# Zukunftsfähige Energienutzung in Österreich

## Beiträge über die Transformation zu einem nachhaltigen Energiesystem

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## Dankeschön!

Ein wissenschaftliches Werk entsteht nie in Alleinarbeit, und deswegen möchte ich meinen großen Dank all jenen aussprechen, die mich bei der Erstellung der Dissertation unterstützt haben. Ganz herzlich möchte ich meiner Betreuerin Sigrid Stagl für die Begleitung und Unterstützung über all die Jahre, die zum Abschluss dieser Arbeit geführt haben, danken. Besonders ihre motivierenden Worte und die zahlreiche Tipps über wissenschaftliches Publizieren haben zum Gelingen der Arbeit beigetragen. Meinem zweitem Betreuer Michael Getzner möchte ich meine große Dankbarkeit für die konstruktive Kritik und Zusammenarbeit aussprechen. Mein aufrichtiger Dank gilt dem Leiter des Instituts für Technikfolgenabschätzung (ITA) Michael Nentwich für seine Unterstützung, ohne die diese Arbeit nie zustande gekommen wäre. Weiters möchte ich allen KollegInnen des ITA für ihre zahlreichen Anregungen und wissenschaftlichen Hinweise danken. Insbesondere Michael Ornetzeder danke ich für die zielführenden Diskussionen und für die Unterstützung mit seinem fundierten Fachwissen. Besonders herzlichen Dank möchte ich Uwe Schubert aussprechen, der mir erst das Feld der Ökologischen Ökonomik eröffnet und mein fortlaufendes Interesse dafür geweckt hat. Vielen lieben Dank an Alexandra Rauter, die meine Texte mit größter Sorgfalt ins korrekte Englisch gebracht hat. Myrtill Simkó möchte ich meine Dankbarkeit für all die Gespräche über den Wissenschaftsbetrieb und über die zehntausend Kleinigkeiten, die es dabei zu wissen gilt, für die sehr hilfreichen Anregungen sowie ganz besonders für die vielen Ermutigungen ausdrücken, ohne die diese Arbeit noch nicht vorliegen würde. Julia Edthofer gebührt Dank für wichtige fachliche Ratschläge und für ihre Geduld im alltäglichen Zusammenleben. Meinen Eltern Ingrid und Hans Wächter danke ich für die liebevolle Unterstützung und den Rückhalt, den sie mir immer in allen Lebenslagen geben. Meiner Schwester Natalia Wächter möchte ich für ihre Motivation, ihre fachliche Hilfe und ihr großes Verständnis für mich danken. Meinem Partner Werner Kabelka danke ich für sein inhaltliches Interesse und die zahlreichen Stunden des technischen Supports sowie für die unendliche Geduld dabei mit mir und noch für vieles mehr.

# Kurzfassung


Klimawandel und Energiekrise sind zwei Schlagworte, die den umwelt- und gesellschaftspolitischen Diskurs dominieren. Das heutige Energiesystem basiert auf dem Verbrennen fossiler Energieträger, wobei große Mengen an Kohlendioxid ($CO_2$) emittiert werden, die in Folge durch den Treibhauseffekt weitreichende Klimaveränderungen hervorrufen. Österreich bewegt sich wie viele andere Industriestaaten bei der Nutzung fossiler Brennstoffe auf einem Niveau fernab von den Zielen der Nachhaltigkeit. Obwohl in der Energieproduktion der Anteil erneuerbarer Energieressourcen laufend steigt und Energieeffizienzmaßnahmen in allen Wirtschaftssektoren vermehrt zum Einsatz kommen, reichen die jetzigen Bemühungen nicht aus, um das österreichische Energiesystem auf einen klimafreundlichen Pfad zu bringen.

Vor diesem Hintergrund werden in drei Artikeln Teilaspekte des österreichischen Energiesystems in Hinblick auf ihren Beitrag zu einer nachhaltigen Gestaltung des Energiesystems untersucht. In der ersten Publikation werden in den vier Sektoren Haushalte, Dienstleistungen, Verkehr und Energie Energieeffizienzmaßnahmen und deren Potenzial zur Vermeidung von Treibhausgasen analysiert. Dabei werden die Kosten einer Maßnahme mit deren $CO_2$-Vermeidungspotenzial gegenübergestellt und so die dementsprechende $CO_2$-Vermeidungskostenkurve erstellt. Die Ergebnisse zeigen ein großes, ungenutztes und rentables Potenzial der $CO_2$-Vermeidungsmöglichkeiten und in Folge werden einige Überlegungen angestellt, warum diese Maßnahmen (noch) nicht umgesetzt wurden. Im zweiten Artikel wird als Beispiel für eine institutionelle Veränderung, die zur Umsetzung eines nachhaltigen Energiesystems notwendig ist, die Rolle der Raumplanung diskutiert. Schon heute zeigt sich bei Themen wie der Nutzung erneuerbarer Energieträger oder nachhaltigen Siedlungsstrukturen, dass Raumplanungsinstitutionen wichtige Weichen für ein nachhaltiges Energiesystem und auch für alternative Wirtschaftsformen stellen können. In der dritten Arbeit wird der konkreten Frage nachgegangen, in welchen Teilbereichen der Energie- und Raumplanung Änderungen stattfinden müssen, damit das österreichische Energiesystem im Jahre 2050 als nachhaltig bezeichnet werden kann. Durch einen Backcasting-Prozess werden wichtige Faktoren identifiziert, die als notwendige Schritte im Transformationsprozess des Energiesystems gelten. Die Ergebnisse aller drei Arbeiten zeigen, dass es noch viele ungenutzte Potenziale sowohl beim Einsatz von erneuerbaren Energieträgern und bei Energieeffizienzmaßnahmen wie auch bei politischen und institutionellen Veränderungen gibt.

# Abstract

Climate change and energy crisis are two of the catchwords that dominate the environmental policy discourse. The current energy system is based on the burning of fossil energy resources that emit enormous amounts of carbon dioxide ($CO_2$) which in turn generates climatic changes by the greenhouse effect. In Austria, the use of fossil energy resources has exceeded the limits of sustainability. Although the share of renewable energy resources in energy production increases steadily and energy efficiency improvements are visible in all economic sectors current efforts are not enough to shape the energy system towards sustainability.

Starting from that background, critical issues in the transformation of the Austrian energy system are discussed in three articles. The first one analyzes energy efficiency measures in the four economic sectors households, services, transport and energy and its potential to reduce greenhouse gas emissions on a national level. The costs of the measures are contrasted with its $CO_2$ abatement potential and are presented in the according marginal abatement cost curve. The results shed light to the existing unused $CO_2$ abatement potential and some of the reasons are discussed why these measures are not implemented immediately. In the second contribution, spatial planning institutions as an example for an institutional change within the energy system are discussed and analyzed. Spatial planning institutions have the potential to set the course for a sustainable energy system and alternative economic systems because current economic structures are considered as one of the main drivers for increasing energy demand. The third article deals with the question which issues of energy and spatial planning dimension are essential to reach a sustainable stadium in the Austrian energy system in 2050. By using the method of backcasting, some factors are identified which have a leverage effect to transform the energy system. The results of all three articles show that there exists unused potential in the use of renewable energy resources and energy efficiency measures on the one hand and on the other by fostering institutional and political changes.

# 1. Einführung in die Thematik

## 1.1 Klima und Energie – Die Energiekrise in Österreich

Klimawandel, Verlust von Biodiversität oder steigender Ressourcenverbrauch sind nur einige der Schlagworte, mit denen seit Jahrzehnten wachsende ökologische Probleme bezeichnet werden. Schon seit den 1970er Jahren wird in verstärktem Maße auf stetig anwachsende Umweltprobleme hingewiesen (Meadows et al., 1972), was auch den Anlass zur Gründung verschiedenster Institutionen wie den Umwelt-Konferenzen der Vereinten Nationen (1. Konferenz 1972 in Stockholm) oder ihrem Umweltprogramm (UNEP) im gleichen Jahr gab. Die Beauftragung der Vereinten Nationen zur Bildung der Weltkommission für Umwelt und Entwicklung 1983 führte zur Veröffentlichung des „Brundtland Reports" im Jahr 1987, der als Beginn der öffentlichen Diskussion über Nachhaltige Entwicklung gilt (Erlemann und Arnold, 2012). Während in den 1980er Jahren noch Themen wie Waldsterben oder saurer Regen im Fokus standen bzw. sogar schon als gelöst galten, verlagerte sich der umweltpolitische Diskurs in Richtung Klimawandel und dessen anthropogene Ursachen.

Einer der Hauptgründe für die zahlreichen Veränderungen des Klimas ist das Verbrennen fossiler Rohstoffe (IPCC, 2013). Bei diesen Verbrennungsvorgängen wird eine hohe Menge an Kohlendioxid ($CO_2$) freigesetzt, wobei die erhöhte $CO_2$-Konzentration in der Atmosphäre den sogenannten Treibhauseffekt erzeugt. In Folge kommt es zu einer globalen Temperaturerhöhung, die den Wandel des Weltklimas mitbewirkt (Crowley, 2000). Die Auswirkungen des Klimawandels sind u.a. das Abschmelzen der polaren und montanen Gletscher, das Ansteigen der Meeresspiegel, Auftauen der Permafrostböden, was in Folge zu einer Freisetzung von Milliarden Tonnen der klimaschädigenden Treibhausgase Methan und Kohlendioxid führt, erhöhte Luftfeuchtigkeit, welche wiederum die Wahrscheinlichkeit auf sintflutartige Niederschläge mit Auswirkungen wie Hochwasser oder Murenabgänge erhöht, vermehrte Trocken- und Dürreperioden in Gebieten der Sahara und Sub-Sahara und generell eine höhere Wahrscheinlichkeit extremer Wetterereignisse (IPCC, 2007). Diese veränderten Lebensbedingungen im Ökosystem Erde bringt für die BewohnerInnen zahlreiche Probleme mit sich: Landflucht aufgrund überschwemmter oder zu trockener

Gebiete, erhöhte Gesundheitsgefährdung durch höhere Temperaturen und neue Krankheiten, Wassermangel sowie Gefährdung der Ernährungssicherheit (IPCC, 2007).

Obwohl sich weltweit institutionelle und gesellschaftliche Akteure schon seit Jahrzehnten der rasch ansteigenden Umweltprobleme bewusst sind, sind die Maßnahmen zu deren Lösungen nicht weitreichend genug, um tatsächlich eine Trendumkehr zu einem umweltfreundlicheren Umgang mit Ressourcen zu erreichen. Noch immer steigt der weltweite absolute Verbrauch an fossilen Energieträgern, die globalen Durchschnittstemperaturen werden höher und extreme Wetterereignisse nehmen zu (IEA, 2013; IPCC, 2013). Nur langsam erhebt sich zumindest in industrialisierten Staaten das Bewusstsein, die Nachfrage nach fossilen Energieträgern zu verringern, erneuerbare Energieressourcen zu verwenden und generell weniger Energie zu verbrauchen.

Auch in Österreich stellt die zu große Energienachfrage besonders nach fossilen Energieträgern ein kaum gelöstes Problem dar. Der Bruttoinlandsverbrauch an Energie hat sich im Zeitraum 1970-2011 nahezu verdoppelt, der Verbrauch im Transportsektor sogar mehr als verdreifacht (Statistik Austria, 2013). Das Klimaziel, zu dem sich Österreich im Kyoto-Protokoll verpflichtet hat, besagt, dass die Treibhausgas-Emissionen (THG-Emissionen) bis 2012 um 13% unter das Niveau von 1990 sinken sollen, das entspricht 68,8 Mio. t $CO_2$-Äquivalente (UNFCCC, 1998). Die Emissionen 2011 betrugen jedoch 82,8 Mio. t $CO_2$-Äquivalente, wobei Schätzungen von einem ähnlichen Wert für 2012 ausgehen (Umweltbundesamt, 2013). Das bedeutet, dass sich eine Steigerung der Emissionen um 4,7% gegenüber dem Basisjahr 1990 und eine Verfehlung des Kyoto-Ziels um insgesamt 17,7% bzw. 14 Mio. t $CO_2$-Äquivalente ergibt (Umweltbundesamt, 2013). Wenn jedoch langfristige schwerwiegende Auswirkungen des Klimawandels vermieden werden sollen, müssen die THG-Emissionen noch weiter reduziert werden: Wie auch der jüngste Bericht des Weltklimarats (IPCC, 2013) betont, muss in den entwickelten Industriestaaten der Pro-Kopf-THG-Emissionsausstoß bis 2050 um 80-95% reduziert werden, um die Steigerung der globalen Durchschnittstemperatur auf 2°C verglichen mit der präindustriellen Durchschnittstemperatur zu beschränken. Es zeigt sich, dass trotz Bemühungen seitens der Politik es noch nicht mit ausreichendem Erfolg gelungen ist, das österreichische Energiesystem auf einen klimafreundlicheren Weg zu bringen. Die Gründe sind beispielsweise im Versagen von marktbasierten Instrumenten wie dem europäischen Emissionshandel zu suchen oder auch im Verhalten von Menschen, wenn durch Rebound-Effekte Energieeinsparungen geschmälert werden.

Dennoch konnten in Teilbereichen auch Erfolge verzeichnet werden: steigender Anteil von erneuerbaren Energieträgern bei der Energieerzeugung (Statistik Austria, 2013), stetig wachsende Zahl an Klimagemeinden, Best-Practice Beispiele stromautarker Regionen wie beispielsweise das Burgenland (Klimabündnis, 2013) oder Österreichs Vorreiterrolle im internationalen Vergleich bei der Anzahl von Passivhäusern. Dazu kommen zahlreiche Verbesserungen im Bereich der Energieeffizienz in den Sektoren Haushalte, Dienstleistungen und Industrie (Schrattenecker et al., 2008), bewusstseinsfördernde Maßnahmen seitens der Politik und zahlreiche BürgerInneninitiativen, die sich mit Fragen der nachhaltigen Energieerzeugung und des -verbrauchs auseinandersetzen (Schreuer, 2010). Trotz dieser positiven Entwicklungen zeigen die Daten zu Energieverbrauch und THG-Emissionen, dass es wohl tiefgreifendere Veränderungen braucht, um das österreichische Energiesystem nachhaltiger zu gestalten.

## 1.2 Maßnahmen zur $CO_2$-Vermeidung in Österreich

Ganz allgemein gesprochen lässt sich der Ausstoß von klimaschädigenden Treibhausgasen auf zwei Weisen vermindern: einerseits kann der Energieverbrauch durch Energieeffizienzmaßnahmen reduziert werden und andererseits können durch das Ersetzen fossiler Energieträger durch erneuerbare die THG-Emissionen verringert werden. Um allerdings quantitative Aussagen über die Vermeidung von THG-Emissionen treffen zu können, muss auf Schätzungen zurückgegriffen werden. Das Potenzial erneuerbarer Energieressourcen wurde für Österreich schon in einer Vielzahl von Studien untersucht (Biermayr et al., 2013; Biomasseverband, 2009; BMLFUW, 2009; Faninger, 2006; Haas et al., 2006; Neubarth und Kaltschmitt, 2000; Clement et al., 1998). Für einzelne Energieträger und ihren Verwendungsmöglichkeiten gibt es detaillierte Schätzungen über deren Potenzial und Roadmaps über ihre Verbreitung unter Berücksichtigung der Kosten, z.B. Solarenergie (Faninger, 2010; Biermayr et al., 2009*;* Fechner und Lugmaier, 2007*)*, Biomasse (Kletzan et al., 2008; Kranzl et al., 2008; Jauschnegg, 2007; Brainbows, 2007; Biomasseverband 2006), Wind (Krenn et al., 2010; Regio Energy, 2008; Hantsch und Moidl, 2007) sowie Wärmepumpen und Geothermie (Haas et al., 2009; Faninger, 2007). Für Maßnahmen im Bereich der Energieeffizienz werden die größten Potenziale im Bereich der thermischen Gebäudesanierung und der Neubauten durch Niedrigenergie- und Passivhausstandard, im Bereich Haushalte durch energieeffiziente Haushaltsgeräte, im Bereich

Transportwesen durch erhöhte Energieeffizienz und Ausbau des öffentlichen Verkehrs und allgemein höhere Energieeffizienz beim Einsatz fossiler Energieträger gesehen.

Obwohl das Wissen um energieeffiziente Maßnahmen vorhanden ist, werden diese zu wenig umgesetzt und ihr Potenzial ausgeschöpft. Dieses Phänomen wird als Energieeffizienz-Lücke bezeichnet und bezieht sich auf die Lücke zwischen beobachtetem Level von Energieeffizienz und dem erwünschten „optimalen“ Niveau (Gillingham et al., 2009), je nachdem, ob das theoretische, technisch mögliche oder wirtschaftliche Potenzial betrachtet wird. Wenn nun auch gesamtwirtschaftliche Kosten anhand negativer externer Effekte in das Optimalitätsniveau inkludiert werden, bedeutet dies, dass sich das wirtschaftliche Potenzial noch weiter vergrößert (Dobroschke, 2012). Es erhebt sich die Frage, warum das Energieeffizienz-Potenzial ungenutzt bleibt und welche Hindernisse es dafür gibt. Verschiedene ökonomische Ansätze wie orthodoxe Ökonomik, Prinzipal-AgentInnen-Theorie, Informationsökonomik, Transaktionskosten-Ökonomik oder Verhaltensökonomik liefern zwar diverse Erklärungen, stimmen allerdings in der Benennung der Hauptgründe für den „energy efficiency-gap“ überein: Risiko, unvollkommene Information, versteckte Kosten, Zugang zu Kapital, „split incentives“ und „bounded rationality“ (Sorrell et al., 2004). Tatsächlich weisen aber unterschiedliche Bereiche einen Mix aus den genannten Hindernissen auf, wobei Bewusstsein und Information, Zugang zu Kapital und die Verfügbarkeit von Gütern und Dienstleistungen am meisten beobachtet wurden (Granade et al., 2009).

Eine Möglichkeit, um durch das Adressieren von Energieeffizienzmaßnahmen auch zu erhöhtem Bewusstsein und Information beizutragen, stellen marginale $CO_2$-Vermeidungskostenkurven (marginal abatement cost curve – MACC) dar (Beaumont und Tinch, 2004). Eine der Stärken von statischen MACCs ist, dass auf einen Blick das Verhältnis von $CO_2$-Vermeidung und den Kosten für Maßnahmen, die entweder zu mehr Energieeffizienz beitragen oder die Verwendung von erneuerbaren Energieträgern beinhalten, erkennbar ist. Auf der y-Achse werden die Kosten des vermiedenen $CO_2$s dargestellt und auf der x-Achse die letzte Einheit der THG-Vermeidung für die verschiedenen Mengen von Emissionsreduktionen der einzelnen Maßnahmen. Diese sind entsprechend der Vermeidungskosten gereiht: Die Vermeidungskostenkurve zeigt die erste Tonne vermiedener $CO_2$-Äquivalente, die mit den geringsten Kosten vermieden werden kann bis hin zu jener Tonne mit den höchsten Kosten. Ein Wert im negativen Bereich bedeutet, dass die Energieeinsparungen höher als die Investitionskosten für die Maßnahme sind, ein positiver Wert zeugt vom Gegenteil. Ein negativer Wert bezeichnet also eine vorteilhafte Situation, bei der mithilfe der neuen

Maßnahme im Vergleich mit der alten weniger Emissionen erzeugt werden und bei der sogar aufgrund der niedrigen Energiekosten Geld eingespart werden kann. Bei Maßnahmen mit einem positiven Wert werden zwar weniger THG emittiert, aber aufgrund der hohen Investitionskosten sind die Maßnahmen teurer als jene, die ersetzt wurden.

Für Österreich wurde erstmals eine marginale $CO_2$-Vermeidungskostenkurve erstellt, indem in den Sektoren Haushalte, Dienstleistungen, Verkehr und Energie nach Maßnahmen betreffend Energieeffizienz und erneuerbaren Energieträgern gesucht wurde (Wächter, 2013a). Die einzelnen Maßnahmen konnten ohne Überschneidungen des Potenzials zu Maßnahmenpaketen zusammengefasst werden und resultieren in insgesamt 14 Gesamtmaßnahmen. Das theoretisch mögliche Potenzial der Einzelmaßnahmen wurde auf nationales Niveau aggregiert. Die Ergebnisse zeigen das enorme, ungenutzte Potenzial zur Vermeidung von klimaschädigenden Treibhausgasen: insgesamt könnten 45,4 Mio. t $CO_2$-Äquivalente eingespart werden, ein Wert, der mehr als die Hälfte der momentanen Emissionen darstellt. Von diesen könnten 18,5 Mio. t $CO_2$-Äquivalente ($CO_2$-e) sogar mit negativen Kosten vermieden werden, womit Österreich schon allein damit das Kyoto-Ziel übererfüllt hätte.

Im Haushaltssektor wurden Einzelmaßnahmen in den Bereichen thermische Gebäudesanierung, Brennstoffwechsel bei Heizungssystemen und Energieeffizienzmaßnahmen bei elektronischen Geräten und Kühl- und Nassgeräten betrachtet. Das kumulierte $CO_2$-e-Einsparungspotenzial wurde mit 11,4 Mio. t $CO_2$-e berechnet, wovon 4,5 Mio. t $CO_2$-e mit negativen und 7 Mio. t $CO_2$-e mit positiven Vermeidungskosten vermieden werden könnten. Das größte Potenzial ist mit 6,6 Mio. t $CO_2$-e dem Bereich der thermischen Gebäudesanierung zuzurechnen. Das $CO_2$-e-Einsparungspotenzial des Dienstleistungssektors wird mit 0,9 Mio. t $CO_2$-e angegeben, wobei die betrachteten Maßnahmen aus den Bereichen effizientes Strommanagement und Sanierung von Heizungssystemen stammen. Im Mobilitätsbereich wurden die Maßnahmen getrennt nach PKW und LKW konzipiert und beschränken sich auf technische Effizienzmaßnahmen, ohne etwa Verhaltensänderungen oder den Umstieg auf öffentliche Verkehrsmittel zu berücksichtigen. Schon alleine durch diese betrachteten Effizienzmaßnahmen könnten insgesamt 6 Mio. t $CO_2$-e eingespart werden, was in etwa 27,5% des Gesamtausstoßes des Sektors ausmacht. Die Maßnahmen im Sektor Energie betrachteten vorwiegend die Strom- und Wärmeproduktion aus erneuerbaren Energieträgern und resultierten in einem Potenzial von 27,1 Mio. t $CO_2$-e, die damit vermieden werden könnten (Wächter, 2013a).

Die Frage erhebt sich, warum diese Maßnahmen nicht umgesetzt, sondern lieber Strafzahlungen zur Kompensation bei Nicht-Erreichung der verpflichtenden Kyoto-Ziele in Kauf genommen werden. Die genannten Gründe für den „energy efficiency gap" lassen sich hier auch auf Österreich übertragen. Besonders Ergebnisse dieser Art sollen dazu beitragen, das Bewusstsein zu erhöhen, dass die Vermeidung klimaschädigender Emissionen auch mit finanziellen Kostenvorteilen verbunden sein kann. Desweiteren kann die Politik zur Überwindung einer weiteren Hürde, nämlich Zugang zu Kapital, durch entsprechende Förderungen beitragen. Wenn nur die Kosten betrachtet werden, kann dazu geraten werden, jene Maßnahmen zuerst umzusetzen, die mit negativen Vermeidungskosten angewendet werden können. Wenn jedoch das Vermeidungspotenzial der Maßnahmen als Entscheidungsgrundlage herangezogen wird, sollen jene mit hohem Potenzial als erstes umgesetzt werden. Außerdem darf nicht außer Acht gelassen werden, dass durch die im Modell getroffenen Annahmen das $CO_2$-Vermeidungspotenzial schmäler als ursprünglich berechnet ist (Wächter, 2013a). Die Ergebnisse leisten dennoch einen Beitrag, das Potenzial und die Kosten von Maßnahmen zur $CO_2$-Vermeidung aufzuzeigen.

## 1.3 Wirtschaftswachstum über alles?

Ein Blick auf die internationalen und nationalen Wachstumsraten von Wirtschaft (gemessen anhand des Bruttoinlandsprodukts – BIP) und Energieverbrauch der letzten Jahrzehnte zeigt vor allem eines: beide sind stetig gestiegen. Es steht außer Frage, dass das Wirtschaftswachstum der Vergangenheit ohne Ansteigen des Energieverbrauchs nicht möglich gewesen wäre. Allerdings ist der kausale Zusammenhang, nämlich ob Wirtschaftswachstum den Energieverbrauch bedingt oder umgekehrt, nach wie vor ungeklärt (Ozturk, 2010; Odhiambo, 2010; Chandran et al., 2010), denn die empirischen Resultate divergieren stark in verschiedenen Ländern und Zeiträumen. Ein weiterer Blick auf die Wachstumsraten von Wirtschaft und Energie weist aber auch darauf hin, dass die Wachstumsraten des BIPs höher als jene des Energieverbrauchs sind. Dieses Phänomen wird als Entkopplung bezeichnet, d.h. die Wirtschaft kann losgelöst von Energie- und Ressourcenverbrauch wachsen. Absolute Entkopplung bezeichnet einen Rückgang des Energie- und Ressourcenverbrauchs trotz Wirtschaftswachstum, unter relativer Entkopplung wird ein langsameres Wachsen des Energie- und Ressourcenverbrauchs als das der Wirtschaft verstanden. Durch technologischen Fortschritt und den daraus resultierenden Effizienzsteigerungen im

Energieverbrauch soll es also gelingen, das Wirtschaftssystem mit der Umwelt in Einklang zu bringen. Dieses Gelingen muss in Frage gestellt werden, solange der absolute Energie- und Ressourcenverbrauch weiterhin steigt, was in der Diskussion um Entkopplung oftmals außer Acht gelassen wird.

Auch in Österreich zeigen die Zahlen zu Wirtschaftswachstum und Energieverbrauch keine absolute Entkopplung, dennoch war in den letzten Jahrzehnten eine relative Entkopplung des Energieverbrauchs vom BIP zu beobachten, d.h. der Energieverbrauch ist weniger stark als das BIP gestiegen. Auch empirisch konnte der Zusammenhang zwischen Energieverbrauch und Wirtschaftswachstum nachgewiesen werden, wobei unterschiedliche statistische Testverfahren zu dem Ergebnis kamen, dass die kausale Wirkung eher von Wirtschaftswachstum zu Energieverbrauch verläuft (Getzner, 2009). Die Hoffnung, dass sich durch ein Wachstum des Dienstleistungssektors der Energieverbrauch und damit einhergehend die THG-Emissionen verringern, lässt sich für Österreich bislang nicht nachweisen.

Aufgrund der endlichen Verfügbarkeit an natürlichen (Energie-)Ressourcen ist es nicht möglich, dass eine Wirtschaft unendlich wächst, die auf genau diese Ressourcen angewiesen ist. Ausgehend von diesem Faktum haben sich Wissenschaftsdisziplinen wie *Ecological Economics* etabliert um zu adressieren, dass wirtschaftliche Aktivitäten als ein Subsystem des Ökosystems zu sehen sind und nicht, dass das Ökosystem lediglich Rohstofflieferant für die Produktion von Wirtschaftsgütern ist. Weil das Wirtschaftssystem nicht von anderen gesellschaftlichen Aktivitäten abgekoppelt ist, müssen grundlegende gesellschaftliche Strukturen verändert werden, um tatsächlich nachhaltige ökologische und soziale Grundwerte umsetzen zu können. Besonders das weltweite Streben nach materiellem Wohlstand als oberste Priorität ist ein Haupthindernis für soziale Gerechtigkeit und eine intakte Umwelt (Jackson, 2009; Victor, 2008), weil einerseits die Kluft zwischen Arm und Reich immer größer wird und andererseits natürliche Ressourcen weit über ihre nachhaltigen Grenzen erschöpft werden. Zudem ist bekannt, dass langfristiges Glücksempfinden bei steigendem Nationaleinkommen nicht zunimmt (Kallis et al., 2012).

Wachstumskritische Stimmen stellen anstatt materiellen Reichtums hohe Standards von Lebensqualität als Lösung von Umweltproblemen in den Mittelpunkt. Darunter wird u.a. eine Reduzierung der Lohnarbeit verstanden, wodurch aufgrund geringeren Geldvermögens auch eine weniger konsum-basierte Lebensweise forciert werden (Schor, 2005) und mehr Zeit für z.B. Aktivitäten für die Gemeinschaft bleiben würde.

Somit würden weniger Ressourcen verbraucht werden, und negative Umweltauswirkungen könnten eingedämmt werden. Solche alternativen Lösungsansätze erfordern aber eine weitreichende Umgestaltung vorherrschender Gesellschaftssysteme, da momentan ein Konsumrückgang zu einem gesellschaftlich unerwünschten Ergebnis wie beispielsweise zu einer Zunahme von Arbeitslosigkeit und mehr sozialer Ungerechtigkeit führen würde. Wachstumskritische Strömungen wie *Degrowth* betonen, dass sich grundlegende Institutionen, die Politik, Eigentum, Finanzwesen oder Umverteilungsmechanismen regeln, radikal ändern müssen, um eine tatsächliche Neustrukturierung des heutigen Wirtschafts- und Gesellschaftssystems zu erreichen (Kallis, 2011; Jackson, 2009), ohne dabei durch einen abrupten Wechsel soziale VerliererInnen zu erzeugen (Schneider et al., 2010; Martínez-Alier et al., 2010; Odum und Odum, 2001). Verschiedenste Forschungsbeiträge beschäftigen sich derzeit damit, wie der Weg zu diesem System und die Ausgestaltung im Detail aussehen könnten (Kallis et al., 2012).

*Degrowth* versteht sich als wissenschaftliches, politisches und aktivistisches Konzept, das auf philosophische, kulturelle und institutionelle Kritik an Wachstum und Entwicklung setzt (Fournier, 2008; Schneider et al., 2010; Wächter, 2013b). Dies bedeutet, dass *Degrowth* als sozial nachhaltige Reduktion des gesellschaftlichen Durchsatzes gesehen werden soll (Martínez-Alier et al., 2010), was mit dem Ziel Wirtschaftswachstum nicht in Einklang stehen kann (Kallis, 2011; Victor, 2008; Daly, 1996; Georgescu-Roegen, 1971), weil dies eine Übernutzung von natürlichen (Energie-) Ressourcen mit weitreichenden Folgen für das Ökosystem bedeuten würde. Das angestrebte Ziel ist aber nicht eine Reduktion des BIPs, sondern vielmehr ist ein verringertes BIP erst das Ergebnis von sozial nachhaltigem *Degrowth*. Angestrebt wird eine Gesellschaft, in der Werte wie direkte Demokratie, Wohlstand ohne finanzielles Vermögen, Sozialkapital oder Gleichberechtigung im Fokus stehen. Der Verbrauch an Energie und natürlichen Ressourcen soll durch weniger Produktion und Konsum von Gütern und Dienstleistungen eingeschränkt und durch einen vermehrten Einsatz von Sozialkapital kompensiert werden (Wächter, 2013b). Damit soll weltweit ein gewisses Maß an Wohlstand für alle erreicht und gleichzeitig die Umweltbedingungen verbessert werden.

## 1.4 Raumplanung als Lösung für die Energiekrise?

Besonders eine natürliche Ressource spielt eine Schlüsselrolle in der Bereitstellung von Energie: die Verfügbarkeit von Land. Einerseits haben die Produktion und die Verwendung von Energie Auswirkungen auf die Landnutzung, andererseits beeinflusst gerade, wie Land genutzt wird, den Verbrauch von Energie (Walker, 1995). Die Raumplanung legt fest, welches Land wie genutzt werden kann und wie diese Nutzung organisiert wird und hat somit entscheidenden Einfluss darauf, welche Auswirkungen die Nutzung von Land hat (Nolon, 2011). In den Umweltwissenschaften wiederum stehen die Auswirkungen der Energieproduktion auf die Landnutzung im Mittelpunkt (Hoogwijk et al., 2005). Für eine nachhaltige Energieplanung ist es entscheidend, diese beiden Wissensgebiete miteinander zu verknüpfen, was durch eine steigende Nachfrage nach erneuerbaren Energieressourcen nochmals verstärkt wird.

Landnutzung hat gleich durch mehrere Aspekte großen Einfluss auf die Energieproduktion und Energienachfrage:

- **Erneuerbare Energieträger** benötigen große Flächen an Land
- **Regional- und Siedlungsstrukturen** bestimmen maßgeblich den Energieverbrauch
- **Werte und Rollenbilder** bezüglich Lebensstile in der Gesellschaft beeinflussen die Nachfrage nach energieintensiven Gütern

### *1.4.1 Erneuerbare Energieträger*

Erneuerbare Energieträger sind aus einem nachhaltigen Energiesystem nicht wegzudenken. Aufgrund ihrer Inanspruchnahme größerer Mengen an Land ist hier die Raumplanung gefordert, die dafür notwendigen Flächen für Pflanzen zur Erzeugung von Biomasse und für die mittels Wind und Sonne stromerzeugenden Anlagen durch Flächenwidmungen die Versorgung an erneuerbaren Energiequellen zu garantieren. Die Verfügbarkeit von Land stellt also auch eine der größten Einschränkungen in der Bereitstellung erneuerbarer Energieressourcen dar. Durch den Ruf nach mehr Unabhängigkeit von fossilen Energieträgern gewinnen regionale Energiesysteme und die Verbindung von Raum und Energie an Bedeutung (Graymore et al., 2008; Walz et al., 2007; Madlener et al., 2007; Bohunovsky et al., 2007). Da jede Region und jede Gemeinde spezifische Charakteristika hat, ist es für eine nachhaltige Energieplanung von Bedeutung, detaillierte Ressourcenpläne anzubieten, die für alle Erneuerbaren die Potenziale ausweist. Ebenso gilt es zu beachten, dass zwischen Erneuerbaren zur Wärmeproduktion und Stromproduktion unterschieden werden muss. Die Distanz zwischen Wärmeproduktion und ihrer Nutzung soll so gering wie möglich sein, um Übertragungsverluste zu vermeiden. Dies gilt zwar auch für eine optimale Stromversorgung, die Übertragungsverluste fallen aber geringer aus.

Obwohl es unbestritten ist, dass erneuerbare Energieressourcen die Basis für jedes nachhaltige Energiesystem sind, ist ihr Einsatz nicht frei von Kontroversen. Das Potenzial von Erneuerbaren, zur $CO_2$-Vermeidung beizutragen, wird oftmals überschätzt. Wenn auch der Energieverbrauch bei der Erzeugung miteinbezogen wird, kann dieser höher als die produzierte Energie sein. Der *Energy Return On Investment* (EROI) misst das Verhältnis von direkt und indirekt eingesetzter und erhaltener Energie (Murphy und Hall, 2010), wobei ein Ergebnis <1 bedeutet, dass im Produktionsprozess mehr Energie eingesetzt wurde als nach dem Prozess zur Verfügung steht. Während Wasserkraft einen besonders vorteilhaften Wert von ca. 100 aufweist, ist der Treibstoff Bioethanol, wenn er aus Mais gewonnen wird, mit 1,3 schon als bedenklich einzustufen (Murphy und Hall, 2010). Da in Biotreibstoffe besonders viel Hoffnung gesetzt wird, weil sie ohne technische Veränderungen von Ottomotoren eingesetzt werden können, ist auch die Nachfrage nach Anbauflächen global stark gestiegen. Ökologische Auswirkungen der vermehrten Anpflanzung sind hoher Verbrauch an Wasser, Pestiziden, Dünger und eine verstärkte Abholzung von Wäldern, was besonders im Fall von Regenwäldern mit unwiederbringlichen Biodiversitätsverlusten einhergeht. Ökonomische Auswirkungen sind vor allem bei den Preisen für Getreide ersichtlich: der Weltpreis stieg im Zeitraum 2000-2005 um 26% gefolgt von einem Preisschock von 42,5% im Jahr 2008. Die erzielten Investitionsrenditen für Biotreibstoffe führen zu einer gesteigerten Nachfrage nach Land insbesondere in wirtschaftlich nicht-entwickelten Staaten, was mit dem Begriff *land grabbing* bezeichnet wird, wodurch der ansässigen Bevölkerung oftmals die Lebensgrundlage entzogen wird. Politische Vorgaben wie die 20-20-20 Ziele der EU (20% weniger Treibhausgasemissionen als 2005, 20% Anteil an erneuerbaren Energien und 20% mehr Energieeffizienz) führen zu einer Verschärfung dieser Problematik.

### *1.4.2 Regional- und Siedlungsstrukturen*

Es wird geschätzt, dass mehr als die Hälfte des Energiebedarfs in den entwickelten Staaten von der Organisation der Landnutzung abhängt (Owens, 1990). Durch die

Bereitstellung relativ billiger fossiler Energieträger in den letzten Jahrzehnten war es möglich, die Organisation des Raumes auf diese aufzubauen. Schon alleine die versiegelte Pro-Kopf-Fläche in Österreich hat sich im Zeitraum 1955-2005 von $200m^2$ auf $560m^2$ nahezu verdreifacht. Die steigende Nachfrage nach Ein- und Zweifamilienhäusern, nach industrialisierten und kommerzialisierten Flächen wie Einkaufszentren und das dazugehörige Straßennetz sind als Hauptgründe für diese Entwicklung zu sehen. Zusammen mit einer intensiven landwirtschaftlichen Nutzung wird die Fläche derart beansprucht, dass die Nutzung weit über ein nachhaltiges Niveau hinausgeht: Für Österreich liegt das nachhaltige Limit der Zunahme an versiegelter Fläche bei 1ha/Tag für Siedlungs- und Verkehrstätigkeit (BMLFUW, 2008), die momentane Zunahme liegt aber bei 7,5ha/Tag (BMLFUW, 2013).

Wesentliche Auswirkungen der räumlichen Organisation auf den Energiebedarf zeigen sich in zerstreuten Siedlungen in ländlichen Gebieten. Diese Streusiedlungen erfordern auch eine Infrastruktur wie Straßen, Stromnetz oder Kanalsystem, die schon in der Errichtung mehr Ressourcen und Energie benötigen als dies in schon erschlossenen Gebieten der Fall wäre. Einfamilienhäuser weisen zudem durchschnittlich einen höheren Energiebedarf pro Quadratmeter als mehrgeschossige Mehrfamilienhäuser auf. In zerstreuten Siedlungen findet sich außerdem kein oder oftmals nur ein sehr geringes Angebot an Einrichtungen der Nahversorgung wie Lebensmittelgeschäfte, medizinische Versorgung oder Bildungseinrichtungen und damit einhergehend auch wenige Arbeitsplätze. Dies bewirkt, dass die täglich notwendigen Wege nicht mehr zu Fuß sondern mit motorisierten Fahrzeugen zurückgelegt werden. Da zerstreute Siedlungen aufgrund der fehlenden Dichte an BewohnerInnen kaum an das öffentliche Verkehrsnetz angebunden sind, werden die Wege des täglichen Bedarfs zumeist mit dem eigenen PKW zurückgelegt. Schon alleine die Arbeitswege haben sich von durchschnittlich 2 km in der Nachkriegszeit auf heute 20-30 km verlängert (Kanatschnig und Weber, 1998), und der Trend zu größeren Shoppingzentren in der Peripherie auf Kosten kleinerer, fußläufig erreichbaren Einrichtungen der Nahversorgung ist nach wie vor ungebrochen (Schriefl et al., 2011; Meixner et al., 2007). Es ist nicht weiter verwunderlich, dass auch deswegen in Österreich die verkehrsbezogenen THG-Emissionen im Zeitraum 1990-2005 um 91% gestiegen sind (Umweltbundesamt 2013).

Es ist aufwendiger und schwieriger, unnachhaltige Strukturen auf einen nachhaltigen Pfad zu bringen als gleich in der Planungsphase Nachhaltigkeitskriterien zu berücksichtigen, weswegen auch die Meinungen über die besten Strategien divergieren. Eine sehr radikale Vorgehensweise wäre Enteignung im Fall von zerstreuten Häusern ähnlich wie bei Enteignungen im Straßenbau, wobei dies aber keinesfalls im Einklang mit nachhaltigen Werten stünde (Wächter, 2013b). Viel eher lässt sich durch Nachverdichtung ein Weg finden, wie ungenutzter Raum in schon bestehenden Siedlungen zu Wohnzwecken oder Einrichtungen der Nahversorgung genutzt werden kann. Die Schaffung solcher multifunktionaler Siedlungsstrukturen liegt nicht zuletzt in den Händen der Raumplanungsinstitutionen auf Gemeinde- und Landesebene (Wächter, 2013b). Ein spezielles Problem in Österreich stellen die schon erteilten Baulandwidmungen in nicht erschlossenen Gebieten dar (Wächter et al., 2012), die auch als ein Haupthindernis auf dem Weg zu nachhaltigen Siedlungsstrukturen zu sehen sind. Eine weitere Barriere zu nachhaltigen Siedlungsstrukturen sind staatliche Förderungen für Neubauten, die besser für Nachverdichtungsprozesse und Sanierungen des Altbestands verwendet werden sollten (Wächter et al., 2012).

### *4.3 Werte und Rollenbilder*

Seit Mitte des 20. Jahrhunderts – mit Beginn des Wirtschaftsaufschwungs in Österreich – traten veränderte Statussymbole in den Mittelpunkt: das Eigenheim im Grünen als Zeichen von Erfolg und ein eigener PKW als Zeichen von Freiheit und Unabhängigkeit, wobei solche Individualisierungsprozesse durch die vermittelten Bilder in Medien wie Filmen und Werbung noch verstärkt wurden. Suburbanisierungsprozesse in den stadtnahen Umgebungen und Zersiedelungstendenzen in ländlichen Gebieten waren die Auswirkungen des Trends zum Eigenheim (Hamm und Neumann, 1996; Alisch und Dangschat, 1993). Doch nicht nur sozio-ökonomische Faktoren sondern auch der soziale Hintergrund und individuelle Lebensstile beeinflussten die Entstehung monostruktureller Siedlungsstrukturen (Löw, 2001). Entsprechende Landwidmungen und Baubewilligungen der lokalen Raumplanung waren eine der Vorraussetzungen für den Trend zum Eigenheim, was durch staatliche Fördersysteme für das Einfamilienhaus im Grünen noch weiter gestützt wurde. Da fossile Energie im Übermaß vorhanden war und die Preise dafür niedrig genug waren, stand eine ressourcen- und energieschonende Planung nicht im Fokus.

Besonders durch die ersten beiden globalen Energiekrisen in den 1970er Jahren erhob sich das Bewusstsein, dass nicht uneingeschränkt auf billige Energie zurückgegriffen werden kann. Ein entscheidender Beitrag zu weniger ressourcen- und energieintensiven Handlungsweisen sind gemeinschaftlich genutzte Ressourcen und Dienstleistungen. Durch die gemeinsame Nutzung gelingt es, die Nachfrage nach dem gesellschaftlichen Energie- und Materialdurchsatz zu verringern und andere Organisations- und

Entscheidungsstrukturen, die auf gemeinsame und nicht auf individuelle Entscheidungsfindung über den Gebrauch von Gütern abzielen, bei der Nutzung von Gütern und Dienstleistungen anzuwenden. Als Beispiele dafür fungieren heute Carpools, gemeinsame Reparaturwerkstätten oder Gemeinschaftsgärten, die Beiträge zu weniger Ressourcen- und Energieverbrauch sind (Wächter et al., 2012). Als Vorbild für eine gemeinsame Entscheidung, weniger Energie zu verbrauchen, gilt beispielsweise die autofreie Siedlung in Wien, in der das Ziel des Autoverzichts und gemeinsamer Ressourcennutzung erfolgreich umgesetzt wurde (Ornetzeder et al., 2008). Gemeinschaftlich genutzte Dienstleistungen betreffen unter anderem Betreuungspflichten für Kinder und ältere Menschen oder Nahrungsmittel-Kooperativen und andere Dienstleistungen, die zu einer höheren Lebensqualität beitragen. Die auf diese Weise verfolgten Werte und Einstellungen zielen also weniger auf eine individuelle Lebensführung sondern vielmehr auf soziale Kooperationen und demokratische Entscheidungsprozesse ab (Wächter, 2013b).

Auch wenn in Österreich Institutionen der Raumplanung auf Gemeinde- und Landesebene momentan nur geringen Einfluss auf umweltpolitische Entscheidungen haben, stehen ihnen dennoch Instrumente zur Verfügung, die durch die Verfolgung gemeinschaftlicher Werte auf einen geringeren Ressourcenumsatz abzielen. Eine dieser Möglichkeiten ist die Schaffung von kollektiv genutzten Räumen, die als Ausgangspunkt für gemeinschaftliche Aktivitäten dienen können (Wächter, 2013b). An der Schnittstelle zwischen BewohnerInnen und anderen staatlichen Institutionen könnte eine Vermittlungsfunktion im Bereich nachhaltiges Wohnen erfolgen und auch bei der Bereitstellung von Informationen über nachhaltige Lebensweisen und deren Verankerung in Bildungseinrichtungen könnten Raumplanungsinstitutionen einen wichtigen Beitrag leisten (Wächter, 2013b). Da in Österreich Raumplanung größtenteils auf lokaler und regionaler Ebene erfolgt, sind auch die Gestaltungsmöglichkeiten davon bestimmt.

Im Forschungsbereich Raum und Energie zeigt sich, welchen Stellenwert Raumplanungsinstitutionen zur Erreichung von Nachhaltigkeitszielen haben. Besonders im Streben nach demokratischen Entscheidungsprozessen, einer nachhaltigen Lebensweise und optimalen Standortbestimmungen für Nutzung von erneuerbaren Energieressourcen werden wichtige Ziele für *Ecological Economics* oder *Degrowth* erreicht. Da die Umgestaltung eines Energiesystems nicht nur durch mehr Energieeffizienz und dem vermehrten Gebrauch erneuerbarer Energieressourcen erfolgen kann, ist es notwendig, sowohl institutionelle wie auch persönliche und individuelle Verhaltensänderungen zu fordern und zu fördern.

## 5. Schlussfolgerungen

Wenn von der Neugestaltung des Energiesystems gesprochen wird, so wird zumeist an erhöhte Energieeffizienz und an den Einsatz erneuerbarer Energieressourcen gedacht. Da weder Effizienzmaßnahmen allein weit genug reichen können, den Energie- und Materialverbrauch in absoluten Werten zu verringern (Haberl et al., 2011), noch die momentane Energienachfrage mit erneuerbaren Energieressourcen zu befriedigen ist, ist es erforderlich, tiefgreifendere Umgestaltungen des Energiesystems vorzunehmen. Besonders institutionelle Veränderungen und infrastrukturelle Maßnahmen können dazu beitragen, den absoluten Energieverbrauch zu senken, damit einhergehend sind vor allem Verhaltensänderungen von Gruppen und Individuen zu nennen. Einer der größten Treiber des Energieverbrauchs sind wirtschaftliche Aktivitäten, die auf Wachstum und damit einhergehend auf erhöhten Energiebedarf ausgerichtet sind.

Da eine Wirtschaft mit einer endlichen Anzahl an Ressourcen nicht unendlich wachsen kann, haben sich Strömungen wie *Ecological Economics* oder *Degrowth* etablieren können, die Nachhaltigkeit als normative Zielsetzung fokussieren. Das Ziel einer immer wachsenden Wirtschaft wird dabei insofern in Frage gestellt, als dies mit den Zielen von starker Nachhaltigkeit, wenn diese auch ernst genommen werden, nicht vereinbar ist. Veränderte Werte und Ziele erfordern zu ihrer Umsetzung andere Organisationsformen und Institutionen sowie strukturelle Änderungen, die nicht unter der Doktrin des immerwährenden Wachstums stehen.

Raumplanungsinstitutionen kommt dabei eine oftmals unterschätzte Schlüsselfunktion zu, da sie über räumliche Strukturen und deren Organisation mitbestimmen, die wiederum entscheidend für den Energieverbrauch sind. Standortbestimmungen und Flächenwidmungen sind einflussreiche Instrumente, mit denen über Siedlungsstrukturen und über die Möglichkeit der Nutzung von erneuerbaren Energieträgern mitentschieden wird. Eine Besonderheit lässt sich in der Raumplanung insofern feststellen, da diese eine Forderung von *Ecological Economics* und *Degrowth* erfüllt: es bestehen schon heute wichtige Anknüpfungspunkte hinsichtlich Zielsetzungen wie geringerer Energie- und Ressourcenverbrauch, nachhaltige Siedlungsentwicklung und veränderte Werte und Rollenbilder, die dazu beitragen sollen, einen abrupten Systemwechsel mit sozialen VerliererInnen zu vermeiden (Wächter, 2013b). Die gebotenen Chancen zeigen Möglichkeiten auf, wie die Raumplanung den Übergang zu einem nachhaltigen Energiesystem entscheidend mitgestalten kann.

Die absoluten Energieverbrauchszahlen für Österreich zeigen seit 2010 in allen Sektoren einen leichten Abwärtstrend (Statistik Austria, 2013), was zwar eine wünschenswerte Entwicklung ist, dennoch ist das erst ein kleiner Schritt auf dem Weg zu einem nachhaltigen Energiesystem. Da trotz dieses leichten Rückgangs das Kyoto-Ziel bei weitem verfehlt wird, muss festgehalten werden, dass die bisherigen Maßnahmen nicht ausgereicht haben, Österreich auf einen klimafreundlichen Pfad zu bringen. Wie schon die Ergebnisse der Vermeidungskostenkurve für Österreich gezeigt haben (Wächter, 2013a), sind immense Potenziale zur Energie- und Treibhausgasvermeidung vorhanden, die bislang ungenutzt geblieben sind. Die Empfehlung an politische EntscheidungsträgerInnen lautet daher, so rasch wie möglich die vorgeschlagenen Maßnahmen auch umzusetzen.

Um allerdings eine tatsächliche Trendumkehr zu einem umweltfreundlicheren Energiesystem zu erreichen, müssen langfristig Weichen gestellt werden. Nur mit grundlegenden institutionellen und politischen Veränderungen kann es gelingen, die gesellschaftlichen Strukturen tatsächlich so zu gestalten, dass sie ein weniger ressourcen- und energieintensives soziales und wirtschaftliches Zusammenspiel ermöglichen. Dazu ist es aber auch notwendig, dass sich grundlegende Werte in Richtung sozialer Kooperation und umweltgerechtes Handeln verändern.

Auch wenn sich das Bewusstsein der österreichischen Bevölkerung und der Politik gegenüber Nachhaltigkeitsthemen geöffnet hat, sind noch zu wenig tiefgreifende Veränderungen geschehen. Da es schon zahlreiche Initiativen und Best-Practice Beispiele gibt, die als Beitrag zu einem nachhaltigen Energiesystem gelten, bleibt zu hoffen, dass diese Bemühungen stetig mehr werden.

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## Anhang A

Wächter, P. (2013): The usefulness of marginal $CO_2$-e abatement cost curves in Austria. Energy Policy 61, 1116-1126

Energy Policy 61 (2013) 1116–1126

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

# The usefulness of marginal $CO_2$-e abatement cost curves in Austria

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## HIGHLIGHTS

- Energy efficiency measures on a national level for Austria.
- First Marginal $CO_2$-e abatement cost curve for Austria.
- Reflections about the applicability of MACCs.
- Measures with negative $CO_2$-e abatement costs identified that fulfill the Kyoto Protocol.

## ARTICLE INFO

*Article history:*
Received 23 December 2011
Accepted 23 June 2013
Available online 19 July 2013

*Keywords:*
Marginal $CO_2$-e abatement cost curve
Austria
Energy efficiency

## ABSTRACT

Energy efficiency measures are manifold in all economic sectors. These measures can be pictured by a marginal abatement cost curve (MACC) which is a common way to show $CO_2$-e abatement potential and its related costs in various fields. In this paper, we calculated the marginal $CO_2$-e abatement cost curve for Austria for the first time to fulfill the need for country specific cost curves. One of the strengths of such curves lies in their ability to highlight that energy efficiency measures can even have negative abatement costs. The weaknesses consist of neglecting a change in energy prices, the rate of diffusion, and compatibility with existing technologies. By using a static bottom-up approach we constructed the MACC for four economic sectors (household, service, transport, energy) and found a national mitigation potential of 45.4 million tons $CO_2$-e. The results further show that even with the measures with negative abatement costs it is possible to make the necessary $CO_2$-e mitigation to fulfill the Kyoto Protocol. The conclusions emphasize that the curve makes a contribution to overcome one of the barriers of implementation by providing enhanced information on energy efficiency measures and its costs.


## 1. Introduction

Climate change and its impacts is one of the most urgent problems in the current social and political debate. Undoubtedly, human activity can be seen as responsible for climate change and therefore it is up to human beings to tackle them. The Kyoto Protocol obliges industrialized countries for the first time to cut $CO_2$-e emissions by 5.2% on average below the 1990 level by 2012. Austria commits itself to reduce its emissions by 13.2% below the 1990 level which means a rate of permitted emissions of 68.8 million tons (Mt) of $CO_2$ equivalents ($CO_2$-e). But implementing compliance of this obligation was too ambitious: In 2009, greenhouse-gas (GHG) emissions exceeded the envisaged rate with 80.1 Mt $CO_2$-e resulting in a gap of 11.3 Mt $CO_2$-e (Federal Environment Agency, 2011).

There are four economic sectors that were seen as responsible for about 85.3% of all GHG emissions (transport, industry, energy production, heating) in 2009 (Federal Environment Agency, 2011). There has been an immense increase of emissions in the transport sector which have risen by 54.4% in the period 1990–2009 (emissions in $CO_2$-e 1990: 14 Mt; emissions 2009: 21.7 Mt), and the corresponding share in the overall emissions increased from 17.9% to 27.8% (Federal Environment Agency, 2011). According to the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (2008) reducing the emissions of the transport sector is the biggest challenge to be overcome if Austria is to achieve the goals of the Kyoto Protocol. In the same period the industry sector also recorded an increase in $CO_2$-e emissions of 5.9%, the biggest polluters being iron and steel production and the mineral processing industry. In this sector, 16.6 of 22.5 Mt are already covered by emissions trading, which is also the reason why the sector was not analyzed in detail. These

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0301-4215/$ - see front matter 
http://dx.doi.org/10.1016/j.enpol.2013.06.125

two sectors also constitute the largest departure from the Kyoto goal. In the energy-producing sector emissions increased by 17.4% to 16.2 Mt $CO_2$-e in the period 1990–2005 (Federal Environment Agency, 2008), but after peaking they decreased to 12.8 Mt in 2009, which is even 1 Mt less than in 1990 (Federal Environment Agency, 2011). This can be explained by an increase in the use of renewable energy sources, which have further potential for the production of electricity. The fourth biggest polluter is heating, although emissions decreased by 21.5% in the period 1990–2009, due to building insulation and changes to low-carbon heating systems. Nonetheless, the biggest challenges here remain efficiency improvements in all buildings and heating systems. Unfortunately, the sectors household and service are not accounted for separately in Austria but instead only the category heating is reported including both household and service sector. Emissions from electricity are accounted for in the energy sector as emissions from primary production.

The aim of this paper is to present $CO_2$-e mitigation options by constructing a marginal abatement cost curve (MACC) for Austria and to critically reflect on the applicability of such curves. By further developing this approach of marginal $CO_2$-e abatement cost curves, this study analyses various high-impact scenarios to reduce emissions for the household, service, transport and energy supply sectors in Austria. The measures are then ranked according to the costs/ton $CO_2$-e ratio. The study provides a quantitative basis for (policy) decision makers as a starting point as to which abatement measures can be pursued and conducted in terms of their overall potential, and how much they would cost. The results show that even the measures with negative abatement cost have the potential to reduce $CO_2$-e exactly to the amount that is needed to fulfill Austria's requirements of the Kyoto Protocol. The paper concludes by emphasizing on how to overcome one of the barriers of implementation of energy efficiency measures by providing further information on the possibilities of reducing energy demand and its costs.

The paper proceeds as follows: Following the introduction, Section 2 shortly describes the barriers of implementation of energy efficiency measures and analyses the results of other studies which used marginal abatement cost curves. Section 3 presents the used method to construct the marginal abatement cost curve for Austria and its further development and explains the data currently used. The discussion in Section 4 shows some advantages of and critical views on MACCs. Section 5 describes the results in general and in more detail for the specific sectors. The paper ends with the conclusions and outlook in Section 6.

## 2. Marginal abatement cost curves

### 2.1. Barriers to the implementation of increased energy efficiency and market failures

Although much progress has been made in the past few decades, both on an individual as well as on an overall system level, most economic sectors still show huge unused potential in energy efficiency. Following the energy efficiency improvements already achieved, the question can be raised as to why the regarding actors and institutions have not already made use of this immense potential and as to what the multiple and persistent barriers to increased energy efficiency are (Granade et al., 2009).

The so called energy efficiency gap refers to the difference between observed levels of energy efficiency and some notion of optimal use (Gillingham et al., 2009). Barriers of implementation are present in various economic fields such as orthodox economics, agency theory, economics of information, transaction cost economics and behavioral economics (Sorrell et al., 2004). Although these different economic approaches have diverging explanations, they widely agree on the main barriers to energy efficiency: risk, imperfect information, hidden cost, access to capital, split incentives and bounded rationality (Sorrell et al., 2004). In practice, each area has its own mix of barriers, with awareness and information, access to capital, and product or service availability the three most commonly observed (Granade et al., 2009). It is exactly that combination of factors which makes it even more difficult and complex and requires more than one single solution to overcome the detected barriers. The impacts of these barriers also seem to be influenced by who the obstacle is actually faced by, such as public organizations, firms or individuals (Weber, 1997). Moreover, it has to be considered in the analysis what kind of action is hindered, such as buying more efficient applications or imposing energy taxes (Weber, 1997). Although firms are choosing the cheapest way of abating emissions, market failures such as unpriced costs and benefits or misplaced incentives (Brown, 2001) contribute to the efficiency gap.

Marginal abatement cost curves make a contribution to overcome at least one main barrier to energy efficiency: awareness and information. One of the strengths of MACCs is their ability to provide information about energy saving opportunities as well as costs involved. The relationship between $CO_2$-e abatement and cost raises the awareness of the manifold mitigation possibilities in all economic sectors and addresses individual persons as well as decision-makers in public and private sector and policy-makers on all levels. MACCs are regarded as an appropriate way to communicate measures to improve energy efficiency (McKinsey, 2007; Stern, 2007).

### 2.2. The usage of MACCs

Abatement cost curves are a common way of disseminating the results of studies regarding climate protection measures and their costs (Barthel et al., 2006; Criqui et al., 1999; Den Elzen and Both, 2002; Kuik et al., 2009; McKinsey, 2007; Morris et al., 2008; Stern, 2007). The first abatement cost curves were developed in the late 1970s to reduce oil consumption after the two oil price shocks, and in the early 1990s they were applied to calculate electricity consumption savings (Farugui et al., 1990). There are basically two general ways to construct marginal abatement cost curves: one is a bottom-up approach using technical mitigation options and the other is to derive MACCs from computable general equilibrium (CGE) models.

The first approach looks for technologies and practices aiming at low GHG emissions including their costs and factors of limitation. Usually a list of GHG abatement measures is assessed in which the scope of sectors and analyzed mitigation options differ widely. $CO_2$-e abatement cost curves with regional or sectoral focus can be found for various countries. A comprehensive compilation of bottom-up MACCs was done by McKinsey & Company, an international consulting company, for countries all over the world and also on a global level, including over 300 options for $CO_2$-e abatement. For the UK, technological options were assessed for the household, service and transport sector (ENVIROS, 2005; Stern, 2007), highlighting a range of mitigation measures with negative abatement costs and concluding that the most significant absolute impact is from the retail sector. For the UK energy sector, Anderson (2006) emphasizes the good technological and institutional basis for the calculation of the curves. The conclusions confirm that a transition to a low carbon economy would not disturb economic growth and development. Barthel et al. (2006) give an overview of GHG abatement options for Germany in the household, service and industry sectors and conclude that there is a need for a more country-specific analysis of the market conditions. By constructing abatement cost curves of

Switzerland (Ziegler and Battig, 2009) the outcome indicates a huge abatement potential in the building sector through the construction of low energy houses.

CGE models are top-down economic simulation models. Basically, marginal abatement costs are defined as the shadow cost that is produced by a constraint on carbon emissions (Klepper and Peterson, 2006), whereas a more strict constraint would lead to higher marginal abatement costs. MACCs are derived by generating the costs associated with different levels of reductions (Klepper and Peterson, 2006). The results depend to a large extent on the model structures and assumptions such as substitution possibilities between carbon and low-carbon technologies and their elasticity and endogenous or exogenous technological change (Anderson, 2006). Various studies using CGE models exist, focusing on different regions and time horizons. The robustness of different levels of abatement across regions and different scopes of emission trading was investigated by Ellerman and Decaux (1998). They produced MACCs from the MIT Emissions Prediction and Policy Analysis (EPPA) model. Their main finding is that $CO_2$-e marginal abatement cost curves are an appropriate means of detecting and evaluating different emissions-reducing measures and that the cost curves are unique for each country. Recent US data was analyzed by abatement cost curves also derived from the EPPA model (Paltsev et al., 2005) and later (Morris et al., 2008) in terms of their robustness regarding time and previously adapted and foreign policies. Their main findings suggest that MACCs are affected by policies abroad and by policies in the past and depend on whether they include only $CO_2$ or all GHG emissions. Klepper and Peterson (2006) use abatement cost curves to establish a cross-country relationship through world energy prices. The results show that national MACCs depend on the abatement levels in the rest of the world through changes in worldwide fossil fuel prices and that MACCs are largely affected by the defined emission targets.

A good overview of US possibilities for mitigating GHG emissions is set out in the Annex to the White Paper “Cost effectiveness Under the Global Warming Solutions Act” (California Air Resources Board, 2008), in which a wide range of existing national and state $CO_2$-e abatement cost curves is summarized. The conclusion of one of the latest overview studies on abatement cost curves (Kuik et al., 2009) is their dependency on the stringency of the stabilization target, the emissions baseline, the time profile and the number of energy sources, while also emphasizing regional disparities.

## 3. Methods and data

A marginal abatement cost curve is defined as a graph which depicts the costs of abated $CO_2$-e on the *y*-axis and the last unit of emission abatement for varying amounts of emission reduction on the *x*-axis (Kesicki and Strachan, 2011). The measures considered are ranked according to their costs of abatement: marginal abatement cost curves depict the first ton which can be abated at lowest cost ranging up to the “most expensive ton”. A negative sign in the results means a financial advantage for the new technology which stems from lower energy costs whereby other benefits such as the residual value of the ‘old’ technology were not included. Dividing the additional positive or negative costs by the $CO_2$-e savings produces the $CO_2$-e unit costs of abatement. A positive value of a single measure therefore means that the life-long discounted costs of investment with the lower emissions are higher than the energy costs saved. The negative value describes a win–win situation in which the new technology causes fewer emissions, and the sum of energy costs and the discounted costs of investment are less than the energy costs of the old technology. In this case, the introduction of the new technology leads to lower emissions and to a financial advantage. Marginal cost-of-abatement curves can also be seen as a method for describing a cost–benefit relationship where the cost of abatement corresponds to the “costs” and the amount of avoided $CO_2$-e to the “benefit”.

For constructing the MACC a technically oriented bottom-up approach was used by assessing technological options of mitigation of today and their related costs. This bottom-up approach makes it possible to feature a large number of discrete energy technologies for being able to substitute energy carriers, for process substitution or efficiency improvements (Böhringer and Rutherford, 2008). The aim of this study was to find out the theoretical, technical feasible mitigation potential of today by technological mitigation options of today without considering any economical or institutional restrictions.

Basically, the considered measures were chosen regarding their $CO_2$-e saving potential, energy saving potential or widespread common use. Static modeling assumptions were used to conduct the calculations for deriving costs and saving potential of mitigation measures. In so far the results were derived by comparing the ‘old’ technology (meaning the presently used technology with high $CO_2$-e emissions) with a respective ‘new’ highly efficient technology with less $CO_2$-e production which replaces the ‘old’ one.

For the options in each sector it was necessary to make specific assumptions in order to be able to calculate the costs of abatement these options have.

### 3.1. Household and service sector

#### 3.1.1. Selection of abatement options

In the household sector, we identified the areas with the most energy consumption, namely heating and electricity for household appliances. To reduce $CO_2$-e emissions from heating, households face two options: insulations of buildings and/or switching to an environmentally less harmful heating system. To include both options, we developed a scenario which is explained in detail in Step 8. The choice of household appliances was guided by how widespreadly they are used, therefore we included refrigerators, dishwashers, washing machines, dryers, televisions and also energy light bulbs. In the service sector, the abatement options also focus on heating and electricity and we therefore included the efficient use of management systems for electricity and the replacement of heating systems.

#### 3.1.2. Specific assumptions

When calculating the measures in the area of building insulation a differentiation was made between single and multiple occupancies and their specific abatement potentials.

#### 3.1.3. Comparison of old and new technologies

Firstly, a comparison between a non-insulated house and an insulated house was conducted. Subsequently, where data was available, all fuel switch options of heating systems were calculated. We specifically focused on changing the heating systems using oil, gas, all sorts of coal and electricity to either a more efficient heating system using the same fuel or to pellets as a common representative for a zero emission technology (see also Table 1). No data was available for the specific energy demand and its corresponding $CO_2$-e emissions in the case of brown, cold and wet appliances currently used in Austrian households. Instead, the energy demand of the most inefficient device available on the market was compared to the highest efficiency one available. In the service sector, the comparison of the two measures was

**Table 1**
Assumptions about fuel switch in the heating systems of households.

| *Single occupancies* | | | *Multiple occupancies* | | |
|---|---|---|---|---|---|
| **Fuel switch from** | **To** | **In % of all users** | **Fuel switch from** | **To** | **In % of all users** |
| Oil | Gas | 35 | Oil | High-efficiency oil furnace | 20 |
| | High-efficiency oil furnace | 20 | | District heating | 50 |
| | Pellets | 35 | | Pellets | 30 |
| | Heat pump | 10 | Gas | High-efficiency gas furnace | 80 |
| Gas | High-efficiency gas furnace | 100 | | District heating | 20 |
| Coal (all coal types) | Pellets | 100 | Coal (all coal types) | Pellets | 100 |
| Electricity | Pellets | 100 | Electricity | Pellets | 100 |

conducted between buildings without efficient electricity use or efficient heating system and buildings which make use of them.

### 3.2. Transport

#### 3.2.1. Selection of abatement options

All regarded measures are technical ones focusing on increased efficiency. Sixty-one single measures were identified for cars and trucks including e.g. engine improvements, lightweight interior components and rolling resistance reduction. Measures from the areas of demand, fuel carbon intensity or modal split were not calculated.

#### 3.2.2. Specific assumptions

Measures regarding efficiency improvements of cars could be clustered into efficiency improvements, the switch to the most efficient car or truck in the regarding vehicle category, and a switch to hybrid cars.

#### 3.2.3. Comparison of old and new technologies

As reference for comparison, average values for cars and trucks were used e.g. regarding their average annual consumption of driven kilometers and their respective $CO_2$-e emissions.

### 3.3. Energy

#### 3.3.1. Selection of abatement options

The four measures are intended to substitute the corresponding $CO_2$-e emissions of the usual electricity mix by a carbon free electricity production by hydro power, wind, photovoltaic and solid biomass. Only one measure was considered as an example for heat production, namely the use of solar heat. The building of new large hydro power plants was not regarded as an ecologically sustainable alternative, therefore only small hydro power plants were considered when assessing the potential from hydro power. As geothermal heat in Austria has only a very small potential it was not considered in this study.

#### 3.3.2. Specific assumptions

As in other sectors there was no consideration of the environmental impact of the construction of new power plants or photovoltaic panels. Therefore, a mitigation level of 100% was assumed. Further, all existing power plants of renewable energy were assumed to persist.

#### 3.3.3. Comparison of old and new technologies

It was assumed that the electricity produced by various renewable energy sources (hydro power, wind, photovoltaic and solid biomass) could replace the same amount of the normally used electricity mix in Austria. For the measure solar heat, the Austrian heating mix consisting of oil, gas, coal, district heating and electricity is replaced by solar heat. When estimating the costs of new power plants on a national basis we used the investment costs per MW of the respective power plants. The maximal technical potential was derived from various potential studies, and the already installed capacities were subtracted.

### 3.4. Steps necessary for deriving the MACC

#### 3.4.1. Step 1: Description of status quo

Every single energy consumption activity is described by energy use per year, by its energy cost per year (based on 2007 energy prices) and its $CO_2$ equivalents. This data of a single measure is then multiplied with the amount available in Austria in order to get the overall impact on a national level. For example, the energy use of a refrigerator on average was multiplied by the according number of refrigerator used in Austria resulting in national energy demand of refrigerators.

#### 3.4.2. Step 2: Description of 'new' technology

As above, energy use per year, energy cost and $CO_2$ equivalents are indicated and then calculated with the according multiplier on a national level.

#### 3.4.3. Step 3: Impact of the replacement of the 'old' by 'new' technology

In order to be able to see the impact of the new technology, the following parameters are calculated by subtracting the 'old' from the 'new' technology, resulting in saved energy per year, saved energy costs per year, and saved $CO_2$ equivalents.

#### 3.4.4. Step 4: Calculation of total costs

For deriving the yearly cost of a measure, a full cost pricing was conducted which includes the costs of investment, specific lifetime of a measure and a discount rate of 4%. Subsequently, the yearly energy costs are added.

#### 3.4.5. Step 5: Total cost savings

For deriving the total cost savings, the calculated total costs of the 'new' technology per year are subtracted from the energy costs of the old technology. A positive value means that discounted investment costs plus energy costs of the new technology are cheaper than the energy cost of the 'old' technology; a negative value means that total cost of 'new' technology are more expensive than the energy cost of the 'old' technology.

#### 3.4.6. Step 6: Deriving the €/$CO_2$-e ratio

This ratio gives the cost of $CO_2$-e abatement: total cost savings per year divided by the abated $CO_2$ equivalents per year.

#### 3.4.7. Step 7: Aggregation of measures

In order to provide a clearly represented picture of the calculated measures, they were aggregated where many sectoral measures were present. In the household sector, single measures in the field of cold and wet appliances and in the field of brown appliances could be aggregated to one measure respectively, and also in the transport sector in case of trucks all single measures could be summed up to one aggregated measure without any overlapping. The aggregation of several measures to one single measure holds the danger of overlapping and double counting of $CO_2$-e emission reductions. To avoid this danger it is necessary to identify all interdependent and competing measures and subsequently to subtract the double counted $CO_2$-e emissions. The regarded single measures in the area of cars consist of technical measures improving efficiency, a switch to cars with hybrid drive and a switch to the most efficient car in the regarding vehicle category. It was easily possible to cumulate the single measures within these three categories, but it would lead to overestimated $CO_2$-e abatement potential if these three categories were added up. Most efficiency measures are only valid with a certain motor and are not applicable to hybrid cars, which already use the most efficient technology. Therefore, the following assumption was used for aggregation: 50% of the cars switch to the most efficient car in the regarding vehicle category, 35% undergo efficiency improvements, and 15% are replaced by hybrid cars. The result leads to one aggregated measure for cars. This procedure provides the advantage that all measures of one sector and also sectors themselves can be added up without providing an exaggerated saving potential.

#### 3.4.8. Step 8: Development of scenarios for the household sector

A special feature was the calculation of emission saving potentials through a two step method for developing and assessing consistent scenarios in the household sector. Single measures in the household sector in the area of building insulation for single and multiple occupancies were calculated on the one hand, and single measures regarding fuel switch in heating systems on the other. Based on the knowledge how many households use which heating system (Statistics Austria, 2007a), various fuel switch measures could be calculated on a national level. As a next step, we combined the insulation measures with fuel switch measures in the respective heating systems: the insulated less energy demanding buildings undergo a change in their heating systems to low or zero emission energy carriers or switch to more efficient heating systems. In order to calculate the respective costs and emission savings without any overlappings, assumptions have to be made how many single and multiple dwellings would change to which heating system. Table 1 gives an overview of these assumptions.

The calculations of the single measure 'building insulation of single occupancies' result in a relative mitigation potential of 48%. Therefore, the lower heating demand (in $\text{kW h/m}^2\text{a}$) requires less energy which also lowers the primarily calculated saving potential of the single fuel switch measures by 48%. Next, all single fuel switch measures with the lower potential were calculated, resulting in fuel switch measures with lower energy savings and mitigation potential than in non-insulated buildings. Finally, all single fuel switch measures together with the single measure 'building insulation of single occupancies' could be added without giving an overestimated mitigation potential. The same procedure was used for multiple occupancies.

### 3.5. Main assumptions for deriving the MACC

#### 3.5.1. Timing

The focus of the study was to assess the overall $CO_2$-e abatement potential which one specific measure could have on a national level if it was to be implemented completely instead of the 'old' technology. This means a market penetration rate of 100%. It was assumed that the measures are completely implemented today.

#### 3.5.2. Technology

As outlined above, only technologies or efficiency improvements available today were considered for statically calculating the feasible mitigation potential of today.

#### 3.5.3. Operating expenses

For the investigated measures in the sectors households, service and transport, the operating expenses were assumed to be the same for the 'old' and the 'new' technologies and consequently, they were not included in the calculations, e.g. single dwellings face the same operating expenses (liquid waste fee, disposal service etc.) whether insulated or not. In the energy sector, operating expenses and also the cost for fuel in case of solid biomass were included when calculating the total yearly cost.

#### 3.5.4. Energy

The calculations of the specific measures are based on the demand of end use energy and its related costs. Except in the energy sector, the production of primary energy was the starting point for deriving the abatement potential.

### 3.6. Limitations of this study

#### 3.6.1. Cost level

For renewable energy sources, the investment costs differ widely depending on where the power plants are located. We did not pay attention to this fact and used average investment costs instead. Also the actual capacity utilization has a wide range depending on the location of power plants which was not considered in the calculations of the respective measures in the energy sector.

#### 3.6.2. Prices

Energy prices and investment costs are used from the year 2007, therefore the curve might look different with prices of today.

#### 3.6.3. Disposal costs

Any sort of disposal costs of the 'old' technology were not considered in the calculations.

#### 3.6.4. Incremental introduction

When introducing the 'new' technology no incremental introduction was assumed such as learning curves or gradual market penetration and moreover, no natural exchange rates of 'old' technologies were considered. Further, we did not pay attention to behavioral aspects, institutional barriers or market imperfections.

#### 3.6.5. Business As Usual scenario

There is no specific description of a Business As Usual scenario which would outline these measures that would be taken anyway.

#### 3.6.6. Emissions

The actual emissions in the production process of certain technologies were not included in the calculations, e.g. production of solar cells.

Many specific sources for primary data were needed for deriving the MACC. The most important variables needed for all sectors were derived from different sources: energy demand for the inefficient 'old' and the efficient 'new' technology (Lechner et al., 2004; Lang, 2007; Statistics Austria, 2007a, 2007b; Topprodukte, 2007), cost of different energy carriers in 2007 prices (Statistics Austria, 2007a; IWO, 2007), emission factors (Federal Environment Agency, 2003; GEMIS, 2000), and cost of investment in 2007 prices [in household and service sector cost of insulation (Lechner et al., 2004; Lang, 2007; Schriefl, 2007); various settings of change of heating systems (Lechner et al., 2004), household appliances (Topprodukte, 2007); transport sector (EC Transport, 2001; OECD, 2005), energy sector (Faninger, 2006; Nakicenovic et al., 2007; Fechner and Lugmayr, 2007)]. The multiplicators necessary for calculating the overall abatement potential from single case to national level were derived from Statistics Austria (2006, 2007b), Lang (2007), and Schriefl (2007).

## 4. The usefulness of MACCs

The method of presenting $CO_2$-e abatement potentials in form of bottom-up MACCs is challenging as it requires receiving the necessary data for conducting the calculations. If this requirement is fulfilled, MACCs give a clear picture of cost and amount of $CO_2$-e mitigation options. Each country has its own specific abatement cost curve independently of other countries' mitigation potential (Ellerman and Decaux, 1998). Although emission reducing targets are a global necessity, it is essential to consider a region specific abatement potential and its costs. How far this goal can be reached with abatement cost curves is discussed by critically reflecting on the usefulness of such curves. The following pros and cons should be kept in mind when looking at the presented results.

### 4.1. Advantages of MACCs

#### 4.1.1. Awareness

$CO_2$-e abatement cost curves are a suitable method for increasing the transparency and awareness of the availability and effects of environmental technologies, especially in a win–win scenario for the consumer and the environment (Beaumont and Tinch, 2004). When introducing a new technology, $CO_2$-e abatement cost curves provide a basis for the understanding of available technologies and their related costs and resulting benefits. This environmental knowledge should encourage people to make use of the less polluting alternatives. Rational economic agents would aim to achieve abatement at the least cost possible, which may also involve a mixture of different measures, as they affect several fields of daily life. Besides, both consumers and politicians should have the freedom to choose between various options and decide on the one that is most suitable to their own interests.

#### 4.1.2. Costs

It is sometimes argued that greenhouse gas mitigation options are "costly" without sufficient specification. Abatement cost curves depict more precisely the volume of costs since they also state the negative costs of abatement. Due to high investment costs, some mitigation options may be seen as very expensive although over time it is possible that they will be more cost-effective than initially cheap measures (Beaumont and Tinch, 2004). The abatement curves highlight this effect, which may otherwise be overlooked.

#### 4.1.3. Recommendations

The underlying calculations provide a clear picture of the abatement options and it is possible to carry out a straightforward calculation if all data is available (Ellerman and Decaux, 1998). The results can be seen as investment guidelines for consumers, entrepreneurs and politicians. Depending on the level of aggregation the amount of greenhouse gases abated by each measure is depicted. It also clearly shows which is the next, more expensive technology which must be applied in order to reach an additional abatement.

Given the advantages MACCs provide they are increasingly used to depict abatement options for several sectors and countries. Although extensive technological details are used there is an easy understanding of technology-specific abatement curves. Their strength lies in the presentation of the abatement potential and its related costs in a comprehensible way to politicians and other decision-makers (Kesicki and Strachan, 2011).

### 4.2. Disadvantages and potential pitfalls of MACCs

Although abatement costs curves provide many advantages, account must also be taken of some important issues that they cannot cover. The inherent structural weaknesses of the static model neglect the following aspects:

#### 4.2.1. Diffusion

Calculating a specific amount of money that should be invested to achieve a certain reduction potential does not take into consideration the difficulties in penetrating the 'technology market'. The diffusion rate plays an important role in the overall effectiveness of the implemented measure. The related time factor depends on a wide range of variables such as legal compliance, policy incentives and the market structure, to name but a few.

#### 4.2.2. Compatibility

Abatement technologies are not always compatible either with the current technologies or with a certain mixture of technologies. This lock-in effect may lead to increased costs when implementing the abatement measure (del Río González, 2008). In this study we focused on technologies which can easily be implemented with the existing technologies. More generally speaking, certain technologies are more cost-extensive in particular regions.

#### 4.2.3. Production

On the basis of a (theoretical) 100% penetration rate of the 'new' technology, it could be expected that the $CO_2$-e emissions level will fall by exactly the amount that engineers had calculated to derive the $CO_2$-e abatement costs. Unfortunately, this is not the case. Account is not usually taken of the fact that the production of certain energy efficient devices itself requires (sometimes a significant amount of) energy. The emissions induced by the production of the intermediate inputs ('technologies') also have to be considered when deciding on policy actions (Sonntag and Schubert, 2008).

#### 4.2.4. Energy prices

If energy prices change radically the cost curve turns to the left and makes it even cheaper to invest in a climate-friendly technology. Therefore, higher fossil fuel prices favor low carbon options (Stern, 2007). The contrary happens with a decline in the energy prices: this development would lead to a shift to the right, making GHG abatement more expensive and the financial incentive to investments weaker (ENVIROS, 2005). Energy market prices are also found to influence consumer decisions on energy consumption: a persistent increase in the energy price leads to a more energy efficient adoption (Gillingham et al., 2009) by replacing high energy consuming devices with more efficient ones. A special case is electricity supply (Anderson, 2006) because the abatement potential depends on the source used for electricity production and its related emissions. If the $CO_2$-e emissions from the electricity production process diminish the potential for any further mitigation, costs rise because a smaller amount can be abated at the same costs.

*4.2.5. Ranking by costs*

One of the core elements of $CO_2$-e abatement cost curves is a ranking of the measures that only relies on the costs of the abated $CO_2$-e and fails to consider the absolute amount that can be abated. The policy recommendation that can be drawn is simply to implement the cheapest measure first, preferring measures with a lower total saving potential but more cost-effective than those with a higher GHG saving potential in absolute terms. One empirical example is the use of low energy light bulbs, which has been analyzed in many studies (Joosen and Blok, 2001; Barthel et al., 2006; McKinsey, 2007; Stern, 2007) as well as in ours, and which proves to be one of the cost efficient measures with very low costs of abatement. The potential saving amount is low compared to other measures, but nevertheless national and European energy policies are introducing regulations that will limit the use of conventional light bulbs step by step over the years to come. Also for competitive reasons it is recommendable to prefer cheaper contributions to $CO_2$-e mitigation but it should be kept in mind that it is not only the costs that are the decisive factor. Political advice should also include measures with a high technological potential, such as photovoltaic systems, in order to achieve mitigation targets and to reduce the costs by increasing market diffusion.

## 5. Results

The calculated measures differ widely in financial costs and in amount of greenhouse gas emissions avoided. Summing up, the results set out in Fig. 1 show that the eight measures below the 0° line show negative costs of abatement and can lower emissions by 18.5 Mt $CO_2$-e. The interpretation of the first measure can be construed in the following way: the first 0.2 Mt $CO_2$-e can be abated at a profit of 694€/t $CO_2$-e by the introduction of efficient electricity systems in the service sector, the next 0.6 Mt $CO_2$-e at a profit of 658€/t $CO_2$-e by using low energy light bulbs and so on.

### 5.1. Household sector

Saving potential was found in the fields of building insulation, fuel switches in heating, efficient brown, cold and wet appliances and lighting, which can be seen in detail in Fig. 1. The accumulated savings potential without overlapping emissions is 11.44 Mt $CO_2$-e from which 4.46 Mt $CO_2$-e can be avoided with profit of abatement and 6.98 Mt $CO_2$-e with cost of abatement.

The biggest GHG mitigation potential could be achieved by insulating single dwellings followed by fuel switches of the heating system (see measure 10 in Fig. 1), which could reduce greenhouse gas emissions by 6.6 Mt $CO_2$-e. The cost of abatement is calculated at 154€/t $CO_2$-e (see also Table A1 in Appendix A). Furthermore, an enormous reduction would be provided by insulating and switching fuel of multiple dwellings with emissions avoided of 4 Mt $CO_2$-e and profits of abatement of 72€/t $CO_2$-e. The overall mitigation potential in the building sector sums up to 10.6 Mt $CO_2$-e which is comparable to the Swiss mitigation potential of 11.3 Mt $CO_2$-e (Ziegler and Battig, 2009). If single measures are compared with other studies the results are similar: building insulation of multiple dwellings has a cost of abatement of −81€/t $CO_2$-e by decreasing the yearly heating demand from 122 to 48 kW h/m$^2$, whereas McKinsey (2007) has a lower cost of abatement with −133€/t $CO_2$-e but only reduces heating demand to 70 kW h/m$^2$ (McKinsey, 2007). In case of building insulation for single dwellings the calculations result in 229€/t $CO_2$-e, whereas in Barthel et al. (2006) cost of abatement is given at a comparable number of 200€/t $CO_2$-e. It is important to consider that the abatement potential in case of single and multiple dwellings is likely to be overestimated. The reason lies in the long term nature of building insulation and of fuel switches in heating systems because the assumption of a 100% market penetration ignores recently conducted building insulation or fuel switches in heating systems. Nonetheless, the theory of sunk costs suggests that these costs should not be regarded in future investment decisions,

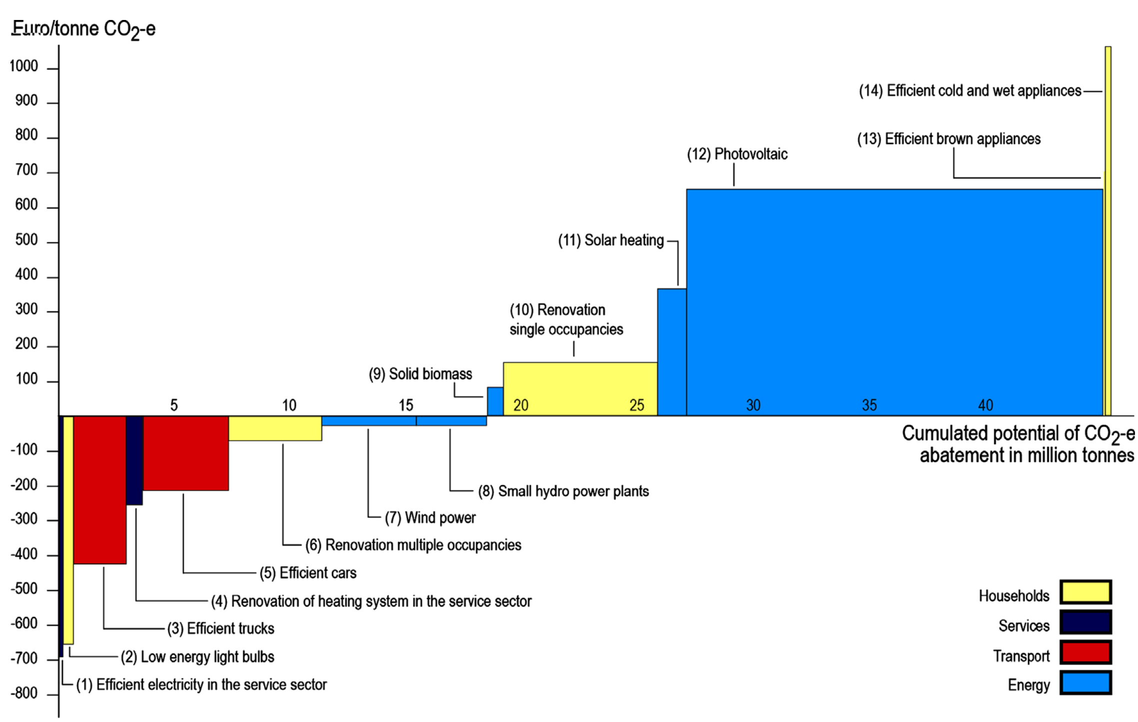


**Fig. 1.** $CO_2$-e abatement cost curve for Austria as of 2007.

therefore it would lead to a suboptimal result not to invest in these abatement options. However, the results would have differed if replacement rates had been considered in the construction of the MACC. Although the financial cost for single dwellings is positive (notice that they are negative for multiple occupancies), policy makers would be well-advised to invest in this alternative e.g. through financial incentives to make it more attractive for house-owners. In the case of Austria, there are governmental subsidies for building insulation but experts doubt their overall effectiveness due to the small amount of money provided. If we look at the results of the single fuel switch measures, the recommendation can be made to change the heating system from electricity to biofuels (the example calculation was made with wood pellets) because it was the cheapest fuel switch measure with a cost of abatement of –194€/t $CO_2$-e. With a share of 7.8% of all heating systems in Austria (Statistics Austria, 2001) it would be possible to avoid 0.6 Mt $CO_2$-e a year. If the price for fossil fuels increases, the cost of abatement falls and makes it more attractive to invest in a more environmentally-friendly heating system. It should be stressed again that this does not mean that the cost of investment is lower but that the relation between the saved emissions and the cost of abatement is more favorable.

The most cost efficient alternative is the use of low energy light bulbs which could save up to 88% of energy and of the related emissions. This option also shows one of the most efficient profits of abatement, i.e. 658€/t $CO_2$-e, although the absolute $CO_2$-e emissions avoided are only calculated at 0.6 Mt $CO_2$-e. In McKinsey (2007), the cost of abatement is calculated as −156€/t $CO_2$-e but in their report it was admitted that this measure would have been less expensive when calculating with full life-time instead of only 4 years (McKinsey, 2007). Nonetheless, based on these findings, the gradual prohibition of the production and selling of conventional light bulbs and pearl light bulbs beginning in September 2009 as introduced by the European Union is—for obvious environmental reasons—a step into the right direction (European Commission, 2009).

The saving potential in the field of brown, cold and wet appliances is comparably low and amounts to 0.37 Mt $CO_2$-e (see measures 13 and 14 in Fig. 1) at the very high cost of 702€/t $CO_2$-e for brown appliances and 1063€/t $CO_2$-e for cold and wet appliances (see also Table A1 in Appendix A). As mentioned in Section 3 the high abatement cost is the result of a lack of data for comparing the 'old' with the 'new' technology. It can be assumed, therefore, that the saving potential is higher because the old appliances are more energy-intensive than even the most inefficient ones on the market nowadays, which were used for the calculation of $CO_2$-e abatement costs. The energy consumption of the new appliances should be a decisive criterion for all consumers to consider.

### 5.2. Service sector

The most efficient measures in the service sector are the efficient use of management systems for electricity and the replacement of the heating systems. The most beneficial turns out to be the introduction of efficient electricity systems with a profit of abatement of 694€/t $CO_2$-e and emissions avoided of 0.2 Mt $CO_2$-e (see measure 1 in Fig. 1). Through replacement of the heating system, 25% of the energy used can be saved, which results in a 258€/t $CO_2$-e profit of abatement. Like in other studies (Lechner et al., 2004) it can be shown that measures concerning buildings in the service sector are amongst the most cost efficient ones. There is also an energy saving potential in the insulation of buildings but as there is insufficient data available it was not possible to quantify the saving potential. The same holds true for the fields of electrical appliances in offices, lighting in buildings and streets and cooling systems (Joosen and Blok, 2001), where no data is available for Austria, either. It can be assumed that the saving potential in the service sector is much higher than could be calculated and that all private and public authorities are expected to minimize the costs for their organization by implementing the cost and energy efficient solutions.

### 5.3. Transport sector

Only technical improvements concerning efficiency and fuel use were calculated for the $CO_2$-e abatement costs. Policy measures like the extension of public transport or any alternatives concerning a fuel switch of cars and trucks could not be considered in the calculations. All single measures for cars and trucks were summed up to one single measure, without overlapping potentials, and both show negative costs of abatement (trucks −428 and cars −216€/t $CO_2$-e; see measures 3 and 5 in Fig. 1). Due to the aggregation of all single measures no comparison to other studies could be conducted. The emissions saved by full implementation are 6 Mt $CO_2$-e.

Especially in Austria, where emissions from the transport sector nearly doubled last 20 years, it is important to figure out that nearly one-third of sector's emissions could be avoided by technical measures only. The aggregate measure for trucks suggests avoiding 2.3 Mt $CO_2$-e which is based on the assumptions about reduction on fuel demand due to weight reduction, rolling resistance reduction, engine improvements, and aerodynamic drag reductions. In case of the aggregate measure for cars, the result differs depending on the assumption how many cars undergo which efficiency measures. If all cars only undergo efficiency improvements total abatement potential would be even higher with 5.5 Mt $CO_2$-e in comparison to the case where all cars switch to the most efficient car in the regarding vehicle category where the abatement potential is calculated with 2.9 Mt $CO_2$-e. Due to the increase in fuel prices in recent years it is expected that the €/t $CO_2$-e ratio becomes even less as higher energy prices favor carbon options. Nonetheless, the measures show which enormous abatement potential lies in these technical measures alone and that even without any radical change of the transport system it is possible to save enormous amounts of $CO_2$-e.

### 5.4. Energy sector

The results of the energy sector show that by using renewable energy sources for the production of electricity and by using solar heat 25.8 Mt $CO_2$-e could be avoided, which is more than one quarter of Austria's overall $CO_2$-e emissions. Within the identified measures, photovoltaics have the biggest capacity to avoid emissions, 17.9 Mt $CO_2$-e (see measure 12 in Fig. 1). Unfortunately, this is still one of the most expensive alternatives with costs of abatement of 652€/t $CO_2$-e. As the calculation was based on the theoretical assumption to include all roofs and facades available in Austria it can be assumed that the actual abatement potential is lower if areas with low efficiency are excluded. However, it can be expected that this technology will become cheaper within the next few years and that as a result the financial incentive to invest will increase. Electricity from small hydro power plants is seen as part of Austria's energy future. On the one hand, the costs of abatement at −29€/t $CO_2$-e lead to the recommendation to invest in this technology, and on the other hand small hydro power plants also provide an alternative for regional energy autarchy. Further fields identified include wind power, which is also calculated at negative costs of abatement of −31€/t $CO_2$-e, and 4 Mt $CO_2$-e could be avoided this way. These comparably low abatement costs (see e.g. McKinsey, 2007: 15€/t $CO_2$-e) are due to the assumption that full technical feasible wind power potential is exhausted. By electricity production from solid biomass 0.72 Mt $CO_2$-e can be avoided at a cost of abatement of 83€/t $CO_2$-e which is especially important in Austria due to its large amount of forested land. To tap into the full potential in electricity production would imply less dependency on electricity imports and less overall use of nuclear power and fossil energy sources. The option solar heating results in cost of abatement of 367€/t $CO_2$-e and an abatement potential of 1.25 Mt $CO_2$-e but it can also be expected that costs will decrease in the near future which would lead to cheaper cost of abatement.

The explicit goal of energy policy in most Western countries is an increase in the share of renewables in energy production. The abatement potential and its related costs serve as guidance for policy-makers about possibilities enhancing a less environmentally harmful energy production. Despite calculating with average investment costs for power plants of different renewable energy sources the results show nonetheless the huge abatement potential that could be achieved by using renewable energy sources for energy production.

### 5.5. Sensitivity analysis

To prove the robustness of the results a sensitivity analysis was conducted by varying three of the key parameters of the MACC: cost of investment, potential of energy savings, and discount rate. Three scenarios were developed where parameters varied according to different assumptions. Regarding estimates concerning future developments it is not very likely that these three parameters develop worse than previous calculated, therefore only more favorable scenarios were defined. Scenario 1 describes an optimistic scenario where improvements in energy savings were assumed with further 50%, a very favorable discount rate of 0.5% (using the same as in Stern, 2007) and a reduction of investment costs of further 50%. The measures of the energy sector were changed according to estimates of their potential in 2050 and according to learning rates leading to lower costs of investment which were especially low in case of photovoltaic. The resulting MACC shows that only two measures still have positive values: using biomass for electricity production results in 49.25€/t $CO_2$-e in comparison to originally calculated 83.03€/t $CO_2$-e which is due to lower efficiency improvements and lower savings in the investment costs than all other measures. The costs of abatement for photovoltaic result in 10.78€/t $CO_2$-e in comparison to originally calculated 652.42€/t $CO_2$-e which is the result of very high learning curves of the costs of investment of 75%. The overall abatement potential increases from 45.4 to 66.7 Mt $CO_2$-e. Scenario 2 is even more optimistic by assuming improvements in energy savings of further 80%, costs of investment decrease by further 75% and a discount rate of 0.5%. Again, different assumptions for the measure of the energy sector were assumed reflecting the lower energy saving potential of biomass which results in the only measure with positive abatement costs of 37.27€/t $CO_2$-e. The total abatement potential is 70.6 Mt $CO_2$-e which would correspond to the Austrian contribution of the goal of an EU-wide GHG emission reduction of 80% in 2050 to avoid an increase of global temperature of more than 2 °C. Scenario 3 is less optimistic with improvements in the potential of further 10%, a decrease of the costs of investment of further 10% and a discount rate of 2%. Even with pessimistic assumptions about learning curves and potential improvements only five measures show positive costs of abatement resulting in a total abatement potential of 52.64 Mt $CO_2$-e. The analysis has shown that the calculated emissions savings are likely to be improved as the literature analysis suggests favorable developments of all three parameters. If the assumption of a 100% market penetration is not fulfilled it could mean that it will be compensated partly by the development of the three parameters.

## 6. Conclusions and outlook

In the public debate it is commonly argued that measures for climate protection are cost intensive and are not really feasible alternatives in times of an economic crisis. By calculating $CO_2$ cost of abatement curves we have shown which measures provide a high potential of avoiding greenhouse gas emissions and what these costs are for each abated ton of $CO_2$-e. Eight measures with negative costs of abatement were identified that add up to a $CO_2$-e emission saving potential of 18.5 Mt $CO_2$-e in Austria. If this potential is fully exhausted it would even exceed the abated $CO_2$-e amount needed of 15.6 Mt $CO_2$-e to fulfill the Kyoto Protocol. An additional implementation of all the six measures with positive abatement costs would save another 26.9 Mt $CO_2$-e and 2007 emissions of 87 Mt $CO_2$-e (in 2009: 80.1 Mt $CO_2$-e) could be more than halved to 41.6 Mt $CO_2$-e (in 2009: to 34.7 Mt $CO_2$-e ) through the 14 cumulated measures.

The results show the huge abatement potential that lies in energy efficiency measures. While no single technology or solution can solve the problem entirely on its own, they have an impressive potential when used jointly. The results emphasize the importance of energy efficiency measures and want to make a contribution to raise the awareness of the unused $CO_2$-e abatement potential. Imperfect and asymmetric information is considered as one of the main barriers in implementing energy efficiency measures. MACCs pose a possibility to provide information that is easy to communicate, and the advantage of energy savings and their positive or negative costs are visible at a glance. The specific Austrian $CO_2$-e abatement curve gives evidence to possible financial advantages in the areas of household appliances, transport, renovation of multiple occupancies and energy. Using this valuable information raises the transparency of energy efficiency measures.

Providing information is one first important step, and it is then up to the policy makers to enforce the dissemination of the results to the public and also to provide financial support to overcome a second barrier of implantation: capital constraints and access to capital. With financial subsidies, e.g. for the investment costs, it would be a societal sign to environmentally friendly enhancement. The detected measures with negative abatement cost should be the first to be focused on by monetary incentives or grants. This could be supplemented by the expansion of codes and standards regarding energy efficiency measures. If households as well as private and also public organizations face the problem of insufficient capital to invest in suitable incentives and grants, internal or external funding based on investment rules incorporating environmental guidelines and standards must be enforced.

The results of MACCs are often compared to current and future carbon permit prices to indicate their economic efficiency. The created market system of buying and selling certificates that allow emitting $CO_2$ is in the focus of critique by the following reasons: From an ecological point of view, carbon market lacks in incorporating all other GHGs which currently makes approximately one-fourth of all GHG emissions. Moreover, this system is not effective in terms of reducing GHG emissions as absolute emissions have grown and still are growing steadily in the economic sectors incorporated in emission trading. From an economic point of view, looking at the price levels only shows that current low prices of carbon certificates make them an economically efficient option to emit $CO_2$. But one of the reasons for the low price level is that too many allowances were issued at the beginning and further development shows that demand was lower than actual supply leading to a price level of nearly zero Euros in 2007 and nowadays of about 3€. Besides, the costs of transaction, information, and controlling needed for trading carbon permits are not reflected in the price level and valuing ecological impacts of $CO_2$ emissions is not incorporated at all. From a political point of view, the low price

**Table A1**
Results for $CO_2$-e abatement measures in all sectors.

| Measures<br>Units | Total cost of investment<br>(€) | Total energy savings<br>(kW h) | $CO_2$-e saving potential<br>(tons per year) | Relative $CO_2$-e saving potential<br>(%) | Costs of abatement<br>(€/tons $CO_2$-e) |
|---|---|---|---|---|---|
| (1) Efficient electricity in the service sector | 597,595,308.54 | 1.206.125.000,00 | 195,392 | 15 | −694.13 |
| (2) Low energy light bulbs | 778,128,438.75 | 2.758.582.425,00 | 446,890 | 88.3 | −657.78 |
| (3) Efficient trucks | 924,147,576.00 | 8.479.810,61 | 2,271,097 | 21 | −427.51 |
| (4) Renovation of the heating system in the service sector | 731,006,807.31 | 2.980.277.777,78 | 690,056 | 25 | −257.96 |
| (5) Efficient cars | 10,258,186,663.80 | 13.912.581,76 | 3,732,488 | 31.4 | −215.69 |
| (6) Thermal insulation and fuel switch of multiple occupancies | 17,622,319,923.00 | 15.163.750.836,83 | 4,013,669 | 63.4 | −72.35 |
| (7) Wind power | 2,805,985,000.00 | [a] | 4,057,690 | 100[b] | −30.96 |
| (8) Small hydro power plants | 2,736,000,000.00 | [a] | 3,051,230 | 100[b] | −29.27 |
| (9) Solid biomass | 449,460,000.00 | [a] | 722,995 | 100[b] | 83.03 |
| (10) Thermal insulation and fuel switch of single occupancies | 54,303,605,067.38 | 23.286.523.533,54 | 6,628,316 | 55.9 | 154.22 |
| (11) Solar heating | 13,718,108,372.11 | [a] | 1,246,014 | 100[b] | 366.76 |
| (12) Photovoltaic | 182,990,500,000.00 | [a] | 17,936,200 | 100[b] | 652.42 |
| (13) Efficient brown appliances | 878,478,380.55 | 410.326.817,52 | 66,473 | 57.6 | 702.50 |
| (14) Efficient cold and wet appliances | 6,261,878,007.30 | 1.734.405.783,52 | 280,974 | 56.8 | 1063.17 |

[a] Due to a change in the energy resources only there is no energy saving.
[b] The underlying assumption is that in the energy production sector, energy from fossil fuels is replaced by zero carbon energy resources.

level does not give any incentive to avoid $CO_2$ emissions and to search for low-carbon options. Moreover, not all parties involved have the same power in price negotiations. Market power of some firms gives them the ability to manipulate prices, to collude or use mark-ups (Spash, 2010). Current poor institutional design of the carbon permit market does not contribute to an effective climate policy but hopefully framework conditions change enhancing a low-carbon policy.

By critically reflecting on the advantages and disadvantages of MACCs it could clearly be shown what MACCs can be used for. Their strength lies in the provision of transparent information and they can easily be compared with other MACCs. Any changes in energy prices, costs of technologies or policy responses are not incorporated in the calculations, which is a limiting factor on the advantages of MACCs. Although the likelihood of the calculated costs of the measures is very high we admit a certain uncertainness regarding future costs. An important contribution is the two step aggregation of measures in the household sector where we could calculate the $CO_2$-e abatement potential for the whole energy scenario. The results can further be compared to other research outcomes, and they underline the uniqueness of MACCs for every country.

Future research is needed to update the curves. Marginal abatement cost curves can be seen as a snapshot of the status quo and should therefore continuously be updated. New technological opportunities and lower costs of existing technologies should also be the basis of new calculations for deriving the costs of $CO_2$-e abatement. With an extended availability of exact data it would be possible to achieve a more solid scientific basis for making statements about the economic and ecological impacts of $CO_2$-e mitigation options.

## Acknowledgments

The author wishes to thank the Austrian National Bank and the World Wildlife Fund Austria for funding the study “MEFA—Monetary Energy Footprint Analysis” prior to this paper and the Institute of Technology Assessment of the Austrian Academy of Sciences for providing the possibility to write this paper. In addition, the author would like to express her gratitude to Prof. Dr. Uwe Schubert for his comprehensive support throughout the whole project. Furthermore, special thanks go to all project members; without them writing this paper would not have been possible. The author is also grateful to Prof. Dr. Sigrid Stagl for her critical and useful comments and motivating words. Heartfelt thanks go to Prof. Dr. Myrtill Simkó for her comprehensive support and understanding. The author wishes to express her deepest thank to Werner Kabelka for his graphical and mental support.

## Appendix A

See Table A1.

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## Anhang B

Wächter, P. (2013): The Impacts of Spatial Planning on Degrowth. Sustainability 5 (3), 1067-1079

http://www.mdpi.com/2071-1050/5/3/1067

*Sustainability* **2013**, *5*, 1067-1079; doi:10.3390/su5031067

OPEN ACCESS

*sustainability*

**ISSN 2071-1050**

www.mdpi.com/journal/sustainability

*Article*

# The Impacts of Spatial Planning on Degrowth

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*Received: 8 November 2012; in revised form: 31 January 2013 / Accepted: 4 February 2013 / Published: 7 March 2013*

**Abstract:** As the current growth economy has created severe environmental pollution and unbalanced distribution of prosperity, there is an increasing amount of critical voices calling for a change. The new concept of degrowth addresses a fundamental change in political, economic and institutional levels underpinning different norms and values towards sustainability. Spatial planning institutions have a decisive role in the transition process insofar as they take decisions regarding the use of land and its attributed space. Especially in three areas spatial planning has influential potentials to stimulate the transition process towards degrowth by enhancing: (i) a sustainable use of renewable energy sources; (ii) sustainable settlement structures; and (iii) the creation of social capital by more community based facilities. The paper explores these possibilities for intervention and shows how spatial planning can have positive impacts on degrowth.

**Keywords:** degrowth; spatial planning; settlement structures

## 1. Introduction

Economic growth and how it is measured has been in the center of criticism for decades. The basis of this criticism is that in a biophysical system with finite resources it is impossible for an economy based on these resources to grow infinitely. The new movement of degrowth, *i.e.*, socially sustainable economic degrowth, gives insight into a more holistic approach towards less exploitation of natural resources, more worldwide equality and a better quality of life. Human progress does not rely on growth enhancing market relations but instead the focal point of interest should be placed upon the broadening of human relationships and the deepening of democracy [1]. Degrowth should not be seen as the counterpart of growth nor as a form of economic recession, but as a voluntary transition to a stadium of less production and less consumption.

In the discussion about degrowth and a sustainable use of resources land and how it is used, the basis of our daily lives and of all our activities, is sometimes forgotten about. In this context, spatial planning institutions have a decisive role to play in determining land use and are responsible for the planning, structure and design of landscapes. There are in particular three aspects in which spatial planning is a crucial factor for degrowth: Firstly, on the one hand, energy demand depends on how land is structured, and on the other, spatial planning can influence if and how renewable energy sources are used. Secondly, how settlements are structured and what this means for resource use also lies in the hands of spatial planning institutions. Thirdly, settlement structures have an impact on the social organization of their inhabitants and on the formation of social capital. This shows how spatial planning as a cross-sectional issue affects relevant topics for sustainable degrowth.

The aim of this paper is to focus on the role that spatial planning institutions can play as an example for institutional change towards sustainable degrowth. It wishes to show the institutions' importance in a transition process by portraying the role these institutions play in the production process of renewable energy and in deciding about settlement structures that in turn influence social capital. Further, it addresses the potential that spatial planning institutions already have which can serve as a point of conduct for a transition towards sustainable degrowth to avoid abrupt societal changes. Based on findings from studies of the area of spatial planning the paper provides theoretical considerations and concrete experiences how spatial planning can enrich the discourse about sustainable degrowth.

The paper is structured as follows: After the introduction in Section 1, Section 2 describes the origins and some of the claims of the currently emerging degrowth movement. Section 3 illustrates the importance of spatial planning and its institutions concerning renewable energy sources, explores the potential of settlement structures for sustainable degrowth and emphasizes the importance of multi-functional settlement structures for the building of social capital. The paper ends with the conclusions in Section 4.

## 2. Sustainable Degrowth

The term "degrowth" has its origins in the French word "décroissance" and tries to capture the manifold paths of a transition to sustainability on different levels of approaches. The catchword "degrowth" addresses a voluntary transition to lower levels of material throughput and less materialistic wealth. However, degrowth is much more than just that. The concept of degrowth in the scientific community attracts those scholars who deal with the limits of economic growth and search for alternative paths to prosperity [1–4]. As a political approach degrowth includes democracy, equality, justice, and self-determination aimed at a society with more direct democracy enhancing structures than we have at present [5,6]. Last but not least degrowth is a social movement including numerous groups, initiatives and associations around the globe [1,7], which advocate values and norms other than the growth paradigm in a large number of projects and initiatives. What defines degrowth is that it incorporates all three strands of approaches in a complementary manner, which can indeed be considered as a new attempt to a transition towards global sustainability.

Less environmental pollution, less resource use and less energy use are not only claims of degrowth. Whereas other theories such as Green Growth see dematerialization and efficiency improvements as the key-solution to current environmental problems, degrowth emphasizes changing the underlying system that has caused this severe environmental depletion [8]. If current economic growth rates continue, the envisaged climate stabilization target of 450 ppm in 2050 can only be reached, if efficiency improvements are ten times faster each year than it is currently the case [9], which is not feasible. Renewable energy sources provide a clean alternative to fossil energy sources in most cases, but also hold the danger of overusing ground, water, air and of needs which are in competition with each other, as the ongoing "food *vs*. fuel" debate shows. As no options exist that could bring energy and resource use to sustainable levels with the current technology, a call for less resource use is the only alternative left. This development has to go hand in hand with a change of institutions, culture and societal networks, which would not be successful in any other way.

Institutional change is needed where the capitalist rationality is subordinated towards an eco-social rationale in which economic activities are subordinated to social and ecological imperatives. The institutions are also criticized because they tend to create multiple impediments to people's autonomy [2]. Although there is no clear concept so far of which institutions should change in what way, there is a general agreement within the degrowth-community that the aim of a post-capitalist alternative requires institutional breaks. Examples of 'new degrowth institutions' include institutions that guarantee a minimum of health and economic security to all [4]. To incorporate the plurality needed in a degrowing society from the beginning, new institutional settings should emerge from bottom-up rather than be implemented from top-down.

Degrowth can also be seen through the concept of natural and social capital. In economic terms, natural capital refers to any stock of natural assets that brings a flow of monetarily valued goods and services. Social capital refers to features of social organisation such as networks, norms or trust which increase a society's productive potential. Social capital can also be seen as a public good since it is not private property of those who benefit from it. What is actually demanded by the degrowth movement is a substantial decrease of the use of natural capital towards sustainable levels without any depletion of natural resources [10]. Instead, social capital should be enhanced, meaning that all features of social capital should be in the focus such as knowledge, understandings or interpersonal interactions. These skills are used to build on bonds of information, trust and interpersonal solidarity. Social capital is not limited by material scarcity and is not driven by illogical thinking of unlimited growth within finite resources. On the contrary, social capital can be increased nearly infinitely and is only constrained by the capabilities of human nature. Therefore, the increase of social capital stands for a basic claim within the degrowth movement: orientation towards values other than unlimited growth.

Spatial planning institutions constitute one of the many institutions that have an impact on energy use, institutional framing and social capital. The crosscutting research field of spatial planning gives theoretical foundations on how the use of land is structured and where regions, cities, villages, and settlements are located and how they are organized. In practice, it is spatial planning institutions, which take decisions over land use mainly by enforcing the strong instrument of dedication of land. According to the powerful decisions of spatial planning institutions, how many resources are needed is determined and how the design of landscapes and cities is to be performed. As these structures also determine the organization of daily activities embedded in a social environment, they are decisive for social skills and relationships subsumed under the notion of social capital. Therefore, the intention of this paper is to further explore how spatial planning institutions could enable a structural framework which contributes to a transition towards degrowth.

## 3. Sustainable Spatial Planning for Degrowth

Economists quickly recognized that land has a special role in economic production as it is impossible to augment the amount of land which is, therefore, much less elastic than the supply of capital goods [11]. Late in the 20th century, land and environmental resources in general completely disappeared from the production function, leaving capital and labor as the only inputs [11]; later still capital is the only remaining input factor left. This trend even strengthens the view of endless substitution possibilities between input factors. However, this development leads to manifold criticism because certain aspects such as irreversibility, non-substitutability of production factors and the pervasiveness of external effects are not adequately reflected upon. Moreover, more recent approaches replace land (and also natural resources) with their assigned monetary values. As land and its use has a key function in living and production processes it can be regarded as its basis.

Spatial planning institutions have the power to decide over land and its use. Depending on national regulation, they differ widely in range and scope and in particular in competences on a local, regional and national level. The perspective taken here focuses mainly on the Austrian situation, but is applicable to all countries where spatial planning institutions have a similar structure and competencies. However, spatial planning institutions operate largely on a regional basis and can be regarded as one of the responsible institutions for local environmental development. Even more, spatial planning institutions are decisive in forming a region's infrastructure and its further development, as they are the determining authority that decides where and which infrastructure is built and maintained [12]. The possibilities of intervention can be found in the strong instrument of dedication of land, further the use for (renewable) energy purposes, for infrastructure of transport, for settlements, commerce and industry as well as in planning decisions in local and regional spatial development concepts and in local planning maps. Therefore, spatial planning authorities can be regarded as one of the influential institutions in the organization of basic needs such as food, housing or work and they can determine the conditions for daily life to a large extent.

### *3.1. Renewable Energy Sources for Sustainable Settlements*

Energy and land use are mutually connected: on the one hand, the production and utilization of energy has impacts on land use and, on the other hand, the use of land determines energy consumption [13]. A sustainable energy system aiming at less GHG emissions has to rely on renewable energy sources, which need a greater amount of land per unit of produced energy than exhaustible energy sources, especially the use of biomass but also solar energy or wind on a large scale. This focuses increased attention on the intertwined relationship between energy and land use. Land use can be considered as "the most important environmental consideration in the development of these resources" [14], because land needs are a potential constraint to make use of renewable energy sources. How land use is planned and organized largely determines energy consumption. It is estimated that more than half of the energy demand in the developed world can be assigned to the arrangement of land uses [15].

Although the use of renewable energy sources is not free from controversies, they constitute the basis for each sustainable energy system. As the availability of renewables differs widely within time and the seasons as well as location, each region and even each municipality has its own possibilities to make use of the supply of renewables on site. A more regional based energy supply therefore requires more intensified regional spatial planning. Spatial planning institutions play an important role insofar as they can provide detailed resource plans for each region and municipality to demonstrate the expected potentials each renewable energy source offers (see, e.g., for Austria [16]). Further, the strong instrument of dedication of land makes it possible to use the envisaged potentials as they give the legitimacy to use land for the production of renewable energy. Nonetheless, the potential sustainable renewable energy sources provide is likely to be overestimated, if the energy needed to produce energy, *i.e.*, their energy return on investment (EROI) is taken into account [17]. Therefore, it has to be doubted that the sustainable use of renewable energy sources can satisfy current energy demands, which means on the one hand a reduction in energy use and on the other a comprehensive re-organization of energy production and use.

Energy-conscious spatial planning also depends on settlement structures. Existing settlements can adapt according to their possibilities ranging from building new power plants using renewables to installing solar panels on roofs and façades of houses. Newly built settlements should be placed where the supply of renewables is on site or nearby. The use of certain energy sources also depends on the settlements' densities: in settlements with higher density, local heating systems are recommended whereas in lower density settlements solar energy may be the more useful alternative. If the potential supply of renewables is limited, municipalities and regions can seek out co-operations in their adjacent surroundings for regional energy networks. It is especially this aspect which is essential for spatial planning institutions, as they can make a contribution for such co-operations in providing spatial information on energy resources, on potential sites for power plants and on energy concepts and models.

One important differentiation has to be made between renewables for heat production and renewables for electricity production. While the distance between heat production and its use should be as short as possible to avoid thermal losses, the distance from electricity production to its use can be much larger because even in far distances losses through transport are smaller. Nevertheless, most favorable electricity production remains on site which means placing the production sites on the most suitable places. As some forms of electricity production such as using wind power can provoke local resistance it is unavoidable to incorporate local population in decisions about power plants. In support of a sustainable use of renewable energy sources, spatial planning institutions should make use of their planning competencies in regard of a sustainable management of land use for renewables.

The special role spatial planning institutions can play is to ensure a sustainable use of renewables, *i.e.*, to avoid any overuse of land, water and air. Spatial planning has to respect the limits of sustainable resource use and to secure that no irreversible damage is done by the use of renewables. While sustainability goals are established in most guidelines of spatial planning institutions, their concrete formulation remains vague and full implementation is rare. The call for more energy-conscious spatial planning [18,19] is not new to the planning community and within the degrowth community the potential of spatial planning institutions to contribute to a more sustainable use of energy sources has not been sufficiently addressed so far. Although the connection of energetic metabolism and space has already gained attention [20], spatial organization and its impacts on energy demand are hardly discussed. In the organization of a sustainable energy system, it is essential to incorporate spatial planning institutions.

### *3.2. Sustainable Settlements for Sustainable Degrowth*

Over the past few decades many industrialized countries have been confronted with an unsustainable development of land use and settlement structures. Ongoing tendencies show an increased per capita land use in developed countries, for example in Austria sealed area per capita nearly tripled in fifty years from 200 $m^2$ in 1955 to 560 $m^2$ in 2005. The main reasons for this development can be found in the increased demand for single and two family houses, for industrialized and commercial sites and their related infrastructure, and in the increasing infrastructure for mobility. Together with an intensified use of agricultural areas the process of an increase of sealed area above sustainable limits continues. In Austria, the sustainable limit of an increase of sealed area is set by 1 ha/day but current development shows an increase of 7.5 ha/day which is far above the envisaged goal. Although this indicator neglects the intensity of use, it clearly shows how much area is in human use and not available for ecological functions [21].

In the field of spatial planning, two phenomena related to increased land use are to be dealt with: urban sprawl and mono-functional settlement structures [22]. Urban sprawl is the term for unregulated development of settlements often leading to dispersed settlements and is regarded as a result of societal organization in space and time [22]. This development of urban sprawl was possible because land in the open country was more affordable than the one near the big cities and energy prices were cheap enough to upkeep the houses [23,24] and to use motorized individualized transport, e.g., own cars [25]. Therefore, there has been a steady rise in mono-functional settlements with living purposes only, which in turn has led to a huge increase in commuter traffic. Apart from the traffic causing GHG emissions and noise, the required network of streets cuts through ecologically important connections within areas, and the habitat of fauna and flora. Besides, mono-functional settlements lack a mix of daily needed amenities such as working places, shops, recreational facilities, schools, kindergartens, health services and so forth [26]. The missing infrastructure enhances the overuse of resources even more, as well as making journeys more time consuming than necessary compared to where used infrastructure is in place. Moreover, spreading settlement structures increase the costs of construction and maintenance of infrastructure systems, especially the costs of systems depending on networks and grids increase substantially. At the same time, infrastructure facilities in cities have to be closed while being newly opened in the suburban areas, the costs of which have to be taken over through public expenses. Therefore, it is urban sprawl as well as mono-functional settlement structures that enhance immense resource use and high societal costs.

For decades, a number of driving forces has caused unfavourable developments of urban sprawl [22]. First, settlement structures themselves produce certain patterns of location and mobility, such as functional specification or social segregation. Political regulation enforces urban sprawl by instruments such as subsidies for single dwellings, tax incentives e.g., commuter tax allowances, land use planning or settlements of companies. Economical structural changes can lead to urban sprawl together with logistical concepts such as just-in-time-production or distribution of goods on the roads instead of on the rails. Additionally, behavioral and ideological changes lead to an idealized picture of "a happy family in their own single family house with a garden and a car in the driveway" which shows the societal requirement for success and status at the expense of increased land use. These drivers show explicitly how a society has developed and is organized in its attributed space.

As it is more difficult to push unsustainable settlements on a path towards sustainability than building new sustainable ones, the opinions on how to make the necessary transition differ widely. The most radical measure would be an expropriation of owners of dispersed settlements similarly to the expropriation for the building of new streets where the reasoning is based on overriding societal importance. A less forceful measurement consists of a process of redensification with the intention to make use of unused space within existing settlements. This provides the chance for spatial planning institutions to initiate multi-functional structures with a mix of daily needed infrastructure. If these facilities were within walking distance, in many cases less cars would be used [27,28]. In urban regions, revitalization and the (temporary) utilization of vacant buildings provides a possibility of structural change of unused dwellings. A different view expects this change to happen anyway when energy prices rise and this life-style becomes less affordable for less people, as high energy prices probably entail that present resources are more likely to be used on a communal basis.

Regarding options for further development of new settlements, spatial planning institutions are well advised to make use of the strong instrument of dedication of land. As dedication of land is the legal basis for the location of new dwellings, it lies in the hands of spatial planning institutions to foster or prohibit urban sprawl and other forms of unsustainable development of settlements. A further option consists of governing and curtailing the unregulated development of settlements by binding concepts and regulations in spatial development plans. One measure to restrict the consumption of resources consists of a quantitative limitation of daily greenfield consumption [29] which would be, at least in the case of Austria, an enforcement to respect sustainable limits.

As most settlements show uniqueness in some attributes, the identification of limiting factors for sustainable development has to be tackled by planning institutions [30]. The call for more sustainable infrastructure for settlements has existed for decades. As spatial planning institutions so far have not succeeded in implementing even minimum sustainability standards in planning issues in the present system in most Western countries, it is system-immanent structures that make the impact of spatial planning much weaker than it should be. Spatial planning forms the basis for the very important decision on where and how to live and is therefore indispensable for a transition towards degrowth. A concrete step towards sustainable degrowth lies in the claim for multifunctional and redensified settlement structures and neighborhoods [30] to secure less resource intensive living conditions and a minimum of daily needed infrastructure. The revitalization of unused buildings can serve as an example par excellence for degrowth, as it fulfills the need to re-use instead of produce something new and as mainly bottom-up initiatives try to make use of urban vacancies. There is also potential for spatial planning institutions to manage its utilization and further development towards sustainable degrowth.

### *3.3. Enhancement of Social Capital by Community Based Facilities*

Multifunctional settlement structures are a valuable contribution to facilitate more community-based activities, which make use of the synergy effects that these structures offer. As theories on spatial organization suggest, it is not so much socio-economic indicators such as income, household size or age but rather the influence of social background and life-styles that influence urban sprawl [31]. The impact population density has depends mainly upon the organization of society in space which is regarded rather as a qualitative indicator than just the quantity and intensity of land use [22]. Therefore, it is all the more important to consider the structural impact of spatial organization on social actors who produce the sprawl.

Setting up more potential meeting places for citizens than in mono-structured settlements makes them a starting point for interaction on the one hand. On the other hand, contact nodes are a valuable basis for the creation of a sense of community where personal contacts can be made and established. These interpersonal relationships are the basis for finding common interests and common needs that could be fulfilled on a mutual basis. These community based services can include child care and care of the elderly, dog-walking, car pools, bike repair shops, food cooperatives or community gardening. Community based services and activities apply at least to one of the pillars of sustainable degrowth: the need for income from wage work could be reduced substantially if available infrastructure of services was provided on a non-monetary basis, which complies fully with the claim to less wage-paid working hours [3]. Moreover, these activities can be organized in a self-esteemed and democratic way, so the citizens themselves can make decisions over resources and services. The objectives are to take some of the power from the markets and the state into the hands of people from the community and to increase the community's self-reliance. This practice also provides a step towards more societal cooperation instead of ongoing individualization [32] and contributes to a rise of social capital.

Another effect is the positive impact and stimulant to regional economic circles. The creation of local employment opportunities in the form of worker co-operatives, community development corporations or even community land trusts could be supported and strengthened by spatial planning institutions in the form of multifunctional settlements. This provides a chance to strengthen the regional economy which does not necessarily mean a rise in regional GDP but gives room to new concepts of employment frames and conditions that contribute to a degrowing community. That includes reduced working hours or the legal and societal recognition of unpaid work. Multifunctional settlements provide a chance to increased self-sustaining economic networks reducing the social dependence on economic growth. The challenge for spatial planning institutions is to enable structures so that community based activities can be established and maintained.

It is not only multi-functional settlement structures that offer the potential to increase social capital but also citizens who demand multi-functional settlements. The possibility that spatial planning institutions could promote consists of enhancing a more democratic access in the planning processes [33]. In planning theory, the tradition of social mobilization states that the planer's role is one of community organization [34]. The involvement of local citizens, politicians or energy planners strengthens direct democracy and implies an institutional change in spatial planning. As the residents of a certain region are the ones that mainly use their land and buildings, they should also be the ones who take part in the decision process concerning their use. Besides, personal engagement is a form of taking over responsibility for the environment and the community and a form of identification with the living space. Therefore, such bottom-up processes support the increase of social capital in planning practices.

Positive examples describe the potential of self-organized cooperative help in construction issues, which is also oriented on ecological criteria [35]. Self-organized cooperatives as well as squatting projects in Germany were able to convince their opponents of the importance of ecological criteria and social improvement, e.g., by denying all attributes of luxurious settlements. With the support of spatial planning institutions as intermediates, it was possible to successfully initiate a process between the self-organized projects and governmental institutions. The projects were legalized and therefore had access to public subsidies to implement their plans. Years later, the results show that the living environment of these projects has a positive impact on employment, education and new self-organized socio-cultural infrastructure [35]. Spatial planning institutions, therefore, have shown to be a valuable factor for the enhancement of more sustainable living structures.

The potential for degrowth that spatial planning institutions can enforce is the increase of social capital by supporting the communal use of living infrastructure. Besides, the utilization of these services is not necessarily bound by any financial conditions of the citizens, if these services are based on mutual exchange and other helping activities. The involvement of all stakeholders in planning processes is a step towards democracy if those who are mainly directly concerned are involved in the decision-making. Spatial planning institutions have the possibility to take the role of communicator and mediator between all stakeholders involved.

## 4. Conclusions

In a society which is characterized by a growth discourse, institutions and their related infrastructure are organized and determined by the need to grow in all their varieties. Degrowth as a political concept clearly questions basic institutions concerning property or work which enable the framework conditions for growth to take place. Spatial planning institutions as part of a political system are one of the institutions facilitating growth by, e.g., unsustainable structures of land use. Their crucial role consists of having the authority decide by whom and for what purposes land—*i.e.*, the basis for all resources—is allowed to be used. Spatial planning institutions have the power to design landscapes and their infrastructure and they have an essential influence on whether these structures enable growth or are oriented towards the needs of the population in a sustainable way. Spatial planning has powerful instruments to guide developments in certain directions, as it is obvious in the case of land dedication. Although the current practices of spatial planning institutions are not degrowth oriented, some of them constitute a valuable support towards degrowth. These practices should be regarded as points of conduct to enhance further change towards degrowth, as a smooth transition is made easier if some links to the current situation exist. Spatial planning institutions that orientate themselves on degrowth-aims, such as sustainable resource use, democracy or self-autonomy would be a decisive next step towards the progress of a degrowing society.

Spatial planning determines largely which and how many resources are needed and used. On the one hand, as the use of renewable energy sources largely depends on the availability of land, it lies in the hands of spatial planning institutions where and to what extent renewables are deployed. On the other hand, it is also spatial planning institutions that decide on the placement of settlements and how they are structured which in turn determines the consumption of resources. As a result, the ecological impact caused by decisions of spatial planning regards the amount of sealed area, energy demand or amount of traffic. Such a key role requires special attention in the degrowth discourse since spatial planning has powerful institutions deciding over basic living conditions. Although it is unrealistic to expect a settlement to fully sustain itself [36] if all needed flows of materials, money and people are considered, spatial planning institutions are valuable in enhancing structures that facilitate a less resource-intensive life style.

The formation and increase of social capital is one of the consequences of how settlements are organized. As spatial planning institutions are responsible for settlement structures, the conclusion can be drawn that spatial planning indeed is responsible for spatial socialization, which in turn influences the formation of social capital. How inhabitants perceive space also influences daily routines and activities. Space produces societal dispositions similar to money or status and is therefore essential when discussing societal transitions such as degrowth. Settlement structures are one example how the organization of space has impacts on social capital.

The democratic aspects of spatial planning are marked by land and who is allowed to dictate decisions on it. As equal access to natural resources is one of the main demands of the degrowth movement [37], this equal access has to start at the level where decisions on land use are taken. Since spatial planning presently does not allow local citizens to participate in the decision making process, the resulting top-down driven structures are not a reflection of the citizens' needs. A democratic access to decisions over land use would imply a right to decisions by the citizens who are the main users of the land in question. As long as land dedications are driven by economic interests—as in the case of land needs for biofuel production, or land needs for big shopping centers with no actual inhabitants, encouraging increased traffic—they do not approach democracy. In a Degrowth Research Proposal of the Second Degrowth Conference why there is no planning *by* people but only *for* people was questioned [38], which addresses exactly the missing self-autonomy by the users of land. A change in the institutions of property could convert land into a common good providing the chance of self-determination of its use.

This paper aims to contribute to the demand of the degrowth movement to change institutions which facilitate endless growth. It further wants to add to the discussion about institutions for degrowth by explicitly addressing spatial planning institutions. The paper discusses how spatial planning can influence settlement structures to enhance a life-style that accomplishes the aims of degrowth, emphasizing less resource use and more democratic structures. The future will show if the envisaged change will ever become a reality.

## Acknowledgments

The author wishes to thank all participants of the second and third Degrowth-Conference for their valuable comments and discussions. Special thanks go to Michael Ornetzeder for commenting a prior version of this paper. The author is grateful to three anonymous reviewers whose valuable comments helped to improve the quality of the paper.

## Conflict of Interest

The author declares no conflict of interest.

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## Anhang C

Wächter, P., Ornetzeder, M., Rohracher, H., Schreuer, A. und Knoflacher, M. (2012): Towards a Sustainable Spatial Organization of the Energy System: Backcasting Experiences from Austria. Sustainability, 4 (2), 193-209 http://www.mdpi.com/2071-1050/4/2/193/

*Sustainability* **2012**, *4*, 193-209; doi:10.3390/su4020193

OPEN ACCESS

*sustainability*

**ISSN 2071-1050**

www.mdpi.com/journal/sustainability

*Article*

# Towards a Sustainable Spatial Organization of the Energy System: Backcasting Experiences from Austria

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*Received: 23 December 2011; in revised form: 19 January 2012 / Accepted: 29 January 2012 / Published: 2 February 2012*

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**Abstract:** The transition to a sustainable energy system faces more challenges than a simple replacement of fossil energy sources by renewable ones. Since current structures do not favor sustainable energy generation and use, it is indispensable to change the existing infrastructure. A fundamental change of the energy system also requires re-organizing spatial structures and their respective institutions and governance structures. Especially in Austria, urban sprawl and unsustainable settlement structures are regarded as one of the main developments leading to increased energy demand. One of the aims within the project E-Trans 2050 was to identify socio-economic constellations that are central to the further transformation of the energy system and to focus on actors and their socio-technical framework conditions. Based on a sustainable future vision for the year 2050 a backcasting workshop was conducted to identify necessary steps for the envisaged transition to a more sustainable energy system. The results shed light on the necessary changes for a transformation towards sustainability in the specific Austrian situation. Critical issues are region-specific production of energy and its use, settlement and regional structures and values and role models, which all have a determining influence on energy demand. Combining the knowledge of extensive energy use with available energy resources in spatial planning decisions is a main challenge towards a long term sustainable energy system.

**Keywords:** sustainable energy system; spatial organization; backcasting; energy transition

## 1. Introduction

In many areas of society, developments resulting in increasing energy consumption can be observed. Planning decisions, transport patterns and new forms of domestic energy use are just a few areas where developments from the past have lead to a massive increase in the use of fossil fuels. In many cases it has been complicated to predict and assess long-term impacts on the environment and consequently some development paths with negative environmental effects were initially not regarded as environmentally relevant at the outset. However, the concept of sustainability certainly brought about a deeper discussion on both the evaluation of long-term effects of decision-making and on the possible interdependencies of different policy areas, as well as on arrangements of social norms and interests, technical means, and natural resources. In this paper we aim to pick up on those insights regarding the area of spatial organization of the energy system.

Especially in planning decisions, the impact of spatial organization on society and the environment is a crucial topic. Spatial organization patterns address a multitude of environmental, organizational and social dimensions. As part of the energy system, these dimensions should be explicitly addressed when talking about an energy transition towards more sustainability. Topics like the further dissemination of renewable energy technologies or the relation between energy consumption and the land use implications of infrastructure are obviously linked to spatial planning [1]. Still, the question of how and to what extent spatial organization affects a far-reaching transition in the energy system towards sustainability has not yet been sufficiently explored.

In Austria various social players with different interests and strategies influence decisions in spatial planning. Moreover a number of legal responsibilities in the field of spatial planning lie with local and regional authorities. These and other framework conditions may explain why normative goals of sustainability found in most guidelines for spatial planning have hardly had any effect so far. Although efforts have been made by planning institutions to foster sustainability goals, few policies have had binding effects and their impact has therefore remained marginal. However, on the local and regional level we can find a few exceptional successful cases, like energy self-sufficient municipalities or energy regions mainly based on locally available renewable sources [2].

In this paper we would like to argue that the specific view on energy and spatial organization will require an entirely new composition of policies, bringing together sustainable energy, spatial planning, and land-use regulation issues. Using backcasting as the main research strategy enabled us to discuss and classify policy options without losing track of more radical long-term transition goals. From the specific Austrian context, the paper suggests a number of novel entry points for decision makers, including the establishment of integrated planning structures or the redefinition of existing political-administrational structures. Although most arguments are firmly linked to the Austrian case which constitutes the empirical background of the study findings presented in this paper hopefully could serve as a framework to discuss similar options in other national contexts.

The paper presents findings from the recently finished project E-Trans 2050 (The project E-Trans 2050 was carried out by three national research-partners, the Inter-University Research Centre for Technology, Work and Culture (lead), the Austrian Institute of Technology, and the Institute of Technology Assessment of the Austrian Academy of Sciences, in the years 2009 and 2010. It was funded by the Climate and Energy Funds and carried out under the programme 'New Energy 2020'.). The main aim of this national project was to achieve a systematic and interactive engagement with socio-technical visions of potential energy futures and to support strategy development at the level of politics, research and companies all involved in the scenario development process. Since we cannot regard a simple substitution of energy sources as a sustainable energy transition, the project tried to address the complex structures of a broadly defined energy system [3]. By evaluating the possible scenarios for the Austrian energy system for the year 2050, the spatial organization of energy production and use has been identified as one of the key fields of action in order to enable more radical changes in the long run. Policy interventions in this crosscutting field have been regarded as central for promoting sustainable transformation pathways of the energy system.

This paper will provide a description of the field of energy and spatial planning. Based on the outcomes of a backcasting workshop, main strategies and policy options will be presented regarding changes in the subfields of renewable energy sources, settlement and regional structures and values and role models. The conclusions reflect on the barriers and opportunities for a transition towards a more sustainable energy system.

The paper is organized as follows: Section 2 gives an overview of critical aspects in spatial planning and organization concerning energy issues, first in general and then specifically from an Austrian context. Section 3 deals with backcasting and experiences made in a workshop, which was held to deepen the understanding of energy issues in spatial planning; whereas Section 4 discusses the results and further explores critical issues identified within the workshop. The conclusions in Section 5 aim to strengthen the need for action and ends with a discussion of further research topics.

## 2. Spatial Planning and Regional Energy System

In recent years, the strong connection between space and energy has gained prominence in the discussions in a mainly regional and local context. With the call for more independence from fossil fuels, regional energy systems are the focus of interest in a number of energy related studies [4–7]. As Walker [8] has already pointed out, energy and land use are tied together by a mutual relationship. On the one hand, the production and utilization of energy has impacts on land use and on the other hand, the use of land determines the consumption of energy in several ways. However, the different sides of this relationship are discussed in different communities whereas a common and integrated discussion focusing on inter-linkages is hard to find. The impacts of energy production on land use are well discussed within the environmental community [9] while the effects of land use, in particular of residential areas, are the focus of the land planning community [10]. The increasing demand for renewable energy sources has given further prominence to the intertwined relationship and it prompts a multidimensional discourse including economic, organizational and social concerns.

Many regions in industrialized countries are covered by disperse and unstructured land use patterns, raising constraints for the reduction of energy consumption over decades. Regional procurement systems changed to global supply networks based on the availability of cheap fossil fuels. Solutions to sustainable energy transitions have to consider the long-term dynamics of land use processes and the need to change already existing unsustainable land use structures to sustainable states through a multitude of activities [11].

A major concern relates to settlement structures that lead to increased energy demand due to the prevalence of detached houses in rural areas, and due to missing infrastructure to fulfill basic needs and connection to public transport. Low prices for fossil fuels have provided opportunities for the construction of energy consuming high-rise buildings, causing an increase in energy use in urban areas, especially in high-income countries [12,13]. Living in Anglo-American suburban houses with gardens or in generous flats in city centers are strong and influential lifestyle prototypes for many people all over the world, creating demand for further expansions of energy-intensive types of land use [14].

As so far alternative visions and concrete models are still hard to find on a more general level, in recent years more practical research activities have been forged in this area. One example is the ECOCITY-project [15] aiming at the development of compact, space saving settlement structures enabling an environmentally compatible energy system combined with habitat structures that correspond to the overall objectives for sustainability. The adoption of the urban structure of seven model settlements in Europe resulted in the recommendation concerning community involvement during the planning phase, public spaces with a high value and a great variety of amenities and sustainable transport concepts adapted to the locally different conditions. Further, Filion [16] argues that the strategy of combining multifunctional nodes with high density, transit orientated corridors with residential density would be effective for successful intensification in order to reduce the every day use of cars.

Transitions towards renewable energy supply systems are strongly dependent on the willingness of society to adopt new paradigms. This includes sustainable land use management strategies as well as adaptive sustainable management strategies for renewable energy production. Such requirements are easy to formulate but challenging in realization. It is a big challenge to overcome the barriers of established decision making structures and processes, divergent interests of actors, traditional habits and, last but not least, of systemic lock-in effects.

### *2.1. The Austrian Case*

Along with other European countries, Austria is currently increasing efforts towards reducing greenhouse gas emissions, increasing energy efficiency and expanding the deployment of renewable energy technologies. Austria's strengths in the area of renewable energy technologies lie mainly in hydropower and, more recently, biomass. Nevertheless, Austria's overall reliance on fossil fuels still amounts to approximately 75% of gross domestic consumption and, in spite of a continuous expansion of energy generation from renewables, its share has recently decreased due to an even stronger growth in energy consumption [17]. Especially in the area of transport, reliance on fossil fuels is high and the trend of increasing energy consumption due to rising mobility remains unbroken [18].

As argued in the previous section, a radical restructuring of the Austrian energy system towards sustainability will also require changes in the spatial organization of the energy system. Indeed, the energy strategy recently put forward by the Austrian government in response to the so-called 20-20-20 goals (These goals involve a 20% share of renewable in the energy mix, a 20% cut in greenhouse gas emissions, and a 20% cut in energy consumption until 2020, with individual target set for each member state.) agreed upon by the European member states in 2009, has for the first time introduced the term of "spatial planning for energy" (Energieraumplanung) into mainstream policy discourse (see also [19]). It is seen as one of several cross-cutting policy measures and is briefly (and rather vaguely) sketched out as an embedding of energy- and climate related goals into spatial planning, mainly in order to reduce mobility demands [20].

In the following, we will attempt to give a more specific and multifaceted picture of central challenges related to the spatial organization of the Austrian energy system. Table 1 outlines the critical aspects concerning the energy system and spatial planning which will be discussed for the Austrian case. Similar issues may be expected to be relevant in several European countries.

**Table 1.** Critical aspects concerning the energy system and spatial planning in Austria.

| Main aspect | Critical issues |
| --- | --- |
| Land use demands of renewables | - Overall land use demand of renewables<br>- Spatial distribution of renewable energy potentials<br>- Land use conflicts between renewables and other land uses<br>- Potential land use conflicts between different renewable energy technologies |
| Energy implications of settlement structures | - Energy demand for heating dependent on settlement structures (higher energy demand of detached houses, use of district heating dependent on dense settlement structures)<br>- Higher energy demand for infrastructure provision of dispersed settlements<br>- Energy use for mobility dependent on settlement structures, proximity of shops, *etc*. |

### 2.1.1. Land Use Demands and Land Use Conflicts Related to Renewables

One of the key issues in the spatial organization of the energy system concerns the land-use demands related to the use of different energy technologies. As McDonald and colleagues [21] demonstrate, energy technologies that can contribute to the reduction of greenhouse gas emissions tend to be associated with larger land-use demands. Any transition to more sustainable systems of energy provision will therefore require careful attention to the spatial potentials and limits of the use of renewable energy technologies in a particular country or region. In 2009, the Austrian Conference on Spatial Planning (Österreichische Raumordnungskonferenz, ÖROK), a governmental agency coordinating spatial planning at the national level, put forward a comprehensive survey modeling the spatial potentials of different renewable energy sources in Austria [22]. Results point to some significant untapped potentials, especially in the areas of photovoltaics, solar thermal technology, wind power and geothermal energy. The potential for hydropower and biomass is already comparatively well developed, though some further development options exist. A scenario study, illustrating different possible pathways for the further deployment of renewables in Austria [17] similarly describes a scenario relying strongly on solar thermal technology, photovoltaics and wind power as the most long-term oriented scenario, not least because this would reduce land use demands, as compared to other possible scenarios relying on a radical expansion of energy from biomass.

In the context of land use demands related to renewables, it also has to be taken into account that the spatial distribution of supply and demand may exhibit quite different patterns. Regional energy concepts attempting to match supply and demand at the regional level have frequently been suggested as a way forward [20,23] and indeed several so-called energy regions in Austria have taken steps in this direction [11]. Detailed models have also been called for, balancing renewable energy potentials and demands at the regional level on the basis of geographic information systems [22]. Nevertheless it may not always be possible to optimize the siting of renewable energy plants according to the availability of natural resources (e.g., wind, solar radiation) and at the same time to ensure a close proximity between energy production and consumption. For example, in Austria the largest share of wind power generation is located in the sparsely populated part of Burgenland and requires investments in the transmission grid to be used in high-consumption areas.

Apart from the spatial distribution of supply and demand one obvious challenge concerning land use demands of renewables concerns (potential) land use conflicts. This issue has recently gained prominence at the global level in the form of the "food *versus* fuel" controversy, in which extensive use of agricultural land for the production of biofuels has been criticized for competing with land use needs for food production [24]. Apart from an uptake of this global debate, land use conflicts over renewables in Austria have so far mainly taken the form of resistance to hydropower plants that are seen to threaten nature preserves and recreational areas. More recently, some wind farm projects have also triggered local opposition due to concerns over negative impacts on the natural environment, recreational areas and settlement areas (noise, visual impact, *etc.*). Furthermore, with an increasing use of energy from biomass, conflicts between the use of biomass for energy and for use in wood-based industries (paper industry, pulp industry, *etc.*) are beginning to emerge [17]. Additional land use conflicts may potentially emerge between different renewable energy technologies (e.g., use of grassland for energy crops or large-scale photovoltaic plants).

#### 2.1.2. Energy Implications of Settlement Structures and Traffic in Austria

Dispersed settlement structures and the resulting increase in individualized transport have turned out to be a key driver in energy consumption and greenhouse gas emissions in Austria. Several reasons can be identified for this development:

The past decades have seen a significant trend towards an increase in the number of buildings, apartment sizes and living space. While Austria's population grew by 4.1% between 1971 and 1991, the number of dwellings increased by 25% [23]. Moreover, Austria is a country of detached single (or double) family houses, which are favored by 73% of all Austrians (ibid.). In combination with a trend towards migration from rural areas to the cities (e.g., because of a shift from industry to services which are more often located in urban agglomerations) this has led to an increasing population pressure in urbanized regions and a move of urban population towards suburban areas. These dispersed settlements have various consequences for energy consumption. On the one hand the energy efficiency of single family houses is lower compared to denser settlements and larger buildings. Side effects of this low building density are high costs for infrastructure investments (sewers, roads, electricity, *etc.*) and the impossibility of supplying such areas with energy-efficient district heating systems. On the other hand sub-urbanization and dispersed settlements increase the volume of traffic. Since post-war times the average distance between home and work has risen from two kilometers to 20 to 30 km [23]. The construction of new roads (along with other drivers) has subsequently led to a vicious circle of a further move towards the urban periphery and further road constructions. Part of this development has also been the increased construction of shopping centers on the outskirts of cities at the cost of grocery shops and convenience stores in the villages and town centers—51% of such centers are being built in the periphery of Austrian cities, compared to only 17% in Germany [25]. Dispersed settlements in the urban periphery and in rural areas not least also mean that public transport services are much less cost-efficient in these areas and have been reduced (or even disbanded) in many places over the past decades. Therefore, it comes at no surprise that traffic-related greenhouse gas emissions rose by 91% between 1990 and 2005 [18].

An important driver for dispersed settlement structures and a lack of spatial planning for energy and integrated mobility systems lies in the particular institutional set-up of spatial planning competencies in Austria. In principle, spatial development and spatial planning is considered a joint task of the federal level, the Länder (provinces) and municipalities. In practice, the specific forms of distribution of spending and competencies which have evolved historically have worked against well-integrated spatial planning procedures (see [19]). The competence for spatial planning resides for the most part at the level of provinces (leading to different terminologies, priorities and procedures between regions). Municipalities (often very small ones) are responsible for "Regional location development", *i.e.*, local zoning and development concepts. The funding of municipalities largely depends on the number of inhabitants on the one hand and the taxation of companies within their boundaries, which in turn leads to a competition for inhabitants and companies and in consequence to very lax zoning laws to draw more firms and home builders into the township. All in all, these splintered planning competencies along with economic growth and restructuration, changing lifestyles and particular building cultures have led to the dispersion of settlements and growing traffic volumes which now pose a major problem to the reduction of energy demand and greenhouse gas emissions.

As Hamin and Gurran [26], however, point out, there is also a certain trade-off between land-use densification as a measure for climate change mitigation on the one side and the requirements of climate change adaptation on the other, e.g., more open space for stormwater management, urban cooling or species migration.

## 3. Backcasting Sustainable Energy Futures

The aim of the project E-Trans 2050 was to investigate the transition to a more sustainable energy future for Austria. Dealing with such a transition means to be aware of the complex processes of social learning involving a multitude of actors and levels. The system innovations required for profound change involve the reconfiguration of technologies, institutions, social practices as well as cultural norms and values. These societal transformations towards a sustainable energy system are explicitly normative and value-laden and driven by the need to break with a business-as-usual path.

Backcasting is a normative scenario approach proposed for long term changes of twenty to one hundred years addressing changes of human behavior [27]. This is one of the main reasons why backcasting has gained increasing attention in energy and sustainability research [28–34]. In contrast to forecasting approaches, where predictions of a future state are conducted, backcasting scenarios are developed according to their desirability of an optimistic and preferable future. As a first step, future goals need to be defined and desirable scenarios have to be developed. Starting from this state in the future, possible paths are examined to reach this desirable future scenario. Therefore, backcasting means working backwards from the desired end-point to the present. Furthermore, backcasting offers a method for exploring the implications of alternative development paths and the values that underlie them [27]. The advantages lie in the possibility to investigate complex problems [35], to address far reaching changes [27], and to outline a common image of the future and make backcasting indispensable for an analysis aiming to identify ways to break with current trends.

The backcasting approach has proven to be useful in identifying development paths under high uncertainty [31] and in emphasizing the long-term impacts of decisions in spatial planning as well as addressing radical changes in energy behavior. Long-term transformations can be visualized and the transition process can be analyzed in depth.

In the project E-Trans 2050 the backcasting procedure started with a highly normative "sustainability scenario" for the Austrian energy system in 2050. This scenario has been tailor-made to cover main aspects at the intersection of energy production and use and spatial organization. It was developed against the background of preceding scenarios, which were formulated at an earlier stage in the project, eight interviews with experts in the areas of spatial planning and development, energy regions, and planning of sustainable energy systems and a literature review (see Table 2). Using this specific vision of the future as a starting point, participants of a one-day backcasting workshop were invited to discuss strategies and necessary milestones that could be helpful in reaching them. Workshop participants were selected on the basis of their specific expertise and institutional background and efforts were made to ensure a diversity of views within the group. The eight participants were representatives of public universities or non-university research institutes (four), a federal agency for environmental issues (one), an association active in the area of environmental issues (one), a private planning company (one), and a private research company (one). Professional backgrounds of the participants included spatial planning, modeling in the area of energy and space, mobility, climate change and its regional impacts, regional development, architecture, and resource-oriented construction. The workshop took place in spring 2010.

**Table 2.** Long-term vision for sustainability in the field of energy and spatial organization.

| **Long-term vision for 2050** | |
|---|---|
| **Main aspect** | **Changes envisioned** |
| General data | - Population in Austria: 9.5 m (2010: 8.4 m)<br>- Gross domestic energy consumption: 800 PJ (approx. 50% less than in 2010)<br>- Electricity consumption is about 20% more than in 2010<br>- Renewable energy sources cover 90% of domestic needs<br>- $CO_2$ emissions are 80% below 1990 levels |
| Energy prices | - All forms of energy are much more expensive than in 2010<br>- Fossil fuels are about twice as expensive as renewable forms of energy<br>- Percentage of household expenditure on energy mirrors 2010 (around 7%)<br>- Social distortion is prevented through the tax system and through transfer payments |

**Table 2.** *Cont.*

| Long-term vision for 2050 | |
|---|---|
| **Main aspect** | **Changes envisioned** |
| Infrastructure | - Energy is used extremely efficiently in all areas<br>- Power grid is completely modernized (new and efficient equipment, smart grids, super grids)<br>- High-efficiency devices are the norm<br>- About 50% of building stock meets the passive-house standard; the rest exceeds 2010 low-energy building standard * |
| Spatial dimensions of production and use | - Widespread use of renewable forms of energy<br>- Use of renewables adapted optimally to local and regional conditions<br>- Previously existing capacities are upgraded and slightly expanded<br>- Consumption and production are located in close proximity<br>- Widespread use of energy cascading ** |
| Mobility and transport infrastructure | - Energy demand for mobility is below 2010 level<br>- More efficient technologies, reduced traffic volume<br>- Improved public transport system<br>- Compact settlement patterns ("short distances")<br>- High proportion of bicycle traffic<br>- Highly efficient logistics solutions for goods transport |
| Settlement structures | - Urban centers and medium-sized cities are the main areas for living and working<br>- Suburban areas are compact; high quality of life in these neighborhoods<br>- Outlying regions are of little economic importance<br>- Settlement in rural areas has decreased; remaining rural settlements are populated by elites; more nature reserves than in 2010 |

* Statistics show that there were more than 7 000 passive houses at the end of 2009 [36]. Approximately two thirds are residential buildings. In 2009, a total of 18 470 new buildings had been constructed in Austria [37]. 15.7% thereof already met passive house standard (2,900 buildings) [36]. It is expected the passive house standard will be obligatory for all new residential building within the next years. The fact that approximately 1 percent of the building stock is replaced per year by new constructions and considering a growing number of retrofits aiming at passive house standard gives the projection for 2050 a realistic basis.

** The term energy cascading is used in referring to a system where a given amount of energy is used on different levels of quality. Co-generation is a simple example for energy cascading; steam (high temperature level) can be used to produce electricity, waste heat (middle or low temperature level) of this process still can be used for industrial of residential needs. In regional energy systems different functions and processes could be linked similar to a cascade.

The proposed long-term vision serves as a widely accepted desirable future state for the year 2050. The used future vision gives a robust and consistent picture of a state in the future with normative descriptions, concepts and values. The idea is to outline a future state in which a specific type of a sustainable energy system has been reached. Apart from some quite well predictable indicators such as population growth, educated guesses were made at the outset of the process concerning less predictable issues such as the patterns of sustainable energy production and use or sustainability requirements for settlement structures. Prices for all types of energy carriers were assumed to rise but energy demand decreases and social distortion is prevented by a balancing tax system and transfer payments. The energy infrastructure is characterized by highly efficient use and powerful electricity grids and a 90% share of renewables. Regarding the spatial dimension of production and use it was assumed that the use of renewables is adapted optimally to local and regional conditions which mean that locally available forms of renewable energy are employed under best conditions, and consumption and production are located in close proximity. Furthermore, dense settlement structures in suburban areas are combined with the required infrastructure, such as employment opportunities and basic services, leading to a high quality of life. Dispersed settlements in rural areas have decreased and people prefer living in small regional centers that also provide high living standards by fulfilling basic needs within short distances. People living in these centers are not dependent on individualized motorized transport but benefit from an improved public transport system and from the use of bicycles.

The participants of the workshop were first asked to comment on and modify the future vision and to discuss about the most important aspects. In the second part of the workshop, participants were invited to discuss guiding questions concerning opportunities for decision-makers to break with current trends and about essential elements to make the transformation process possible. In order to develop a variety of possible development paths two groups were formed. A more realistic temporal sequence was achieved by answering the crucial question which goals have to be fulfilled in 2030 in order to be able to achieve the desired vision by 2050. The participants proposed and discussed strategies and necessary milestones that could be helpful in reaching the future vision. The biggest challenge in the backcasting process was to think from an imaginary point of time in the future back to the present because our thinking usually takes place in the other direction. The participants were provided with a description of the future vision before the workshop took place but it took some time to until they could sufficiently identify with the vision in order to be able to look back from it. Especially the long time horizon of forty years made the visualization of the transition path difficult. Backcasting requires an abstract way of thinking in an unusual manner which, on the one hand, is a challenge, and on the other hand, it provides the chance to analyze possible solutions by different modes of thinking.

## 4. Key Issues on the Transition to Sustainable Energy Structures and Its Spatial Dimension in Austria

The aim of the backcasting procedure was to identify cross-cutting areas and possibly mutually dependent factors that enforce or hinder the envisaged future vision for the specific situation in Austria. This aim could be achieved on the basis of a brainstorming exercise in two groups focusing on how the envisaged future vision could be reached. The collected items were clustered in certain areas and subsequently prioritized by importance by the participants. The following areas were identified which are critical for a sustainable transition: renewable energy carriers, new and existing settlement structures, regional structures, and values and role models. The development of break-through technologies and different technical-organizational conditions were considered to be of minor importance for reaching the future vision.

*4.1. Renewable Energy Sources*

As the use of renewable energy sources is steadily growing in Austria, assessments of potentials are available but differ widely in range and in their assessment of related costs. What is still missing are plans focusing on regionally available materials and energy flows to be able to optimise supply and demand and to incorporate this information in planning decisions as early as possible. Austria has a high share of biomass due to large forested areas but estimates consider the potential to be nearly fully exhausted, unless the use of forest resources is organized in a different way. The immense land use is criticized for being a major disadvantage. More potential was seen in the area of solar energy, even in Austria. From the point of spatial planning institutions, the use of solar energy can be optimized by development plans in the construction phase of new buildings, making use of roof areas and facades. Further potential was seen in local and district heating systems in dense settlement areas. As the availability of renewable energy sources is limited, the proximity of production and use is particularly important. Heating plants should be built where renewables are available and users are near in order to avoid long distance transport of e.g., biomass in rural areas and to minimize losses in transport. In the area of electricity, however, the situation is somewhat different. Electricity from renewables is fluctuating and thus requires complementary innovations in the energy system, such as new forms of supply and demand management (e.g., based on smart grids) or new high-power grids connecting the hubs of renewable electricity production at a supra-national level. At the same time, energy regions have an important function as a role model and should be supported and subsidized. The development of big role model projects where the focus lies on integrated solutions concerning settlement structures, mobility and energy should further increase the amount of best-practice examples.

*4.2. New Settlement Structures*

A major part of the discussion focused on the development of sustainable settlement structures. In order to get closer to this target in the next forty years the development of new settlements has to be directed towards new pathways avoiding ongoing urban sprawl and the construction of detached houses in the open country. One of the major structural barriers for energy efficient settlement structures are already granted planning permissions for settlements in the open country. To a large extent these permissions allow the construction of detached houses that usually do not consider any sustainability requirements or do not depend on energy standards, like geographical adjustment, higher degrees of densification or obligatory district heating connections. Institutions such as the Austrian Conference on Spatial Planning have developed a set of sustainability criteria but they merely serve as a recommendation and have not been turned into binding criteria at the national level is still missing and their sustainability guidelines can merely serve as a recommendation. Already granted planning permissions are not likely to be revoked; therefore the participants emphasized the importance of best-practice examples. New developments of settlements should be compact, built according to ultra-low energy-demand standards, connected to district heating systems, provided with necessary infrastructure and well connected to public transport systems. Apart from sustainability criteria for planning permissions, also new subsidy schemes provided by federal states are an effective tool in stimulating changes in the building sector in the short run (including a shift from subsidies for new construction to refurbishment and densification measures). These subsidies have a high impact on a desired polycentric development and could also reduce new constructions by not subsidizing them.

### *4.3. Existing Settlement Structures*

The question arises how to deal with unfavorable existing settlements. As the removal of existing buildings was not considered as a realistic option because of expected resistance from local population and authorities, the challenge was rather seen in how to integrate existing settlements into sustainable structures. It is expected that increasing energy prices will lower the attractiveness of dispersed settlements and will possibly lead to more vacancies in settlements in the open country. Most promising instruments are incentives that should enhance compact settlements in already existing regional centers. Settlement structures with a high share of single-family houses should be provided with further infrastructure to be able to organize daily activities in a less energy consuming way such as short distances from housing to work. A main problem in this context is individual motorized traffic which is heavily supported by existing infrastructures. In addition to the changes aiming at a rise in the density of population, it has been argued that existing public transport systems have to be improved in close cooperation with other means of transport in order to solve the "first and last mile problem" in an environmentally sound way, e.g., through the use of electric vehicles or electric bicycles. Moreover improving other local infrastructure as well as offering new services were regarded as an important strategy. Examples for local amenities include a broad variety of shops, health institutions, schools, or recreational facilities. These redensification processes are most promising in suburban areas near larger cities and in smaller regional centers. In regional centers special attention should be paid to a wide variety of businesses and locally available work places leading to less volume of traffic caused by commuters. However, regional centers also have to be connected by high-capacity public transport systems to the main urban centers.

### *4.4. New Regional Structures*

In Austria, the room for maneuver in regional planning largely depends on existing political-administrative structures. On the one hand the boundaries of administrative units (e.g., municipalities, districts) limit the spatial scope of planning decisions. On the other hand this also narrows down the policy options available to regional governmental institutions. A stronger focus should be placed on the idea of the region, beyond political-administrative regional borders: specific characteristics must be taken into account such as the availability of natural resources and possibilities for their use and availability of infrastructure. Special attention should be paid to renewable energy sources and in the case of thermal energy care should be taken to ensure a high proximity of energy production and use. Regional planning needs to take account of the functions to be fulfilled, such as housing and working, and consider how they can be optimally fulfilled in terms of their related energy use. Depending on the functions that regions have to fulfill, the size of the region may vary from the original political-administrative unit. By defining regional functions region specific strengths and weaknesses can be incorporated into planning processes and additional financial support can serve to enhance such programs. Workshop participants pointed to the successful implementation of overarching regional energy structures such as the Austrian region of Eastern Styria where close to 200 municipalities joined to implement a renewable energy region [2].

### *4.5. Visions, Role Models and New Practices*

As in most other industrialized countries, traditional role models portrait an unsustainable life-style in Austria: The picture of a happy family with children living in a large single-family house with two big cars in the driveway is the dominant image of a desirable life in the media, in movies and in commercials. Owning a house is related to success and owning a car is associated with freedom and considered as an indispensable need for the organization of daily activities. Structures aiming at less energy demand are definitely not in the focus of these distribution channels. According to the participants, community based use of resources such as community gardening, carpools, bike repair shops demonstrate possible contributions to less energy intensive social practices. Combined with other communal services e.g., shared childcare or care of elderly, dog-walking and some other facets of a neighborhood with high living quality, the basis could be laid for a successful transformation towards new less energy demanding role models on the settlement level. Forerunners like Vienna's car free settlement give some evidence how such new qualities can merge into convincing concepts [38]. At the institutional level, the aim of enhanced societal cooperation instead of ongoing processes of individualization has to be promoted forcefully. One example would be the promotion of owner collectives instead of single house owners that make decisions on a community based level. The provision of information on less energy demanding structures and life styles was seen as another important element in order to break with current trends. Moreover educational programs for children as well as for adults but also regional energy agencies or other information centers in close proximity to people were regarded as a relevant tool in promoting long-term behavioral change towards sustainability.

### *4.6. Other Areas*

Further results emphasize the temporal sequence which is necessary to achieve the envisaged future vision. After collecting the most important steps and milestones, the participants were asked to determine which steps are the most urgent ones and have to happen as soon as possible and which ones are more important in the year 2030. Although the participants were divided into two groups both identified the financial equalization scheme between federal, regional and municipal authorities as an immediate leverage for change and recommended that negotiations to reallocate financial resources should start immediately. The reorganization of these financial transfer payments should allow for more flexibility than the current binding budgets for a period of four to six years and payments to municipalities should not only be dependent on population size as it is now. Regions and municipalities could profit from the possibility to devote themselves to special duties, tasks and functions such as the support of renewable energy production or investment in the infrastructure of large-scale demonstration projects. Another issue that has to be tackled as soon as possible aims at the reorganization of housing subsidies schemes that should be abolished for houses outside of regional centers and for single detached houses in general. These subsidies were considered as a powerful tool to promote energy efficient settlement structures and to advance refurbishment projects. Although it was seen as too difficult to implement, participants agreed that the future vision for 2050 could only be achieved if spatial planning responsibilities shift from the mainly local and regional level to the federal level and if binding concepts are drawn up to end urban sprawl. Even so, the impact of this administrative reform will need at least 20 to 25 years to take effect.

The workshop participants' explicitly mentioned a number of hindering factors that are likely to hamper necessary transformations towards the envisaged future vision until 2050. The distribution of competencies between spatial planning institutions at the municipal, regional, and federal level was seen as unfavorable for enhancing less energy demanding structures. Planning decisions such as local zoning and development concepts are in the authority of municipalities. What is even more important, several zoning decisions from the past may lead to outcomes inconsistent with political objectives at higher levels or with development plans of other municipalities. The claim for a change in the distribution of competencies is not new but it was seen as unlikely that it will ever happen. Other development routes appear more promising, such as the implementation of large scale infrastructure plans for 30–50 years on a federal level, binding sustainability-criteria in zoning decisions and in landscape planning and long-term local development plans. Some further topics were mentioned but not discussed in detail such as the influence of the building sector and economic interests of financial institutions in the provision of loans for builders of single family detached houses.

Changes of infrastructure and the spatial structure are difficult to implement due to their long life cycles. As it is harder to modify established structures, the best chances of change are seen in the building of new settlements and their related infrastructure, avoiding problematic decisions from the past. The transformation process to more sustainable structures of energy and space was seen as a challenge regarding time, actors and political framework conditions. Furthermore, it was emphasized that even gradual steps of infrastructure change are difficult to achieve and that mutual expectations of experts and decision-makers in the field of energy and spatial planning institutions are sometimes too high.

## 5. Conclusions

In this paper we have focused on spatial organization as a major field of action to influence the transition of the energy system towards more sustainability. It was argued that the energy system and questions of land use are highly interconnected. In the past, inefficient land use patterns and other forms of unfavorable spatial organization have provoked high levels of energy demand. However, alternative forms of spatial organization offer huge opportunities for more radical changes in the energy system. Especially by way of planning new and gradually changing existing infrastructures (regional energy networks, transport and settlement infrastructures) we are able to unfold far-reaching and long-term impacts regarding the production and use of energy.

The results have shown that it would be of decisive importance to improve the coordination of energy policy, spatial planning, and land-use regulation issues on the whole. Among other aspects this would require the establishment of new integrated planning structures at the national and regional levels, the redesign of building subsidy schemes, the closer adjustment of land development plans to energy efficiency and sustainability criteria, and the fostering of increased cooperation across political-administrative borders in the future. In order to support the further expansion of renewable energy resources, it will also be necessary to rebuild regional structures in a way that matches available resources to the existing demand for energy services as closely as possible. It will therefore be important to provide regional resource management plans and to develop and implement local and regional energy strategies. Moreover it has been argued that a reallocation of political and legal competences would be essential—one that goes across and beyond the existing political-administrative structures. Finally, a set of recommendations has dealt with the development and implementation of sustainable settlement showcases. Radical new settlement models that combine new social and organizational structures with the latest energy technology and transport infrastructure are not yet available in Austria, but such models were given high priority in the backcasting workshop as a first step towards a more sustainable energy system. In order to get these models to work in practice, actors from research, technology development, planning, architectural, and political fields must work together in close cooperation with investors and on-site users. Hence it is necessary to set up appropriate developer and participation models and to establish the necessary policies and frameworks. The implementation of innovative settlement showcases would be an important first step towards a more sustainable energy future and could open up much-needed opportunities for social and technical learning.

Apart from these short-term opportunities, the discussions in the workshop has also pointed to some of the limits to structural changes—at least in the Austrian context. In two fields it seems very unlikely that strategies and policies will be successful in the near future: One is the change in the distribution of competencies in spatial planning institutions on a federal, regional and local level and the other is a rearrangement of unsustainable settlement structures. Instead of those top down oriented strategies, it was argued that social engagement and bottom-up processes should be encouraged and established. The spatial planning authorities could be re-organized and new incentive structures for local authorities should be established in order to make ecologically more favorable planning decisions.

In terms of spatial planning, a planning period of forty years is not long. Changes in spatial organization, even if they are implemented today, would need a time span of at least twenty years in order to produce any effects and allow us to profit from more sustainable regions including energy production and transport and more sustainable planning decisions. The critical issues discussed in this paper reflect the need for action and strengthen the importance of linking energy and space.

**Acknowledgments**

The authors want to thank the Austrian Climate and Energy Fund for providing financial support to conduct the project E-Trans 2050 on which the results are based. Further, special thanks go to all backcasting-workshops participants for their valuable comments and contributions. The authors are grateful to two anonymous reviewers whose valuable comments helped to improve the quality of the paper.

**Conflict of Interest**

The authors declare no conflict of interest.

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# Anhang D

## Darstellung der genauen Beiträge der Erstautorin

Die Erstautorin des Artikels „Towards a Sustainable Spatial Organization of the Energy System: Backcasting Experiences from Austria“ Petra Wächter war für folgende Aufgaben und Textteile verantwortlich:

- Konzeption und Aufbau
- Gesamt- und Endredaktion

- Abstract
- 1. Introduction
- Mitarbeit bei 2. Spatial Planning and Regional Energy System
- 3. Backcasting Sustainable Energy Futures
- Mitarbeit bei 4. Key Issues on the Transition to Sustainable Energy Structures and Its Spatial Dimension in Austria
- 4.2 New Settlement Structures
- 4.3 Existing Settlement Structures
- 5. Conclusions