)$ in physical units with the dimension of *f* energy goods and *m* sectors of the energy balance.
- The transposed use matrix $\mathbf{U}_{\mathrm{EN}}(f,j)$ in monetary units with the dimension of *f* energy goods and *j* sectors of the monetary SUT.

For aggregation of the *j* industries to the *m* sectors a transformation matrix $\mathbf{T}_{\mathrm{EN}}(j,m)$ with row sum of unity has been constructed. The necessary information for the construction of this matrix is the correspondence of classifications and the splitting up of transformation processes of the energy balance into industries. This is in most cases straightforward, except in the case of auto-producers of electricity. Their energy input has been distributed according to the structure of electricity production of industries as defined in the make matrix of the monetary

SUT. Multiplying the transformation matrix $\mathbf{T}_{\mathrm{EN}}(j,m)$ with a diagonal matrix of each of the *f* energy goods vectors in *j* industry dimension (in monetary units), $\hat{\mathbf{u}}_{\mathrm{EN}}^{\mathrm{f}}$, yields in a first step a transformation matrix in absolute numbers for all four energy goods, which can be converted into a transformation matrix of column sum one, for each energy good: $\mathbf{T}_{\mathrm{EN}}^{\mathrm{f}}(j,m)$, by dividing through the column sum $\hat{\mathbf{u}}_{\mathrm{EN}}^{\mathrm{f}}(m)$:

$$\mathbf{T}_{\mathrm{EN}}^{\mathrm{f}}(j,m) = \hat{\mathbf{u}}_{\mathrm{EN}}^{\mathrm{f}}(j)\mathbf{T}_{\mathrm{EN}}(j,m)\hat{\mathbf{u}}_{\mathrm{EN}}^{\mathrm{f}}(m) \tag{10}$$

These matrices $\mathbf{T}_{\mathrm{EN}}^{\mathrm{f}}(j,m)$ are used to convert physical energy of each of the *f* energy goods, i.e. each row in matrix $\mathbf{U}_{\mathrm{E}}(f,m)$, into a vector of physical energy of *f* by industry *j*. Those energy categories that are not included in *f* (waste, wind and photovoltaics, hydropower) have also been converted and are treated with an implicit price of zero. Finally, this procedure yields the following parts for the data link:

- The use matrix $\mathbf{U}_{\mathrm{E}}(f,j)$ in physical units with the dimension of *f* energy goods and *j* sectors of the monetary SUT.
- The use matrix $\mathbf{U}_{\mathrm{EN}}(f,j)$ in monetary units with the dimension of *f* energy goods and *j* sectors of the monetary SUT.
- The matrix $\mathbf{P}_{\mathrm{E}}(f,j)$ of implicit energy prices, by dividing each element of $\mathbf{U}_{\mathrm{EN}}(f,j)$ by each element of $\mathbf{U}_{\mathrm{E}}(f,j)$.

The next step consists of defining the nest of the *k* energy categories by disaggregating the *f* energy goods. This needs to be done at the level of the *j* industries in the DYNK model now, as both monetary and physical data at the level of *f* energy goods are available in this classification from the procedure described above. The quantity shares of the *f* energy goods in industry *j* are defined by $w_E(f,j)$ and the sub-shares of the *k* categories as $w_E(k,f,m)$, because they are in principle only available in classification *m*. Assigning the $w_E(k,f,m)$ from the energy balance data to $\mathbf{U}_{\mathrm{E}}(f,j)$ could only be done by taking into account the classification correspondence and not the other information that entered in the original transformation matrix ($\mathbf{T}_{\mathrm{EN}}(j,m)$), because this is not available. That, in turn, lead to a new unbalanced matrix $\mathbf{U}_{\mathrm{E}}(k,j)$, which does not match the correct margins of the energy balance sum by *k* for energy use and the original sum in $\mathbf{U}_{\mathrm{E}}(f,j)$ of energy use by *j* industries. These differences have been eliminated by applying RAS to matrix $\mathbf{U}_{\mathrm{E}}(k,j)$. This, in turn, also led to a new adjusted matrix $\mathbf{U}_{\mathrm{E}}(f,j)$ and new implicit prices. The results from this second step of adjustment have been taken as the final consistent data set of monetary and physical energy data, from which the sub-shares of the *k* categories in classification *j*, $w_E(k,f,j)$, can be derived.

With exogenous energy prices at the level of *k* categories, which are uniform for all users (market prices), the implicit prices in $\mathbf{P}_{\mathrm{E}}(f,j)$ are defined by:

$$p_E(f,j) = \sum_k w_E(k,f,j) p_E(k) \tag{11}$$

for each industry *j*.

The implicit prices $p_E(f,j)$ yield, together with the quantity shares $w_E(f,j)$ the implicit price of the total energy input for each industry, $p_E(j)$. As laid down in 2.1., the DYNK model combines the total value share of energy by industry (v_E) with a use structure matrix for energy with elements s_E^d and s_E^{im} for domestic and imported shares respectively. The link between the DYNK model and the physical dataset works into both directions now:

- Nominal shares of the use structure matrix s_E (then further split up into s_E^d and s_E^{im}) are derived from the $w_E(f,j)$ by multiplying with $(p_E(f,j)/p_E(j))$. Both implicit prices are defined, once exogenous energy prices $p_E(k)$ are given and the $w_E(f,j)$ are in turn a function of $p_E(f,j)$ in the module of inter-fuel substitution in DYNK (see section 2.1.). Once the s_E^d and s_E^{im} are determined, the energy commodity balance of the DYNK model can be solved.
- The value share of energy by industry (v_E) from the solution of the DYNK model can then be converted into a physical share per unit of output (w_E) and split up into *f* and *k* categories of energy in physical units.

2.3 Linking of DYNK with bottom-up approaches

Technologies are in the model given by the structure of inputs in the production block, which – as far as intermediate inputs are concerned – has a nested structure. The Translog model determines the value shares of the *K*, *L*, *E*, *M* inputs and the use structure matrices for *E* and *M* determine the input by commodity in each industry. For the energy input *E* this is available in monetary and physical units at the level of *f* energy goods and in physical units at the level of *k* energy goods.

The DYNK model with the integrated energy balance has further been linked to bottom-up technologies in different industries. The first candidate is the link of the electricity and heat production sector in DYNK to the bottom-up model of electricity (TIMES) operated by the AEA. The electricity and heat generation data from the solution of the TIMES model are taken to determine the structure of heat and electricity generation in the framework of the energy balance, which – in turn – determines the variables that define the technology of the electricity and heat generation in the DYNK model in terms of energy inputs. For this purpose, in addition to the classification of *f* energy goods and *k* categories of energy the classification of *p* technologies of electricity and heat generation are introduced. The aggregate data for these technologies can be taken from the Austrian energy balance and coincide with the structure of results from the TIMES model. These *p* technologies comprise 20 different power (including combined cycle) and heat generation plant types, which are relevant for Austria.

In the TIMES model the detailed structure of these technologies by plant is modeled and the solution of the optimization algorithm in TIMES yields input and output of energy by these *p* technologies. Combining physical and monetary data of the sector we can derive an implicit output price, $p_q(E)$ for the output of the sector, which in turn is linked to the output price index p_q from the Translog model.

From the TIMES result we can calculate a share of each technology in electricity and heat output (in physical units, TJ) $w_E(p,q)$, which – given that we have only one output price $p_q(E)$ – is also valid for splitting up the output in monetary units. The physical share of energy input per unit of output (w_E) can now be expressed as a function of the physical shares of energy input for each technology $w_E(p)$ and the technology shares in output $w_E(p,q)$:

$$w_E = \sum_p w_E(p,q) w_E(p) \tag{12}$$

This total input coefficient is further used to define the sub-shares of each technology $w_E(p,E)$ in this total input coefficient, (w_E):

$$w_E(p,E) = w_E(p,q)\left(\frac{w_E(p)}{\sum_p w_E(p,q) w_E(p)}\right) \tag{13}$$

These sub-shares can be simply aggregated in order to yield the energy input sub-shares of the *k* categories for the electricity and heat generation sector, $w_E(k,f)$, as well as the quantity shares $w_E(f)$ in the classification of energy goods. The definition of the prices of energy goods $p_E(f)$ stays the same as in equation (11) and the implicit price of the total energy input of the electricity and heat sector, p_E, is given by multiplying the prices $p_E(f)$ with the shares $w_E(f)$. The derivation of the variables for the commodity balance of energy goods in monetary terms is not affected. Once the shares $w_E(k,f)$ and $w_E(f)$ and the prices $p_E(f)$ and p_E are determined, the nominal shares of the use structure matrix s_E can be derived.

Different sources (mainly IEA) have been further used to derive data of capital costs by technology. These data have then be calibrated in a way that applying the output shares $w_E(p,q)$ of the base year, the total capital cost term of the electricity and heat sector in the DYNK model is matched. This specification substitutes the Translog model in this sector and determines the output price of the electricity and heat sector. The DYNK model is also linked to the TIMES model in the other direction, as electricity demand of the solution of the DYNK model is introduced in TIMES.

To run the linked model, some cautious assumptions about the development of the total efficiency of each technology (expressed in $w_E(p)$) are made in accordance with the TIMES model. These efficiencies are not expected to increase significantly and are in principle limited by the thermodynamic restrictions for each technology. The solution of the TIMES model then delivers the output shares $w_E(p,q)$ which determine all further variables of the electricity and heat sector in the DYNK model.

Another industry, where this kind of link between the DYNK model and bottom-up approaches is envisaged, is the steel industry. As Schumacher und Sands (2007) emphasize, this needs to be done by simultaneously modeling electricity generation, as technological change in this industry might lead to considerable increases in electricity demand that needs to be met from the supply side by adjusting generation capacities. In principle, this methodology can also be applied to other energy-intensive industries, if the data availability allows it.

Other lines of cooperation and links from the DYNK model to bottom-up approaches refer to vehicle and housing stock models. These two categories of durable demand are modeled at the aggregate level in DYNK and shall be linked to the data of the structure of these stock data, as used in the bottom-up models for transport (TU Graz) and for buildings (TU Wien). The structure data of the stocks (year of construction of the building, lifetime and age of heating system, type of vehicle) are relevant for the embodied energy efficiency of the aggregate stock. This efficiency is an important variable in consumers' energy demand in DYNK and defines the link.

3 The WEM Scenario

The philosophy of the WEM ("with existing measures") scenario corresponds to the continuation of trends (as far as criteria for this can be found) under energy and climate policies that are already in place. The assumptions for this scenario are taken from international publications and – as far as the policy measures in Austria are concerned – from sources of Austrian stakeholders. One important source are the positions for subsidies and taxes that are built into the Austrian public budget stability program.

3.1 Assumptions for the WEM Scenario

From the perspective of the DYNK model there are two different sets of assumptions about 'exogenous' data. One is the main exogenous data, which is common to all research institutions and triggers the results of the DYNK model as well as of the bottom-up approaches. The other data set that is 'exogenous' from the perspective of the DYNK model are results for variables in the energy system from the bottom-up models, that are carried over to the DYNK model.

The main exogenous data comprise population and household development, as well as energy prices and the Euro/Dollar exchange rate. The assumptions are taken from recent global (IEA) or European (PRIMES model) energy scenarios and have been discussed with the other research institutions.

In *Table 1* the global energy prices (converted into €) for the three main fossil fuels (crude oil, natural gas, coal) in current and constant (2015) prices for the WEM scenario are shown.

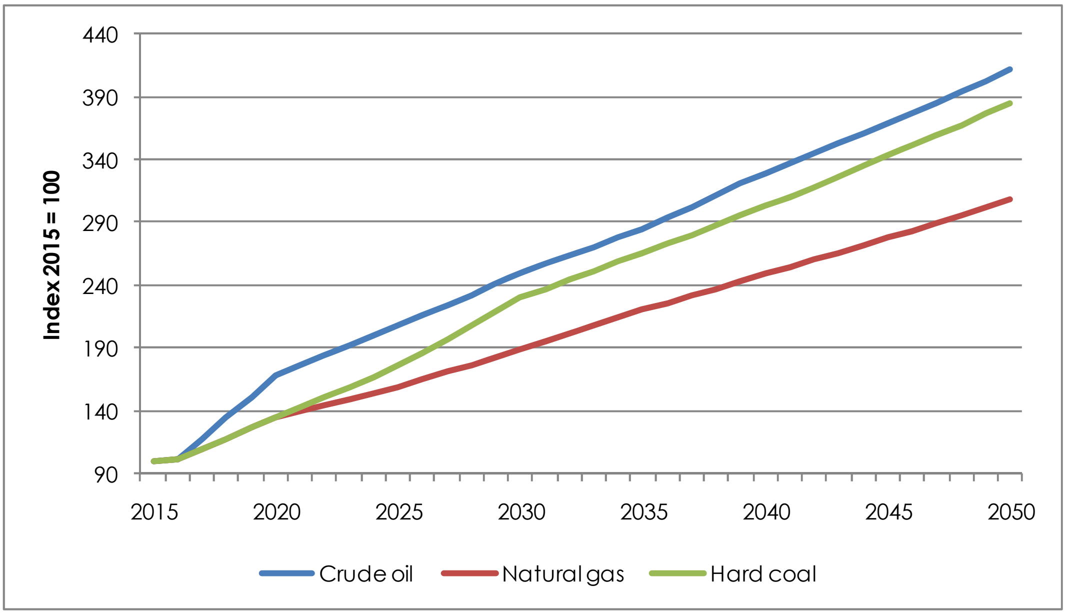
Table 1: Global energy prices (€/physical quantity) in the WEM scenario

	2015	**2020**	**2030**	**2050**
Crude oil (€/bbl, real, 2015)	49	77	96	111
Gas (€/MMBtu, real, 2015)	5	8	10	11
Coal (€/t, real, 2015)	51	64	92	108
Crude oil (€/bbl, nominal)	49	83	124	203
Gas (€/MMBtu,nominal)	6	9	12	20
Coal (€/t, nominal)	51	69	118	198

S: IEA (2016), PRIMES results (mimeo), own calculations.

As Figure 1 also reveals, the crude oil price is expected to see the sharpest increase and the price for gas the lowest. This clearly shows the decoupling of gas prices from oil (product) prices in Europe through the creation of a European gas market with many different hubs and more flexible transport infrastructure (pipelines and LNG terminals). In general, fossil fuel prices are expected to recover soon from the current low levels and show modest linear increases between 2020 and 2050.

Figure 1: Global energy prices (€/barrel of oil equivalent in current prices) in the WEM scenario

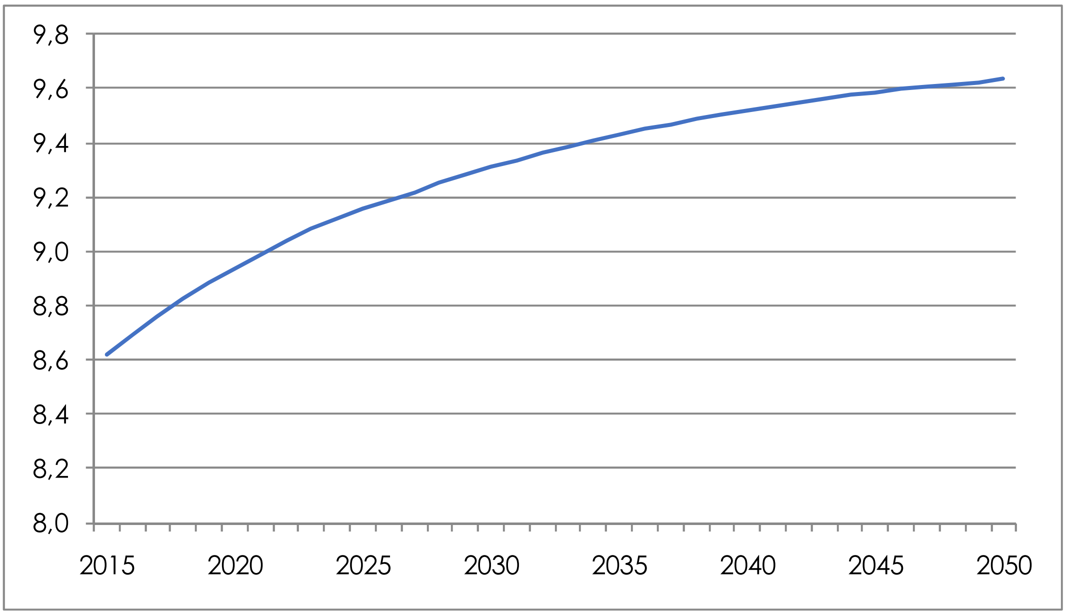


S: IEA (2016), PRIMES results (mimeo), own calculations.

The global energy prices drive the exogenous energy prices of *k* categories (equation (4)) in the DYNK model and are one important determinant of energy demand.

The population forecast for Austria is taken from Statistik Austria and shows a non-linear (declining) increase in the population numbers, which are in turn the driver for the number of households and one important component of household energy demand.

Figure 2: Austria's population forecast in million persons

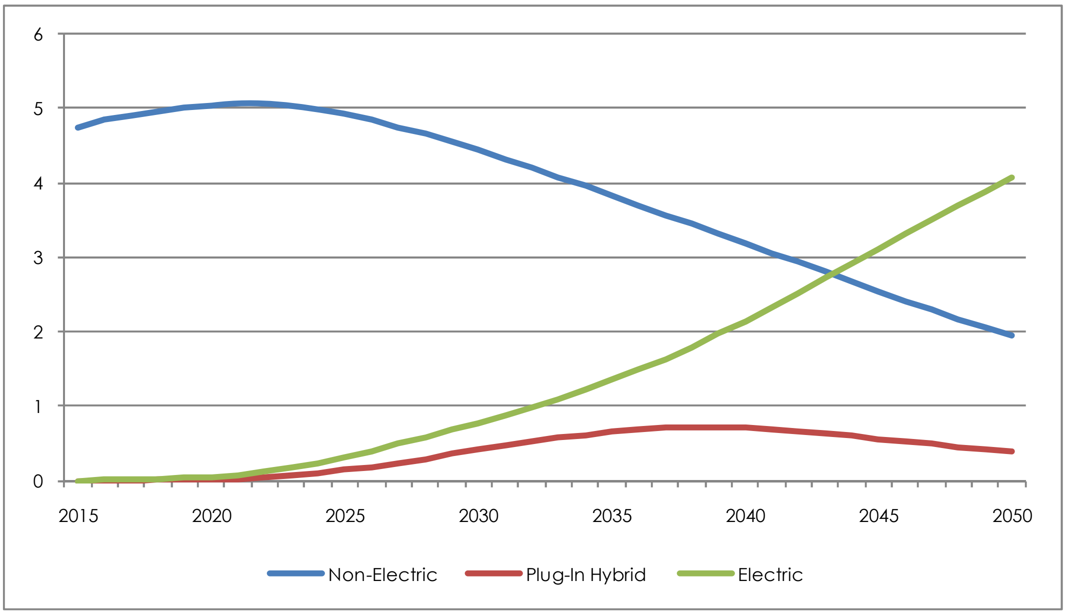


S: Statistik Austria.

Other variables that need to be built in the model are those that are determined by the "existing measures" of energy and climate policy in this scenario. That refers especially to the development of energy efficiency in household demand (vehicles, buildings) and in the production sector.

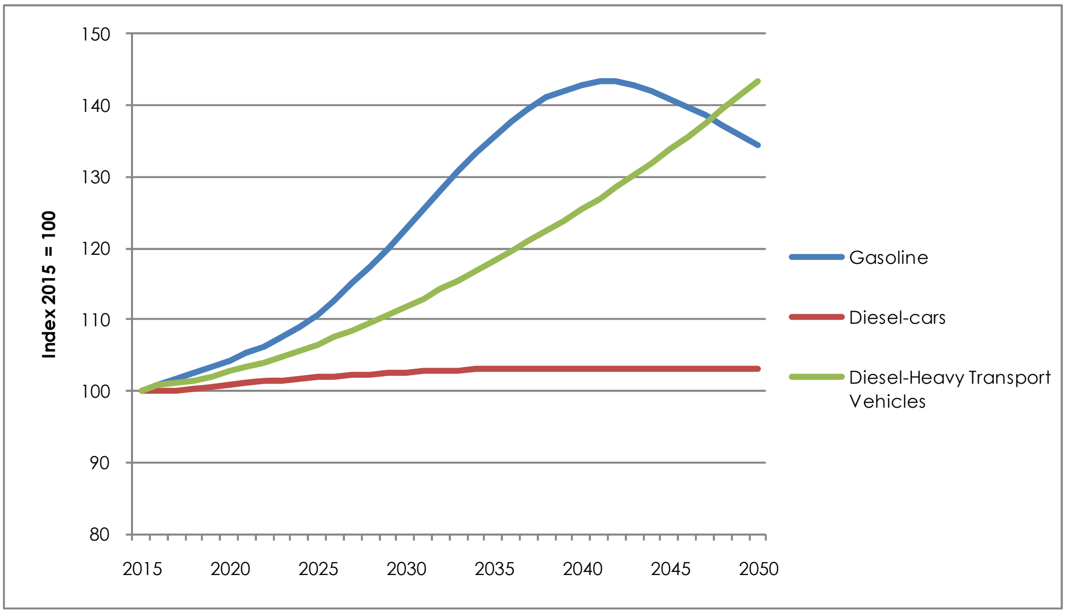
The bottom-up model for transport, operated by TU Graz yields results for the coverage of vehicles per person and the structure of the vehicle fleet by types (gasoline, diesel, electricity). These results reveal an increase of coverage up to 660 vehicles per 1,000 persons in 2050 and a share of electric cars of over 60% (Figure 3). The total fossil fuel efficiency of the vehicle fleet is based on the assumed CO_2 emission requirements of the different vehicle fleets in the bottom-up model of TU Graz. Due to the high penetration of electric cars at around 60% of the stock in 2050, only minor investments in fossil fuel efficiency is needed to achieve CO_2 emission requirements. Therefore, we assume only a slight increase in gasoline motor efficiency and for heavy transport vehicles (Figure 4). For diesel powered cars no improvement is assumed.

Figure 3: Stock of private vehicles in Austria in the WEM scenario in million vehicles



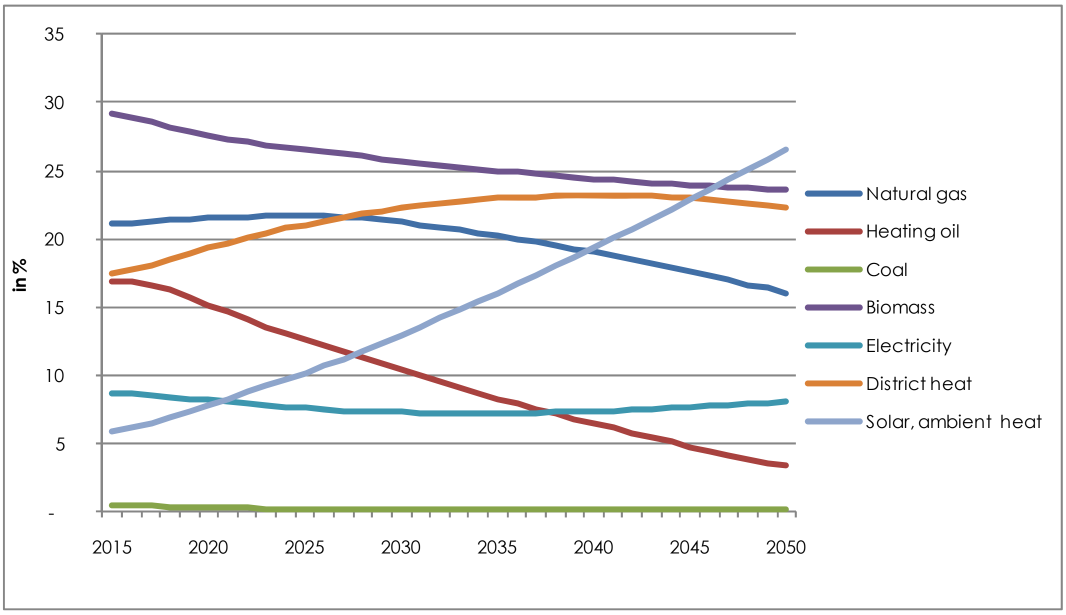
S: TU Graz.

Figure 4: Fossil fuel efficiency of private vehicles in Austria in the WEM scenario



S: TU Graz.

Figure 5: Fuel shares of private heating systems in Austria in the WEM scenario



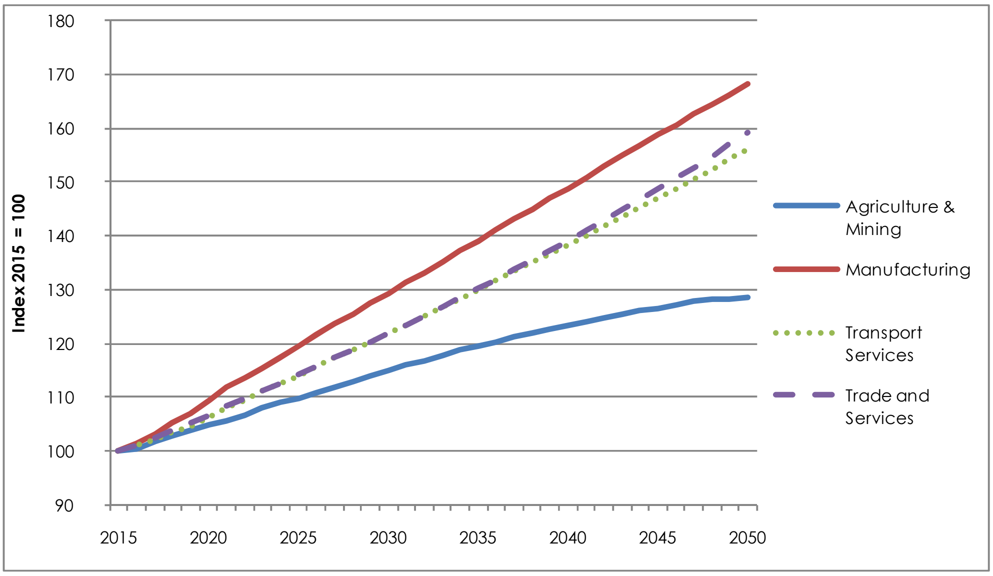
S: EEG (TU Wien).

Based on the detailed bottom-up model of the EEG we include the development of heating systems of the residential buildings in the model structure of DYNK. The results of EEG are determined by technology diffusion (non-linear trends) and relative prices of fuels. The information about shares of fuels in heating of households is introduced into the DYNK model by overwriting the equations that determine inter-fuel substitution in the household sector. In Figure 5 one observes that especially heating oil is decreasing according to these results, while solar and ambient heat become the top supply type of ambient heat (heat pumps "deliver" ambient heat, accounted for in "Solar and ambient heat" and use input of electricity, accounted for in "Electricity").

3.2 Economic results of the WEM Scenario

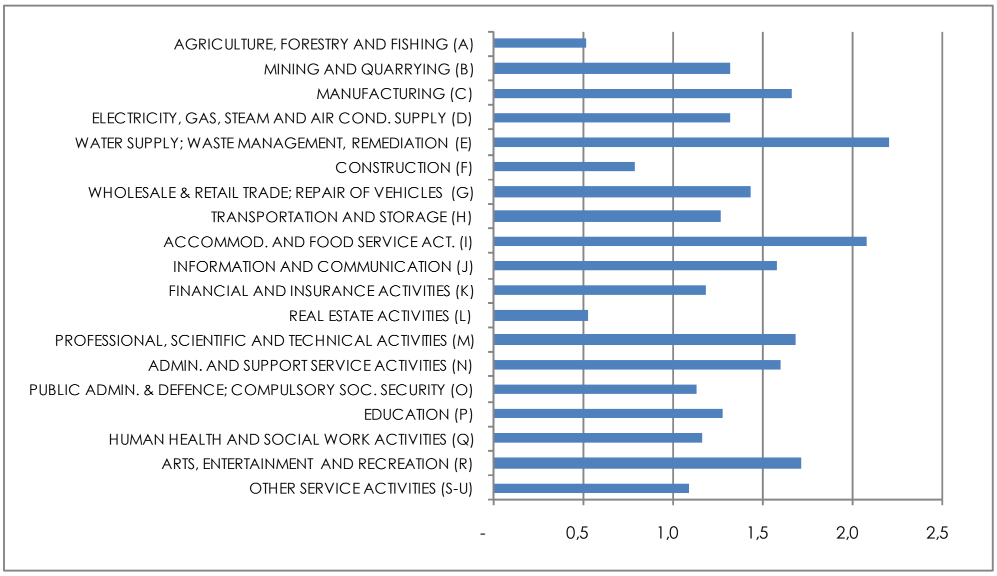
The main drivers of economic growth in the DYNK model are total factor productivity (TFP) growth (supply side) and global demand for Austrian exports (demand side). In a global/multi-regional model these two variables would be directly linked and the supply side (TFP) would be the ultimate source of economic growth. In our case we need to be aware that there is this link between both variables via price competitiveness and we chose both variables in a consistent way, compatible with plausible implicit values of parameters. Lower TFP growth in the future, for example, would lead to lower participation of Austrian exports in global trade, given a certain exogenous growth rate of global trade. In the WEM scenario we adjusted TFP and export development to achieve an average GDP growth in real terms of around 1.5%. The GDP in the solution of the DYNK model is derived from aggregation of sectoral developments, which are very heterogenous. This is shown in Figure 6.

Figure 6: Growth of value added (constant prices) in main economic sectors in the WEM scenario



S: own calculations.

Figure 7: Growth of value added (constant prices) in selected economic sectors in the WEM scenario



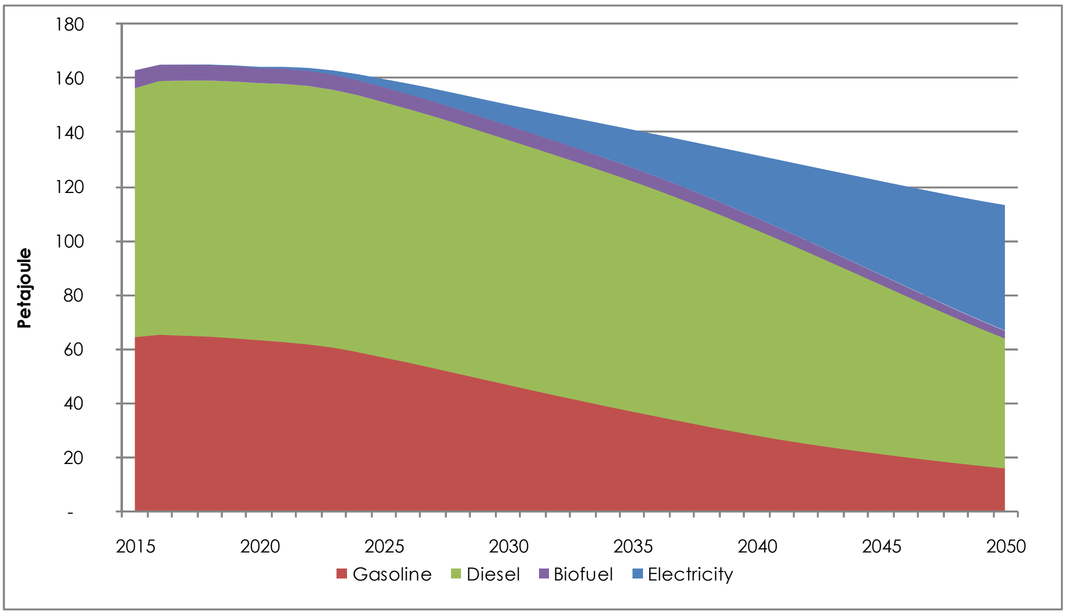
S: own calculations.

3.3 Results of the WEM Scenario for the energy system

Two important sectors of energy demand also crucial to Austrian climate and energy policy are transport demand of households, other households' energy demand and freight transport. The development in these sectors has contributed positively (transport) as well as negatively (households) to overall energy demand and GHG emissions in the last decade.

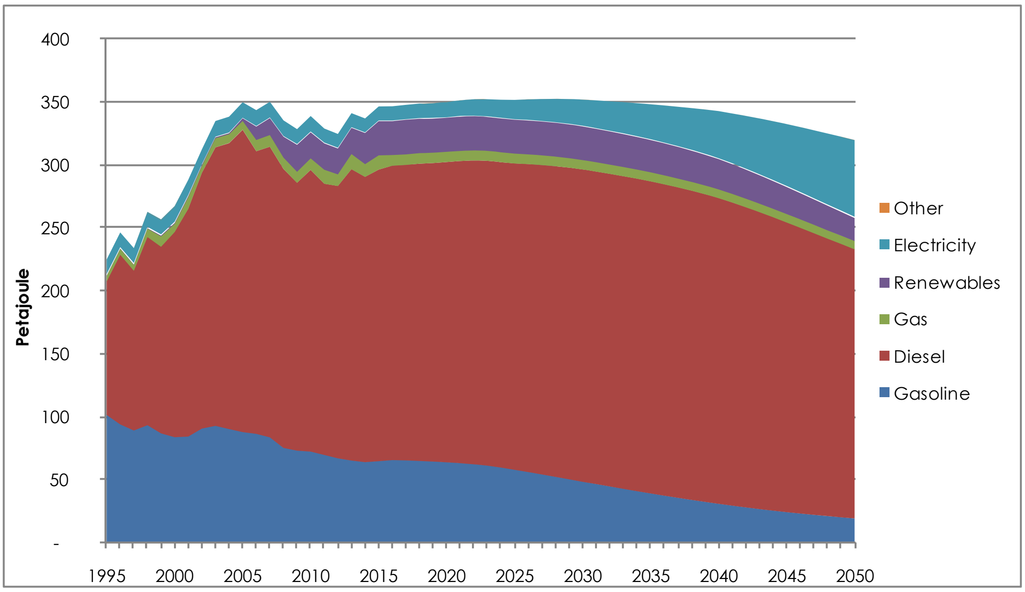
The results in the transport sector are mainly influenced by overall economic activity, the demand of private households and the development of the penetration of electric mobility. Even though the kilometers driven are increasing, the total energy demand for transport decreases (Figure 8) due to the low specific (per km driven) energy demand of electric vehicles compared to fossil fueled ones. Overall, diesel stays the main fuel source of transport activities (Figure 9).

Figure 8: Transport energy demand of private households in the WEM scenario



S: own calculations.

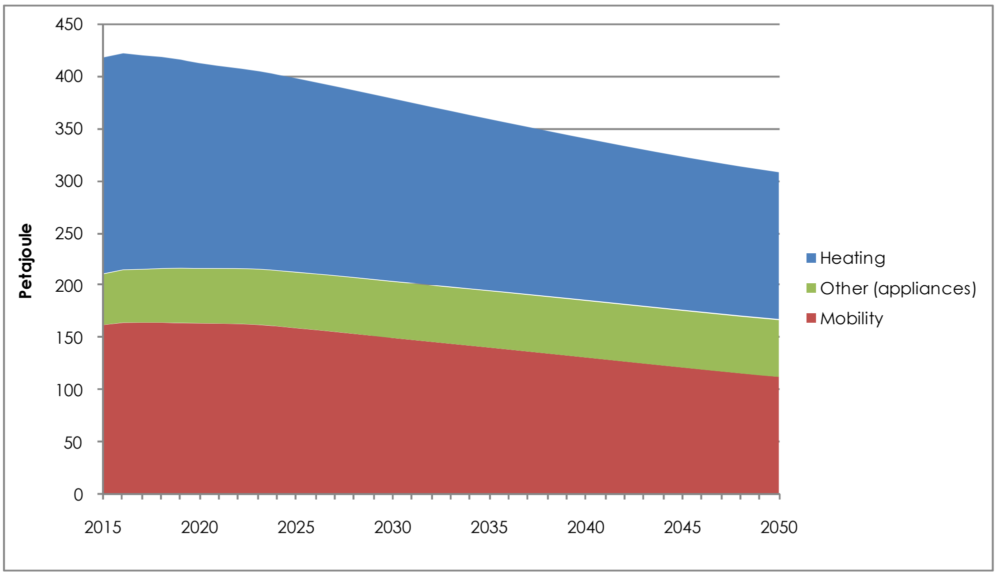
Figure 9: Total transport energy demand in the WEM scenario



S: own calculations.

For total energy demand of private households (including transport) we observe a downward slope that is on the one hand driven by the decreasing demand for diesel and gasoline (Figure 9) and on the other hand due to decreasing heating demand. The latter is caused by the assumed improvements in the buildings' energy efficiency (Figure 10).

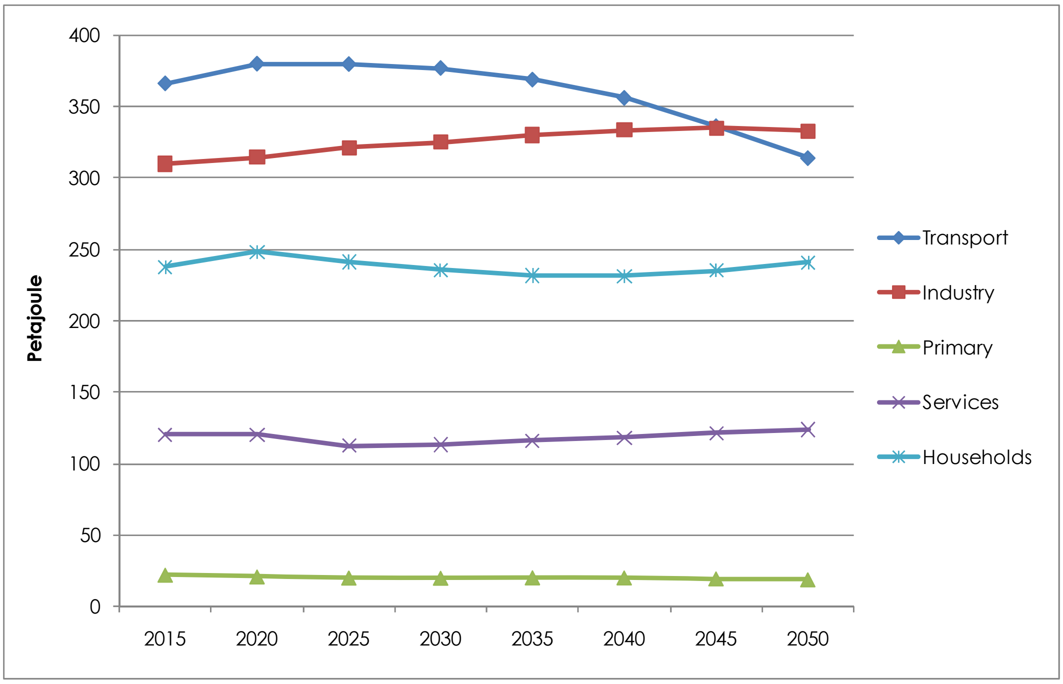
Figure 10: Private household energy demand in the WEM scenario



S: own calculations.

The final energy demand over all sectors is slightly decreasing in the WEM scenario. We see a diverging development between the increasing demand of the manufacturing sector and the decreasing demand of the transport sector. Please note that in the representation in Figure 11 the private demand for diesel and gasoline is assigned to the transport sector (according to the energy balance concept of Statistik Austria), while the electricity demand of electric cars is assigned to the private household sector.

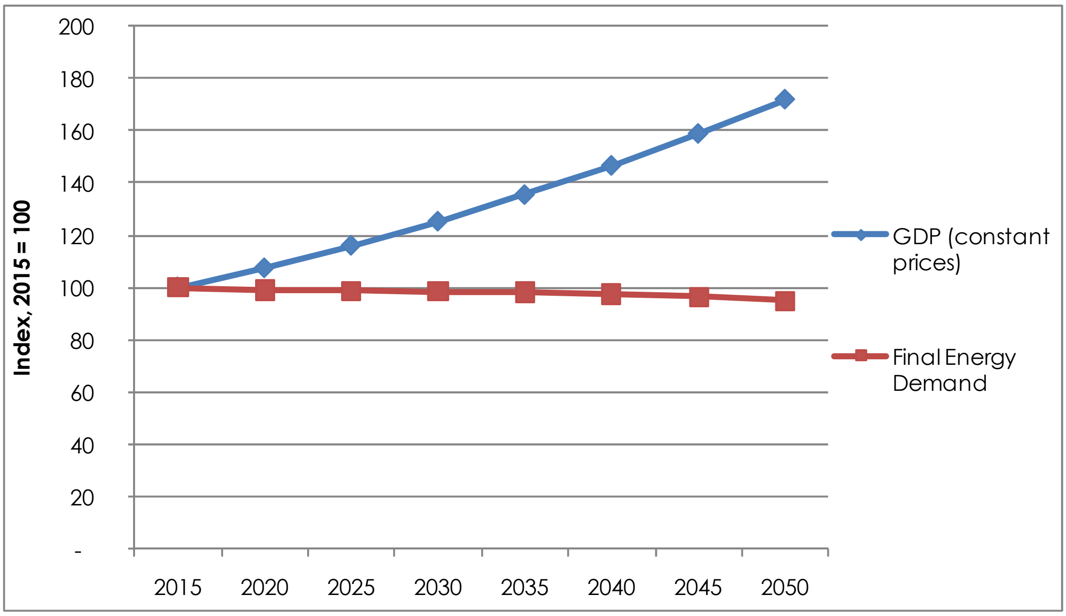
Figure 11: Final energy demand of main sectors in the WEM scenario



S: own calculations.

Overall in the WEM scenario we find a small absolute decoupling between economic growth and energy demand. A GDP growth rate of 1.5% p.a. is combined with a slightly decreasing final energy demand.

Figure 12: Total final energy demand and GDP (constant prices) in the WEM scenario



S: own calculations

4 The WAM plus Scenario

The WAM ("with additional measures") plus scenario is oriented along the mid-term and long-run targets of European climate policy with the final objective to reach 80 to 95% reductions in GHG emissions until 2050, compared to the base year of 1990. As specific policies of decarbonization are not covered by this study (CCS) or are not relevant for Austria (nuclear power), the scenario must incorporate significant reductions in energy consumption in all sectors and at all levels (final energy, transformation, losses) as well as the utilization of all renewable potentials (considering environmental constraints). Besides technological innovations and cost improvements in energy efficiency and converging technologies this must include behavioral change in energy-relevant demand patterns and lifestyle changes in particular (OECD, 2017). Therefore, a common understanding on how to successfully transform the energy system, decarbonize the economy, and overcome social as well as political obstacles in the transition process is needed. The conceptualizing of the WAM plus scenario including a broad stakeholder involvement is considered one major building block of such a process.

Structural change becomes a major driver in this scenario, especially as far as infrastructure investment is concerned. Infrastructure determines energy consumption in the long term (path dependence) and plays a major role for energy networks (electricity, gas, district heating) as well as for buildings and transport systems.

The starting point for this scenario is a WAM plus scenario of a recent study (UBA, 2015), which describes partly very ambitious measures in the individual sectors of the economy from 2021 onwards and analyses the impacts from implementing these measures on the Austrian economy and the energy system. These storylines have been revised and updated, based on stakeholder consultations.

General assumptions for the revised WAM plus scenario are summarized below. The WAM plus scenario is a global climate action scenario which describes global commitment towards achieving the objectives of the Paris Climate Agreement to limit global warming well below an average temperature increase of 2°C, or even 1.5°C, compared to the preindustrial level. Global action implies a steep and substantial rise in energy or CO_2 prices (see section 4.1.).

The long-term focus of the WAM plus scenario up to 2050 enables the assessment and analyses of durable goods stocks or lock-in effects from bad investments. The storyline incorporates significant changes with respect to behavior of agents as well as economic structures (technologies and production processes). Improvement in energy efficiency (per unit of output or energy service) plays a major role. This is driven by structural change towards new products, services and materials, new production processes and improvements in general technologies (steam generation, motors, etc). It also involves policies aiming at less resource use like extending lifetime, re-manufacturing, recycling (Meyer et al., 2018), sharing, and others. Refurbishing of buildings is a major part of an energy efficiency strategy as well as organizational reforms of transport (combination of modes, alternative technologies).

Another important sector in this scenario is electricity generation. On the one hand, due to investments in the grid, domestic generation can increase and grid management improves. This development decreases generation from fossil fuels, as – on the other hand – the potential of different renewables is also utilized.

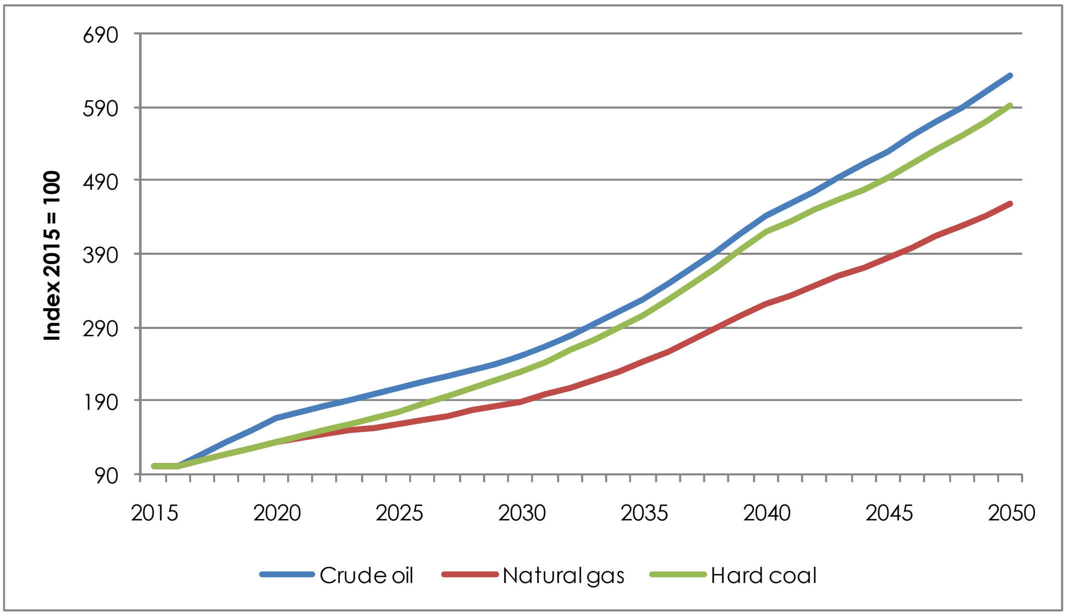
4.1 Assumptions for the WAM plus Scenario

4.1.1 Energy prices in the WAM plus Scenario

A global climate action scenario implies global energy prices to rise substantially and being differentiated according to the carbon content of the specific energy carrier. In the WAM plus scenario CO_2 prices on oil, natural gas and coal are rising from 2025 onwards with respect to the WEM scenario. The CO_2 price that leads to these effective energy price increases starts off from 8 €/t CO_2 in 2020, and continuously rises to 40 €/t CO_2 in 2030 and further to 200 €/t CO_2 in 2050 (in € of 2013).

The price for coal, the most carbon-intensive of the three fossil fuel energy carriers, exceeds the price for oil in 2031, and reaches a 700-fold increase in 2050 with respect to the year 2015. The oil price shows about a 600-fold increase in 2050 (with respect to 2050) and the price for natural gas shows the most moderate trajectory due to its lower carbon content, rising about 400-fold until 2050. Based on these general price assumptions, differentiated energy prices for households (diesel, gasoline, electricity, gasoil for heating) and industry are derived, partly from solutions of the bottom-up models and fed into the DYNK model. Diesel and gasoline prices rise to about 2.4 €/liter (in € of 2014) until 2030 and further to 5.7 €/liter, and the price difference between both fades out. Other oil products (for heating purposes) rise from an index of 100 in 2015 to 130 in 2030 and further to 176 in 2050. Prices of solid biomass (wood products) rise slightly less than oil prices (index of about 160 in 2050).

Figure 13: Global energy prices (€ per barrel of oil equivalent in current prices) in the WAM plus scenario



S: PRIMES, recent energy scenarios for Europe.

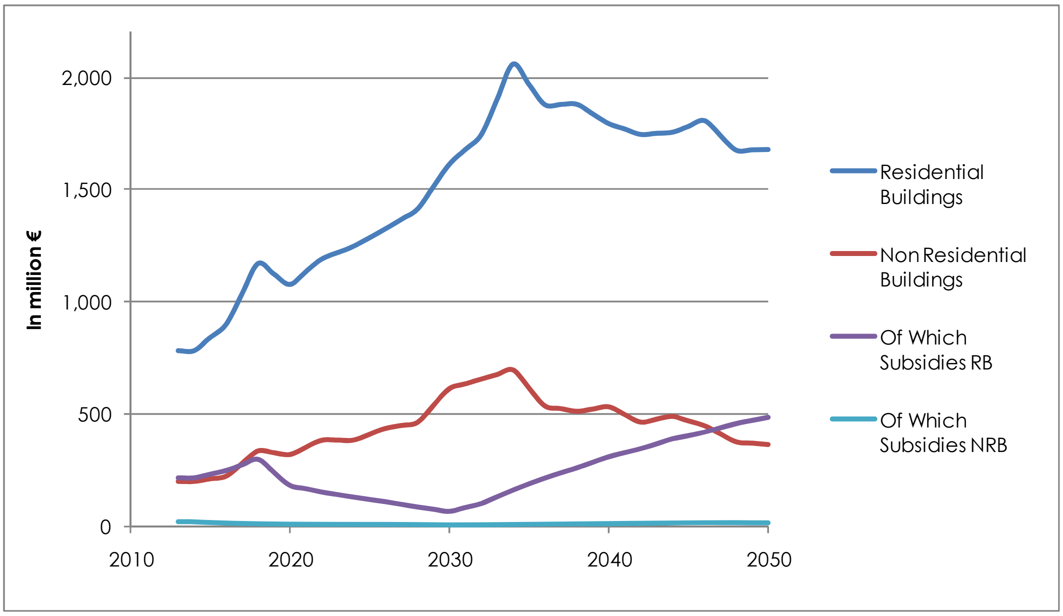
4.1.2 Investments and energy saving progress in the building sector

In the WAM plus scenario the capital stock is transformed into a more energy efficient and less fossil fuel intensive stock. That refers to energy efficiency investment in industry, in the building sector and the use of electric drives and modes in the transport sector. The building sector in the WAM plus scenario is characterized by substantial investments into refurbishments, new construction of buildings and new heating systems thereby improving the energy-efficiency of the building stock which includes residential buildings and non-residential buildings. The underlying measures are mainly regulatory, leading to a 'refurbishment plan' for buildings and a 're-switching plan' for heating systems.

This higher efficiency of the durable stock for heating (buildings and heating systems) is directly carried over to the same variable in the DYNK model. The impact is twofold: the 'engineering' impact of higher efficiency as in the bottom-up model (from EEG, TU Vienna) is combined with a decrease in the 'service' price that triggers a direct rebound effect. Figure 14 shows investment costs including subsidies of the different categories that represent data input to the DYNK model. The refurbishment investment in residential buildings amounts to 450 million € per year on average, with investment about 600 million € from 2030 on. Subsidies represent a 30% share of this investment, and need to be compensated with lower public expenditure in other parts, whereas investment has a direct positive macroeconomic impact.

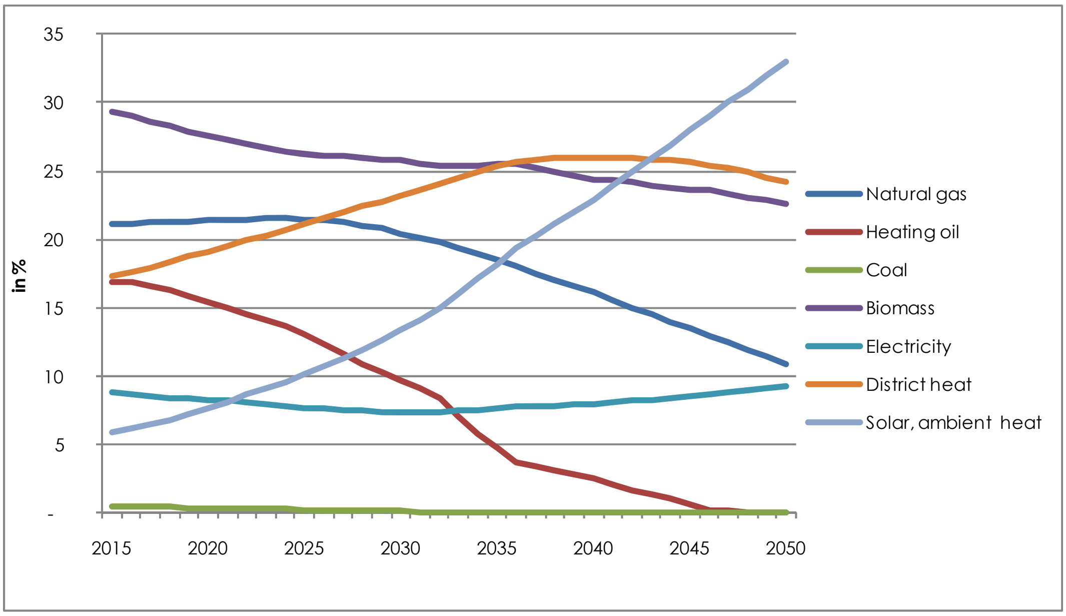
Based on the detailed bottom-up model of the EEG we include the development of heating systems of the residential buildings in the DYNK model. In Figure 15 one observes a steep rise in solar and ambient heating systems and a phasing out of oil heating in residential housing.

Figure 14: Investments in building sector refurbishment, WAM plus Scenario



S: EEG TU Wien, own calculations.

Figure 15: Fuel shares of private heating systems in Austria in the WAM plus scenario



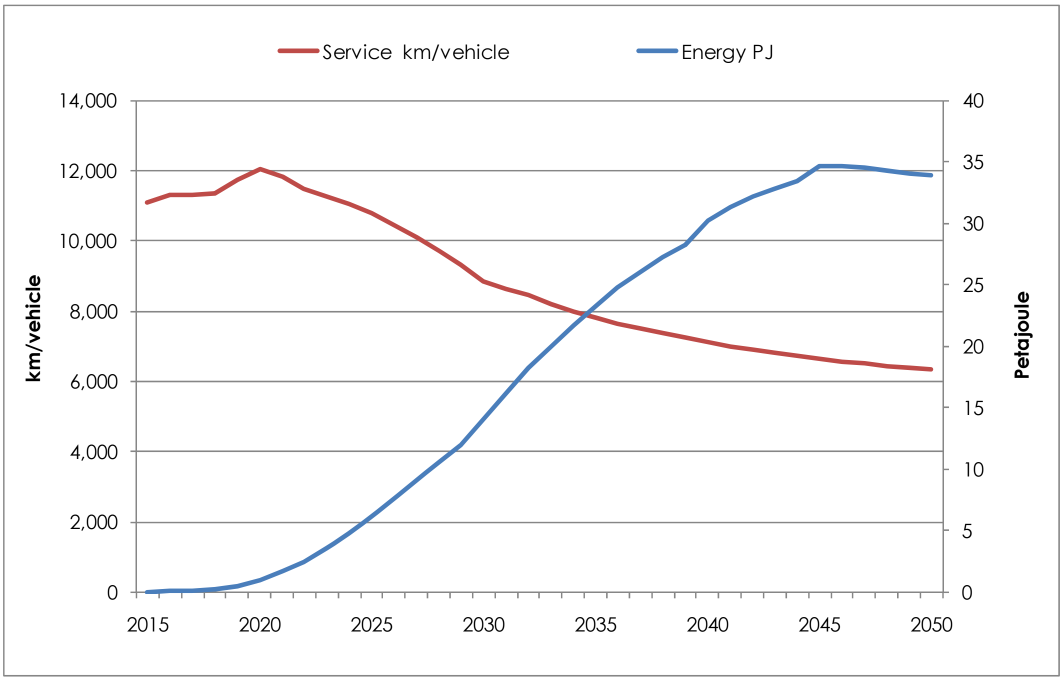
S: EEG TU Wien.

4.1.3 Investment and fuel shift in the transportation sector

In road transportation, fuel export in the WEM scenario is calculated to amount to 77.8 PJ in 2020 (TU Graz). Fuel price increases (partially driven by adjusting the taxation of diesel towards the taxation of gasoline) in the WAM plus scenario are, however, responsible for a phasing out of the fuel export to neighbour countries by 2020. According to the bottom-up model for transport operated by TU Graz, the vehicle stock per fuel type (gasoline, diesel, electricity) is lower in the WAM plus scenario and the stock of electric cars higher than in the WEM scenario. This is the result of a portfolio of measures to reduce individual motorized mobility schemes, especially in cities. The focus of energy-related transport policies is directed towards the enhancement of public transport as well as biking and walking. Another important measure is the exchange of the existing flat-rate road pricing system on highways by a general system that charges mobility services on all roads. Revenues from road pricing compensate for revenue losses from higher taxation of gasoline and diesel and thereby lowering the demand of fossil fuels. Therefore, no additional compensating fiscal measure had to be assumed. These measures have impacts on different variables in the DYNK model that determine energy consumption for transport.

One important result of these measures – that have all been simulated by a bottom-up transport model – is that transport services (km driven per car) decrease in parallel with a high diffusion of electric cars in the vehicle fleet. This has a double impact on fossil fuel use in private transport. Diffusion of electric vehicles also takes place in the WEM scenario, but in the WAM plus scenario it is enhanced in a way that leads to a share of 100% in 2045 (Figure 17). The energy demand in Figure 16 is derived from the solution of the DYNK model. The bottom-up model would yield a slightly lower (5 PJ) energy demand, but the DYNK model incorporates the rebound effect in driving that arises due to a lower car stock per household (and therefore less 'second cars') in the WAM plus scenario.

Figure 16: Mobility demand and energy consumption of electric vehicles in the WAM plus scenario

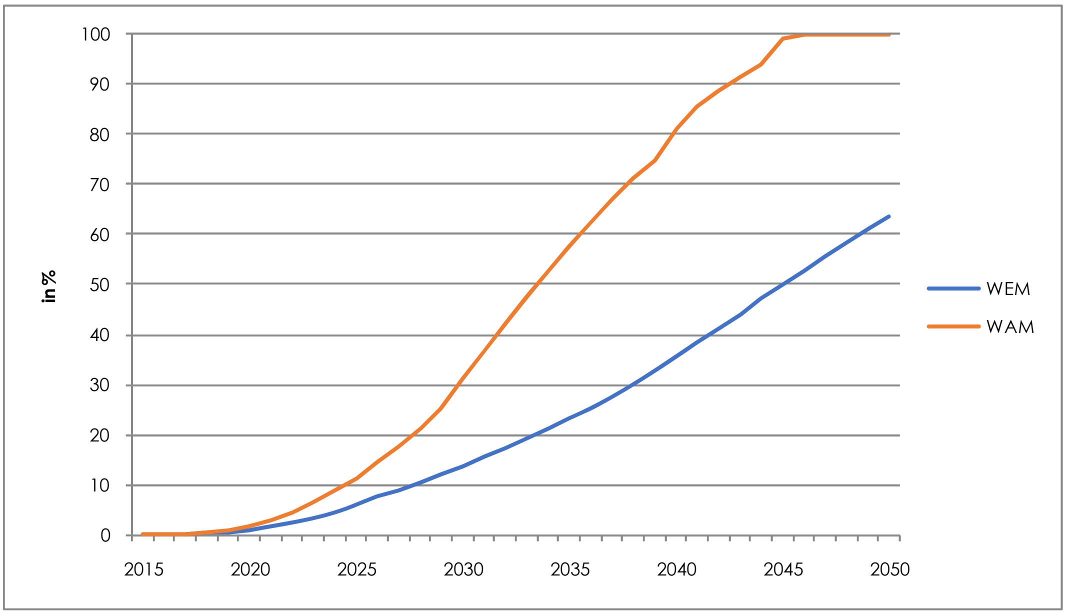


S: TU Graz.

For freight transport the measures in the WAM plus scenario result in a fuel shift to electricity, both by a shift in the modal split (higher share of rail transport) and by drives. Figure 18 shows the direct shift in drives of freight transport vehicles, compared to passenger cars. The development of light duty vehicles follows the path of passenger cars, according to the solution of the bottom-up model of the TU Graz. The electrification of high duty vehicles (including hydrogen drives) slightly falls behind.

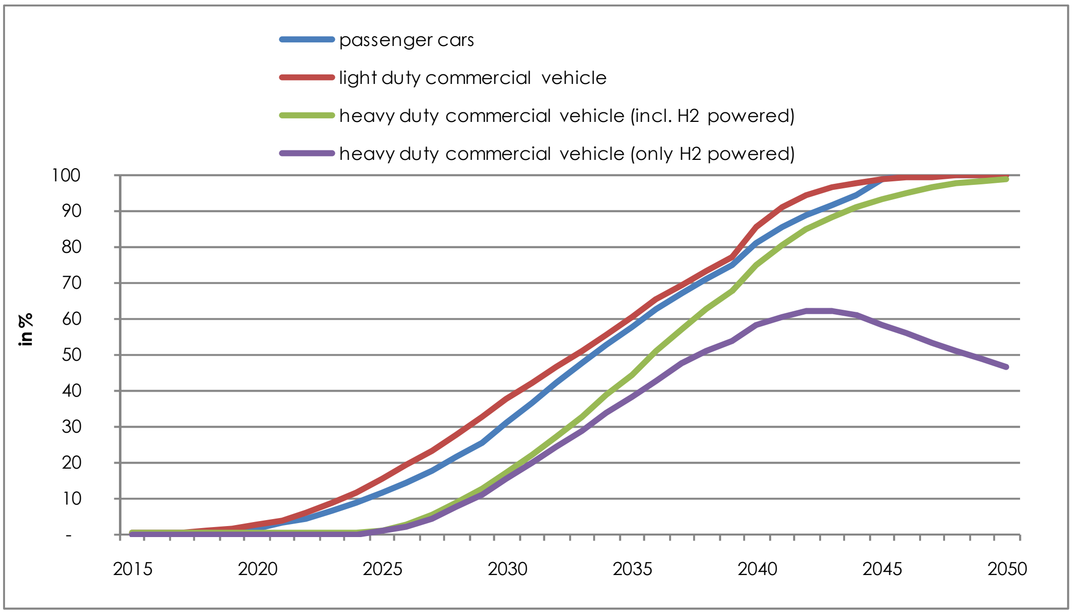
The measures in freight transport include investment for realizing the modal split shift in the electricity grid (150 million € p.a.) and other infrastructure (1,700 million € p.a.). This significant amount of investment is financed out of the investment budget of the public sector and the rail companies and therefore has no compensating financing effect somewhere else in the economy.

Figure 17: Share of electric cars in WEM and WAM plus scenario



S: TU Graz.

Figure 18: Shares of electric vehicles by passenger cars, light duty, and high duty vehicles



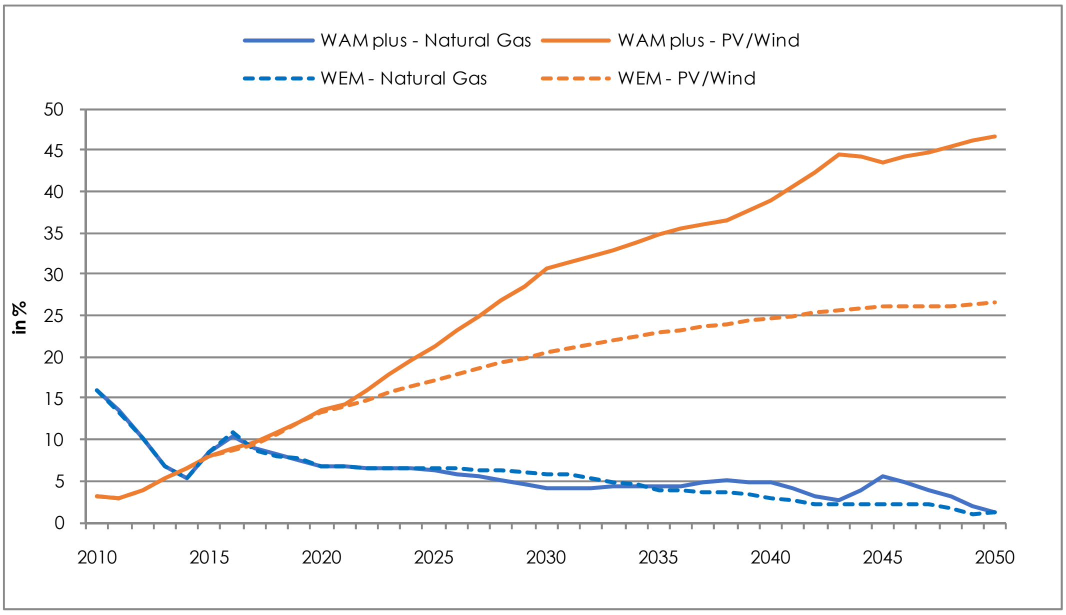
S: TU Graz.

For air transport it is assumed that 33% of air transport (in person kilometers) is shifted to the rail mode. The focus is here on limiting short distance flights, which are particularly inefficient. The energy demand for flight travel is calculated at 52 kWh/pkm and train service at 11 kWh/pkm. The assumed decline in air transportation final energy demand is compensated by shifting this transport demand to trains in the order of about 21%.

4.1.4 *Investment and fuel shift in the energy sector*

Fuel shifts from fossil fuels towards electricity in the WAM plus scenario can only exert significant decreases in GHG emissions, if structural changes in electricity and heat generation take place. For given energy prices and support measures, the potential of renewables is fully used in the WAM plus scenario. That refers especially to Wind and PV capacities and partially crowds out fossil generation, partially hydropower (in terms of shares) as well. Net imports of electricity are also completely reduced in this scenario. As described in section 2.2 above, the physical data of the electricity and heat sector are taken from the solution of the TIMES model (AEA) and consistently introduced in the DYNK model. The increase in renewable electricity generation from the TIMES model lies within the range of the results of studies about the sustainable potential of different renewable sources.

Figure 19: Fuel shares in electricity generation in the WEM and WAM plus scenario



S: AEA.

4.1.5 Investment and energy saving technical progress in manufacturing

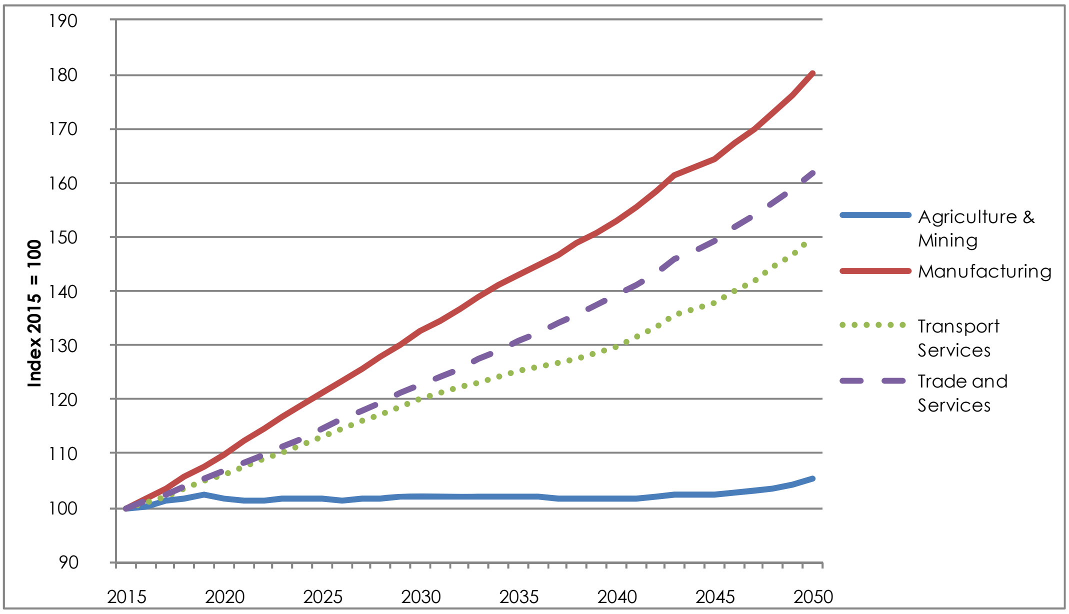
The WAM plus scenario also comprises the exhaustion of energy saving potentials in the different industry sectors. This is mainly driven by intra-industrial structural change towards new production processes, leading to different energy demand in terms of quantity as well as fuel mix. In general, the production processes are described in the DYNK model via the column (of each industry) of inputs and are divided into two nests: (i) the inputs of K, L, E, M^m and M^d in the Translog model, and (ii) the inputs by commodity in total M^m and M^d, defined by the use structure matrices. The energy input E is split up into aggregate fuels (monetary and physical units) and the 26 detailed energy carriers of the energy balance (physical units). This model structure allows for a wide range of ways to incorporate technological change from bottom-up models of an industry into the use matrix of the IO core of the DYNK model. Besides the specific changes in production processes in certain industries the potential of energy saving technological progress in cross-cutting technologies, which already takes place in the "WEM scenario", is exhausted in the WAM plus scenario. That leads to a reduction in inputs E, M^m and M^d per unit of output that is partially compensated by a higher input of K per unit of output (if investment is necessary to carry out the technological change). If no compensation in terms of a higher input in K takes place, the technological progress has the same impact as a rise in TFP and triggers income rebound effects.

Specific changes in production processes in the WAM plus scenario comprise a shut-down of refinery and coke production and – in general – a reduction in mining of oil and gas, as well as building materials. The latter is due to a higher recycling activity of building materials. Additionally, the process of direct reduction in the steel industry leads to a considerable reduction of lime input (in physical units).

4.2 Economic results of the WAM plus Scenario

The investment in building refurbishment, renewable electricity generation, and transport infrastructure represents a significant positive impulse for the Austrian economy. The same holds true for investment in energy saving equipment in manufacturing. This investment is partly financed by shifting financial resources from other investment purposes (in the case of transport) or by mobilizing investment plans that have been planned already (electricity grid). Partly the investment needs to be financed by support measures, which in part represent a negative impulse for the Austrian economy. An example for financial support measures that does not need a restrictive compensation within public budgets is a degressive depreciation allowance for energy saving investment in manufacturing. Energy saving technological progress combined with fuel shifts have an additional macroeconomic impact that is captured in the DYNK model. That refers to lower heating demand, lower energy expenditure for electric cars, etc. This cost saving effect triggers an income effect towards other commodity demand and partially for energy as well (rebound effect). In general, we observe a small positive macroeconomic (as the sum of all industries/commodities in the DYNK model) effect in the WAM plus scenario. The annual average growth rate of GDP in constant prices rises from 1.5% in the WEM scenario to 1.7% in the WAM plus scenario. Figure 20 reveals the development by the four main aggregate sectors. The most striking difference to the value added-growth of these aggregate sectors in the WEM scenario is the stagnation in the primary sector (agriculture & mining), which is due to very low demand for mining products, due to the energy and material saving technological progress in this scenario. The manufacturing sector grows significantly faster in the WAM plus than in the WEM scenario.

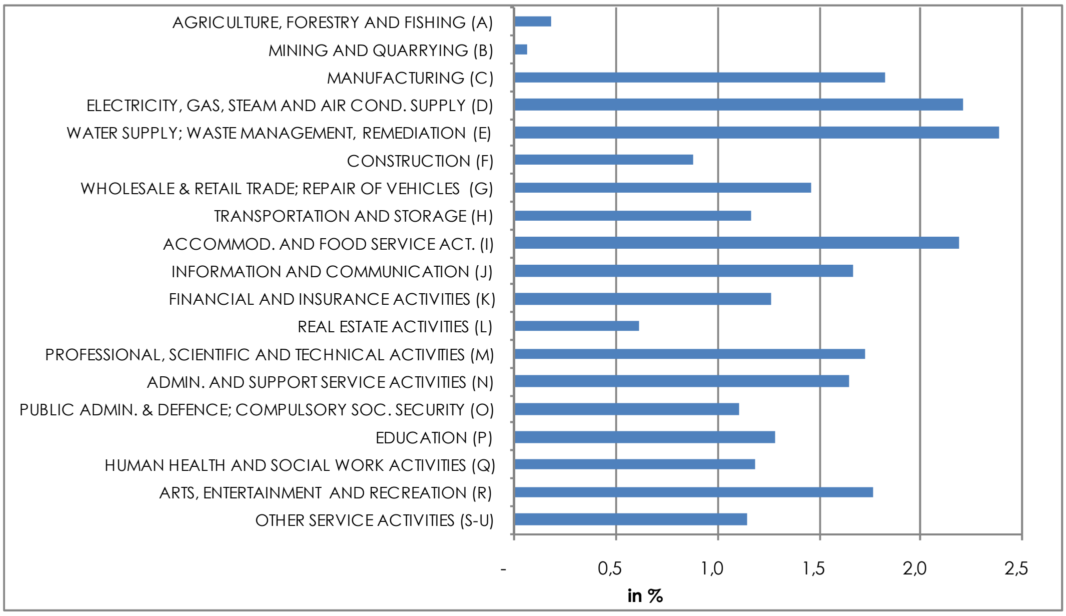
Figure 20: Value added (constant prices) in main economic sectors in the WAM plus scenario



S: own calculations.

The development by industries shows that services as well as manufacturing sectors that are linked to investment demand grow significantly more in the WAM plus scenario.

Figure 21: Growth p.a. of value added (constant prices) in selected economic sectors in the WAM plus scenario

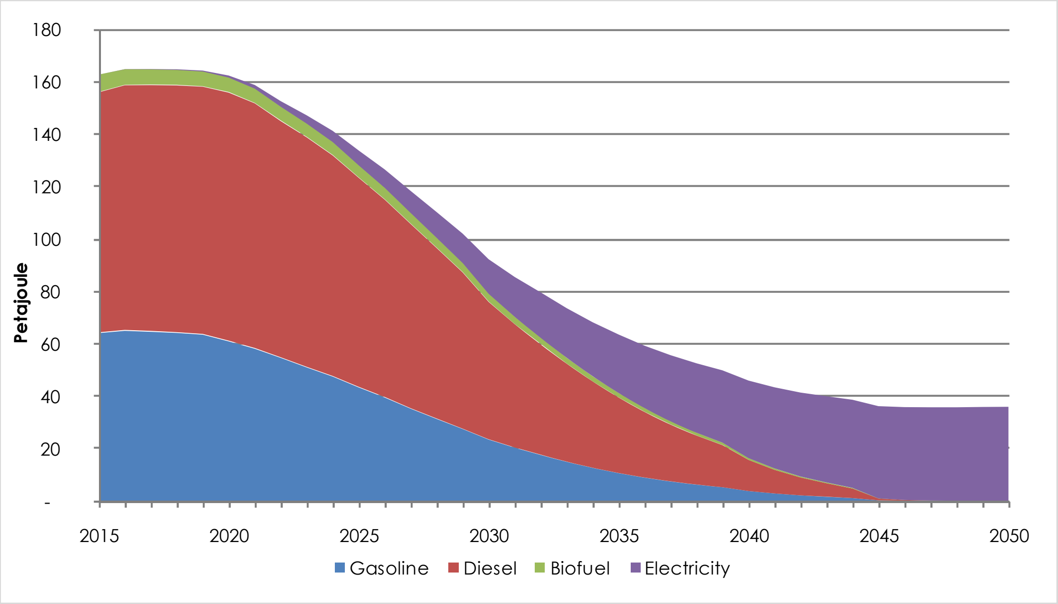


S: own calculations.

4.3 Results of the WAM plus Scenario for the energy system

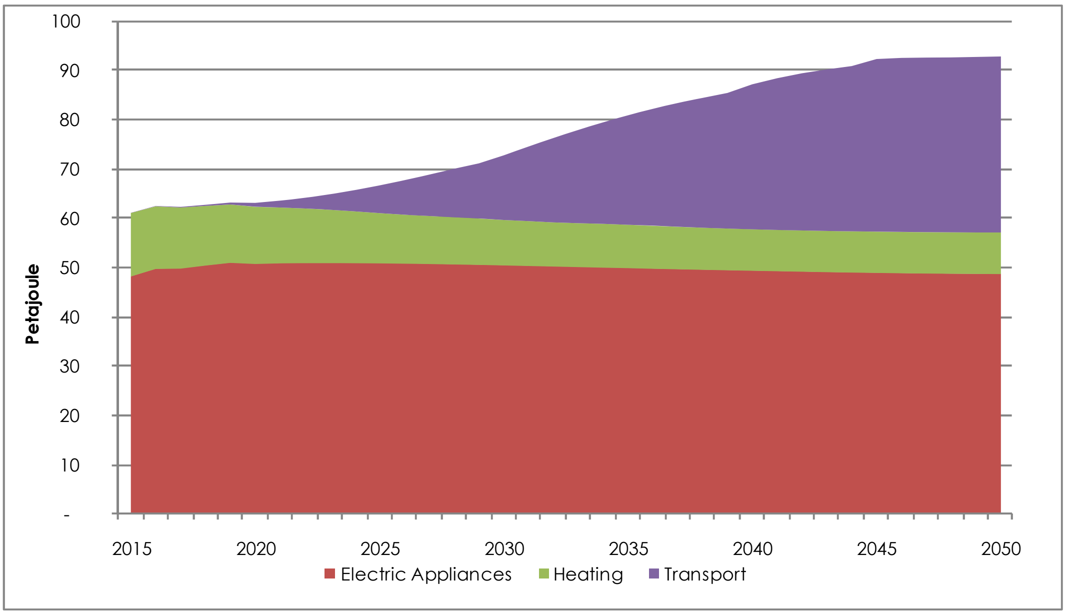
The measures in the WAM plus scenario are a combination of energy saving technological progress and fuel shifts, supported by investment. The most important fuel shift takes place in transport, from fossil fuels to electricity. In parallel also the modes of transport are shifting and mobility demand is reduced to some extent. This, together with the higher efficiency of the electric drive, leads to an overall reduction of households' demand for transport purposes (Figure 22). Nevertheless, the wedge of electricity demand in transport demand of households increases considerably. That leads to the issue of total electricity demand of households' demand. Figure 23 reveals a significant electricity demand increase of households, which is completely due to transport demand, whereas electricity for other purposes (appliances and heating) slightly decreases. As Figure 20 has shown, the renewable share rises in electricity generation, so that the additional electricity demand is met by non-fossil generation input. As electrification also takes place in freight transport, partly by modal shifts as well, the same development as for households can be observed for the overall transport sector (Figure 24).

Figure 22: Transport energy demand of private households in the WAM plus scenario



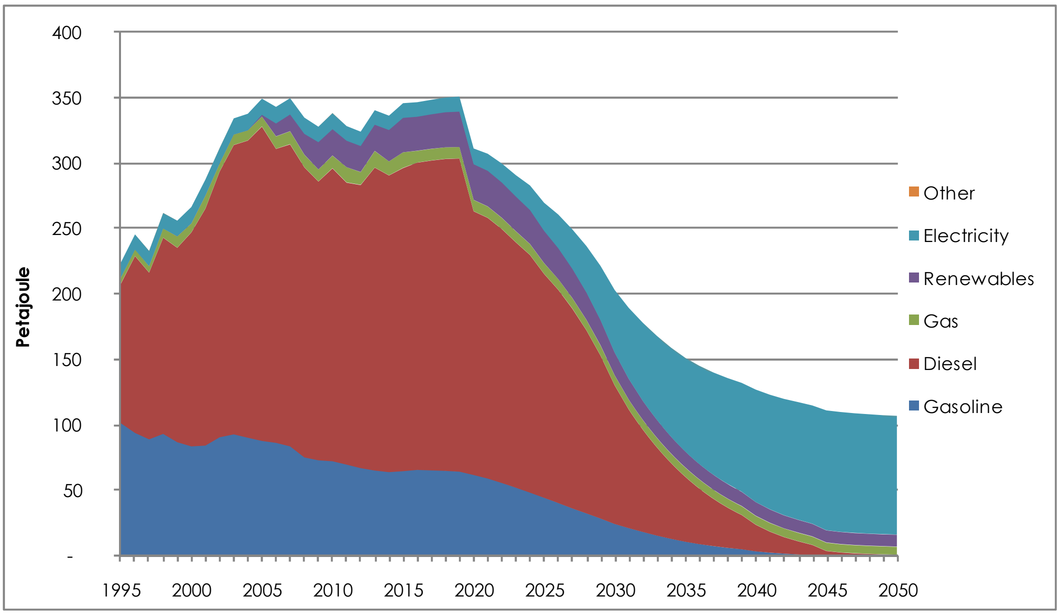
S: own calculations.

Figure 23: Electricity demand by households including cars in the WAM plus scenario



S: own calculations.

Figure 24: Total transport energy demand in the WAM plus scenario



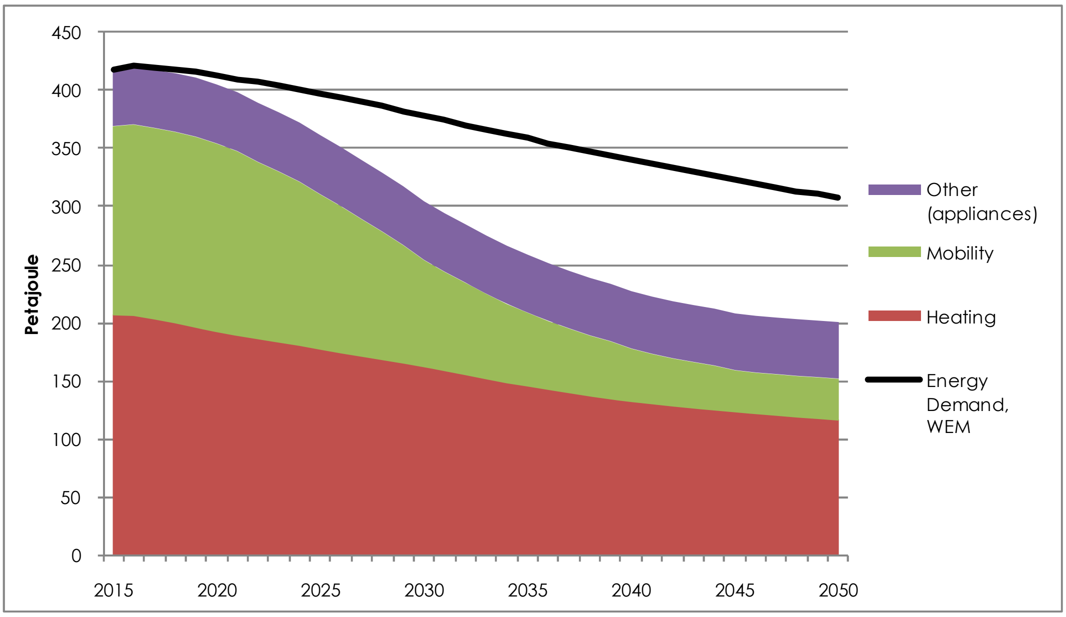
S: own calculations.

Total households' energy demand decreases exponentially and more pronounced than in the WEM scenario (Figure 25). Heating demand decreases in a linear manner in the WAM plus scenario, like total demand in the WEM scenario. The large difference between the two scenarios stems from the significant decrease of transport demand of households in the WAM plus scenario.

In the WEM scenario energy demand of the main aggregate sectors (Figure 11) stagnated. In the WAM plus scenario energy demand of these main aggregate sectors reveals a significant decline, with the most pronounced reduction in the transport sector (Figure 26). For all manufacturing sectors, output growth is higher than in the WEM scenario, whereas energy demand is significantly reduced. Absolute decoupling of energy from output therefore becomes a general and widespread characteristic in the WAM plus scenario. The aggregate picture of absolute decoupling can be obtained by simultaneously observing drivers of energy demand and effective energy demand (Figure 27). Again, the transport sector stands out by its energy demand reduction, which is partly also due to low growth of drivers of energy demand (km driven). The household sector also contributes significantly to aggregate decoupling, as income growth by 1.5% p.a. is combined with an energy consumption decrease by more than 2%.

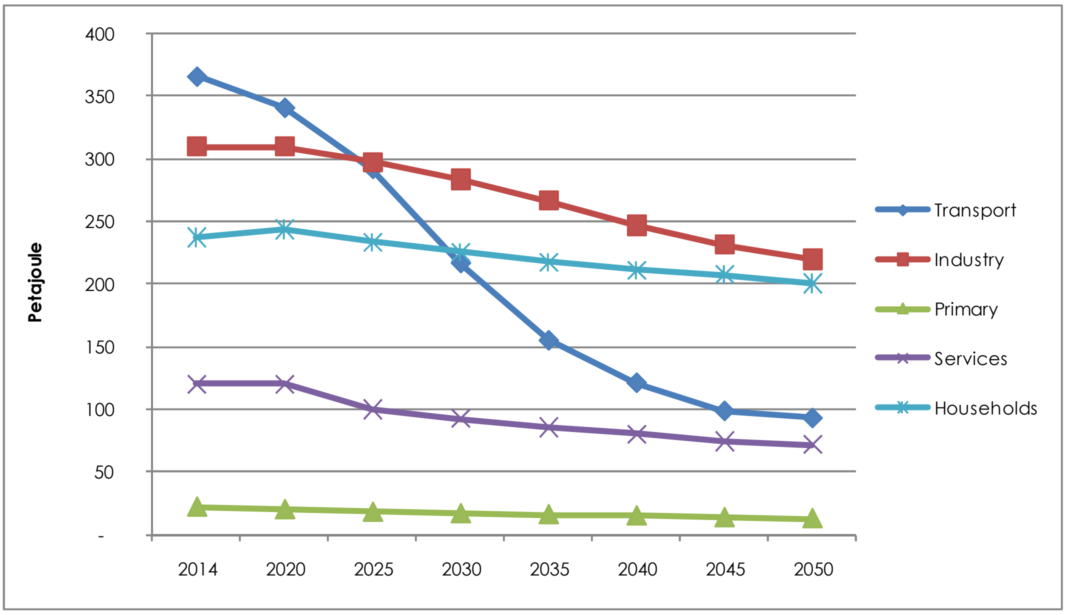
The aggregate reduction in energy intensity (per unit of GDP) is 3.4% p.a. in the WAM plus scenario.

Figure 25: Final energy demand by households including cars



S: own calculations.

Figure 26: Final energy demand of main sectors in the WAM plus scenario



S: own calculations.

Figure 27: Growth p.a. of drivers and energy demand in the WAM plus scenario

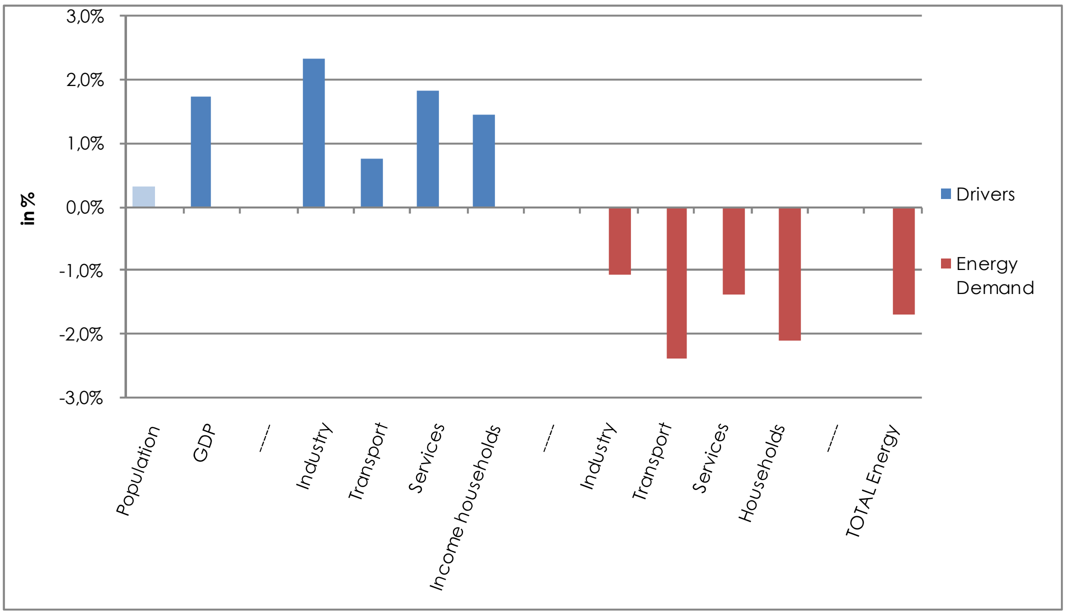


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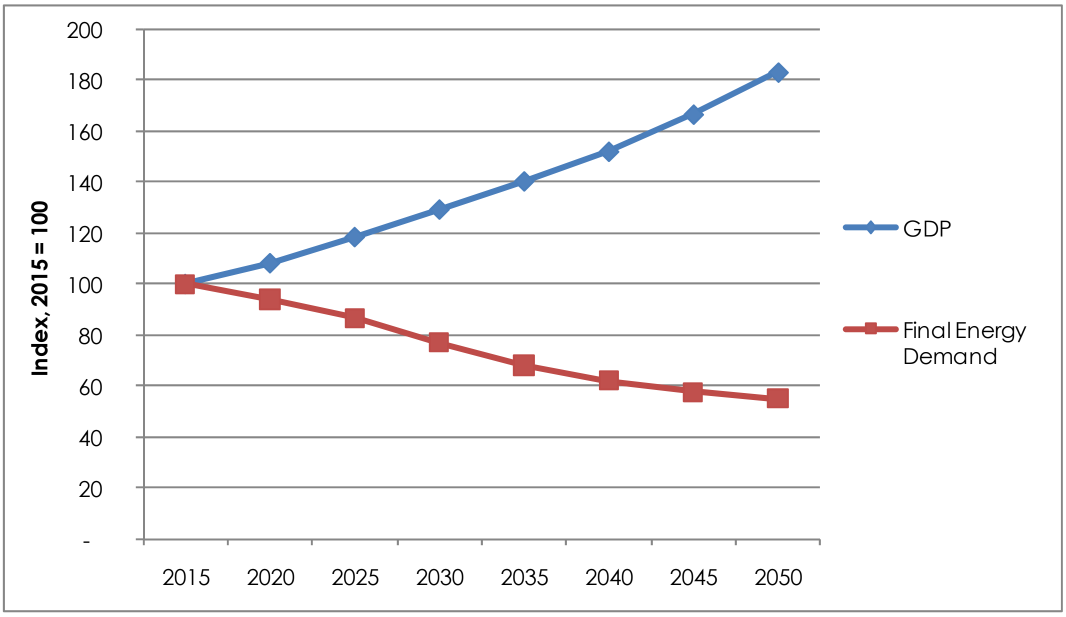
Figure 28: GDP (constant prices) and final energy demand in the WAM plus scenario



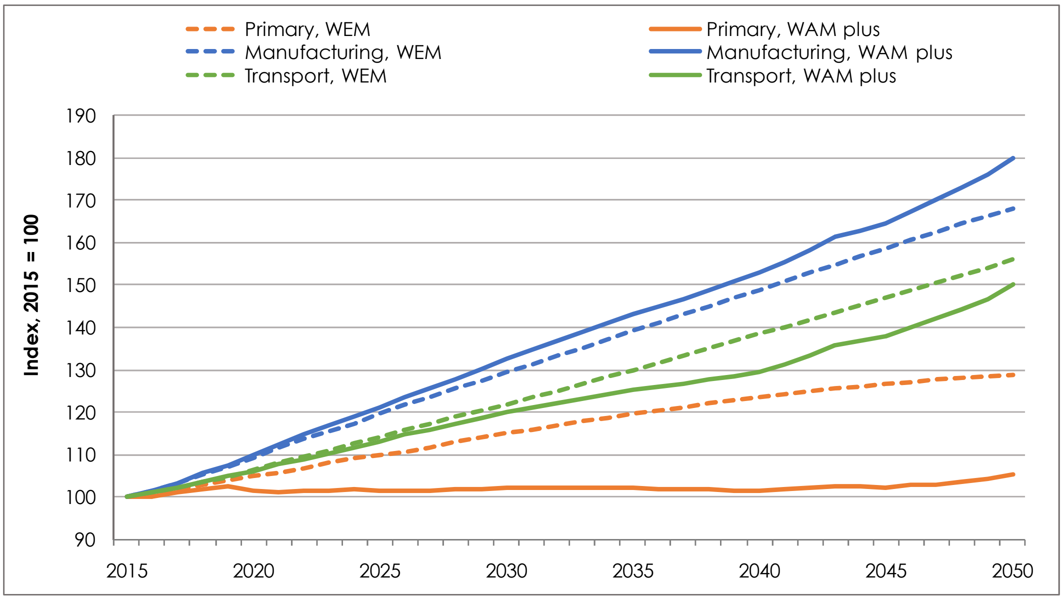
S: own calculations.

4.4 Economic impact of the WAM plus Scenario

Whereas in section 4.2 the economic results per se of the WAM plus scenario have been presented, in the following a comparison of economic results between the two scenarios (WEM and WAM plus) are presented. One can observe differences, for example by comparing the GDP lines of WEM and WAM plus in Figure 29: in the WEM scenario the index (2015 = 100) of real GDP increases until 2050 to about 170, whereas in the WAM plus scenario this value is higher than 180. The average GDP growth rate p.a. is 1.56% in the WEM scenario, and increases to 1.74% in the WAM plus scenario. For real disposable income of households, the difference is above 0.1 percentage points p.a. as well, the growth rate increases from 1.35% in the WEM scenario to 1.46% in the WAM plus scenario.

A direct comparison of value added growth in three of the four main sectors reveals that especially manufacturing is positively affected in the WAM plus scenario. Energy efficiency improvement drives productivity and price-competitiveness in this sector. The service sector (not shown in Figure 29) is positively affected as well, though less than manufacturing. The transport sector grows less due to the measures in this area in the WAM plus scenario. The decrease in energy demand and other primary resources reduces imports of these materials on the one hand. This reduced import ceteris paribus stimulates domestic value added. On the other hand lower demand of primary products also reduces the domestic output in the primary sector (Figure 29 the sum of agriculture and mining).

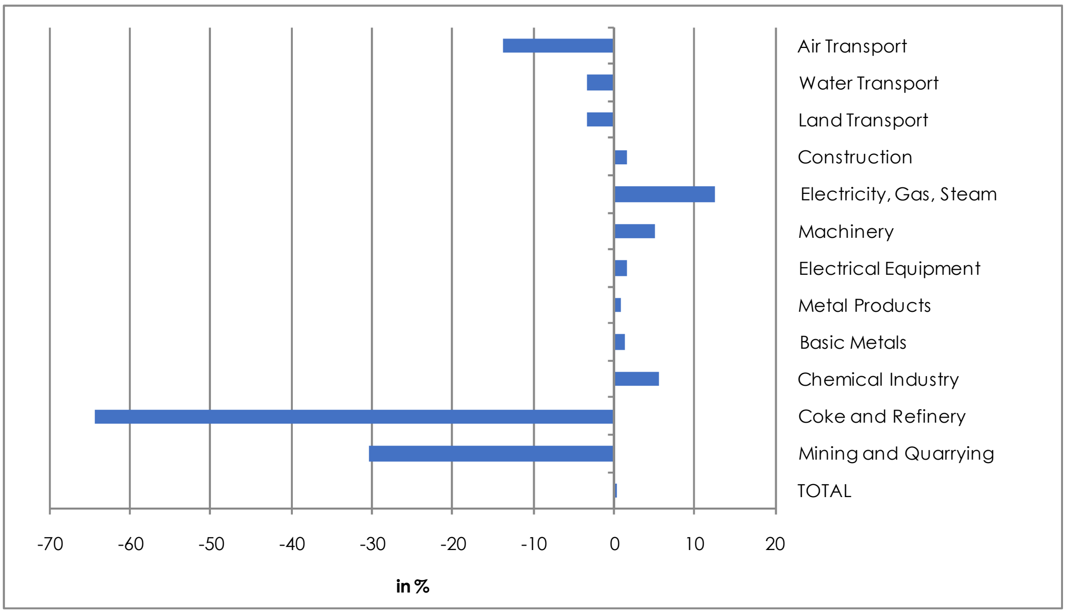
Figure 29: Value added (constant prices) in three main economic sectors in WAM plus and WEM scenarios



S: own calculations.

The positive impact on value added also leads to corresponding employment effects (Figure 30). These employment effects are very heterogenous and also reflect the reduction and shift in energy demand. The total employment impact is about 9,000 employees in 2030 (+0.2%) compared to the WEM scenario and 60,000 employees in 2050 (+1.1%). Employment in the transport sector is slightly smaller, employment in oil and coal (mining) production is significantly smaller than in the WEM scenario. Investment and energy efficiency improvements increase employment in manufacturing sectors like machinery, metal industry, electrical equipment, and construction. The shift within energy demand towards electricity increases output and employment in this sector.

Figure 30: Difference in employment level WAM plus vs. WEM scenario in 2030



S: own calculations.

The main economic mechanisms that drive these positive impacts are higher energy efficiency that works like a positive exogenous productivity shock to the economy as well as the necessary investment for the transformation of the energy system. The higher efficiency reduces the service price of using durables in the household sector, thereby also inducing a price rebound effect. In production, the higher energy efficiency (as far as it is not fully compensated by higher capital costs) leads to an improvement in price competitiveness and higher output. The cost reductions in households and in production therefore lead to income rebound effects.

These positive impulses come at a cost: higher effective energy prices due to CO_2 prices on oil, natural gas, and coal from 2025 onwards with respect to the WEM scenario. The subsidies and support schemes that are necessary for inducing the investment reduce income in the economy and restrict economic activity. In the design of the WAM plus scenario the balance is positive. It must be mentioned, though, that this is not a full analysis of instruments and their fiscal consequences on public budgets with all repercussions on income in the economy. Such a detailed analysis with emphasis on fiscal instruments and feedbacks from public budgets is still pending.

The same holds true for the analysis of distributional impacts of the underlying measures in the WAM plus scenario. Recently, Kirchner et al. (2017) have shown – applying a similar model to the one used in this study – that compensation schemes of carbon/energy taxes in the area of private transport can avoid negative impacts for low income households. The introduction in Austria of a uniform 50 €/t CO_2 tax with a VAT tax rebate reduces fuel related GHG emissions by –2.2% and has a weak inverted U-shape distributional impact on household income quintiles in Austria. Lower income groups are hit less than middle-income groups and high income groups as well.

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Annex

Table 2: Global energy prices (€/physical quantity, 2015 = 100) in the WEM scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Oil price	100	169	210	253	288	334	373	418
Gas price	100	135	160	190	222	251	280	311
Coal price	100	136	177	232	269	306	347	390

Table 3: Population Austria (in 1,000 persons) in the WEM scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Population	8.62	8.94	9.16	9.31	9.43	9.52	9.59	9.63

Table 4: Stock of private vehicles in Austria in the WEM scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Vehicles Non-Electric	4,741,503	5,044,995	4,918,409	4,441,977	3,829,288	3,191,728	2,545,772	1,952,995
Vehicles Plug-In Hybrid	1,513	16,286	143,697	413,611	659,394	705,158	562,493	386,195
Vehicles Electric	5,032	54,266	325,634	778,092	1,351,539	2,149,875	3,115,826	4,062,231

Table 5: Fuel share of private heating systems (in %) in Austria in the WEM scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Natural gas	21	21	21	21	20	19	17	16
Heating oil	17	15	12	10	8	6	5	3
Coal	0	0	0	0	0	0	0	0
Biomass	29	27	26	25	25	24	24	23
Electricity (Direct and heat pump)	9	8	8	7	7	7	8	8
District heat	17	19	21	22	23	23	23	22
Solar and ambient heat	6	8	10	13	16	19	22	26

Table 6: Global energy prices (€/physical unit, 2015 = 100) in the WAM plus scenario in the WAM plus scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Oil	100	168	208	257	342	486	598	722
Gas	100	135	159	195	257	363	449	539
Coal	100	135	176	255	354	546	675	806

Table 7: Investments in Building Sector Refurbishment (in million €) in the WAM plus scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Residential Buildings	843	1,079	1,287	1,611	1,966	1,792	1,780	1,677
Non Residential Buildings	208	317	408	612	616	531	468	362
Of Which Subsidies RB	233	183	120	66	189	311	405	487
Of Which Subsidies NRB	17	9	7	5	8	11	16	16

Table 8: Fuel share of private heating systems (in%) in Austria in the WAM plus scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Coal	1	0	0	0	0	0	0	0
Oil	18	16	14	12	8	3	2	0
Gas	21	21	21	21	19	17	15	12
Biomass	30	28	27	26	25	25	24	23
Electricity direct	8	8	7	6	5	4	4	4
Electricity, heat pump	2	2	3	3	4	5	6	7
District heating	17	18	20	22	24	25	25	25
Solar and ambient heat	5	6	9	11	15	20	24	29

Table 9: Share of electric cars (in %) in WEM and WAM plus scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Share of Electric cars WEM	0.1	1.1	6.0	13.8	23.1	35.6	50.1	63.5
Share of Electric cars WAM plus	0.1	1.7	11.4	31.1	57.7	81.1	99.0	100.0

Table 10: Share of electric vehicles (in%): passenger cars, light duty, and high duty vehicles

	2015	2020	2025	2030	2035	2040	2045	2050
passenger car	0	2	11	31	58	81	99	100
light duty commercial vehicle	0	2	15	37	60	85	99	100
heavy duty commercial vehicle (incl. H2 powered)	0	0	1	17	44	75	93	99
heavy duty commercial vehicle (only H2 powered)	0	0	1	15	38	58	58	46

Table 11: Fuel shares (in %) in electricity generation

	2020	2025	2030	2035	2040	2045	2050
Gas, WEM	10.1	9.8	8.7	6.1	5.3	4.0	2.1
Gas, WAM plus	8.9	7.1	5.2	2.1	1.9	1.3	0.5
Wind/PV, WEM	11.6	15.3	18.8	22.0	25.2	28.4	30.9
Wind/PV, WAM plus	15.5	22.1	27.8	33.2	37.7	42.1	46.1

Table 12: Growth of value added (constant prices, 2015 = 100) in main economic sectors in the WEM scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture & Mining	100	105	110	115	120	124	127	129
Manufacturing	100	109	120	129	139	149	159	168
Transport Services	100	106	114	122	130	138	147	156
Trade and Services	100	107	114	122	130	139	149	159

Table 13: Growth of value added (constant prices, in %) in selected economic sectors in the WEM scenario

AGRICULTURE, FORESTRY AND FISHING(A)	0,2
MINING AND QUARRYING(B)	0,1
MANUFACTURING(C)	1,8
ELECTR., GAS, STEAM AND AIR COND. SUPPLY(D)	2,2
WATER SUP.; SEWERAGE, WASTE MAN. & REMED. ACTIVITIES (E)	2,4
CONSTRUCTION(F)	0,9
WHOLESALE & RETAIL TRADE; REPAIR OF MOTOR VEHICLES (G)	1,5
TRANSPORTATION AND STORAGE(H)	1,2
ACCOMMODATION AND FOOD SERVICE ACTIVITIES(I)	2,2
INFORMATION AND COMMUNICATION(J)	1,7
FINANCIAL AND INSURANCE ACTIVITIES(K)	1,3
REAL ESTATE ACTIVITIES(L)	0,6
PROF., SCIENTIFIC AND TECHN. ACTIVITIES(M)	1,7
ADMIN. AND SUPPORT SERVICE ACTIVITIES(N)	1,6
PUBLIC ADMIN. & DEFENCE; COMP. SOC. SECURITY(O)	1,1
EDUCATION(P)	1,3
HUMAN HEALTH AND SOCIAL WORK ACTIVITIES(Q)	1,2
ARTS, ENTERTAINMENT AND RECREATION(R)	1,8
OTHER SERVICE ACTIVITIES(S-U)	1,1

Table 14: Growth of value added (constant prices, 2015 = 100) in main economic sectors in the WAM plus scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture & Mining	100	102	102	102	102	102	102	105
Manufacturing	100	110	121	133	143	153	164	180
Transport Services	100	106	113	120	125	130	138	150
Trade and Services	100	107	115	123	131	139	149	162

Table 15: Growth of value added (constant prices, in %) in selected economic sectors in the WAM plus scenario

AGRICULTURE, FORESTRY AND FISHING(A)	0.2
MINING AND QUARRYING(B)	0.1
MANUFACTURING(C)	1.8
ELECTR., GAS, STEAM AND AIR COND. SUPPLY(D)	2.2
WATER SUP.; SEWERAGE, WASTE MAN. & REMED. ACTIVITIES (E)	2.4
CONSTRUCTION(F)	0.9
WHOLESALE & RETAIL TRADE; REPAIR OF MOTOR VEHICLES (G)	1.5
TRANSPORTATION AND STORAGE(H)	1.2
ACCOMMODATION AND FOOD SERVICE ACTIVITIES(I)	2.2
INFORMATION AND COMMUNICATION(J)	1.7
FINANCIAL AND INSURANCE ACTIVITIES(K)	1.3
REAL ESTATE ACTIVITIES(L)	0.6
PROF., SCIENTIFIC AND TECHN. ACTIVITIES(M)	1.7
ADMIN. AND SUPPORT SERVICE ACTIVITIES(N)	1.6
PUBLIC ADMIN. & DEFENCE; COMP. SOC. SECURITY(O)	1.1
EDUCATION(P)	1.3
HUMAN HEALTH AND SOCIAL WORK ACTIVITIES(Q)	1.2
ARTS, ENTERTAINMENT AND RECREATION(R)	1.8
OTHER SERVICE ACTIVITIES(S-U)	1.1

Table 16: Growth of value added (constant prices, 2015 = 100) in three main economic sectors: difference of WAM plus scenario to WEM scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Primary, WEM	100	105	110	115	120	124	127	129
Primary, WAM plus	100	102	102	102	102	102	102	105
Manufacturing, WEM	100	109	120	129	139	149	159	168
Manufacturing, WAM plus	100	110	121	133	143	153	164	180
Transport, WEM	100	106	114	122	130	138	147	156
Transport, WAM plus	100	106	113	120	125	130	138	150

Table 17: Growth of employment in selected sectors (in %): difference of WAM plus scenario to WEM scenario

TOTAL	0.19
Mining and Quarrying	–30.29
Coke and Refinery	–64.36
Chemical Industry	5.62
Basic Metals	1.29
Metal Products	0.97
Electrical Equipment	1.50
Machinery	5.04
Electricity, Gas, Steam	12.44
Construction	1.68
Land Transport	–3.31
Water Transport	–3.32
Air Transport	–13.85