reclip:tom

Research for climate protection: technological options for mitigation

Wilfried Winiwarter
Barbara Amon
Martina Fröhlich
Ernst Gebetsroither
Andreas Müller
Nebojsa Nakicenovic
Marion Ramusch
Melanie Sporer

AIT-F&PD-Report

Vol. 6, September 2009

reclip:tom:
Research for climate protection:
technological options for mitigation

Wilfried Winiwarter [1]
Barbara Amon[2]
Martina Fröhlich[2]
Ernst Gebetsroither[1]
Andreas Müller[3]
Nebojsa Nakicenovic[3]
Marion Ramusch[2]
Melanie Sporer[1]

Endbericht zu Projekt Nr. 1.S2.00007.0.0
in einer ARGE Wien im Auftrag der AIT Austrian Institute of Technology GmbH
vormals Austrian Research Centers GmbH - ARC

AIT-F&PD-Report
Vol. 6, September 2009

[1] AIT Foresight & Policy Development
Regional- & Infrastructure-Policy
[2] Universität der Bodenkultur (BOKU)
[3] Technische Universität Wien (TU Wien)

Abstract

This report presents a comprehensive framework to link Austria's greenhouse gas emissions directly to possible abatement measures. Emission sources are grouped into "entities", which describe the magnitude of an activity and its related emissions. Entities are selected such that external projections can be taken to characterize their current and future activity level, and that they comprise all emission sources. The framework attributes abatement measures to specific entities and describes their respective effects in terms of abatement efficiency, applicability, influence towards activity of entities (also cross-influence to other entities) and costs. It is thus able to cover also cascading influences as in the energy chain. In contrast to the entities, the measures presented in this report are not meant to be comprehensive. Instead, they serve as examples and are so far limited to those determined by technology (in a general sense) and do not include change of lifestyle. The framework allows a consistent examination across sectors, such that abatement costs as well as abatement potentials can be compared directly. In order to demonstrate the opportunities provided, we have applied this framework to Austrian projections for the years 2020 and 2050, and provided a set of measures under different scenarios.

Kurzfassung

In der vorliegenden Studie wird ein umfassendes System beschrieben, das die Verbindung der österreichischen Treibhausgasemissionen mit konkreten Maßnahmen zur Reduktion untersucht und ihre Auswirkungen quantifiziert. Die Emissionsquellen werden zu „Entitäten" zusammengefasst, die die Größe einer jeweiligen Aktivität und die zugehörigen Emissionen darstellen. Die Entitäten werden so ausgewählt, dass externe Projektionen herangezogen werden können, den Umfang der jeweiligen Aktivität auch in der Zukunft abschätzen zu können. Alle Emissionsquellen werden in den Entitäten erfasst. Das System ordnet Reduktionsmaßnahmen spezifisch den Entitäten zu und beschreibt ihre Auswirkungen auf Minderungseffizienz, Anwendbarkeit, Einfluss auf die Aktivität von Entitäten (auch Einflüsse auf andere Sektoren) und Kosten. Auch Einflusskaskaden können abgebildet werden, wie etwa für die Energiekette erforderlich. Die Maßnahmen sind, im Gegensatz zu den Entitäten, nicht als vollständig zu verstehen, sondern sie dienen als Beispiele und sind zunächst auf technologische Maßnahmen (im weiteren Sinn) beschränkt. Änderung des Verhaltens und des Lebensstils sind nicht inkludiert. Das System erlaubt eine konsistente Betrachtung auch über Sektoren hinweg, sodass Kosten und Potentiale vergleichbar gemacht werden. Um die Möglichkeiten zu demonstrieren, haben wir Projektionen der österreichischen Emissionen für die Jahre 2020 und 2050 erstellt und einen Satz von Maßnahmen unter verschiedenen Szenarien getestet.

Zusammenfassung für Entscheidungsträger („Executive Summary“)

Die Freisetzung von Treibhausgasen durch Aktivitäten der Menschen hat global zu einer Zunahme der Temperaturen und zu einer Änderung des Klimas geführt. Diese Entwicklung wird sich in Zukunft weiter fortsetzen. Um die weitere Zunahme von Treibhausgaskonzentrationen in der Atmosphäre zu mindern, wurden im Kyoto-Protokoll international verbindliche Vereinbarungen getroffen, die zur Verringerung der Emissionen führen sollen. Österreich hat sich dabei zu einer Reduktion der Emissionen aller relevanten Treibhausgase von 13% gegenüber dem Jahr 1990 verpflichtet. Dieses internationale Übereinkommen stellt aber nur einen ersten Schritt dar, weitergehende Maßnahmen werden in Zukunft erforderlich sein und voraussichtlich auch international akkordiert werden.

Das Projekt „reclip:tom“ diente dazu, darzulegen, welches Potential für technische Maßnahmen in Österreich besteht, die Emissionen von Treibhausgasen zu reduzieren. Insbesondere sollte ein System geschaffen werden, das es erlaubt, verschiedene Kombinationen solcher Maßnahmen miteinander vergleichen zu können, wobei gleichzeitig die Auswirkungen und Nebenwirkungen im Gesamtsystem berücksichtigt werden können. Wesentliche Ziele dabei waren:

- **Vollständige Erfassung aller Quellen**. Die in System dieses Berichtes zusammengestellten Emissionsdaten der Treibhausgase Kohlendioxid (CO_2), Methan (CH_4) und Lachgas (N_2O), als CO_2-Äquivalent (CO_2-eq) vergleichbar gemacht, wurden mit den historischen Daten der Treibhausgasinventur des Umweltbundesamtes für das Jahr 2000 abgeglichen. Damit wurde sichergestellt, dass alle Quellen der offiziellen österreichischen Berichterstattung im Rahmen des Kyoto Protokolls einbezogen wurden.
- **Definition technischer Maßnahmen**. Maßnahmen wurden definiert, die entweder Auswirkungen auf das Emissionsverhalten der Treibhausgase haben (geänderter Emissionsfaktor), oder die es erlauben, die Einsatzmengen zu verringern (Effizienzerhöhung). Die ausgewählten Maßnahmen erheben keinen Anspruch auf Vollständigkeit. Die Einschränkung auf „technische“ Maßnahmen erlaubt eine genauere Charakterisierung, grundsätzlich ist jede Art von Maßnahmen (auch Verhaltensänderungen) im Gesamtsystem integrierbar.
- **Vergleichbarkeit unterschiedlicher Wirtschaftssektoren**. In vielen Gesprächen mit Experten wird konzediert, dass Emissionsreduktionen grundsätzlich möglich sind, aber leider nur sehr schwer in der jeweils betroffenen Branche. Solche Aussagen beruhen auf der bislang nur bedingt möglichen Vergleichbarkeit der unterschiedlichen Emissionssektoren. Das Schaffen eines Systems, in dem Daten für unterschiedliche Sektoren gleichartig behandelt werden, soll deutlich machen, in welchen Bereichen Einsparungen effizient möglich sind, und wo tatsächlich größerer Probleme vorliegen.
- **Untersuchung von Auswirkungen**. Das erstellte System wurde so gestaltet, dass jede Maßnahme auch in ihren Konsequenzen auf andere Emissionsquellen dargestellt werden kann. Dies erlaubt die Berücksichtigung von Nebenwirkungen genauso wie die von Synergien.
- **Vergleich der Kosten.** Eine wichtige Möglichkeit, Maßnahmen unterschiedlicher Sektoren auf die gleiche Stufe zu stellen, besteht darin, den jeweiligen finanziellen Aufwand zu beurteilen. Die einfachste Möglichkeit dazu ist die Schätzung der Kosten, angegeben als zusätzlichen Aufwand pro Einheit reduziertem Treibhausgas.
- **Vorschau auf eine zukünftige Entwicklung.** Daten werden nicht nur für das Basisjahr 2000 präsentiert, sondern es werden auch – basierend auf konsistente externe Informationen über den Umfang zukünftiger Tätigkeiten – Vorschläge der zukünftigen Entwicklung der Sektoren und implementierten Maßnahmen in Form von Szenarien geboten. Jede der Szenarien beinhaltet ei-

nen Satz von Erwartungen an die Implementierung von Maßnahmen, wie sie von den Autoren der Studie zusammengestellt wurden. Somit ist eine Betrachtung der Situation für die Jahre 2020 bzw. 2050 möglich.

Diesen Anforderungen wurde durch Entwicklung eines umfassenden Systems zur Darstellung von Emissionsdaten und zur Bewertung emissionsmindernder Maßnahmen Rechnung getragen. Dieses System konnte seine Flexibilität bereits dadurch zeigen, dass es möglich war, Maßnahmen aus den unterschiedlichen Sektoren zu integrieren. Grundsätzlich war genau dies die Herausforderung: Daten mussten gefunden bzw. abgeleitet werden, die eine vollständige Abbildung von Maßnahmen im System erlaubten. Ab diesem Moment waren die Ergebnisse vergleichbar und auswertbar, auch in Hinblick auf die Kosten.

Dieses System besteht somit aus

– einer Auflistung aller relevanten Quellen/Quellgruppen (hier als „Entitäten" bezeichnet);
– einem Satz an Maßnahmen, der so gestaltet ist, dass eine Maßnahme jeweils genau einer „Entität" zugeordnet ist;
– den Parametern, die erforderlich sind um das Emissionsverhalten der „Entitäten" und die Auswirkungen der Maßnahmen detailliert zu beschreiben, inklusiver deren Auswirkungen und Nebenwirkungen;
– den Verknüpfungsvorschriften zwischen den einzelnen Datensätzen.

Wie erwähnt, ist die Auswahl der Maßnahmen nicht umfassend. Entsprechend sind auch die dargestellten Szenarien nicht vollständig in dem Sinn, dass weiterreichende Emissionsreduktionen durchaus denkbar sind, insbesondere in Hinblick auf die Situation von 2050, wenn Technologien angewendet werden können, die heute noch nicht entwickelt sind.

Konkret wurden folgende Szenarien verglichen:

– BAU: Die Fortschreibung der derzeitigen Entwicklung (business-as-usual, BAU) berücksichtigt lediglich die durch die technische Entwicklung erwartbaren Effizienzerhöhungen.
– DEF: Das Standardszenario „mit Maßnahmen" (default, DEF) gibt Implementierungsgrade von Maßnahmen vor, die bei ambitionierter Zielsetzung erwartbar sind. Dieses Szenario verlangt aber bereits deutliche Änderungen in Industrie- und Infrastruktur.
– MFR: Das Szenario „mit zusätzlichen Maßnahmen" (maximum feasible reduction, MFR) unterscheidet sich im wesentlichen dadurch, dass der Großteil der Maßnahmen bereits zum frühesten Zeitpunkt (also 2020) als implementierbar gelten – weiterführende Maßnahmen konnten im gegenständlichen Projekt nicht definiert werden.

Emissionsminderungen werden jeweils gegenüber einer Fortschreibung „NOOPTION" angegeben, die weiterhin von heutigen Energieeffizienzen ausgeht, also auch die „autonome" technische Weiterentwicklung vernachlässigt.

Die Gesamtsumme der Treibhausgasemissionen in Österreich gemäß den verschiedenen Szenarien wird in Abbildung S1 gezeigt. Alle drei Szenarien starten vom gleichen Ausgangspunkt des Jahres 2000, der genauso wie bei den anderen Jahren die Aufnahme von CO_2 in Böden („carbon sequestration") als Element der Gesamtsumme berücksichtigt, daher niedriger ist als die „reinen" Emissionen des Jahres 2000 (81 Mt CO_2-eq, von denen 16 Mt CO_2-eq als Aufnahme in Böden in Abzug gebracht werden). Bereits 2020 zeigen die Szenarien drastische Unterschiede. Unter dem „realistischen" Szenario DEF ergeben sich deutliche Reduktionen der Emissionen auch gegenüber dem jetzigen Stand, maximal möglich scheint eine Reduktion auf weniger als einem Drittel der Fortschreibung BAU und deutlich unter der Hälfte der Emissionen von 2000. Für 2050 gleichen DEF und MFR einander an, da eben weiter in die Zukunft wirksame Maßnahmen, die für 2050 grundsätzlich vorstellbar wären, nicht im Paket von MFR enthalten sind. Diese Emissionen, diesmal auch für das „realistische“ DEF Szenario, liegen weiterhin etwa bei einem Drittel der BAU Emissionen und knapp über der Hälfte der Emissionen von 2000.

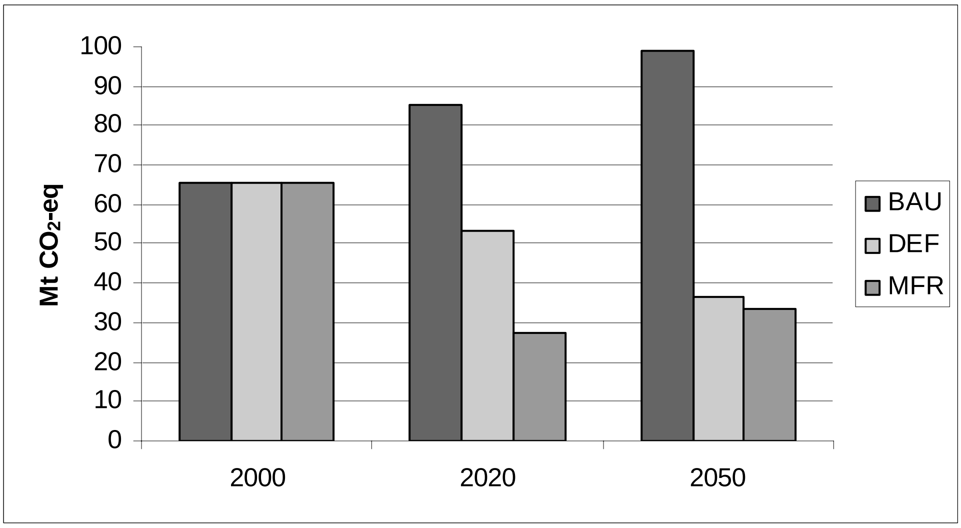

Abbildung S1: Entwicklung der Treibhausgasemissionen Österreichs in unterschiedlichen Szenarien. Die Summen berücksichtigen nicht nur die Emissionen, sondern auch die Aufnahme von CO_2 in Böden.

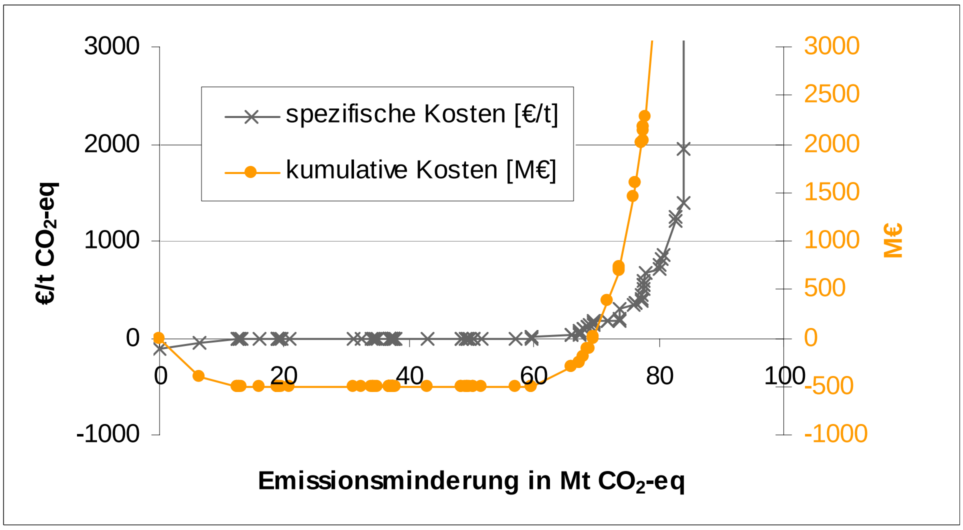

Abbildung S2: Kostenkurve für das Standardszenario DEF, 2050.

Ein für das Projekt zentrales Ergebnis stellt die ermittelte Kostenkurve dar (Abbildung S2). Kostenkurven sortieren Maßnahmen in der Reihenfolge aufsteigender Kosten (spezifische Kosten pro erzielter Einheit Emissionsreduktion), und vergleichen diese Kosten mit den erzielten Emissionsminderungen. Gleichzeitig werden die kumulativen Kosten, die zur Erreichung einer bestimmten Emissionsminderung mindestens erforderlich sind, angegeben. Die Darstellung in Abbildung S2 zeigt, dass eine Reihe von Maßnahmen verfügbar ist, die sogar ohne Berücksichtigung der Treibhausgasreduktionen ökonomisch sinnvoll wären. Die Implementierung der Maßnahmen führt zu Kosteneinsparungen, zu „negativen Kosten". Ein weiterer, großer Block an Maßnahmen kann ohne Kosten oder mit geringen Kosten durchgeführt werden, sodass das volkswirtschaftliche wirksame Bilanz der „kumulativen Kosten" neutral bleibt, obwohl gegenüber dem BAU Szenario fast die Hälfte der Emissionen eingespart wurden. Erst Maßnahmen, die über eine Emissionsminderung von etwa 70 Mt CO_2-eq hinausgehen sind insgesamt kostenwirksam. Der genannte Wert inkludiert zwar auch Gewinne durch die normale technische Weiterentwicklung bis 2050 (ca. 20 Mt, die mit Nullkosten angegeben wurden) und bezieht sich auf das insgesamt gegenüber heute gestiegene Aktivitätsniveau, zeigt aber deutlich, welche Reduktionen aus heutiger Sicht plausibel möglich scheinen. Volkswirtschaftlich ohne Kosten ergibt sich demgemäß eine Reduktion der Emissionen auf ca. 50 Mt CO_2-eq im Jahr 2050, was deutlich unter dem derzeitigen Niveau liegt.

Über diesen Bereich hinaus können die Kosten sehr schnell sehr hohe Werte erreichen. Auch die betrachteten Maßnahmen in diesem Bereich sind bereits sehr teuer, sie können einige Hundert bis Tausend Euro pro Tonne eingespartem CO_2-eq betragen.

Kostengünstige Maßnahmen sind in jedem der betrachteten Bereiche (Energie, Industrie, Landwirtschaft, Boden) zu finden, allerdings in unterschiedlichem Umfang. Die einzelnen Maßnahmen bedingen durchaus beträchtliche Einschnitte, auch strukturelle Änderungen für einzelne Quellen oder Branchen. Im Rahmen dieser Veränderungen gibt es sowohl Gewinner als auch Verlierer, es sind also ökonomische Verschiebungen zu erwarten. Insgesamt betrachtet entstehen für die Volkswirtschaft erst dann Kosten, wenn auch die teuren Maßnahmen berücksichtigt werden müssen.

Unter den hier ausgewählten Maßnahmen findet man das bei weitem größte Potential für Emissionsreduktionen im Energiebereich. Die erfolgreichsten Maßnahmenbündel für 2050 umfassen verbesserte Effizienzen im Bereich Raumwärme und Warmwasserbereitstellung (hier sind auch die großen Kosteneinsparungen zu finden), aber auch den weiteren Ausbau der Wasserkraft und den Einsatz verbesserter industrieller Elektromotore. Auch die Optimierung von Infrastruktur fließt in die Maßnahmen ein: eine Siedlungsverdichtung wirkt sich sowohl auf Raumwärme als auf den Anteil öffentlicher Verkehrsmittel positiv aus. Weitere Einsparungen durch CO_2-Aufnahme (allerdings verbunden mit beträchtlichen Kosten) sind durch Extensivierung der landwirtschaftlichen Bewirtschaftung von Böden zu erhalten; die Erhöhung der Milchleistung auf jährlich 10000 kg Milch pro Kuh verringert die Viehbestandszahl und damit die Emissionen. Die größten Einsparungen im industriellen Bereich sind durch weitere Reduktionen des Anteils gebrannten Anteils (Klinker) im Zement zu erwarten. Nicht alle, aber einige dieser erfolgreichen Maßnahmenbündel werden Zielkonflikte mit anderen berechtigten Erwartungen an die zukünftige Entwicklung auslösen.

Durch Schaffen einer konsistenten Struktur, wie sie im Rahmen der vorliegenden Arbeit vorgenommen wurde, können diese Maßnahmen nun einzeln bewertet werden, und auch weitere Maßnahmen können eingebaut und in einen Vergleich einbezogen werden. Dafür müssen nur die entsprechenden Parameter abgeleitet werden, die den Umfang sowie die Kosten der Minderungsmöglichkeiten und die Interaktionen mit anderen Sektoren bzw. Maßnahmen beschreiben. Gerade im Hinblick auf ein Szenario für 2050 sind noch beträchtliche Verbesserungen und Ergänzungen möglich, insbesondere in der Betrachtung der anderen Sektoren über „Energie" hinaus. Hier sind sektorale und branchenspezifische Untersuchungen der Zusammenhänge sinnvoll und empfehlenswert.

Inhaltsverzeichnis

1 Introduction

1.1 Research for climate protection – reclip

The reclip program (research for climate protection) has been initiated by the Austrian Research Centers under a collaborative scheme between applied research institutions and universities. Within this framework, two diverging aspects related to climate change have been investigated. In the light of an impact of anthropogenic activities to climate, strategy for action extends into two fundamentally different directions: adaptation to the effects of a changing climate and mitigation of climate change by reducing anthropogenic emissions of greenhouse gases (GHG's).

Work on reclip:more (model run evaluation) started in autumn 2003 (Loibl et al., 2004, 2005). Regional climate models have been applied to the alpine ridge, and then have been downscaled to Austria to create high resolution climate scenarios. Results have been compared by individual model, uncertainties and sensitivities have been assessed and conclusions have been drawn in terms of the climate situation in Austria (period 2040-2050, summer temperatures, winter temperatures, rainfall, extreme events and similar). Model runs for a historical period also allow understanding the model results in comparison to actual measurements, in order to judge the models' predictive qualities. reclip:more is now completed, the final report and subsequent publications for the scientific literature are under preparation.

reclip:tom (technological options for mitigation) started in 2005. The project attempts to provide a common platform for evaluating potential options for reducing emissions of greenhouse gases in Austria. Austria is already committed to a 13% reduction of greenhouse gas emissions compared to the 1990 levels in the Kyoto protocol, and further abatement will be required in possible subsequent international accords. An understanding of potential and costs of the options available facilitates a sound preparation of such accords. Instead of focusing on just one source sector, reclip:tom covers all potential sources and makes abatement options comparable, while also considering interactions (synergies or conflicts of interest) between source sectors. The options covered are limited to technological and technology-related options, based on external constraints and assumptions like energy projections, and the potential of switching consumer behaviour is not touched.

In addition to the two operative projects, the complementary reclip:strat (strategic monitoring) is evaluating the quality, extent and potential controversies in co-operative projects between an applied research company and university institutes.

1.2 Scope of the work

Much of the general structure of reclip:tom has been developed already during the first year of the project. The outcome of this extensive discussion process has been described in detail by Winiwarter et al. (2005). Basically, so-called "entities" have been defined which cover a certain section of similar activities, a source sector. reclip:tom uses these entities to re-create GHG emissions for the year 2000 based on emission balances as published by the Austrian Federal Environment Agency. Scenarios for the further development of emissions allow to estimate emissions to the years 2020 and 2050. Available and officially accorded activity projections (energy, agricultural activity) and extrapolations are used from sources external to this project. Entities have mostly been described by Winiwarter et al. (2005), only few adaptations to these structures seemed useful since. Full coverage of entities is an important part of the project's concept, i.e. accordance in total emissions between official national data and reclip:tom.

For each entity, one or more abatement options can be defined. Abatement options are measures either affecting the release of greenhouse gases from an entity (change of emission factor) or changing the underlying activity (statistical parameter). Especially changing activities is an important but challenging concept, as these – by definition – derive from external sources. In practice this means that a measure can affect such a predefined (external) datum in an organized manner. Process chains (options and measures may be applied at different process levels) as well as linkages and interferences between entities can all be integrated in this concept. The data structure is described in detail in section 1.3.

For practical reasons and in order to benefit from specific expertise, reclip:tom is being operated in form of work packages. Within each work package, entities and measures are being developed. Special consideration is given to overcome barriers between work packages and to define and discuss the linkages. The work packages and the division of responsibilities are presented in Table 1.

Table 1: Work packages in reclip:tom

Work package name	Institution	Persons in charge
Energy	Environment Economics Group (Vienna University of Technology)	Andreas Müller, Nebojsa Nakicenovic
Industry & Processes	AIT Austrian Institute of Technology*	Wilfried Winiwarter, Melanie Sporer
Agriculture	Division of Agricultural Engineering, University of Natural Resources Vienna	Barbara Amon, Martina Fröhlich, Marion Ramusch
Soil & Landfills	AIT Austrian Institute of Technology*	Ernst Gebetsroither
Data structure & overall coordination	AIT Austrian Institute of Technology*	Wilfried Winiwarter

* formerly Austrian Research Centers -ARC

A full treatment of all potential abatement options is beyond the limits of reclip:tom. Instead, in this report we try to present an overview on a number of measures we deem important. For some of these, we will be able to present the quantitative data required to make them comparable. For other options we may only partly be able to fill the data structure, or just to provide a placeholder until further research can be performed to include them. In both cases, contribution of options to emission abatement and sorting according to costs will not be possible. While we aim at a complete coverage in terms of entities, only a very partly coverage of measures is realistic.

There is, however, a common thread between entities, especially projected entities, and measures. Projected activities, especially when externally calculated, may to some extent implicitly include some of the measures developed here. In a similar way, measures may be part of the base year situation. Adequate treatment of implementation of measures requires to understand and collect information on such situations.

reclip:tom is able to provide a consistent set of data on activities, including activity projections, and assumed certain measures to be implemented at different degree (for different scenarios). Due to the project structure, activity projections have been taken from external sources. With the economic situation at publication time of this report rapidly changing, such projections are quickly outdated. Projections on future energy demand, industrial production and activity in agriculture therefore do not reflect the latest turmoil. But as the projections reflect periods of more than 10 or more than 40 years, respectively, to cover the situation of 2020 and 2050, short term changes should not be expected to immediately affect the overall trends. In this respect it seems even useful that neither the current crises, nor the boom period immediately before the crises is reflected in the projections taken. Consequently the latest improvements in emission estimates were also not considered, as regards even past data (for the year 2000) and instead older reports are being referred to. In a similar way, due to the editorial deadlines involved in the process, very recent relevant publications could also not be taken into account (specifically, this regards Umweltbundesamt, 2009).

1.3 Common data structure

The data structure of reclip:tom basically consists of *entities* and *measures*. Entities are characterized by their activity. An abatement option (measure) requires information on the emission factor (EF), the cost, and the extent to which it may be applied (degree of implementation). Implementation depends on the assumptions taken for a respective emission scenario; it is constrained by the applicability, describing the technical potential of a measure. The applicability represents the fraction of the entity that can be covered by a measure. Normally limitations are when certain technical features prevent a measure being taken, or when a measure applies to a sub-process (part) of the entity only and does not cover the entity as a whole. This basic data structure is displayed as Figure 1.

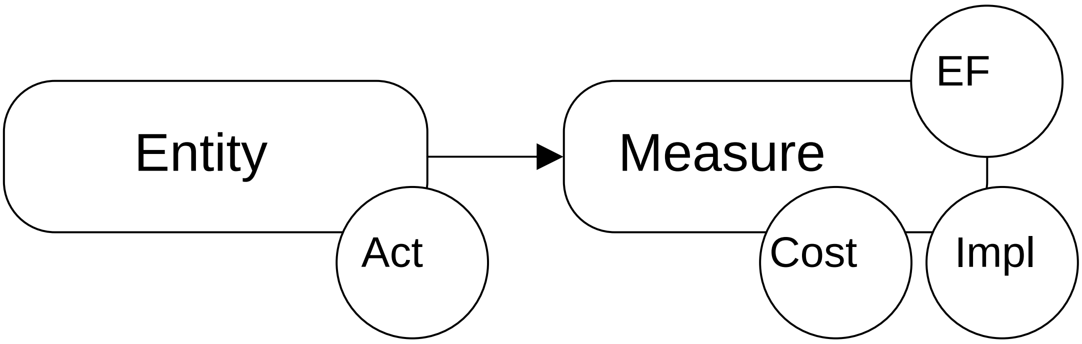

Figure 1: Direct interaction of entity and measure in reclip:tom

This concept may be extended. One entity may have one or several measures. Furthermore – and most importantly in terms of covering interactions and process chains – a measure may not only effect the emission factor, but also “influence” the activity of an entity. This influence can refer to the entity it belongs to originally, but it may also extend to one or more other entities, reflecting a “process chain” idea (see Figure 2).

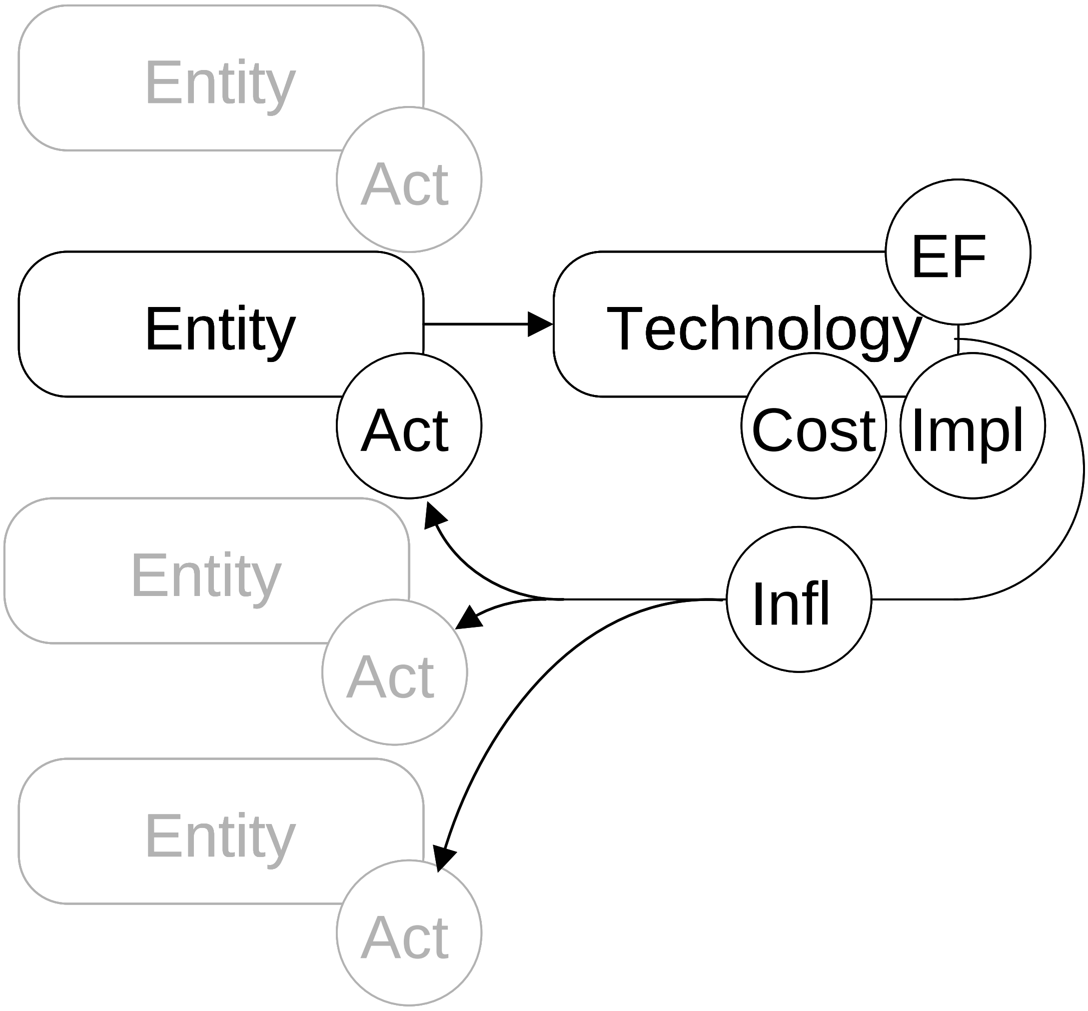

Figure 2: Bi-directional Interaction between entity and measure

Thus we may use the following definitions:

Entities are explicitly defined units of activity within a specific sector. The selection of entities is performed according to availability of related statistics and according to applicability of measures. The default level of activity for each entity, especially the activity level for projections, is derived from exogenous information. As will be described in the individual chapters of this report, exogenous information is typically derived from economical models or other expectations for future development.

Measures are purposeful interventions into the emission characteristics of entities. Measures considered within the framework of reclip:tom will be limited to options for mitigation of greenhouse gas emissions. It needs to be understood that measures may be applied both towards the amount of gas emissions per activity unit (emission factor) and the material throughput itself (activity). In the case of activity chains, this means that a measure affects all previous elements of this chain. Moreover, a measure may also have side effects to other entities, including entities of different sectors. All these possibilities need to be considered in the structure.

Considering process chains also requires to define the system boundaries appropriately. In line with IPCC's system of attributing GHG emissions to individual countries, we also set the system boundary around Austria. This means, for example, that imports of CO_2 relevant secondary energy or energy services (e.g., electricity imports) are not considered part of this study. Tank tourism is also not considered, assuming that in the forecast period unified taxation in Europe will prevent this to become a major concern. Instead, emissions will be derived from the service level again, specifically passenger transport and goods transport on inland roads (see section 2). This limitation is the only meaningful option for projections, in order to avoid arbitrary assumptions on "carbon leakage" (i.e., maintaining the full service of a sector while exporting the emission generating processes).

In terms of emission projections, we differentiate different expectations for a future development. The "no options" scenario (only used for the purpose of comparison) assumes no measure to be implemented beyond those that are already available in 2000. Changes are due to the expectations in the future activity of the respective entities only. The "Business as usual" (BAU – also termed "baseline") scenario projects certain improvements in processes, like efficiency increases, as autonomous development derived from similar developments in the past. The "default" scenario applies measures and also estimates the extent to which such measures can be reailized at a certain year. Finally, the "maximum feasible reduction" (MFR) scenario applies all available measures to their full extent. Note that, as measures implemented in reclip:tom are not necessarily exhaustive, the MFR scenario as defined here may considerably underestimate full reduction potentials.

2 Energy

2.1 Baseline – Business as usual scenario

The baseline scenario we use is based on the Wifo study *energy scenarios until 2020 for Austria*, which has been performed by a conservative top-down model. Using similar input parameters as the European Primes model, model outcomes of the Wifo study are pretty similar to the ones of the Primes model whose time horizon is 2030.

To come up with a baseline scenario until 2050 for Austria we used the following literature:

- (1) Wifo Energy scenarios for Austria until 2020 (2005)
- (2) European Energy and Transport Trends to 2030 (2004, DG TREN, PRIMES-Model)
- (3) IPCC Special Report on Emissions Scenarios (SRES) (IPCC 2001b, Model runs performed by the MESSAGE-MACRO model)

Until 2020 the baseline scenario is fully based on (1) Wifo Energy scenarios, for 2050 we extrapolated a consistent path by adopting the intensities we got from (2) and (3). The following section briefly points out the development of the society in general, represented by population growth, economic growth and improvements in energy intensities.

Economic development and population growth

Table 2: Underlying average Austrian economic growth rate per year until 2050. Values until 2020 are based on the Wifo forecast

	2005 - 2010	**2010 - 2020**	**2020 - 2030**	**2030 - 2040**	**2040 - 2050**
Wifo 2005 - 2020	2.3%	2.1%			
reclip:tom 2020 - 2050			1.9%	1.6%	1.4%

The decrease in GDP growth results from the economic theory that the GDP growth decreases with increasing GDP per capita (Figure 3).

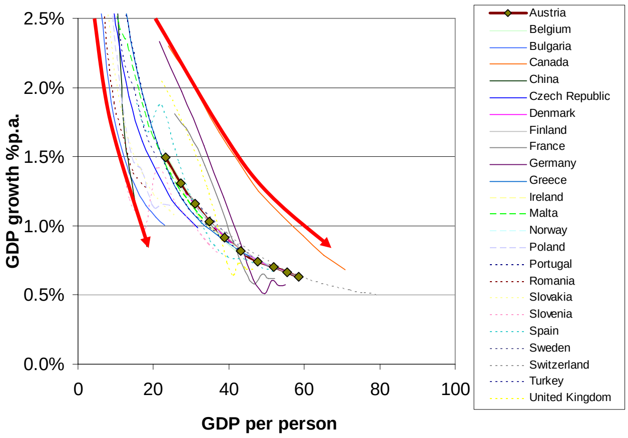

Figure 3: Economic growth for selected European countries according to the IPCC A2r Scenario (IPCC, 2001b). Common to all countries is the idea, that GDP growth decreases with increasing GDP per capita.

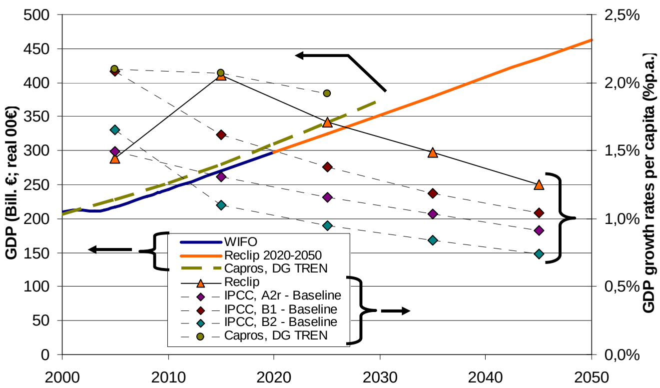

Figure 4: Development of the Austrian gross domestic product and underlying annual growth rate in comparison to the three IPPC baseline Scenarios A1r, B1, B2.

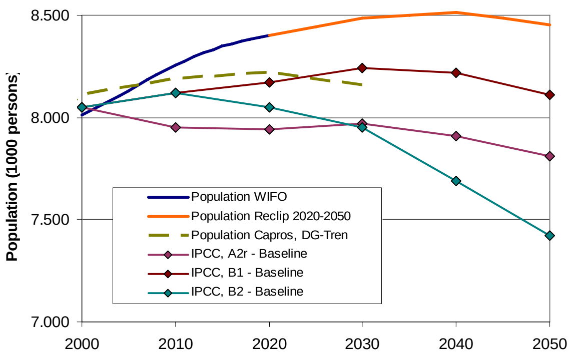

Figure 5: Development of Austrian population compared to other reference sources (Capros, 2006; IPCC, 2001b)

As can be seen from figure 4 and 5, the present baseline scenario includes both high economic as well as high population growth. The impact of population times affluence - in terms of GDP per capita – of the shown three IPCC-reference scenarios is up to 10% less in 2020 and lies between -10% and -33% in 2050, compared to the baseline scenario we use for the study. This means that under consistent global development and by using the same technologies than those assumed to be used in the IPCC scenarios, global emissions in 2050 would incline by 60% (B1), 150% (B2) and 200% (A2r) compared to the global GHG-Emissions in 2000.

In terms of energy intensities (final energy), the three IPCC scenarios show improvements of 12% (15%) (A2r), 15% (17%) (B2) and 23% (31%) (B1) in 2020 (2050). By comparison, the reference scenario we use shows improvements in the energy intensity of 8% in 2020 and 36% until 2050. To summarize this comparison, the baseline scenario of this study results in similar results than the high emission scenario A2r baseline scenario, yet due to higher population and economic growth it already includes additional energy efficiency measures, comparable to those which are included in the middle path scenario B1.

As we have pointed out above, the basic assumptions of this project are very conservative, which results in an energy and emission intensive baseline scenario. This implies that in order to reduce emissions down to a low level – in absolute terms – technological options always become expensive, since mitigation cannot be based on a more sustainable life style.

2.1.1 Households

In 2000, households consumed almost 30% of the Austrian final energy demand. 85% or about 230 PJ were used for low temperature applications: heating, hot water and cooking.

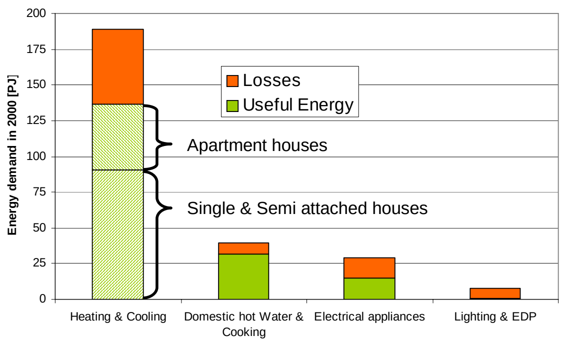

Figure 6: Energy demand of Austrian households in 2004 (Statistik Austria, 2004)

The total conversion efficiency from final energy demand into useful energy, which provides the energy service, is about 70%. In absolute numbers, heating accounts for the main losses, even if measures to reduce the heating demand of buildings are not taking into account.

Subdivided into energy carrier it can be seen that roughly 50% of the final energy has been provided by oil and renewables - mainly wood log – electricity and gas account for additional 20% each. Up to 2050, the baseline scenario implies a shift in the ratio of the requested energy carriers. The use of coal is declining to almost zero until 2050; the fraction of electricity is increasing by more than 10%, mainly at the expense of coal and oil. Gas and District heat are increasing as well. Renewables are decreasing slightly. In the baseline scenario we expect that the energy consumption is increasing by 32% until 2020, an increase by additional 5% is expected for the period between 2020 and 2050.

Currently, most energy that is consumed by the household sector is used for space heating. Over time, the relative share is decreasing, even though the energy required for space heating is increasing until 2020 and still holds a major fraction in 2050. Broken down to energy demand per square metre, the baseline scenario assumes a stable demand of 215 kWh/m².a for heating until 2020, which is decreasing by 50% to 110 kWh/m².a until 2050. The domestic hot water consumption per living space is increasing by almost 40% until 2020 and remains constant afterwards. Electrical appliances are increasing sharply, mostly because of electrical motors, which include space cooling.

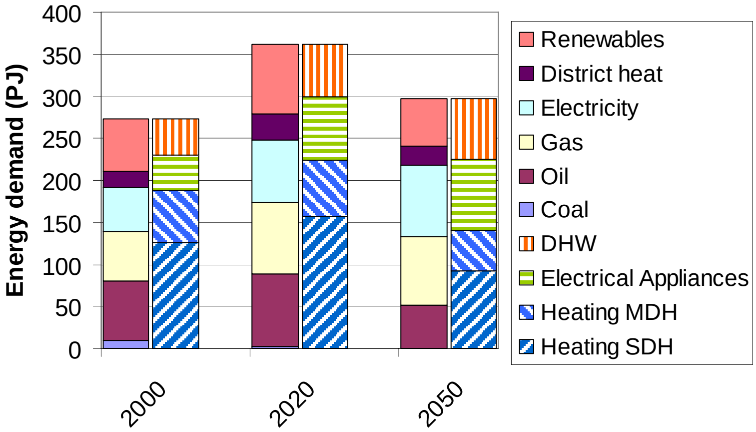

Figure 7: Baseline scenario: energy consumption by energy carrier of the Austrian households sector for the years 2000, 2020 and 2050.

The development outlined above results in more or less constant direct Greenhouse gas emissions until 2050, yet the indirect emissions which are released by upstream processes, mainly the electricity and district heat production, are increasing significantly. Starting from about 14.5 Mt CO_2 Equiv. which are released due to household activities in 2000, in the baseline scenario the emissions are increasing to about 18.5 Mt CO_2 Equiv. in 2020. Afterwards they are decreasing to 16 Mt CO_2 Equiv. in 2050. The fractions of emissions which are released due to multiple dwelling houses (apartment houses) are slightly increasing from 43% in 2000 to 47% in 2050.

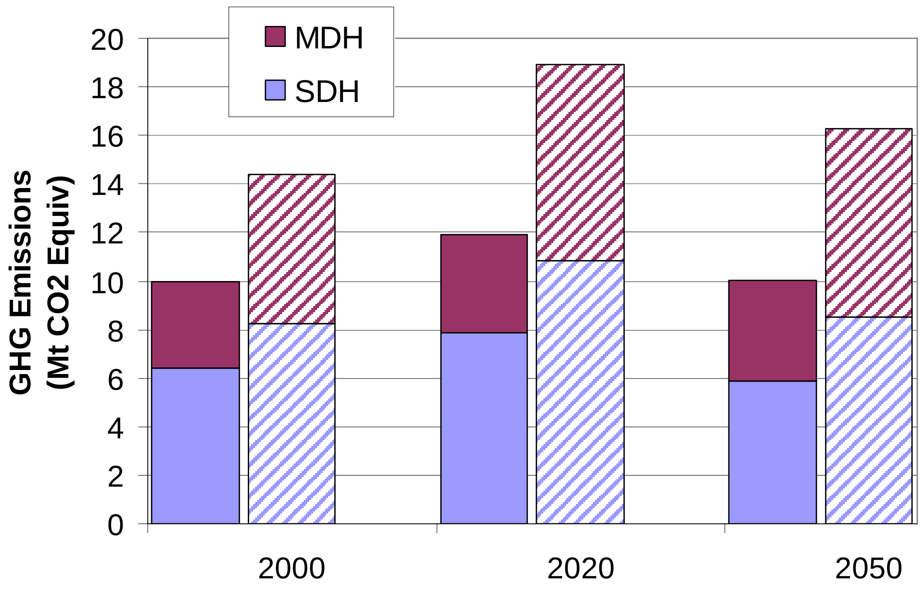

Figure 8: Baseline scenario: Greenhouse gas emissions released due to households activities, subdivided in emissions from single and semi detached houses (SDH) and multiple dwelling houses (apartment houses – MDH). The solid bars represent direct emissions; the striped bars include emissions released by upstream processes.

Key technologies

Key technologies to reduce the energy demand of buildings can be subdivided into two categories: technologies to reduce the heat demand – which means mainly space heating and – and efficient appliances.

Options to reduce the space heating demand and subsequently the fuel demand are well know, however they are not being implemented efficiently and widely enough:

– Isolation of the building envelope
– Passive solar construction which allows the optimal use of the direct solar radiation through large windows with a very low R-value (high resistance to heat flow) and orientation towards south
– Mechanical ventilation systems with heat recovery
– Solar collector
– Efficient heating systems such as well designed district heating systems and CHP systems, heat pumps and condensing boilers, which allow to recover the latent heat of the water vapour in the flue gas.

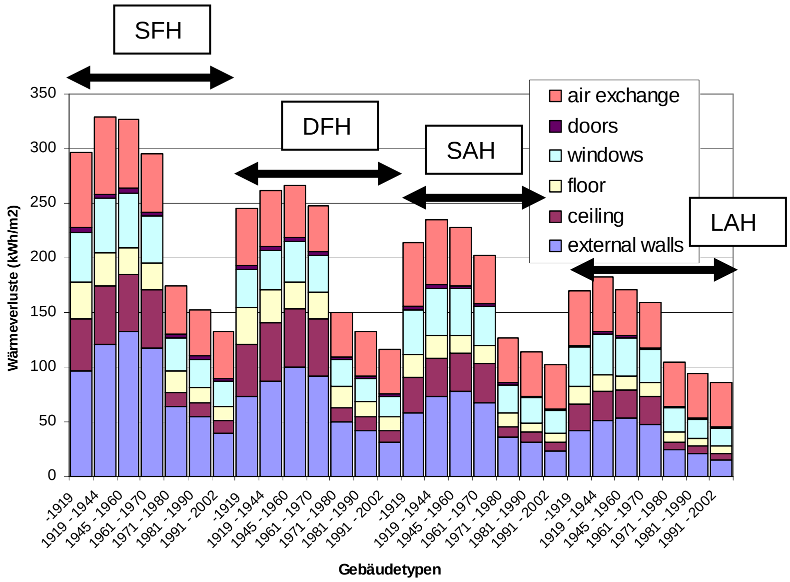

Figure 9: Average heat losses by envelope unit and air exchange of different buildings (SFH: single family houses, DFH: semi detached houses, SAH: small apartment houses, LAH: large apartment houses) classes in Austria.

Various technologies exist to reduce the energy demand of appliances:

Lighting (10% of residential electricity demand)

The efficiency of different lamps varies by the factor of ten (low pressure sodium lamps ~200 lm/W, Incandescent less than 15 lm/W), yet because of the characteristics of these different kind of lamps such as warm up time, light distribution and colour makes only a few of them interchangeable. Still, especially in the residential sector, compact fluorescent could improve the performance by the factor of five.

Refrigerators and freezers (17% of residential electricity demand)

Even though this technology has matured already, still a lot of improvements are going on such as vacuum isolation, adaptive defrost systems, replacing AC by DC motors, bigger evaporator and condenser heat exchanger, better compressors. Globally, in 2005 new refrigerators used about 60% of the amount of energy that equivalent models used in 1992 (IEA, 2006).

Washing machines and dishwashers (11% of residential electricity demand)

Most of the energy that is used by these appliances is used to heat up water. Therefore, energy demand can be reduced by technologies that operate with low water demand. In addition, hot water, from the hot water circuit, could be supplied to the appliances, which would be more efficient as long as the water heater isn't powered by electricity but by gas or, in the ideal case, by solar thermal energy. The IEA expects an increase of efficiency of dishwashers by 15% until 2010, slowing down afterwards to 0.5% p.a. For washing machines, improvements are expected as well, especially when it comes to the washing temperatures. To illustrate that, the average energy demand per machine and year was about 220 kWh/year in Europe, in the OECD Pacific region less than 100 kWh/year (IEA, 2006).

Reduction of stand-by losses of electronic and entertainment devices

Many appliances such as radios, televisions, set-top boxes, printers or computers, consume a good portion of their total annual electricity demand during stand-by mode. Reducing these losses could substantially decrease the residential electricity demand.

2.1.2 Service Sector

In 2000, the final energy consumption of the service sector amounted into 127 PJ, or about 15% of the total Austrian final energy demand. The conversion efficiency from final into useful energy is about 70%, in contrast to the household sector, lighting and computing cause significant losses, which account for nearly 40% of the total conversion losses of this entity. Heating and cooling processes account for the same losses. With a conversion efficiency of less than 50% motors (electrical motors and diesel/gas engines) cause for significant losses as well.

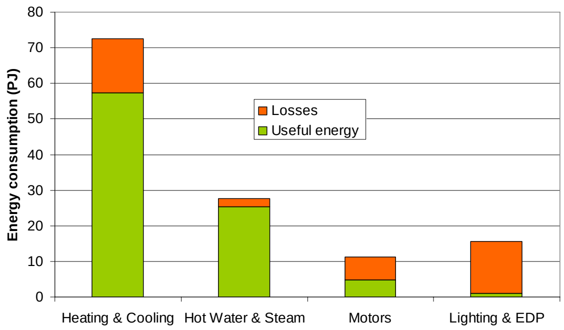

Figure 10: Energy demand of Austrian service sector broken down by application categories in 2004 (Statistik Austria, 2004)

A break-down of the used energy into energy carriers shows that today nearly 45% of the consumed energy is supplied by electricity. Another 18% comes from oil and district heat, ~14% from natural gas. According to the WIFO Scenario, electricity makes up 70% in 2020, which is assumed to increase to more than 90% in 2050. The underlying bottom-up reasons are the decreasing heat demand, especially space heating, increasing demand for space cooling which is assumed to be performed by electrical air conditioners, increasing electricity demand for computing and electronic devices as well as a general shift from chemical energy carriers towards electricity to provide motion and high temperature heat.

The underlying growth rates until 2020 were taken from the Wifo study. For the time period from 2020 to 2050 we assumed a slow down of the service sector's economic growth from 1.6% p.a. to 1.1% p.a., which is consistent with the development shown in Figure 4 and Capros (2006). Wifo assumes that the energy intensity of the service sector will be increasing until 2020. For the period after until 2050, we assumed that the intensity will first be increasing until 2030 and afterwards decreasing.

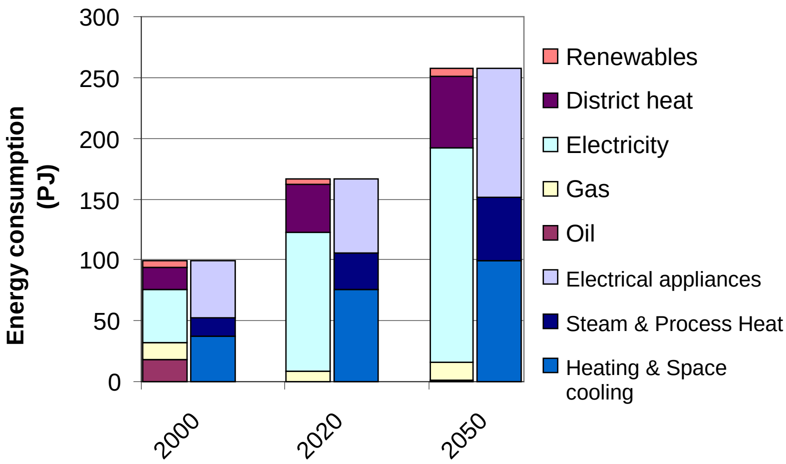

Figure 11: Baseline scenario: Energy demand of the service sector by energy carrier until 2050. We expect that the change from chemical energy carriers towards electricity will continue, which means that energy would be supplied almost exclusively by electricity in 2050.

This development leads to the increasing Greenhouse gas emissions, if emissions released during electricity production are accounted for as well. Starting from annual released Greenhouse gas emissions due to activities of the service sector of about 5.5 Mt in 2000, emissions are going to double almost until 2020 and triple until 2050 (figure 12). At the same time, on-site emissions, which account for 30% in 2000, are more or less completely diminished within the next 15 years – the discharging process is going to happen during the upstream process of electricity production.

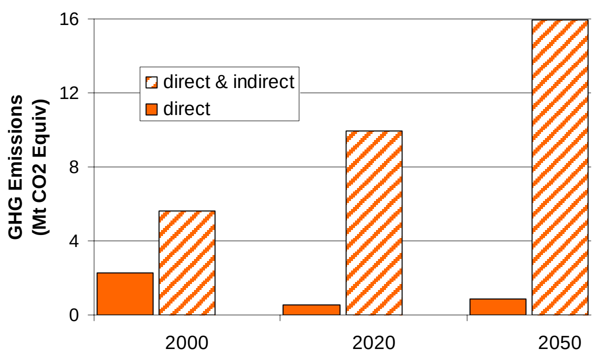

Figure 12: Baseline scenario: Greenhouse gas emissions released due to activities of the service sector. The solid bars represent direct emissions; the striped bars include emissions released by upstream processes. The baseline scenario presumes that on-site emissions are virtually eradicated until 2020, whereas upstream emissions are increasing.

2.1.3 Transport

In our study we divide the transport sector into the three passenger transportation units: (1) individual transportation including light duty vehicles (<3.5 t.), buses and railways – which are below summed up as public passenger transport; (2) two freight transportation units: road transport and freight transportation via railways and (3) a unit which sums up other transportation activities, mainly national shipping and aviation and transportation via pipelines.

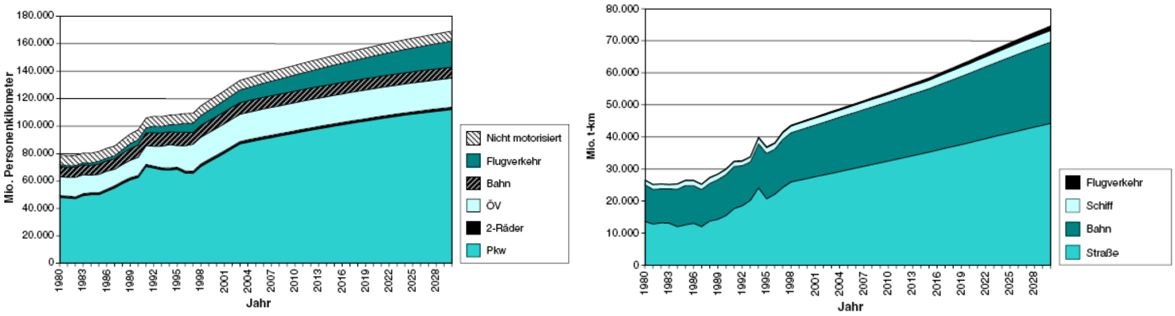

Figure 13: Development of transportation in terms of passenger (left) and tonne (right) kilometre in Austria by transport mode. About 30 billion passenger kilometres and 17 billions tonne kilometres were provided by non-individual transportation systems, i.e. buses and train in 2000 (source: Umweltbundesamt, 2001)

In 2000 individual passenger transportation and freight transport by trucks consumed about more than 85% of the energy for the transport system, not counting international aviation, which doesn't account for the Kyoto-Protocol. Based on the assumption that electricity for trains is produced by thermal power plants, and that the *Other transport* unit is neglected as well, again the same number is consumed by individual transportation systems. Yet, viewed from the service rendered, these transportation modes provided, in terms of passenger and tonne kilometre, about 70% of the total transportation request. Of course, the transportation service fulfilled by a car isn't apparently the same as is that provided by a public bus or a train, and the public transportation cannot be reasonably extended arbitrarily. Nonetheless, it can be concluded that transportation service provided by non-individual transportation modes is more energy efficient, in the case of Austria, by a factor of 4-6.

What can be observed too is the fact, that the engine power of new vehicles is increasing rapidly (figure 14). Starting from an average engine power of 67 kW of sold vehicles in 1999, this indicator has increased by 15% within the last 7 years to 75 kW in 2006.

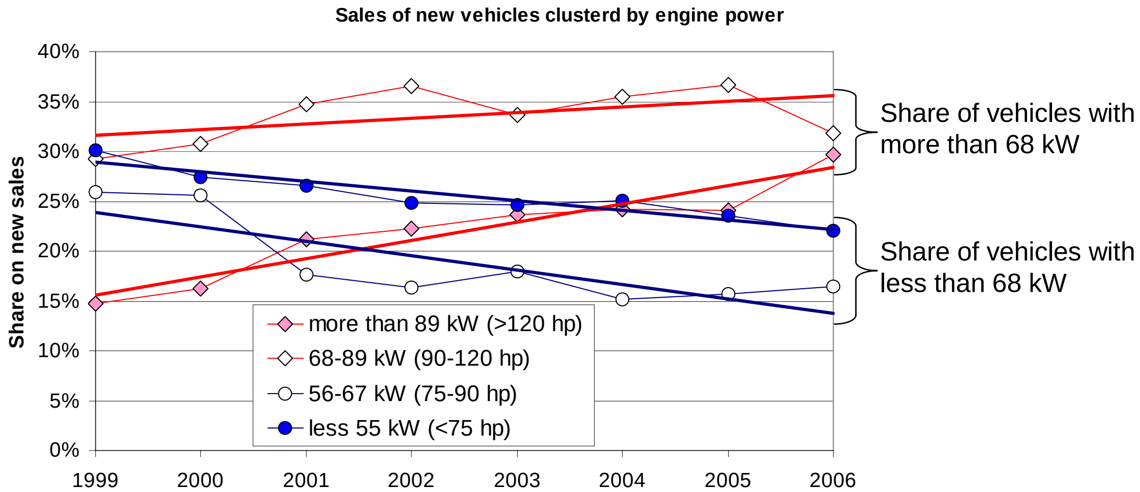

Figure 14: Sales of new cars in Austria clustered by engine power.

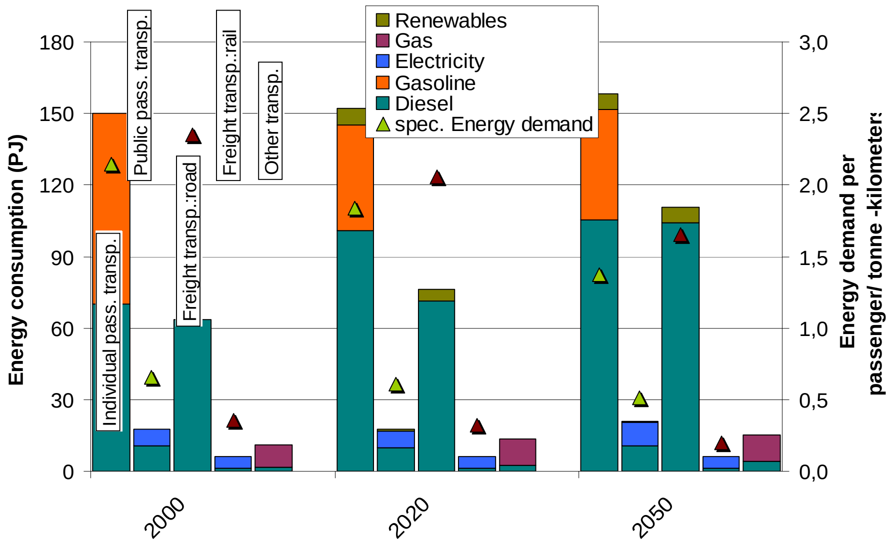

Figure 15: Baseline scenario: Energy consumption by transport mode and energy carrier until 2050. The energy consumption is dominated by the individual passenger transport – mainly cars – and freight transport by trucks. The efficiency in terms of energy demand per passenger- (green) and tonne- kilometre (red) is indicated by triangles.

The baseline scenario assumes an annual decrease in fuel consumption of 0.3-1.1%, depending on the transportation technology for the time period until 2020, afterwards the annual decrease is set to be 1%, except freight transportation by road, which increase in efficiency is set to be 0.7%p.a[1].

When it comes to greenhouse gas emissions released by transport activities, a similar picture can be drawn. Individual passenger cars and freight transportation by road are responsible for the majority of almost 90% of total GHG emissions. In the baseline scenario emissions remain stable until 2020, a development which is mainly based on the strong decrease in the energy specific energy demand, especially cars (-1.1% p.a.) and their very low increase in transportation activity which is ~0.8% p.a., which is about half of what has been assumed by Mantzos et al. (2006). For the time period between 2020 and 2050 emissions are increasing, mainly because of the increasing freight transportation activities. In general it can be said that the baselines scenario assumes stable emissions of the passenger transport activities while emissions from freight transportation are increasing.

The share of the added biodiesel to conventional diesel is assumed by Wifo to increase to 6% until 2010 and remains constant afterwards; gasoline is not mixed with biofuels at all. Natural gas does not become a significant energy carrier for road transportation. We extrapolated these assumptions in our baseline scenario until 2050, even though it is not a very tenable assumption.

1 Values adapted from Mantzos and Capros (2006)

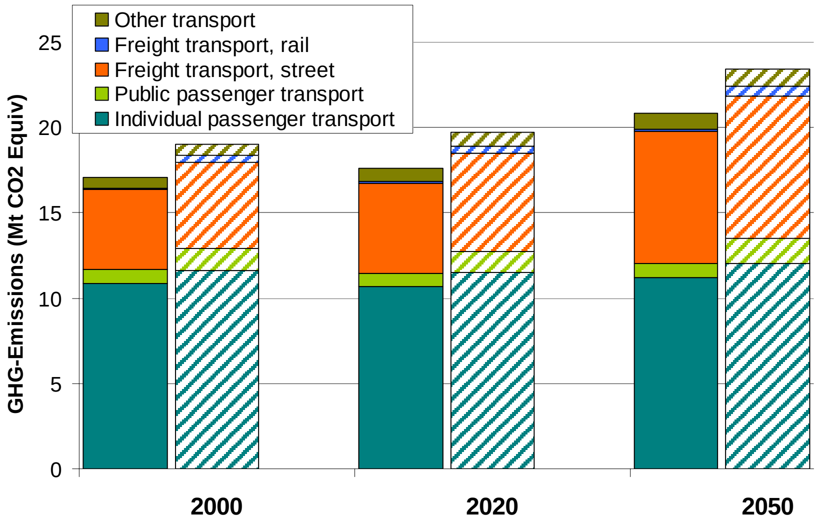

Figure 16: Baseline scenario: Greenhouse gas emissions of the transport sector per transport mode.

Future technologies and technology improvements

The following options are assumed to be key technologies to increase fuel efficiency of today's vehicles:

Charged Engines (either super- or turbocharged)

The charging of engines increases the efficiency by downsizing the engine compared to aspirated engines, which intake air at atmospheric pressure. In contrast to turbochargers, superchargers are geared to and therefore driven by the engine directly. Turbochargers, which are the more common technology and widely used in diesel engines and sport cars, use the hot flue gas to power the charger, and reach therefore better performances at high engines speed. Variable turbine geometry (VTG) helps to improve the performance at low speed. Another possibility is to combine super- and turbocharger ("biturbo") and intercooling or electrically assisted turbocharger, which are also seen by the IEA to be a key technology beyond 2020 to improve the engine's performance.

Advanced combustion technologies for spark ignition engines

Such options are variable valves, laser instead of spark ignition which could help to reduce the fuel consumption by about 10%.

Heat recovery

Most of the fuel energy leaves the engine via hot flue gases. Heat recovery, e.g. by steam-based turbine cycles could increase the engine efficiency by up to 15% (IEA, 2006, BMW: Turbosteamer[2])

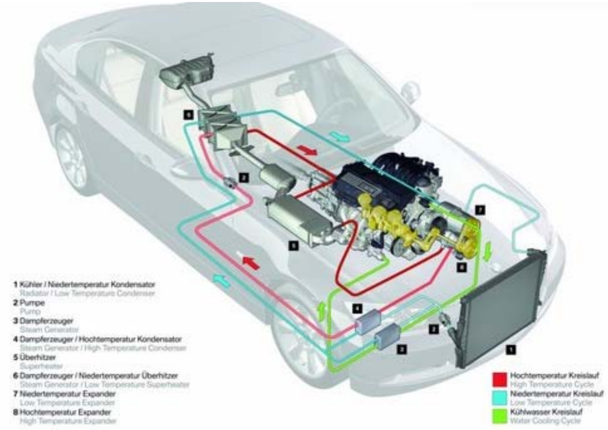

Figure 17: Heat recovery to improve fuel efficiency: BMW's concept to use waste heat to drive a steam turbine, which could improve fuel efficiency by 15% (Source: BMW company).

Electric and hybrid vehicles

Electric vehicles do not have emissions at the tailpipe (they don't have even have tailpipes) and convert the energy carrier very efficiently into traction. Yet the main disadvantage is the onboard storage of the energy carrier and hence the low driving range. Lithium-ion (500-600 $/kWh) accumulators could double the performance of the currently used lead-acid batteries (50 $/kWh), yet these are still very expensive to reach the majority of existing electrical vehicles. Hybrid vehicles offer the combination of high driving ranges and relatively low fuel consumption. Possible configurations are mild hybrid, which use the electric motor as starter and alternator during braking and a torque booster if additional power is required, while the internal combustion engine mainly powers the driving train. In contrast, full hybrids can also operate in all-electric mode, where the electric motor powers the driving train. A concept which is currently discussed widely is the so called plug-in hybrid, which does have a large battery stack that allows them to be recharged directly via electricity from the grid.

Fuel cell vehicles

Since the late 1990s, a lot of effort has been put into the development of vehicles powered by fuels cells. Yet in contrast to expectations 10 years ago, it is going to take some decades to reduce the costs of fuel cells to make them affordable for mass market. Additionally, the production, distribution and on-board storage of the prospected fuel for such vehicles which is hydrogen, still requires a lot R&D too.

2 http://www.bmw.de/de/faszination/bmw_aktuell/index.html?aktuellcontent= http://www.bmw.de/bmw_aktuell/innovation/turbosteamer2006.html

Other technologies to improve fuel performance

Non-drive train options to increase fuel performance are light weight constructions and smaller vehicles, tyres with low rolling resistance which could improve vehicle performance by up to 5% for light duty vehicles and a better aerodynamic design of the vehicles, which could significantly improve the aerodynamic drag of long haul vehicles such as heavy-duty trucks and intercity busses usually drive with high speed and better-performance of the on-board electricity production and electricity demand of on-board equipment, since conventional vehicle produce electricity with a efficiency of slightly above 10%.

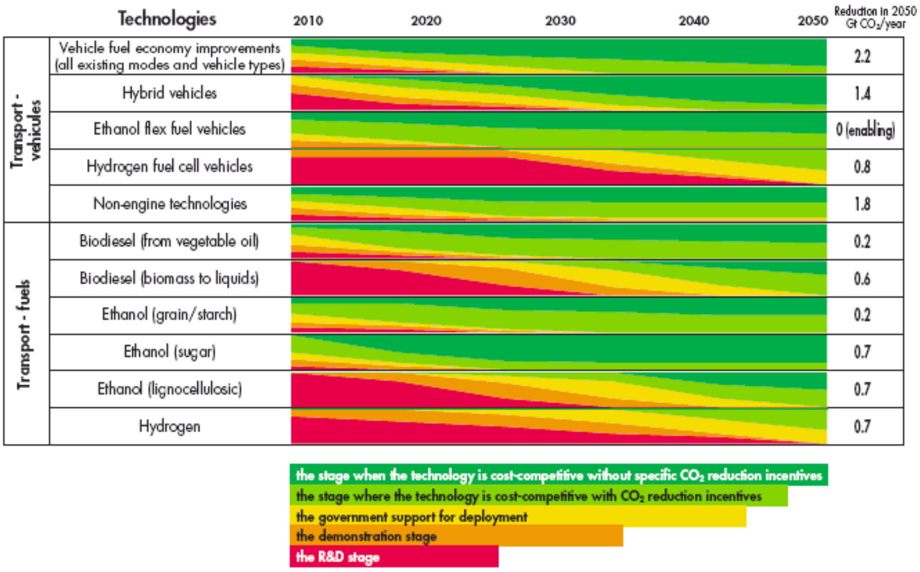

Figure 18: Development of cost-competitiveness of various transportation technologies including alternative fuels and global CO_2-reduction potential according to IEA assumptions. (Source: IEA, 2006)

2.1.4 Energy demand of other sectors: Industry and Agriculture

The scope of this section are the energy related emissions of the sectors industry and agriculture, emissions related with industrial processes and manure and emissions from livestock are considered in chapter 3 and 4.

Energy demand and emissions of the agriculture sector

The agricultural sector consumed about 3% of the total end energy demand (27.5 PJ) in 2000; oil holds the biggest share with more than 60%, followed by renewables and electricity with 18% and 16% respectively. When it comes to energy related greenhouse gas emissions, this sector is responsible for 2 Mt CO_2 equiv., if indirect emissions are also counted. These emissions represent again about 3% of Austrian's total energy related emissions. Based on Wifo's study, the baseline assumes a slightly decreasing energy demand until 2020, mainly due to fuel changes emissions are decreasing by ~15%. Based on the assumption that no drastic changes are going to happen, we neglected further changes and extrapolate that the 2020's fuel consumption will remain constant until 2050.

Energy demand and emissions of the industrial sector

The industrial sector consumes about 30% of the end energy and is responsible for energy related emissions to the same extent. The main energy carriers are gas and electricity with a share of 29% and 27% respectively, followed by oil with roughly 20%. Within this sector, over 40% of the energy demand and 45% of the energy related emissions are released by the energy intensive branches: manufacture of basic metal and fabricated metal products, chemical and petrochemical products and non-metallic mineral products are responsible for 40% of the consumed energy and 45% of the released emissions in 2000.

It has to be noted that these figures aren't fully comparable with the ones from the Austrian's national inventory report (Umweltbundesamt, 2005) which is released annually. The discrepancy in these figures lies in the fact that that report splits up total emissions according to IPPC Sectors of the Common Reporting Format (CRF). Yet, in this study we aren't simply reporting emissions but are building up an energy model. We used the same sectoral approach as is applied by the energy balance, which is easier to handle. The main difference between these two approaches is that energy conversion facilities, such as power plants, coke ovens or blast furnaces, owned by manufacturing companies are accounted for as emissions from industry with the CRF, yet seen as energy conversion with our approach. Therefore, compared to the emissions quoted in the inventory report, our approach results in lower emissions for the industrial sector, and higher emissions of the energy conversion sector. In line with both approaches we consider CO_2-emissions from coke that is required as reducing agent in blast furnaces, according to Hiebler et al. (as cited by Statistics Austria, 2008) 56.3% of coke input for blast furnaces, as process related emissions. In the official national submission (UNFCCC, 2006), Austria uses the almost identical figure of 55.8%.

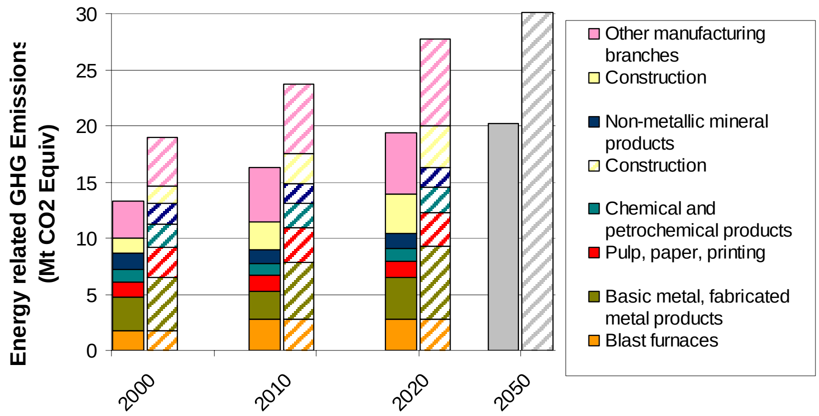

Figure 19: Baseline scenario: Energy related greenhouse gas emissions of the manufacturing sector. Four manufacturing branches are responsible for about 60% of the released emissions.

The projection up to 2020 is based on energy consumption and economic growth rates per branch that are consistent with the Wifo study. To project the economic growth from 2020 to 2050 we used a single growth rate, starting with 2.2% p.a. and slowing down to 1.5% p.a. with an average of 1.8%, and decrease in energy intensity (in average -1.6% p.a.) - until 2030 inline with that from Capros - and slowed down the macro economy consistently with the development shown in figure 4. A comparison, where we applied this methodology per branch, showed that our approach results in a lower energy demand (~10-15%) but - because of fuel mix changes that takes place – in similar emissions.

Key technologies

Efficient electro motors and compressed air supply systems

Electro motors consume about 65% of the industrial electricity demand. Therefore substantial energy savings can be achieved by improving electrical motors efficiency. RPM-regulation is seen as the key technology as it improves the performance especially under part load conditions as can be seen in table 3.

Table 3: Improvement of compressor efficiency under part load conditions through using an induction machine with RPM regulation (Source: TU München, 2006)

		RPM regulation				**conventional regulation**			
		Induction machine		DC machine		Induction machine			DC M
Flow rate	**RPM n/n_N**	**U-converter**	**I-converter**	U-converter	I-converter	bypass	Full load-idle	suction throttle	bypass
[m³/h]	[%]	[kW/m³/min]							
4657	100	**2.3**	**2.3**	2.4	2.4	2.2	2.2	2.2	2.3
3267	75	**2.5**	**2.5**	2.8	2.8	3.1	3.2	4.0	3.2
1878	50	**3.1**	**3.1**	**4.3**	**4.3**	**5.4**	**5.6**	**8.6**	**5.6**
488	25	**6.9**	**7.4**	**21.3**	**21.3**	**20.9**	**22.1**	**39.4**	**21.5**

The report “Möglichkeiten, Potentiale, Hemmnisse und Instrumente zur Senkung des Energieverbrauches branchenübergreifender Techniken in den Bereichen Industrie und Kleinverbrauch“ (Schmid, 2003) cites a study (Cremer, 2001) which states that economical energy saving potential for pumps and ventilators is in the range of 12-15%.

Compressed air supply systems offer another large energy saving potential. Critical factors are reduced leakage, RPM-regulation and high efficient electrical motors, optimal design with respect to compressor type, unit site and system pressure, heat recovery and periodically maintenance and service. The already quoted study (Schmid, 2003) concludes that the total energy demand of compressed air supply systems could be reduced by on third. Extrapolated to the whole industrial electricity demand, 2-2.5%[3] could be saved.

3 According to Schmid (2003) a 2% reduction could be achieved, the “Duckluft effizient” campaign by the German energy agency DENA sums up to 2.5%

Table 4: Possible energy saving by optimizing the compressed air system (Source: ISI, 2003[4])

Manufacturing sector	Electricity demand per turnaround (MWh/Mill. €)	Possible savings with optimal compressed air system
Food products and beverages	110	3.0%
Tobacco products	15	3.8%
Textiles products	**215**	**6.6%**
Clothing	22	3.6%
Leather and leather products	47	1.2%
Wood and wood products	215	3.5%
Pulp, paper	560	2.6%
Printing and reproduction of recordable products	**70**	**5.8%**
Refineries, coke ovens	88	1.6%
Chemical industry	368	0.6%
Plastics, rubber	**215**	**5.0%**
Glass, ceramics	**368**	**5.6%**
Basic metals	703	0.8%
Fabricated metal products	112	1.5%
Machinery and equipment	**57**	**5.0%**
Office machinery and Computers	**19**	**5.0%**
Electrical and optical equipment	**53**	**5.0%**
Radio, television and communication	57	2.3%
Medical, precision and optical instruments	46	3.3%
Motor vehicles and trailers	**62**	**4.0%**
Other transport equipment	**63**	**4.0%**
Furniture, games and toys	71	3.5%
Recycling	**124**	**4.6%**

In total the technical electricity saving potential in the industry sector by using optimized cross-technologies compared to the current status amounts to 4000 GWh (Müller et al., 2008). According to the literature above about 75% could be implemented cost effective. Yet one has to bear in mind that the total saving potential of 4000 GWh can be seen as additional potential in 2020, since it is already included to some - in detail unknown - extent in the baseline scenario.

4 Einsparrechner: http://www.druckluft-effizient.isi.fhg.de/index.php

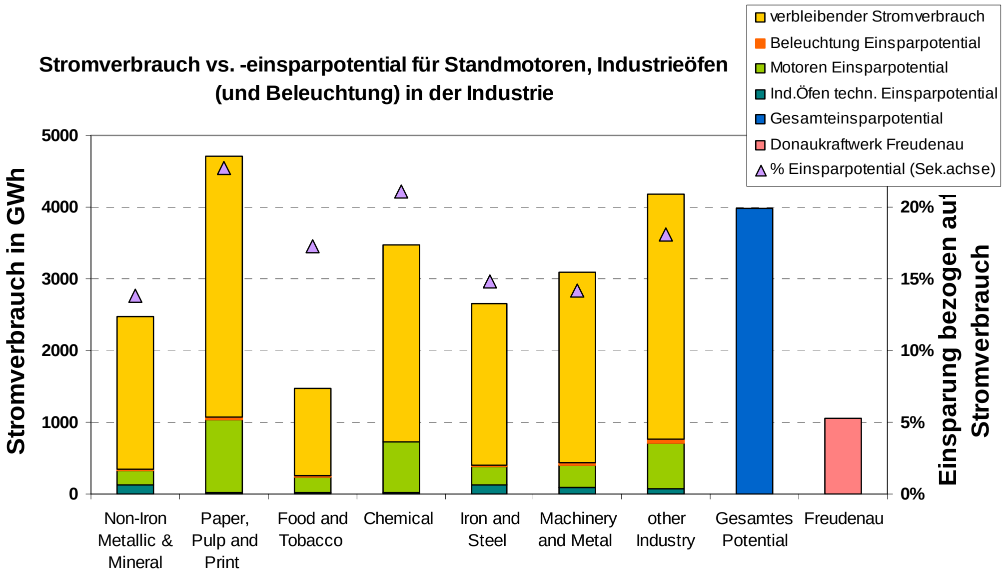

Figure 20: Technical electricity saving potential in the industry sector by using optimized cross technologies compared to current status (source: Müller et al., 2008)

Industrial process heat

Energy saving measures concerning industrial ovens are: (1) new and suitable burner technologies (recuperation burner, regenerator burner, FLOX-burner), (2) oxygen enrichment, (3) recovery of the radiant heat, (4) advanced control technology and simulation-based process management, (5) optimized insulation and (6) heat recovery. According to Schmid (2003), these measures offer an energy saving potential for process heat of 26%. Another prospective option offers solar thermal energy for low temperature applications, which to account for 14% of the current industrial heat demand.

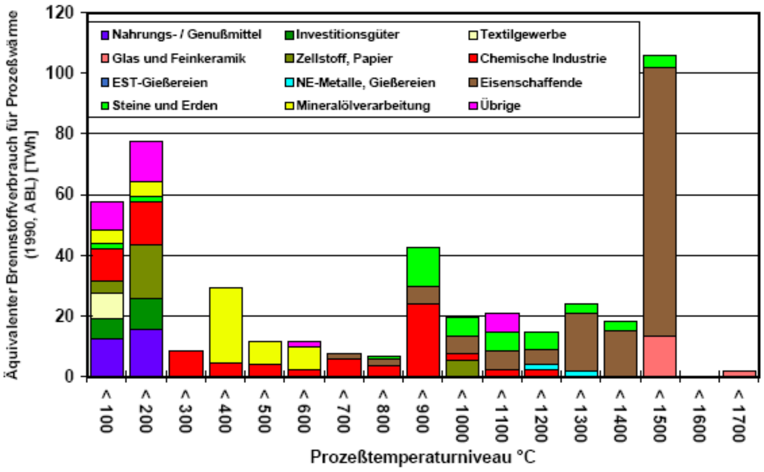

Figure 21: Fuel demand for industrial process heat in Germany (1990) (Source: Schmid et al., 2003; Hofer, 1994)

Steam supply

Key technologies to reduce the energy losses of steam supply systems are as followed: (1) exhaust vapour compression, (2) closed condensate recirculation, (3) improved heat exchanger, (4) optimized insulation of pipes and other equipment, (5) economizer, (6) improved process management and control, (7) fluidized bed technology and (8) condensing boiler technology. Schmid (2003) evaluates that energy demand for steam purposes could be reduced by 11.3%. Drying applications offer another energy saving potential. According to Cremer (2001), the technical saving potential is 17%, about half of that potential is economically realizable.

2.1.5 Energy conversion

This subcategory sums up all facilities that primarily convert primary energy into another type of secondary energy. In addition to electricity and district heat production from renewables and fossils these are refineries, coke ovens and biofuel production facilities.

As mentioned above, the drafted baseline is an energy intensive scenario, since it is based on low energy prices and non-stringent climate change mitigation policies. Therefore, the final energy consumption is going to increase significantly. The final energy consumption is increasing by 32% until 2020 and 40% until 2050. Not surprisingly electricity and gas are increasing with an even higher rate; electricity covers 50% of the additional energy demand, natural gas about 20%. Renewable energy carriers are increasing by 30%. Based on the final energy demand, renewables will then have a share of 26%. Refinery products remain stable, other types of final energy carriers to not play a significant part and provide about 5% of the requested final energy.

For this reason we mainly focus on electricity and district heat production, which play the dominant role of the energy conversion sector. To reduce the complexity of this scenario, we kept the efficiency of refineries, coke ovens and biofuel production constant over time, which seems to be justified as emissions from these facilities are responsible for only 15% of the conversion sector, with decreasing the share to 7% in 2050.

Electricity

Today, electricity in Austria is produced to more than 50% (~60% in 2000) by large hydro power plants. Even tough the technical potential for this type of resource is exploited by about three-quarters, it is quite difficult to use this energy source to a much higher degree since people's resistance to new projects is very high. Other technologies for renewable electricity production, which hold a share of 8-9% of the total electricity production in 2005, lack the short-term ability to fill the gap between increasing electricity demand and limited expansion of large hydro power. As a result, the share of fossil-produced electricity is increasing constantly.

The baseline scenario assumes that no additional large hydro power plants will be installed within the considered time frame; relying on the Water Framework directive released by the European Commission, it is assumed that electricity production from large hydro power is going to decrease between 2010 and 2015 by 5% compared to now.

Electricity production from new renewables, which make up about 8% of the total annual national production, is more than doubling until 2020 and more than tripling until 2050. The share of the national production is about 16% in 2020, decreasing slightly less than 15% by 2050. Strong growth rates are assumed until 2010; afterwards they are more moderate.

In 2005, small hydro power plants were responsible for about 60% of the total electricity production from new renewables, followed by wind and solid biomass which hold shares of 23% and 10% respectively. This is assumed to change over time. In 2020, wind converter produces 5300 GWh, small hydro power plants produce 4200 GWh, electricity production from solid biomass contributes 3250 GWh, municipal and industrial waste 1100 GWh. Between 2020 and 2050, mainly electricity from biomass is increasing (doubling). This is mainly because of the decreasing heat demand for residential space heating, which leads to surplus biomass. In total, energetically used biomass is increasing to 235 PJ (30 PJ used as an input for biofuels) in 2020, starting from 130 PJ today. Afterwards, the level remains stable. The national environmentally-compatible bioenergy potential has been assessed to be 140 PJ from forestry products including forestry residues, 130 PJ from waste products which includes agricultural residues such as straw and manures and 60 PJ from agriculture products by the European Environment Agency (EEA, 2006).

Table 5: National environmentally-compatible bioenergy potential (in PJ) in 2010, 2020 and 2030 and biomass consumption according to the baseline scenario (Source: EEA, 2006)

	2010	2020	2030
National environmentally-compatible bioenergy potential			
Agricultural products	25	60	90
Forestry products	140	140	145
Biogenous waste	125	130	130
Total	**290**	**325**	**365**
National biomass consumption in the baseline scenario			
Agricultural products	16	18	22
Other biomass	159	193	202
Total	**175**	**211**	**224**

Kranzl et al. (2008) estimated the maximum feasible potential of biomass that could be used energetically until 2050. Their results are basically in line with EEA (2006), getting a potential of 350 PJ in 2030 increasing to 390 PJ in 2050 (figure 21).

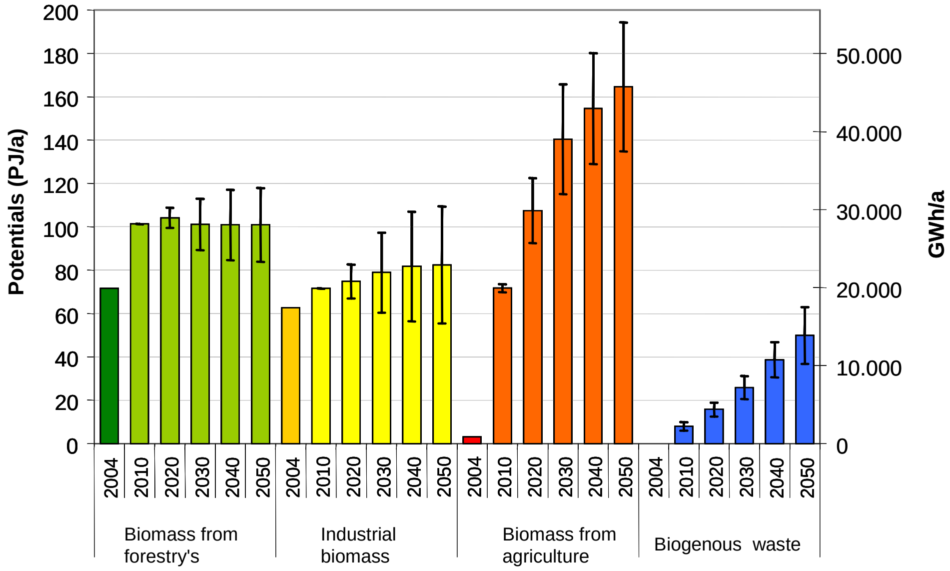

Figure 22: Dynamic national biomass potential that could be used for energetic conversion until 2050 according to Kranzl et al. (2008). Values for 2004 represent the current (2004) utilization; from 2010 they indicate the maximum exploitable potential. Uncertainties are mainly determined by the uncertain activities of wood processing industry (pulp & paper, sawmill industry …). The last category (Waste wood and biogenious waste) includes only the additional potential.

Other technologies such as photovoltaic or geothermal heat do not play a significant role up the 2050 in the baseline scenario.

The two important fossil energy carriers for electricity production are coal and gas. The current Austrian coal power station stock mainly consists of facilities from the mid 1980's (Voitsberg 3:1983; Dürnrohr, Mellach, Riedersbach 2: 1986) which contributes almost 30% the national fossil produced electricity, with an average annual operation time of about 5000 hours in 2005. In the baseline, importance of coal is slightly increasing, in 2020 to 30%; 33% in 2050, which is related to the expected increasing price difference between gas and coal. This development implies that new coal power stations have to be built between 2010 and 2020 (~1000 MW), between 2020 - 2025, the current stock of coal power plants has reached the end of its expected lifetime (30 years) and has to be replaced. Until 2050, the scenario implies a cumulative installed capacity of new coal power plants of about 4,3 GW including the replacement of old ones.

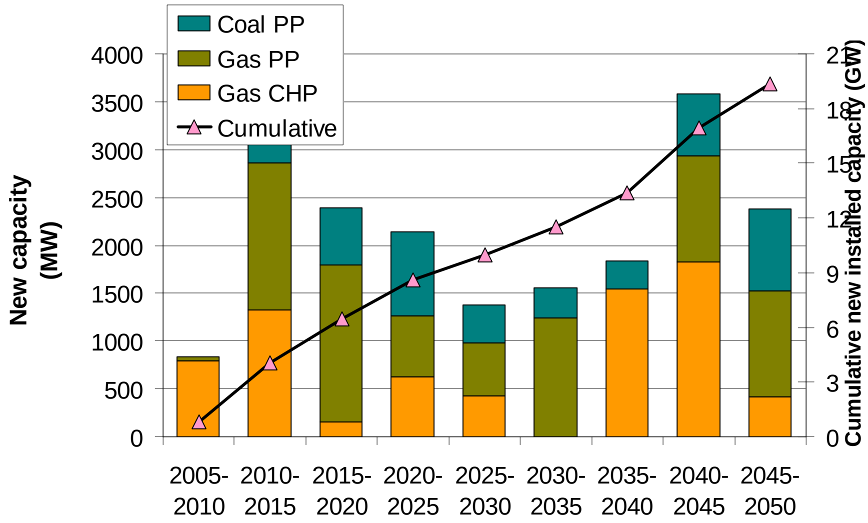

Figure 23: Baseline scenario: Installation of new, fossil-driven public electricity production capacities. It is assumed that coal contributes about 30%-33% to the publicly produced electricity from fossil fuels. Fossil CHP plants are restricted by the district heat demand. Over the considered time frame, more than 20 GW fossil power plant and CHP plants are going to be installed.

Today, gas powered plants are responsible for 15%-20% of the annual national electricity production. Nearly half of it is produced at CHP mode, which is restricted by the district heat demand. In the baseline, we assume that the ratio of district heat from fossil fuels, produced by CHP (combined heat and power) and HP (heat plants without electricity production) remains stable at its current level of about 3:2 until 2020, afterwards this ratio is slightly increasing in favour of CHP production. Within the upcoming 15 years the development drawn above requires an cumulative installation of 1,5 GW gas powered power plants and 2,2 GW CHP plants (calculated with 4000 operation hours per year). Until 2050, cumulative installation of 7,1 GW CHP plants and 7,9 GW PP are required, again the calculation is based on 4000 full load hours.

Future technologies

Currently it is expected that gas and coal still remain the main energy carrier for power generation within the upcoming 50 years. In this area major R&D efforts are tackling the following issues:

- Advanced Steam Cycles (Ultra-Supercritical Steam Cycles)
- Integrated Gasification Combined Cycles (Gasification of solid energy carriers prior combustion)
- Carbon Capture and Storage (CCS): flue gas separation, oxyfueling, chemical absorption flue-gas separation, chemical looping

Advanced Steam Cycles (Coal)

Supercritical steam cycles are nowadays the state of the art technology for coal power stations. Ultra-Supercritical Steam Cycles plants are operating with the steam parameters of 700-750°C and 300-350 bar. Barriers for that technology are costs due to materials (nickel alloys) that can withstand such conditions. It is expected that investment costs are about 10-15% above those of supercritical plants, yet due to reduced flue gas handling and coal consumption, electricity costs could be lower by about 15%. Electrical net efficiencies are expected to reach 50% maybe even 55% (IEA, 2006).

Integrated Gasification Combined Cycles (Coal)

IGCC are expected to be the most efficient power producing technologies for all kinds of solid fuels and a key technology for CCS, since carbon capture costs are much less than those of steam cycles would be. Yet, because investment costs are higher compared to other technologies, it is not clear now whether electricity costs are going to cost-compositeness or not (IEA, 2006). Today's demonstration plants reach efficiencies around 45%; it therefore is expected that in 2020 efficiencies of 50% could be state of the art for that technology, and afterwards even still increasing to 55% (IEA, 2006).

Carbon Capture and Storage technologies

Carbon Capture and Storage is expected to become the most important technology in a CO_2 constrained world. Yet, there are still many uncertainties and therefore concerns regarding the undergrounds retention of geological stored CO_2. The technology itself still requires a lot of R&D. Following technology options to remove the CO_2 are discussed today:

- Post combustion: removal from flue gas
- Pre combustion: gasification, chemical looping
- Oxy fuelling: combustion with oxygen instead of air

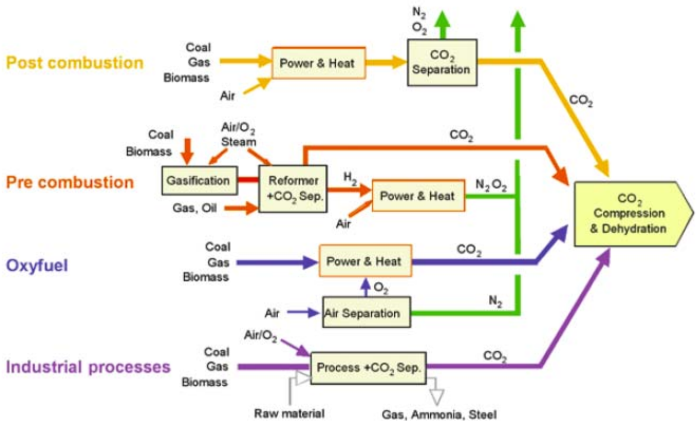

Figure 24: Prospective Carbon Capture Systems (Source: IPCC, 2005)

Implementation of technology development in the model

In our model, we used exogenously determined efficiency increases for implemented power production technologies, which we divided into gas, coal and low quality fuels (biomass, waste). For natural gas combined cycles (CC) we assumed an increase in performance of new power plants to 60% in 2020 and 65% in 2050, CC with CHP capability are assumed to have a by 6% lower electrical efficiency, derives from heat extraction during winter time. New coal power technologies are increasing their efficiency to 49% in 2020 and 54% in 2050, which is in line with IEA's expectations shown in figure 24. Low quality fuels (which means fuels with a low heating value) are assumed to produce electricity with an efficiency of up to 35%.

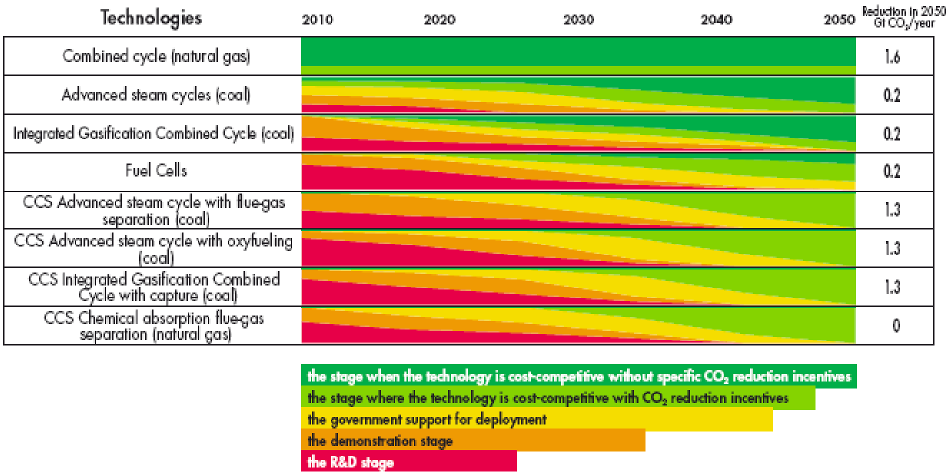

Figure 25: Development of cost-competitiveness of various power generation technologies and global CO_2-reduction potential according to IEA assumptions. (Source: IEA, 2006)

District heat

District heat is in general considered to be an environmentally friendly – if produced by cogeneration or biomass – and a convenient energy carrier. Currently about 25% of the supplied heat is produced by renewables, about 45% by fossil cogeneration plants. This structure isn't changing much in our baseline scenario: the share of renewables and fossil cogeneration heat is increasing by a few percentages. Yet, the total energy requested is quite dynamical. Until 2020, the requested district heat is increasing strongly. After this period it is declining, the basic reason for that is the increasing thermal quality of the building stock (Table 6).

Table 6: Baseline scenario: District heat production by fuel input und Technologies in PJ

	2000	2010	2020	2030	2040	2050
Biomass	11	18	23	23	23	23
Natural gas CHP	22	31	42	45	48	49
Natural gas HP	15	20	24	26	27	27
Total	**48**	**69**	**89**	**94**	**97**	**99**

2.1.6 Total energy demand and energy related emissions

The baseline scenario, as already mentioned, can be considered as an energy intensive, high emission scenario with low effort to decrease energy consumption and emissions. The considered economic growth is even above the IPCC A2r scenario, which is an energy intensive, high growth scenario by itself. Nonetheless our baseline scenario already implies significant improvements compared to today's energy supply chain. The frozen technology reference scenario, which is a scenario in which the future energy service demand is going to be supplied by today's technologies, results in much higher emissions: additional 50% in 2020 and 125% in 2050.

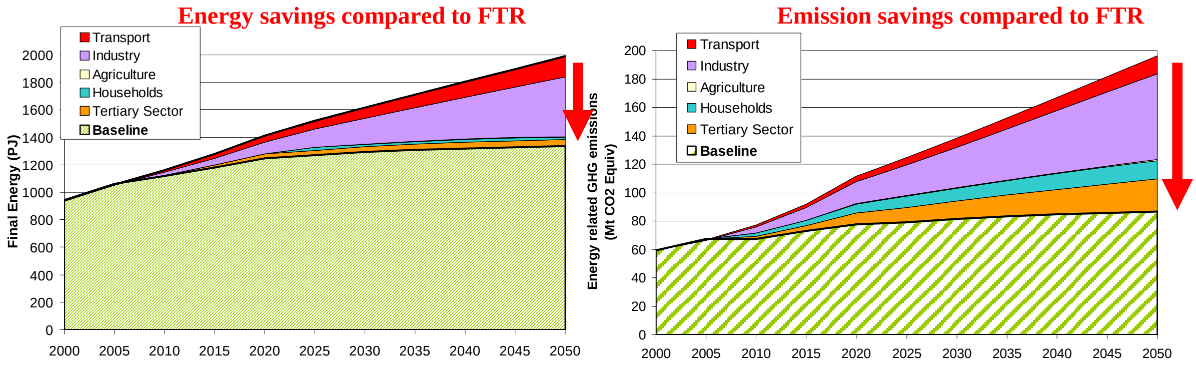

Figure 26: Comparison of the baseline scenario with a scenario, which doesn't include neither technologies changes nor fuel changes as long the aren't restricted by potential (Frozen technology reference scenario: FTR). This restriction related with potentials is only relevant only for renewables, mainly hydropower and biomass.

In our baseline scenario, the total final energy is increasing by 32% with respect to 2000 until 2020: In 2050 it is 42% above our base year 2000. The share of electricity is increasing constantly from 20% to more than 30%. The share of oil is declining, especially until 2020. Starting from a level of 40% of the final energy demand in 2000 it is declining to 32% in 2050. Oil and electricity are the main final energy carrier.

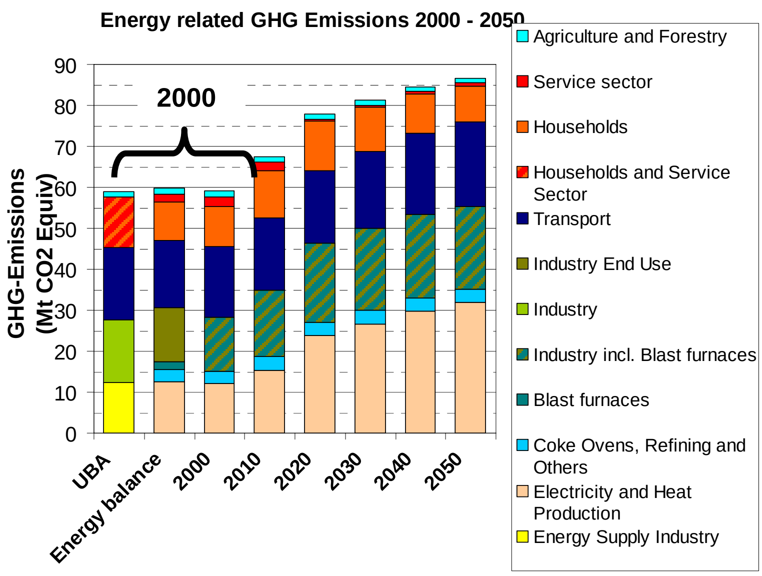

Figure 27: Baseline scenario: Annual national energy related greenhouse gas emissions until 2050. Emissions from electricity production are increasing because new renewables cannot keep up with the increasing demand.

As is the energy consumption, so are emissions increasing as well. Until 2020 emissions are increasing by 30%, in 2050 emissions are 45% above the level of 2000. The carbon intensity of the used fuel is decreasing until 2020 because of the decreasing share of oil and the strong increase of *new renewables*. Afterwards, *new renewables* cannot keep up with the still increasing energy demand. In addition, the fuel change between fossil energy carriers isn't that distinct any more.

2.2 Mitigation options

As noted before, the target mitigation options are technological ones. This means that we don't consider life style changes or decreasing demand on energy service. Therefore, all mitigation options can be classified into one of the two categories: energy efficiency and fuel change.

A third possibility, the removal and geological storage of CO_2 (CCS: Carbon Capture and Storage; CSS Carbon Sequestration and Storage) is not considered as an explicit option. First, CCS is an end-of-the-pipe technology. Emissions are removed after they have inevitable been going to be produced - independently from the actually used technology: removal emissions before or after combustions, burning with oxygen or air. This means CCS can always be added to the scenarios afterwards.

Second, the national geological storage potential, neither the total nor the annual, and the costs of this technology have been evaluated consistently so far. Heinemann (2004) identifies the total national storage capacities of oil and gas reservoirs to be between 400 (currently) and 550 (ultimately) Mt CO_2, if every oil and gas field were used to store CO_2. Yet, the author argues, that not every reservoir is appropriate, be it due to tightness, size, available infrastructure and location of the field or the structure of the reservoir itself. Appropriate, according to the same author, seems to be the Schönkirchen Tief (oil) and the Schönkirchen Übertief (gas) with a total capacity of about 60 Mt CO_2, with an additional capacity of 60 Mt if the surrounding of 20 km (Höflein, Reyersdorfer Dolomit) is considered. In Upper Austria the prospective storage capacity of oil and gas reservoirs (Atzbach-Schwanenstadt (gas), Voitsdorf (oil)) comprises up to 30 Mt CO_2 (Scharf, 2004).

Deep fossil water aquifers (Aderklaa Conglomerate which is located in Lower Austria) could increase the total capacity by additional 10 Mt CO_2, if the water would be pumped up, highly speculative 1000 Mt could be stored.

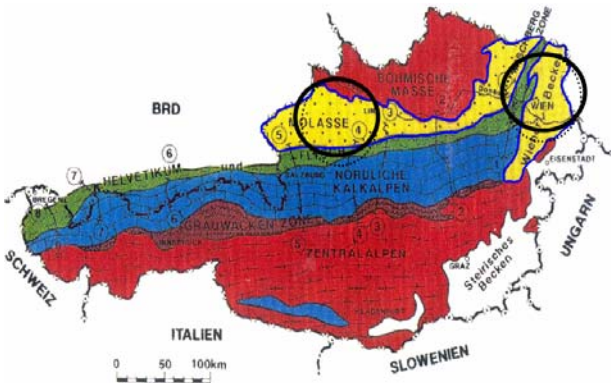

Figure 28: Prospective CO_2-storage reservoirs in Austria. The black circle in Lower Austria indicates oil and gas fields with a possible storage capacity of 120 Mt CO_2, the one in Upper Austria a storage capacity of 30Mt CO_2. The annual storage has been evaluated to be 1 Mt (2008) up to 3 Mt (2018) in Lower Austria and about 1 Mt CO_2 in Upper Austria. (Source: Heinemann, 2004)

The annual storage of CO_2 could be in range of 1 Mt in 2008 increasing after 2018 to up to 3 Mt in Lower Austria and about 1 Mt CO_2 in Upper Austria, decreasing after 15 years of operation time. The annual CO_2 storage capacity in aquifers hasn't been evaluated so far.

To summarize our conclusions on CCS: From the economic point of view, CCS appears to be an appropriate technology to reduce the released CO_2-emissions, and therefore it could help companies to cut down their costs if CO_2 emission certificates are expensive enough. Viewed from the national emission balance, with cumulative emissions of 3500 Mt CO_2 in our baseline scenario, this technology doesn't seem to have the potential to reduce emissions significantly in a long term – even with respect to the highly speculative national maximal storage capacity of 1500 Mt.

2.2.1 Energy efficiency

The first, and in our opinion most the important mitigation option is the rational use of energy. This doesn't means just to reducing the energy service consumed, but more importantly this option focuses on providing these energy services in an efficient way. The effects of increasing the efficiency of the supply of energy services are the focus of this section. In particular, we are focusing on space heating and other low temperature heating demand (water heating), electrical appliances, efficient automotives and a change in the preferred transportation modes.

Measure 1: Increase thermal quality of the residential building stock

The measure evaluates the effects of energy efficiency for the space heating energy demand of the building stock. This measure evaluates the effects of the refurbishment of the current buildings stock based on an average refurbishment rate of 1%p.a. This rate has been observed in the past decade. In contrast to the observed refurbishments done in the previous years, a more comprehensive renovation is assumed. In this measure, the renovation of the buildings in done in such a way, that the thermal quality of the building envelop meets the current building code. This leads to an energy consumption of 70 kWh/m² for single family and semi attached houses and 55 kWh/m² for apartment buildings and buildings of the commercial and public service sector after the renovation.

Measure 2: Additional decrease of the space heating demand in all sectors and increase of the conversion efficiency of domestic water heating.

This measure includes additional efforts to reduce the space heating demand and fuel input for domestic hot water production. These measures clearly exceed the economic potentials, yet are still realistic if subsides and incentives are provided. Furthermore, measure 2 implies a renovation rate of 1.5%p.a.

Measure 2 cuts down the heat demand after the renovation to a low energy performance level. Small buildings achieve a energy performance of 45 kWh/m², and large ones 40 kWh/m². Fuel input for hot water has been reduced by 10% in 2020 and 30% in 2050 in relation to the baseline scenario. The use of solarthermal energy is also considered. It is assumed, that 30% of the building stock is equipped with solar thermal panels for hot water production. Each device supplies 70% of the energy demand required. Out of these 30%, 20% of the buildings are considered to have solarthermal combi systems, which assists the space heating system. It is considered, that each system supplies 20% of the energy demand for space heating. To achieve this targets, buildings have to be equipped with solarthermal applications at a rate of 1.5%p.a., starting from 2005.

The fraction of energy supplied be solarthemal applications increases after 2020. It is assumed, that in 2050 55%[5] of the buildings stock supplies 50% of the space heating demand with solarthermal energy. Furthermore, every building covers 80% of the energy demand for hot water production (process heat is not included) with solar energy in 2050.

We assume that the service sector and industrial buildings would establish efficiency measures to the same extent as apartment buildings do.

5 According to Novak et al. (2000), 55% of buildings are suitable to for solar applications.

Switching from single family houses to apartment buildings hasn't been included in any measures even though the energy demand of an apartment building is much lower than that of a single family house. Nonetheless people living in apartments consume in average much less energy than those living in single family households, which is due to the in average higher population density of those areas and consequentially lower energy demand for transportation.

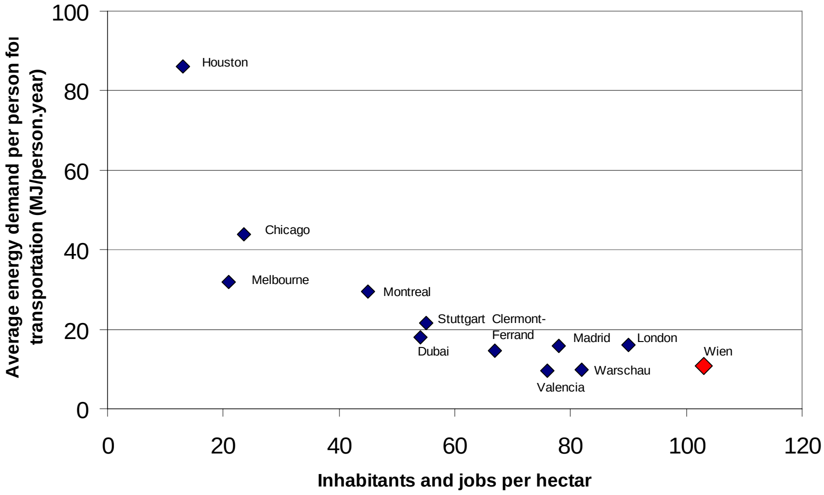

Figure 29: Influence of the population density (inhabitants and jobs per hectare) on average energy demand for transportation purposes. In general, higher population has two effects: travel distances are shorter and the share of alternative transportation systems such as public transportation, bicycles or walking is higher. (Source: UITP, 2004)

Measure 3: Increase of the efficiency of electrical appliances in the residential and service sector
and
Measure 4: Increase of the efficiency of electrical appliances in the manufacturing sector

Even though electrical appliances could convert electricity into any kind of energy form in a very efficient way, in reality conversion efficiencies are quite poor. Conventional light bulbs are still the primary technology to convert electricity into light in residential buildings, with efficiencies of about 5%. Energy efficient bulbs provide the same service by cutting down the electricity input in the range of factor 5. Electrical motors, a technology that could convert electricity into motion with an efficiency of 90%, do that in households with an efficiency of less than 20% to 45% (http://www.bine.info). Energy efficiency programs of the German and Austrian Energy Agencies (DENA and EA) showed that efficiency measures in manufacturing sites are often paying part of the additional investment within a couple of months. Within the same program, DENA evaluates the cost effective electricity reduction potential of the German manufacturing and service sector due to efficient applications to be 30%. (http://www.stromeffizienz.de, http://www.druckluft-energieeffizienz.de, http://www.energieeffizienz-im-service.de).

The evaluation of an additional potential – set up on the baseline scenario – is difficult, since some of these efficiency measures are already included in the baseline scenario. In the service sector a efficiency increase of 5% compare to the baseline scenario is assumed. The specific electricity consumption for electrical applications remains then on a level of 0.45 TJ / Mio. € value added. It is assumed, that this index is been reduced by 10% (0.4 TJ / Mio. €) until 2050.

Measure 5: Reducing the fuel consumption of vehicles

Measure 5 evaluates the emissions reduction potential of the transport sector. The baseline scenario implies that the vehicle stock increases its mileage by 18% within the next 15 years (6.8 litre / 100 km stock consumption in 2020. This is in line with Pehnt (2001): 6.0 – 6.5 and WBCSD (2004): new vehicles in 2020: 6,1 litre (gasoline) – 4,5 litre (hybrid)). Until 2050 the mileage is increasing by 40% (WBCSD: 3 for H2-FC) – 5,4 for gasoline), resulting in a average fuel consumption of 5 litre / 100 km.

Measure 5 assumes an additional increase in mileage for new cars until 2012 of 5% p.a. This would result in an average fuel consumption of 5.5 litres per 100 km in 2020 and corresponding average CO_2-emissions of new cars of 120 g CO_2 / km, which is the EU-target for new vehicles (incl. supporting measures) in 2012. Extending this path until 2050 this would lead to an average fuel consumption of slightly less than 4 litres per 100 km in 2050. Taking the typical life span of cars in Western Europe of slightly more than 15 years into consideration implies that after 2015 new cars are mainly hybrid vehicles. In the long term, it is expected that combustion engines are not longer the preferred choice of technologies. Instead, hydrogen with fuel cells or electrochemical energy storage with batteries, both in combination with electrical motors, are expected to displace combustion engines. The introduction of these vehicles is implemented in this measure.

Other transport vehicles such as buses, trucks and light duty vehicles are assumed to reduce their fuel consumption to the same extent.

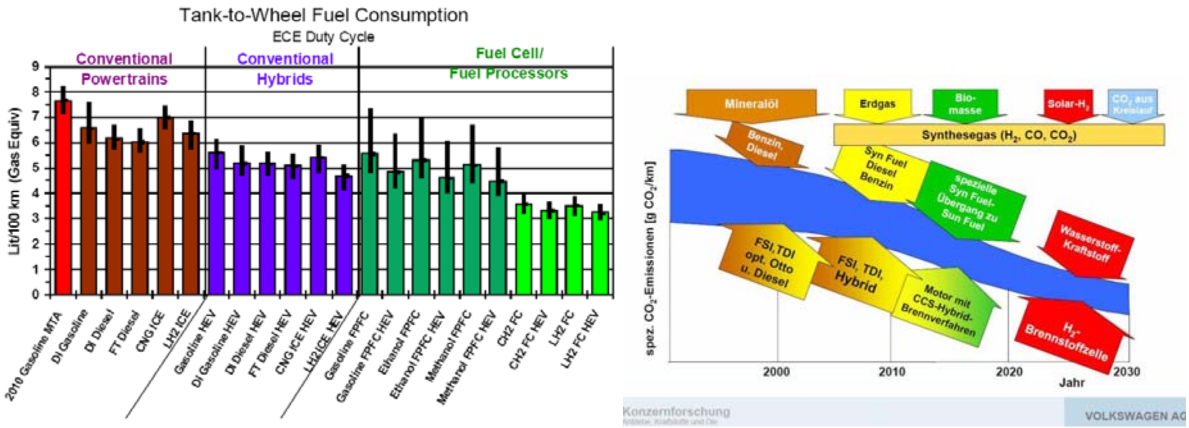

Figure 16: Fuel consumption cars with different power train technologies in 2010 (left) and VW's vision of roadmap of technology introduction (right). (Source: L-B-Systemtechnik, 2002; Volkswagen AG)

Measure 6: Comprehensive improvement of the fuel consumption of vehicles

This integrated measure doesn't only assume changes of the power train but of the whole concept of transportation by reducing vehicle size and weight and allows therefore much lower consumption as measure 5 does. Based on an increase of mileage for new cars of 5% p.a. until 2012 and additionally a switch of 20% between cars size categories towards smaller car, the average fuel consumption for gasoline and diesel cars is assumed to be reduced to 5 litres / 100 km in 2020 and 3.5 litres in 2050. This development would lead to average CO_2 – emissions of the fossil fuelled automotive stock of 135 g CO_2/km in 2012, decreasing further to 100 g in 2020 and 72 g CO_2/km in 2050.

Additionally electric vehicles are included in this measure after 2020. Based on Haas et al. (2008) a share of 50% of electrical vehicles is included in this measure. The electricity consumption for this type of vehicle decreases from 25 kWh / 100 km in 2020 to 1.8 kWh/100 in 2050.

Measure 7: Increase share of public transportation

Currently public passenger transportation holds a share of about 28%, freight transportation on trails about 36% (in terms of passenger kilometres and tonne kilometres respectively). This share declines in the baseline line slightly. Measure 7 increases this number to 40% in 2020 and 50% in 2050 (passenger and freight transportation).

Effects of all energy saving measures

The effect of all measures above cannot be simply added up, since measures interact, are embedded in the energy system or already include other measures (Measure 2 includes Measure 1, 6 includes 5). As shown in Table 7, the effect of energy saving measures results in emission reductions of -19 Mt (-24%) in 2020 and -35 Mt (-40%) in 2050, compared to the baseline scenario.

As can be seen from the table below, if all of these measures are implemented simultaneously, the mitigation effect would be reduced by roughly 10% as opposed to the effects of each single measure.

Table 7: Effects of energy saving measures

	Final energy demand (PJ)		**GHG-emissions (Mt CO_2 Equiv)**	
	2020	**2050**	**2020**	**2050**
Baseline	1245	1335	79	87
Difference compared to baseline				
Measure 1	-99	-159	-6	-9.8
Measure 2	-143	-266	-8.7	-16.8
Measure 3	-30	-57	-3.1	-6.7
Measure 4	-8	-8	-0.6	-2.5
Measure 5	-46	-55	-3.5	-4.2
Measure 6	-69	-144	-5.1	-7.2
Measure 7	-20	-46	-1.4	-3.2
All energy saving measures	**-267**	**-497**	**-18.7**	**-35.3**

2.2.2 Fuel change

The switch to less carbon intensive energy carrier offers another mitigation option. The measures below evaluate the GHG-saving potential by switching to gas or renewable energy carriers.

Measure 8: Increase share of natural gas fuelled vehicles

Measure 8 evaluates the effects on total emissions if the share of natural gas fuelled vehicles increases to 20% in 2020 and further to 50% in 2050.

The presumed share of 20% in 2020 results from considering the change behaviour of the vehicle stock. The left figure below shows the shares of sales of new Diesel and Otto Light Duty Vehicles (LDV) in Austria for the last 28 years, the right figure the resulting share of these vehicles on the stock. As it can be seen from these figures, it took almost 20 years to increase the share of new sales of diesel vehicles from more or less zero to 50%, a time frame that is in the range of the average vehicle life time of about 15-20 years. Due to this time lag the stock changes rates are significantly lower, a share of 50% has been reached after about 25 years.

The idea now is, that the introduction of natural gas fuelled vehicles (NGV) is similar to that of the diesel vehicles 25 years ago. In the beginning both technologies had the comparable drawback (early diesel vehicles: poor engine agility and noisy, NGV: lower range), the investment costs are higher, but the fuel is cheaper. Based on this hypothesis and an ambitious infrastructure development, NGV could increase their share of the stock within the remaining 12 years until 2020 to an order of magnitude of about 20%. The share of 50% in 2050 results from the assumption, that if oil is still available in 40 years – an assumption we presume in this work – it is most likely that it is used in the transport sector.

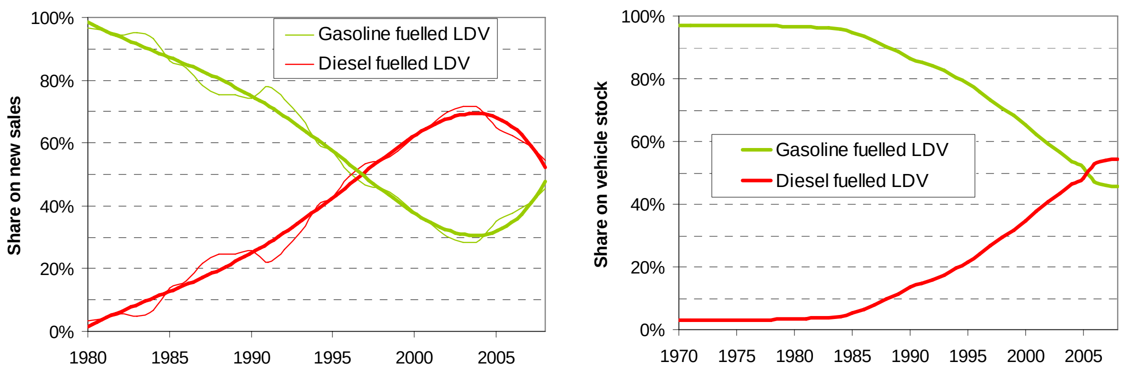

Figure 30: Historical share of Diesel and Otto Cars on new sales (left) and on the fleet stock (right).

Measure 9: Increase share of biofuels

Based on the targets set by the European Commission, Austria announced to increase the share of alternative fuels to 20% in 2020. The share of biofuels is supposed to increase to at least 10%.

Measure 9 evaluates the effects on total emissions, if the share of biofuels, based on the total gaseous and liquid fuel demand, would increase to 17% in 2020 and further to 35% in 2050. Such a high share is absolute ambitious and much higher than current targets. It has be noted, that under baseline conditions and the premise that the main biomass input has to come from national sources, this scenario is not feasible. The national request for energetically used biomass would increase to 255 PJ (62 PJ biomass input for biofuels) in 2020 and to 355 PJ in 2050, 150 PJ out of that would be used as biomass input for fuels. Even if we can assume that in 2050 biofuels would rather be produced from lignocellulosic biomass than from agricultural products such as grain and rapeseed the requested biomass would increase very close to the absolute environmentally-compatible bioenergy potential as stated by EEA (2006). Yet in combination with highly efficient cars, and a significant share of electrical and gas fuelled cars, these targets are feasible.

Measure 10: Gas powered combined cycle plants instead of new coal power plants

This measure evaluates the effects if coal power plants would not be installed any more. Few years ago, the idea of installing new coal power plants was rather unlikely. Yet in 2007 the Kovats Group revealed plans to buy the Voitsberg lignite coal PP which were shut down by the Verbund, retrofit the site and convert it into a hard coal PP and operate it for an additional 20 years. From the point of energy supply security, electricity production based mainly on the energy carrier natural gas is also very critical. If electricity productions from domestic sources cannot increase its share significantly, it might be important to diversify the used fossil fuels and therefore to operate at least some coal fired PP. Therefore we would like to add, that this measure is only plausible in combination with energy efficiency measures and an ambitious deployment of electricity production from renewable energy carriers.

Measure 11: Replace coal and oil by gas in the residential and service sector
and
Measure 13: Replace coal and oil by gas in the industrial sector and increase the share of renewable energy carriers for industrial process heating

These measures evaluate the additional emissions saving potential if no other fossil energy carrier than natural gas (except for blast furnaces) and electricity in the case of non-mobile engines would be used as final energy carrier in the stated sectors. For the industry sector this measure appears to be very hypothetical, since natural gas is significantly more expensive than coal, and energy intensive industry branches such as the concrete production could not produce a competitive product. Nonetheless, it can be seen as the remaining mitigation potential of fossil fuel switching that can be exploited to some degree, depending on the politically willingness to reduce the GHG emissions and hence increase energy prices, introduce CO_2-tax or subsidies low-carbon energy carriers.

Additionally to the substitution of fossil energy carriers by natural gas, the introduction of heating technologies for industrial process heating based on renewable energy carriers after 2020 is included in this measure. The underlying assumption is, that until 2050, 50% of the heating demand below 100°C will be supplied by heat from solar thermal applications, biomass supplies 50% of the heating demand below 500°C.

Measure 12: Increase the share of renewables elecricity production

Measure 12 includes an increased electricity production of 8 TWh compared to the baseline scenario in 2020. This can be achieved by implementing the proposed “master plan hydro power” (Wasserkraft Masterplan), which has been announced by the minister of economic affairs in 2008 (Bartenstein and Windtner, 2008). The production of electricity increases by 16 TWh compared to the baseline scenario in 2050. In order to achieve this target, we assume that electricity production from hydro power is extended by 15 TWh, which is in line with the technical – economical potential of 12.8 – 17.8[6]. Furthermore photovoltaic is contributing 10 TWh in 2050. This value represents a mean scenario according to Müller et al. (2008).

6 The lower value represents the current technical – economical potential excluding ecologically sensitive areas.

Table 8: Renewables used in 2020 and 2050 under the assumptions presented in measure 12 compared to "achievable mid term potential" according to Green-X database which has been conceived for time frame of 2020.

	2020	2050	Green-X
	Electricity (TWh)		
Hydropower	45	53	44.5
Wind	5.3	10	5
PV	0.04	10	1
Biomass	3.7	5.1	15
	District heat (TWh)		
Biomass	3.9	3.9	17.5

Total effects of all fuel switching measures

The effects strongly depend on the level of requested energy. Therefore we evaluated the measures based on three energy demand levels (1) baseline, (2) medium energy level basis which assumes that measure 1, 3 and 5 and 8 has been implemented and (3) if all energy saving measures would be integrated.

Table 9: Effects of fuel switch measures evaluated on three different energy consumption basis: (1) baseline, (2) medium energy level basis and (3) all energy saving measures are implemented

	Baseline		Medium energy level		Implementing all energy saving measures	
	GHG-emissions (Mt CO_2 Equiv)					
	2020	**2050**	**2020**	**2050**	**2020**	**2050**
Basis	79	87	65	67	57	52
	Difference to compare basis					
Measure 8	-0.6	-2.1	-0.8	-1.7	-0.3	-0.9
Measure 9	-2.2	-6.4	-1.7	-4.8	-1.3	-2.4
Measure 10	-1.4	-7.3	-1.4	-6.1	-1.6	-6.6
Measure 11	-2.1	-1.1	-1.7	-0.7	-1.4	-0.3
Measure 12	-2.8	-11.7	-2.0	-14.0	-2.0	-14.7
Measure 13	-1.8	-3.5	-1.7	-3.5	-1.2	-1.1
All fuel change measures	**-10.8**	**-28.6**	**-9.4**	**-25.6**	**-8.2**	**-21.0**
Total emissions after fuel change	**67**	**58**	**56**	**41**	**51**	**31**

If all options considered for fuel switching are fully implemented, the GHG-emissions are reduced by 8 Mt in 2020 and 21 to 29 Mt in 2050 compared to the scenario with the corresponding energy consumption.

The implementation of all fuel switch and energy saving measures would reduce emissions to 51 Mt in 2020 and further to 31 Mt in 2050.

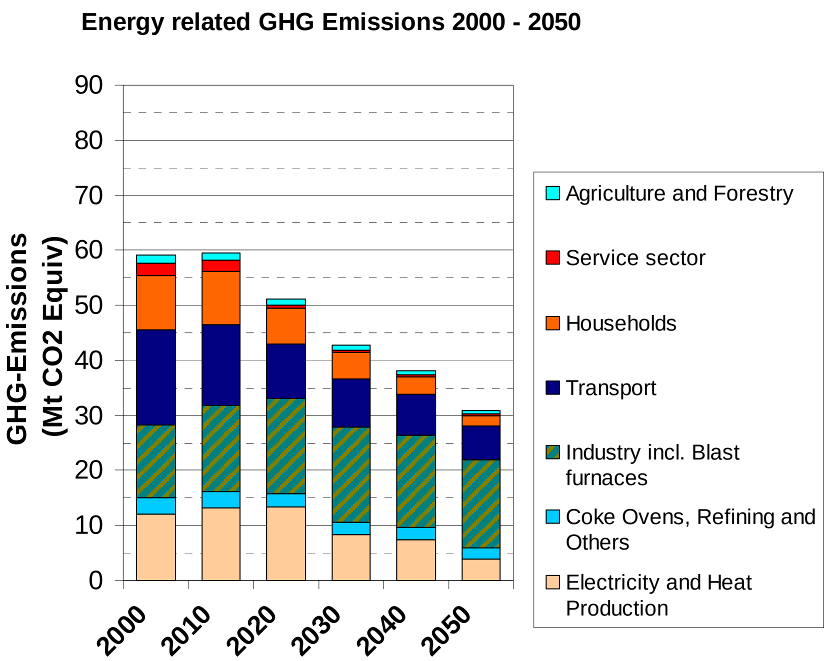

Figure 31: Annual national energy related greenhouse gas emissions until 2050 after implementing all mitigation options.

2.3 Mitigation Options Costs

Measure 1: Increase thermal quality of the residential building stock

According to Beckmann (2007), refurbishing and insulation measures on buildings cause CO_2-mitigation costs in range of -135 €/t CO_2 for apartment buildings, which were built before the 1980's, and are insulated to the 70 kWh/m² energy demand standard up to mitigation costs of 900 €/t CO_2, which occur if single family houses (construction period later than 1980) are insulated the passive house standard of 20 kWh/m². According to Thomas et al. (2006) and Haas et al. (2001), energy efficiency measures in the building stock cause mitigation costs between -65 €/t CO_2 and 200 €/t CO_2. Kletzan-Slamanig et al. (2008) estimate renovation costs of 580 €/m² if a single family house would be renovated according the Lower Austrian building regulation code. For apartment buildings the related costs are in the range 180 €/m². Kollmann (2009) proposes costs of 210 €/m², based on offers from various companies.

Assuming that renovation costs cannot not be solely assigned to the energy saving measure but also to the overall improvement of the building, we assume costs of 250 €/m² for small buildings and 90 €/m² for buildings with more than two housing units are related to the energy savings measure. In average this assumptions result in negative mitigation costs 90 €/t CO_2.

Measure 2: Additional decrease of the space heating demand in all sectors and increase of the conversion efficiency of domestic water heating

Measure 2 assumes not only a low energy performance standard but also a higher renovation rate than observed in the past. Referring to mitigation costs calculated by Beckmann (2007) and Thomas et al. (2006) and Kletzan-Slamanig (2008) mitigation costs are assumed to increase steadily from 0 €/t CO_2 up to 150 €/t CO_2

Table 10: Mitigation potential cost curve for measure 1 and 2 (space heating and efficient hot water production)

Share %	**Cost per saved emission** €/t CO_2	**Cost per saved energy** €Cent/kWh
Measure 1		
100%	-91	-2
Measure 2		
33%	0	0.0
33%	75	1.6
33%	150	3.3

Measure 3: Increase of the efficiency of electrical appliances in the residential and service sector and
Measure 4: Increase of the efficiency of electrical appliances in the manufacturing sector

Mitigation costs related to energy efficient electrical appliances have been reported again by Beckmann (2007) and Thomas et al. (2006). In the case of households, Thomas et al. calculated mitigation costs to be between -53 €/t CO_2 for lighting applications up to 27 €/t CO_2. According to Beckmann, efficient electric appliances cause negative mitigation costs of -350 to -100 €/ t CO_2. In the case of the industrial and commercial sector Thomas et al. (2006) quote mitigation costs of -20 to -60 €/t CO_2, in Beckmann (2007) mitigation costs are in range of -200 t o 0 €/tCO_2. Based on Thomas et al. and considering the Austrian marginal emission factor for electricity production of 0.3 t CO_2/MWh, we calculate a mitigation potential cost curve as shown in Table 11.

Table 11: Mitigation potential cost curve for measure 3 and 4 (energy efficiency of electric appliances)

Share %	**Cost per saved emission** €/t CO_2	**Cost per saved energy** €Cent/kWh
Measure 3		
30%	-102	-3.3
13%	-81	-2.6
20%	-71	-2.3
14%	-37	-1.2
11%	0	0.0
11%	9	0.3
Measure 2		
10%	-124	-4.0
55%	-102	-3.3
10%	-80	-2.6
25%	-31	-1.0

Measure 5: Reducing the fuel consumption of vehicles

Measure 5 evaluates the effects of the of the European Commission white paper, that proposes the average emission reduction of new cars in 2012 to a level of 120 g CO2/ km. Based on the assumption, that the White Paper will go into effect we consider this measure to be cost neutral. Yet it has to be kept in mind that this will come at high mitigation costs, if technical options are exclusively considered and structural changes, such as the switch to smaller cars, are not part a significant portion of the outcome of this process.

Measure 6: Comprehensive improvement of the fuel consumption of vehicles

Measure 6 is mainly based on the idea that consumers will request smaller cars. This is not a technical measure and involves loss of convenience and status. Therefore we considered mitigation costs to be equal to cost differences between different cars sizes in a way that mitigation costs increase with decreasing car prices.

Measure 7: Increase share of public transportation

Mitigation costs are calculated based on the comparison of transportation costs for public and individual passenger transportation. For inner city transportation public transportation is assumed to be cost effective compared to cars. Transportation costs for interurban travelling depend not only on the fuel consumption of the used vehicle, but also strongly on the average number of passengers. Based on Austrian railway tariffs for medium to long distance travels, price per kilometre are in the range of 11 – 18 €Cents/km. The Austrian Automotive Association ÖAMTC calculates average costs per kilometre of 42-47 €Cents/km for a new VW Golf taking all payments into account. Fuel costs are responsible for 4.2 €Cents/km. Other costs – such as maintance, tyres,… - which also do depend on the kilometres driven, sum up to 9.2 €Cents/km. Based on this comparison, we assume, that using public transportation instead of individual cars is in many cases cost efficient.

Table 12: Mitigation potential cost curve for measure 5, 6 and 7

Share %	Cost per saved emission €/t CO_2
Measure 5	
100%	0
Measure 6	
25%	160
15%	335
35%	600
25%	1050
Measure 7	
100%	0

Measure 8: Increase share of natural gas fuelled vehicles

According to the Well-to-Wheel study 2007 (JRC, 2007), production costs for natural gas fuelled vehicles are currently about 1000 – 2000 € higher than those for diesel and gasoline fuelled vehicles. This is mainly due to the relatively high investment costs for natural gas on the board tank. In the long run, it is expected that additional costs will decrease to 1000 due to learning effects and increasing costs for conventional vehicles due to emission regulations (Haas et al., 2008). Based on current prices, taxes for annual mileage of gasoline and diesel vehicles, annual refuelling savings amounts to 150 – 250 € for diesel vehicles and 300 to 450 € for gasoline cars[7] and over-compensates for the additional investment costs. Yet, when the same taxation is assumed for natural gas as for gasoline, natural gas becomes as expensive as gasoline and diesel. In this case, mitigation costs increase significantly. WTW quotes mitigation costs of 300 to 600 €/t CO_2 compared to a conventional vehicle. Yet, compared to other technical options which may become necessary to reduce the average emissions of new vehicles to 120 g CO_2 per 100 km, switching from oil to natural gas is a rather cheap option.

Measure 9: Increase share of biofuels

Mitigation costs of biofuels do strongly depend on the type of technology, whether fuels are imported from low income countries or from domestic sources and, most important, from the mitigation effect. In this study we considered GHG reduction efficiency of 60%. This efficiency is rather optimistic; in many cases the mitigation effect is much lower. Based on this GHG reduction effect of biofuels and Kranzl et al. (2008), 50% of the considered biofuel potentials can be exploited at mitigation costs of 200 €/t CO_2, the remaining potential at costs of 400 €/t CO_2.

7 http://progs.wiennet.at/cng_rechner/

Table 13: Mitigation potential cost curve for measure 8 and 9: Fuel switch in the transportation sector

Share	Cost per saved emission
%	€/t CO_2
Measure 8	
100%	380
Measure 9	
50%	200
50%	400

Measure 10: Gas powered CC plants instead coal power plants

Depending on interest rates and the assumed life time, operation independent cost of 50 €/kW for natural gas combined cycle plants and 90 €/kW for coal power plants occur. Based on an assumed coal price of 7 €/MWh and a gas price of 15 €/MWh, mitigation costs are about 10-15 €/t CO_2. Based on Primes model runs the European Commission (2008) estimated future CO_2-prices somewhere in the range 37-47 €/tCO_2 for 2020. The CO_2-price will certainly depend on the relation between the gas and coal price. Lower gas and higher coal prices will make electricity production from natural gas more attractive, thus lowering the CO_2-emissions and the CO_2-price. The same applies vice versa. It is expected, that the CO_2 price will balance the electricity produced from coal and gas, therefore it is assumed in this project that the replacement coal power plant by natural gas fired combined cycle plants is cost neutral.

Measure 12: Increase the share of renewables electricity production

Electricity production costs from renewable electricity spread within a wide range, mainly depending on the primary energy carrier. In addition to the new installed capacities already implemented in the baseline scenario, we assume that additional renewable energy will be large hydropower for electricity production. According on the national hydro power action plan (Masterplan Wasserkraft, Bartenstein and Windtner, 2008; Pöyry, 2008), the assumed additional capacity is going to be installed in Austria until 2020.

Table 14: Mitigation potential cost curve for measure 10 and 12

Share	Cost per saved emission
%	€/t CO_2
Measure 10	
100%	0
Measure 12	
100%	0

Measure 11: Replace coal and oil by gas in the residential and service sector
and
Measure 13: Replace coal and oil by gas in the industrial sector and increase the share of renewable energy carriers for industrial process heating

Mitigation costs are calculated based on the retail prices. In the residential and service sector, coal is not common anymore; oil is mainly used for heating applications. As natural gas and heating oil actually have rather similar retail prices per heat value mitigation costs are considered to be zero.

In the case of industry, fuel substitutions costs amount are in the range of 10 €/MWh, which then result in mitigation cost of about 40 €/t CO_2.

Table 15: Mitigation potential cost curve for measure 11 and 13

Share	**Cost per saved emission**
%	€/t CO_2
Measure 11	
100%	0
Measure 13	
100%	40

3 Industry and Processes

3.1 Entities

In the industry and processes sector, close interactions exist between energy-related release of greenhouse gases and release determined by the (chemical) conversion of the produced goods. This fact had to be considered in defining the entities. Following the definition of entities as “explicitly defined units of activity within a specific sector” (see section 1.3) seven such entities were specifically selected (see also Winiwarter et al., 2005).

Entities in the sector “industry and processes”:

– Pulp and paper production
– Cement production
– Iron and steel production
– Lime production
– Fertilizer production
– Other processes with contact
– Other processes without contact

This classification is compatible to the division suggested by the International Panel on Climate Change (IPCC) and the subdivision made by the Federal Environmental Agency in Austria (Umweltbundesamt). The main difference is that not only the chemical process emissions are included as in Common Reporting Format-CRF Sector 2, but also the particular CO_2 emissions from energy consumption associated with the manufacturing of the product are added (parts of CRF Sector 1), as far as they are not covered in the energy section of this project. Still we take care that assignment of emissions is transparent and remains comparable with official Austrian emission data. We generally tried to focus on the dominant CO_2 sources in IPCC sector “industrial processes” (IPCC Category 2, CRF Sector 2), namely “pulp and paper production”, “cement production”, “iron and steel production” and “lime production”, as well as the entity “fertilizer production” which is an important source of N_2O. All minor emitters are agglomerated in “Other processes with contact” or in “Other processes without contact”. The distinction between these two entities is generally made by the manner of contact between fuel and intermediate during the process. Processes assigned to “Other processes with contact” are characterised by a close interaction between fuel and processed material such as in limestone and dolomite use, soda ash use, sinter production, bricks, tiles (decarbonising) and others (CRF Sector 1.A.2.f) but here we exclude cement production. Processes as in food production occur without a direct contact between fuel and processed material. Besides food processing, the boilers from non-ferrous metals, chemicals, beverages and tobacco production are allocated in “Other processes without contact”.

As mentioned before, in this approach we discuss both aspects of each entity in sector “industry and processes”, the emissions from the industrial process (e.g. decarbonisation) and fuel-related emissions. In other approaches mentioned (e.g. Umweltbundesamt, IPCC), the pyrogenic emissions from industrial activities mostly are allocated in the “energy” sector (IPCC Category 1, CRF Sector 1). The module „industry and processes“ here covers emissions from combustion processes caused by direct heating, process emissions and the indirect emission from steam and electricity consumption (CRF Sector 1.A.2 and Sector 2). The main reason for the difference is that emission reporting is basically derived from energy statistics, while applying measures needs to refer to specific processes and installations. Establishing potentials and effectivities of measures in industry often requires consideration of the process as a whole. This requires interaction (and consideration) of measures defined in the energy sector (see section2).

3.2 Emissions

The major greenhouse gas (GHG) in Austria is CO_2, which represented 84.4% of total national greenhouse gas emissions expressed in CO_2 equivalents in 2004. The industrial processes sector accounted for 10.8% of the total GHG emissions (Umweltbundesamt, 2006a). Therefore, the emission factors (EF) of CO_2 are shown in Table 16, for the entity “fertilizer production” we present the N_2O EF in addition.

The following emission factors are partly provided by the respective industrial community or official Austrian inventories (see “References” presented in Table 16) and usually refers to the total production process, both process and pyrogenic emissions.

Table 16: CO_2 Emission factors

Entity Description	Emission factors unit CO_2(N_2O)/ unit product (2000) or fuel	References
Pulp and paper production	507 kg/t	Own calculations and Austropapier, 2006
Cement production	868 kg/t	Hackl und Mauschitz, 2003
Iron & steel production	1700 kg/t (1997)	Winiwarter & Orthofer, 2000
Lime production	750 kg/t	IPCC, 2006
Fertilizer production (ammonia production, nitric acid production)	461 kg/t 3 kg N_2O/t	Own calculations and Umweltbundesamt, 2002
Other processes with contact (limestone and dolomite use, soda ash use, sinter production, bricks and tiles (decarbonizing),”others”: energy without cement)	59.8 t/TJ	Own calculations and Umweltbundesamt (as reported by UNFCCC, 2006)
Other processes without contact (non-ferrous metals, chemicals, food processing, beverages and tobacco)	60.0 t/TJ	Own calculations and Umweltbundesamt (as reported by UNFCCC, 2006)

The implied EF for “pulp and paper production” comprises pyrogenic emissions as calculated below.

$$emission\ \ factor\left[kg/t\right]=\frac{specific\ energy\ consumption\left[\mathrm{GJ}/t\right]}{calorific\ value\ of\ \ fuel\left[GJ/t\right]}\times 1000\times\frac{44}{12}\times\frac{carbon\ content\ of\ \ fuel\left[\%\right]}{100}$$

The specific energy consumption for fossil fuels (coal, fuel oil, natural gas) expressed in GJ/tonne for the year 2000 was provided by Austropapier, the Austrian community for pulp and paper industry. The calorific values (ÖSTAT, 1997) and carbon contents (Stanzel et al., 1995) used in the present report are as follows:

28.5 GJ/tonne for coal with a carbon content of 70%, 42.6 GJ/tonne for fuel oil with 87.5% carbon and 50 GJ/tonne for natural gas with 74%. The factor 44/12 converts the carbon content in fuels into the carbon dioxide emitted.

The given implied EF for “cement production” covers emissions from clinker production, which consists of combustion and calcination processes and was taken from Hackl and Mauschitz (2003). The CO_2 emissions from Austrian cement industry have been published regularly (Hackl and Mauschitz, 2003) based on plant level investigation.

The implied emission factor for “iron and steel production” derives data of the Austrian inventory as presented by Winiwarter and Orthofer (2000). As in “cement production” the EF is composed of fuel related and process emissions. In contrast to the EF for other sectors the data for “iron and steel production” is given for the year 1997. However, the implied emission factor is due to the input of fuel and reducing agent and their carbon content, consequently, annual variability is not expected.

In “lime production” only emissions generated during the calcination process are considered. The default EF was taken from the latest IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). CO_2 emissions from combustion process are contained in “Other processes with contact”.

The CO_2 and N_2O implied emission factors for “fertilizer production” were added up combining the emissions of the various steps involved in the manufacture of fertilizer products. The respective emissions were made up of the CO_2 or N_2O emissions from ammonia production, nitric acid production and a small amount of “others” given in the National Inventory Report (Umweltbundesamt, 2002).The activity data inserted is the production quantity of the IPCC-Sector 2.B chemical industry, assuming that this data is dominated by production of ammonia and nitric acid. These emission and activity data was substituted into the following equation to obtain the EF for the entity “fertilizer production”.

$$emission\ \ factor\left[kg/t\right]=\frac{emissions\left[kg\right]}{activity\left[t\right]}$$

For the entities “Other processes with contact” and “Other processes without contact” the activity data in the majority of cases was given as energy consumption in TJ. Accordingly, the emission factors in Table 16 are given in t/TJ and therefore, only depend on fuel. Data on emissions and energy input for the respective sector have been compiled by the Austrian Federal Environment Agency (Umweltbundesamt), and they are available in sufficient detail in their database submitted to UNFCCC (UNFCCC, 2006). The EF of “Other processes with contact” and “Other processes without contact” are calculated by dividing the sum of CO_2 emissions in tonnes over the sum of consumption of energy in TJ, basically as shown in the equation above.

Previously, some CO_2 emissions in tonnes e.g. of food production has to be converted into energy consumption. Thus, we selected adequate energy carriers for the respective processes and substitute into equation below.

$$activity\ [TJ] = emissions[t] \times \frac{calorific\ value\ of\ \ fuel\ [GJ/t]}{1000} \times \frac{12}{44} \times \frac{100}{carbon\ content\ of\ \ fuel\ [\%]}$$

We selected natural gas for food production (CRF sector 2.D.2) allocated in “Other processes without contact” and fuel oil for limestone and dolomite use (CRF sector 2.A.3), for soda ash use (CRF sector 2.A.4), for sinter production and bricks and tiles (both CRF sector 2.A.7) which are assigned to “Other processes with contact”.

The activity data listed in Table 17 for “lime production”, “fertilizer production”, “other processes with contact” and “other processes without contact” for the year 2000 derives from UNFCCC (2006), which is data originating from the Austrian Umweltbundesamt as discussed above. The entity breakdown follows the classification pointed out for calculating the EF. Austropapier (2006) provides the data for “pulp and paper production”, Hackl and Mauschitz (2003) supplied data for “cement production” and the activities for “iron and steel production” were taken from Umweltbundesamt (2006a).

Table 17: Activities

Entity Description	**2000 [Mt]**	**2020 [Mt]**	**2050 [Mt]**
Pulp and paper production	4.950	4.816	4.616
Cement production	4.047	4.379	4.877
Iron & steel production	5.724	7.226	9.480
Lime production	0.654	0.705	0.780
Fertilizer production	1.067	1.109	1.150
	2000 [TJ]	**2020 [TJ]**	**2050 [TJ]**
Other processes with contact (e.g., limestone and dolomite use, soda ash use, sinter production, bricks and tiles (decarbonizing), but not including energy use in cement burning)	68173	68173	68173
other processes without contact (e.g., non-ferrous metals, chemicals, food processing, beverages and tobacco)	46877	46877	46877

The projections were created scaling deviations from the year 2000 according to the GAINS database, except for “other processes with contact” and “other processes without contact” which are not directly available in GAINS (IIASA, 2006). Accordingly, we keep these entities constant as a first, imprecise approximation for these entities. The GAINS data base contains energy projections from the PRIMES model in order to allow forecasts for most European countries (Capros, 2006). Projections of process activities derive from consultations with national authorities, in case of Austria with information obtained from Umweltbundesamt.

The resulting emissions have been calculated and are shown in Figure 32 (for “iron and steel production”) and Figure 33 (for all other entities).

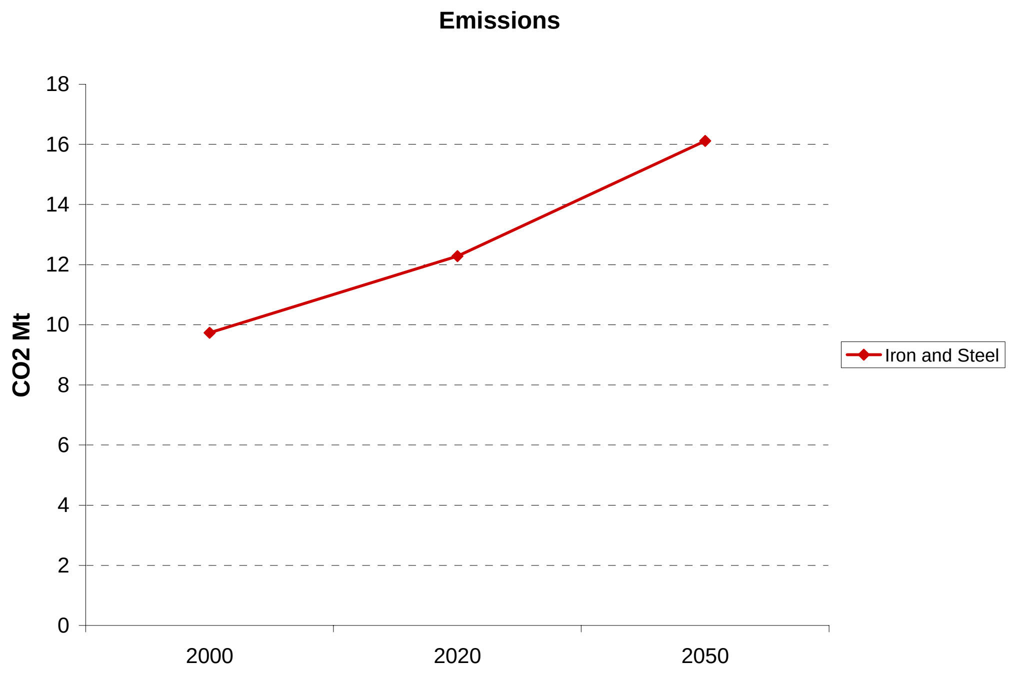

Figure 32: CO_2 emissions in "iron and steel production" in Austria

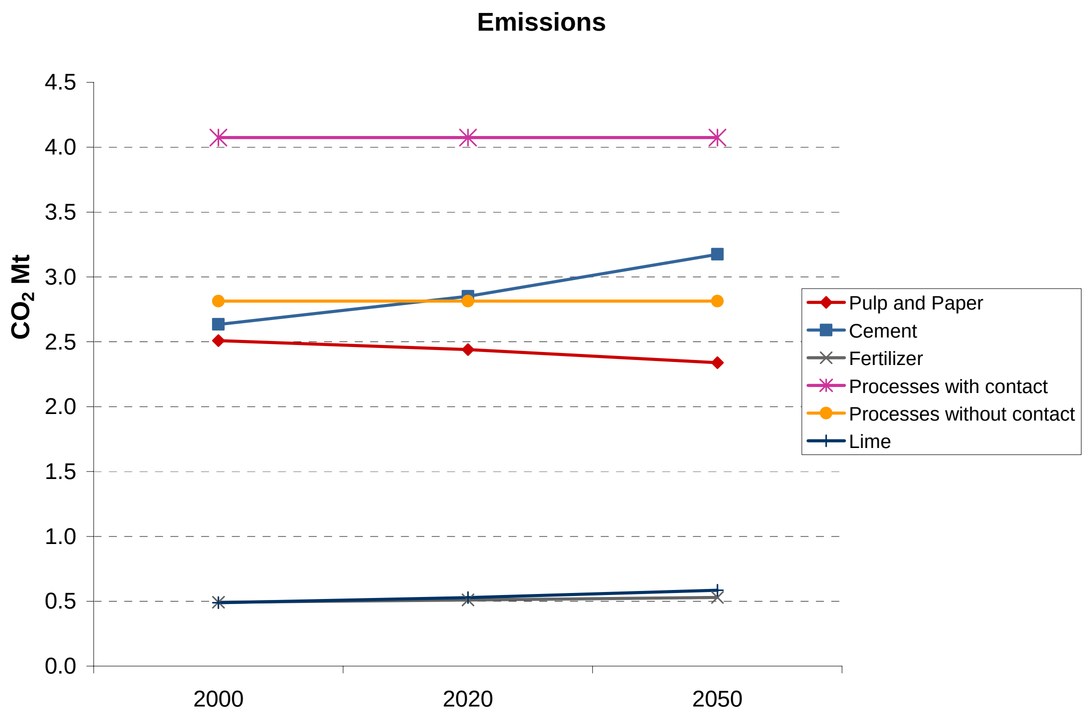

Figure 33: CO_2 emissions in "pulp and paper production", "cement production", "fertilizer production", "other processes with contact" and "other processes without contact" in Austria

As can be seen in the figures above, especially the entity “iron and steel production”, but also “pulp and paper” and “cement production” make up a large majority of CO_2 emissions from industrial processes. The entities “Other processes with contact” and “Other processes without contact” consisting of a number of smaller sources not covered elsewhere add up to considerable emissions too, but only when seen as combined entities.

Activities and emissions of these three dominant CO_2 sources in Austria: “pulp and paper production”, “cement production” and “iron and steel production” are given in Figure 34, Figure 35, and Figure 36.

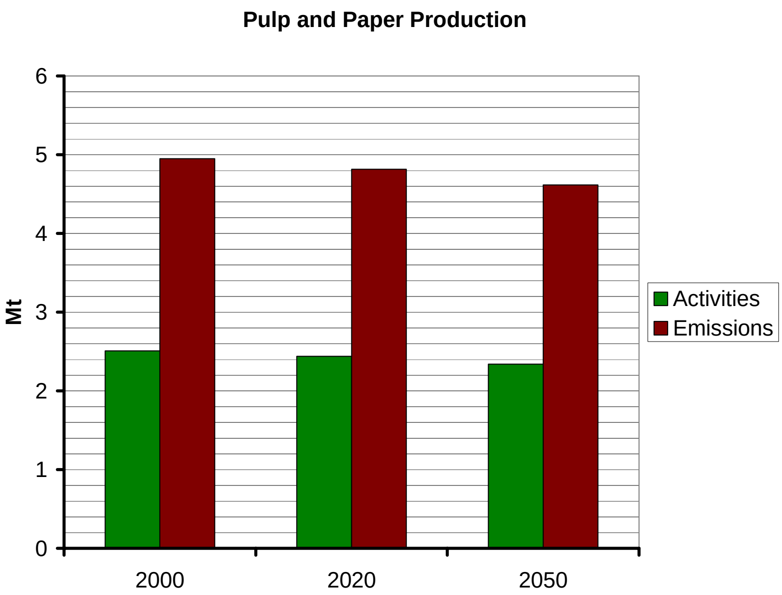

Figure 34: CO_2 Emissions and Activities in “pulp and paper production” in Austria

It can be seen that activity as well as the emissions are assumed to decrease in the next 50 years in “pulp and paper production” in Austria.

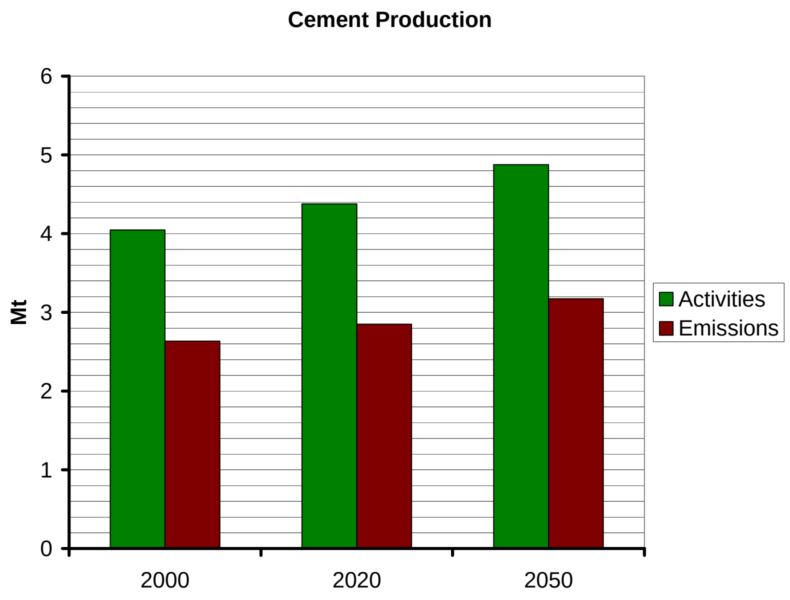

Figure 35: CO_2 Emissions and Activities in “cement production” in Austria

An expected increase in cement production is also reflected in increasing CO_2.

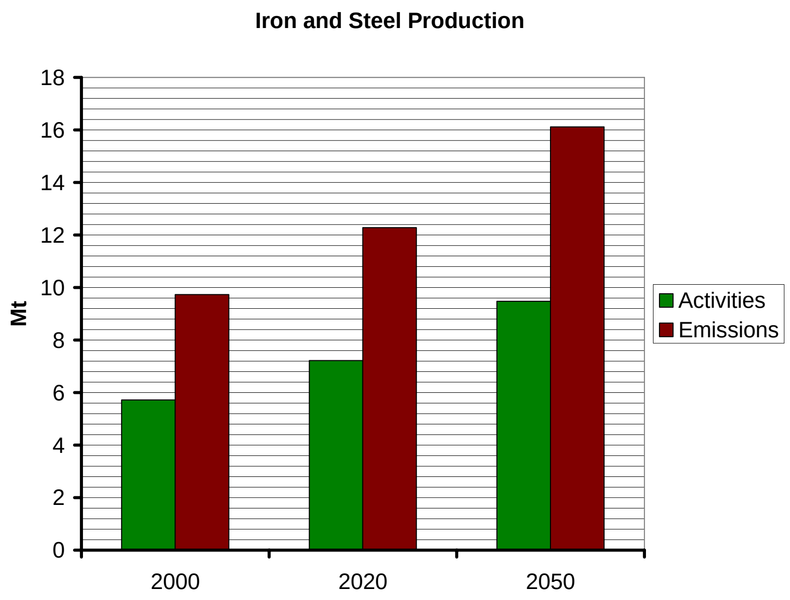

Figure 36: CO_2 Emissions and Activities in “iron and steel production” in Austria

Figure 36 shows the activities and emission data for “iron and steel production” for 2000 and projections for 2020 and 2050. Expected increases surpass those of the other entities, even when starting at a high level already.

The data for the activities for the year 2000, as described in Table 17, have been implemented into the reclip:tom database. Also, the scaling to the future years, as based on GAINS data, has been implemented, such that the resulting emissions as shown above fully reflect the respective data as published by the Austrian Umweltbundesamt.

Accordingly, in identifying measures reducing emissions we focused on the three main CO_2 sources, i.e. “cement production”, “iron and steel production” and “pulp and paper production”.

3.3 Measures

In this project measures were defined as: „ […] purposeful interventions into the emission characteristics of entities. Measures considered within the framework of reclip:tom will be limited to options for mitigation of GHG emissions. It is needed to be understood that measures may be applied both towards the amount of gas emission by activity unit (emission factor) and the material throughout itself (activity)” (see section 1.3).

In the sector “industry and processes” emission reduction options were identified to basically reduce emissions of industrial carbon dioxide. Furthermore, some measures deal with the reduction of emissions of nitrous oxide. The following measures were determined at the level of industrial sub-sectors but not at plant level. In Austria, the differentiation becomes indistinct very easily because of the small number of plants in some entities, for instance, there are only two major plants which make up the sub-sector iron and steel industry. However, data availability and time constraints impede working at plant level.

It is the intention of this project to analyse quite a number of highly plant-specific processes but it can not be aim of the present report to give a specification of every single measure including all technological details. In this respect, we try to bring together the information and results of different sources and those who want to know more details will have to consult the background literature cited in this document.

3.3.1 Description of the method

The reduction efficiency, applicability, implementation and costs presented for individual measures relate to data for the year 2000, even when more recent data is available.

Each measure of the following description will be indicated by a unique identification code. Note that the technological ID, IND_#, is based on the numbering in the project-database, in view of that it is not always a consecutive numbering. Nevertheless, we use the same numbering here to clearly associate the measures to their ID.

The reduction efficiency describes the extent of emission reduction facilitated by a specific measure. As will be shown below, emission reductions are often presented in form of energy savings – separately for fuel savings and electricity savings. Especially considering electricity savings, it can not be ruled out that measures applied in the industrial sector reflect savings at the same time defined in the energy sector as well. We avoid double counting of measures (i.e., an underestimation of emissions after applying measures) by strict separation of entities. Thus we make sure that, if measures are applied twice, they are at least applied to different fractions of the overall emissions.

The reduction efficiency in percent may be calculated from the emissions saved in tonnes CO_2 divided by the amount of product (in tonnes) and by the unabated implied emission factor of an activity (specifically, an entity) in kg CO_2 per tonne product:

$$reduction\ efficiency\,[\%] = \frac{\Delta CO_2\,[t]}{product\,[t]} \times \frac{100 \times 1000}{emission\ \ factor[kg/t]}$$

The amount of saved emissions in tonnes CO_2 per tonne product is presented in different ways in the available literature. In its most general notation, we describe it as the added saved emissions from electric energy in GJ saved per tonne, named GJe, from energy in GJ saved per tonne and from energy in kWh saved per tonne product. These terms are formally identical to emission factors, but nevertheless should not be confused with them as they refer to emission savings instead.

$$\frac{\Delta \mathrm{CO}_2\,[\mathrm{t}]}{product[t]} = \frac{\Delta CO_2\,[t]_{GJ/t}}{product\,[\mathrm{t}]} + \frac{\Delta CO_2\,[t]_{GJe/t}}{product\,[\mathrm{t}]} + \frac{\Delta CO_2\,[t]_{kWh/t}}{product\,[\mathrm{t}]}$$

Energy recovered expressed in GJ saved per tonne product is calculated using the calorific factor and the carbon content of the selected energy source for the particular entity.

$$\frac{\Delta CO_2\,[\mathrm{t}]_{GJ/t}}{product[t]} = \frac{specific\ energy\ savings\ [GJ]/\,product[t]}{calorific\ value\ of\ \ fuel\ [GJ/t]} \times \frac{44}{12} \times \frac{carbon\ content\ of\ \ fuel\ [\%]}{100}$$

Savings in electric energy are assumed to effect emission reductions in coal fired power plants. We assume a conversion efficiency of 40% in power plants for electricity generation.

$$\frac{\Delta CO_2\,[\mathrm{t}]_{GJe/t}}{product[t]} = \frac{specific\ energy\ savings\ [GJ_e]/\,product[t]}{calorific\ value\ of\ \ fuel\ [GJ/t]} \times \frac{1}{0.4} \times \frac{44}{12} \times \frac{carbon\ content\ of\ \ fuel\ [\%]}{100}$$

Savings in electric energy given in kWh per tonne needs a conversion of kWh to kJ as product are calculated as electric energy savings in GJ per tonne product in addition to required conversion factors.

$$\frac{\Delta CO_2\,[\mathrm{t}]_{kWh/t}}{product[t]} = \frac{specific\ energy\ savings\ [kWh] \times 3.6/\,product[t]}{calorific\ value\ of\ \ fuel\ [GJ/t] \times 1000} \times \frac{1}{0.4} \times \frac{44}{12} \times \frac{carbon\ content\ of\ \ fuel\ [\%]}{100}$$

As a further complication, emission reductions or reduction efficiencies normally do not refer to a full entity, such that derived emission factors can be readily applied. Instead, they cover specific processes that comprise only a part of the entity. Consequently, the application of the measure is limited to the fraction of emissions of an entity which can be affected by a specific measure. We introduce a parameter “applicability” to describe this behaviour. Furthermore, emission abatement measures may have been introduced in the base year already. This is described by “implementation”. The extent of implementation obviously limits the further possibility of introducing measures. We may therefore define an overall “reduction potential”, describing the fraction (percentage) of an entity’s emissions that can be abated by a certain measure. As the reduction potential allows comparing individual measures directly, we present this figure in the tables at the end of each sector.

$$reduction\ potential\,[\%] = reduction\ efficiency\,[\%] \times applicability \times [1 - implementation]$$

The calculation of the reduction potential as well as of the resulting emission changes is implemented in the modelling algorithm of the data handling tool (see section 0), it does not require the conversion that is presented here for reasons of comparison. Emissions are directly calculated considering the respective implementation, changes are then derived from the difference or from the difference in implementation in the base year and the applicability in the target year (as a maximum feasible reduction scenario). For quantifying the degree of implementation we used different approaches which are described in the specific chapters.

Costs are not yet available completely for all reduction efficiency improvements mentioned below. We obtained the data for costs from the study “Economic Evaluation of Carbon Dioxide and Nitrous Oxide Emission Reductions in Industry in the EU” (de Beer et al., 2001) which is a contribution to the study “Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change” (Blok et al., 2001). In this study calculations were made assuming a real interest rate of 4% and using the lifetime of the option, i.e. equipment (de Beer et al., 2001).

3.3.2 Pulp and Paper Production

In this section parameters of measures for reducing emissions of CO_2 from the entity “pulp and paper production” are assessed. Pulp and paper industry is one of the most considerable carbon dioxide emission sources, although 44.4% (2000) of fuels are biogenic in this entity. Usage of biogenic fuels in pulp and paper production is due to the incidental waste liquor, the bark and waste water sludge during the manufacturing process. Naturally, these materials were burned prior buying other fuels (Austropapier, 2006).

Therefore, in the current project suggested technological measures mostly result in energy savings and as a consequence in CO_2 reduction. According to Austrian Institute for Economic Research (WIFO) data (Kratena & Wüger, 2005), we assume that typical energy carrier in pulp and paper industry is natural gas. Thus CO_2 reductions assume decreased gas consumption.

Applicability in pulp and paper production:

In order to derive applicability, we derive two factors: first, we define subprocesses at a certain level per entity (see listed processes below) and allocate the CO_2 emissions from the chosen entity (here pulp and paper production) to emissions from these subprocesses (in % energy demand in pulp and paper production listed below). For building the second factor, we investigated the distribution of defined subprocesses in Austrian plants (see production data in Austrian plants listed below, which we assume to represent also the relations in terms of energy demand).

Processes (energy demand in pulp and paper production) (E.V.A., 2005)

- Pulp production (includes mechanical wood pulp, chemical pulp and recovered paper): 60%
- Paper production: 40%

Austrian plants: (production data 2000) (Austropapier, 2006)

- Mechanical wood pulp: 8.9%
- Chemical pulp: 31.2%
- Recovered paper: 38.0%
- Paper: 100%

In the following, the individual measures are shortly introduced, and the respective parameters required for quantification are presented. The results are presented on a comparable scale (i.e., reduction efficiency converted to the entity level) in Table 18.

IND_1: Miscellaneous measures: low cost tranche: better dimensioning refiners, more efficient steam distribution, energy management, optimisation of process control, use less steam in stock preparation (de Beer et al., 2001)

This set of measures is meant to represent easily implementable energy savings, without giving specific details. De Beer (2001) discriminates along costs of measures. IND_1 includes measures at less than 25 €/GJ.

Estimations of reduction efficiency underlie the following savings as input data: 0.5 GJ/tonne product and 0.2 GJe/tonne product (de Beer et al., 2001). The reduction efficiency resulting from this accounts for 14.2%. Considering the applicability and the implementation factors of measure IND_1 defined in the paragraphs below, the reduction potential is 1.9%.

The applicability consists of two factors as defined above in the section "Applicability in pulp and paper production". IND_1 is allocated in paper production. Paper production demands a share of 40% of energy in pulp and paper industry. Related to Austrian production data, paper has a production share of 100% of pulp and paper production.

It is difficult to estimate the Austrian implementation of "miscellaneous measures" taken in pulp and paper mills. The situation in Austria is not fully comparable to Europe, because of the small number of plants and should be investigated independently. Moreover the standard in energy efficiency is already high (E.V.A., 2005). Regarding to that, we estimate that the major potential of measure IND_1 was already implemented in 2000 and estimate this implemented potential at two-thirds.

Costs provided by de Beer approximately amount to < 25 €/GJ saved annually (de Beer et al., 2001). For purposes of comparison, here we enter an indicative value of 20.

IND_2: Miscellaneous measures: high cost tranche: energy efficient motor drives, direct drive motors, waste heat recovery, matching components pumping system (de Beer et al., 2001)

This set of measures is similar to IND_1, only that it describes the more costly options (>25 €/GJ) (de Beer et al., 2001).

The underlying energy savings published by de Beer are 0.3 GJe/tonne product and 0.2 GJ/tonne product (de Beer et.al., 2001). The reduction efficiency starting from that data results in 15.5%. The reduction potential is a product of reduction efficiency, applicability and implementation factors of measure IND_2.

The percentage composition of the applicability of measure IND_2 is equal to IND_1.

Correspondingly to IND_1 the implementation is estimated at two-thirds as a first approximation.

The investment costs are given at >€ 25/GJ saved annually by de Beer (2001), for the same reason as in IND_1 we set the estimated costs at € 40/GJ saved.

IND_5: Improved pressing techniques, e.g. condensing belt drying (de Beer et al., 2001), (E.V.A., 2005)

The reduction potential of this measure is due to "a combination of pressing and drying [that] can increase the drying rate and simultaneously reduce the energy consumption. […] Energy can be saved because heat can be recovered easier than with conventional drying." (de Beer et al., 2001).

The estimated savings on heat demand given in de Beer are 0.5 - 1 GJ/tonne product. Hence, the reduction efficiency comes to 8.0% and the reduction potential results in 3.2%.

That implies an applicability factor of 0.4. IND_5 is allocated in paper production with 40% of energy demand in pulp and paper industry and with a production share of 100% of pulp and paper production in Austria.

Implementation: "The first commercial units are already in operation, albeit at a small scale". (de Beer et al., 2001). As this first operation unit is not located in Austria, we assumed the implementation to be zero.

The costs were estimated at € 450 - 900/GJ saved annually. "A first commercial condensing belt unit with a capacity of about 25 kt/a had investment costs of € 12.5 million." (de Beer et al., 2001).

Interactions: This measure competes with IND_7: Pressing to higher consistency and with IND_5a: Impulse drying (de Beer et al., 2001). Furthermore, paper dried by condensing belt drying is not as suitable for recovering paper as for paper which is dried conventionally (E.V.A., 2005).

IND_5a: Improved pressing techniques, e.g. impulse drying (de Beer et al., 2001), (E.V.A., 2005)

The reduction efficiency of this measure is due to the same reasons demonstrated in IND_5, both measures are similar. Unfortunately, we could not find any references for quantified energy savings yet, even in de Beer's publication it is noted that it is not clear whether impulse drying will result in an energy saving (de Beer et al., 2001). Thus, it is excluded from further evaluation but it remains here as a placeholder.

The percentage composition of the applicability of measure IND_5a is equal to IND_5.

Implementation: "Impulse drying is not expected to be implemented before 2010." (de Beer et al., 2001).

Interaction: This measure competes with IND_7: Pressing to higher consistency and with IND_5: Condensing belt drying (de Beer et al., 2001).

IND_7: Pressing to higher consistency, e.g. by extended nip press (paper making); (de Beer et al., 2001), (E.V.A., 2005)

The measure “pressing to higher consistency” can result in a reduction of energy demand because extended nip presses used in the pressing section are far less energy intensive than removal of water in the drying section (de Beer et al., 2001).

Energy savings are estimated to be on the order of 0.5 - 1.6 GJ/tonne product. 11.2% is the reduction efficiency calculated from the underlying data; therefore, the reduction potential is 2.6%.

Applicability: IND_7 is allocated in paper production with 40% of energy demand in pulp and paper industry and respectively to production with 100% of pulp and paper production in Austria.

Implementation: The Austrian Energy Agency (formally E.V.A.) made a survey concerning technological measures in the Austrian pulp and paper industry. 12 questionnaires have been returned as far as nip presses were concerned. Five of 12 plants have nip presses implemented (E.V.A., 2005). From this result we extrapolated to 28 pulp and paper plants as a first approximation in Austria.

Investment costs are estimated at € 25/GJ saved annually (de Beer et al., 2001).

Interaction: This measure competes with IND_5 and IND_5a: Improved pressing techniques (de Beer et al., 2001).

IND_8: Reduced air requirements, e.g. by humidity control in paper machine drying hoods; (de Beer et al., 2001)

“By better insulation of the hood condensation of water vapour shall occur at a higher temperature reducing the amount of ventilation air required”. (de Beer et al., 2001). Therefore, energy savings can be expected.

A reduction of the heat demand of 0.3 GJ/tonne product is declared by de Beer. The reduction efficiency resulting from this account for 3.2% and the reduction potential reaches the total of 0.7% including the applicability and the implementation of measure IND_8.

Applicability: IND_8 is also allocated in the paper production with 40% of energy demand in pulp and paper industry and in respect of production with 100% of pulp and paper production in Austria.

We used the same method as in IND_7 to estimate the implementation of this measure in Austria. Five of 11 plants have a measure for humidity control implemented in Austria (E.V.A., 2005).

Investment costs are estimated at € 35/GJ saved annually; additional the operation and maintenance (O & M) costs are estimated at € 1/GJ saved annually (de Beer et al., 2001).

IND_57: Improved sortation process (E.V.A., 2005)

The separation of larger wood chips prior to the cooking process results in a reduction of vapour and energy demand (E.V.A., 2005).

The estimated savings on heat demand given by the Austrian Energy Agency aggregate 0.06 GJ/tonne product. The resulting reduction efficiency amounts to 0.6% and the reduction potential comes to 0.03%.

Applicability: IND_57 is allocated in the pulp production with 60% of energy demand in pulp and paper industry and as far as production is concerned, this measure is allocated in mechanical wood pulp with 8.9% of the pulp and paper production in Austria.

We used the same method as in IND_7 to estimate the implementation of this measure in Austria. Three of 13 plants have a measure for improved sortation in mechanical wood pulp processing implemented (E.V.A., 2005).

IND_58: Soot blower steam (E.V.A., 2005)

Providing additional air to combustion air during the combustion of heavy liquor in the recovery boiler boosts the flow rate. Consequently, carbon black originated from dust fraction of heavy liquor will be removed without using “soot blower steam” which in turn yield to a higher electricity output (E.V.A., 2005).

Energy savings are estimated to be on the order of 0.05 GJ/tonne product (E.V.A., 2005). The reduction efficiency starting from that data results in 0.5% and the reduction potential comes to 0.1%.

For specifying the applicability factor we assigned IND_58 to pulp production with a share auf 60% of energy demand in pulp and paper industry and concerning the production data, to chemical pulping with 31.2% of the pulp and paper production in Austria

IND_59: Iso-Thermal Cooking, ITC (E.V.A., 2005)

ITC features cooking at lower temperature compared to Modified Continuous Cooking (MCC). The decreased overall cooking temperature as a result of an extended cooking zone and a longer cooking time is less energy intensive than a conventional cooking process (Ferguson K.H., 1998).

The underlying energy savings published by the Austrian Energy Agency are estimated at 0.2 GJ/tonne product (E.V.A., 2005). Thus, the reduction efficiency comes to 2.1% and the reduction potential results in 0.4%.

That implies an applicability factor of 0.2. IND_59 is allocated in pulp production with 60% of energy demand in pulp and paper industry and related to production, in chemical pulp with a share of 31.2% of the pulp and paper production in Austria.

Implementation: The Austrian Energy Agency received 12 questionnaires concerning ITC. One of 12 plants in Austria has ITC implemented (E.V.A., 2005). We extrapolated the percentage as a first approximation as we did for IND_7.

IND_60: Multiple-effect evaporation (E.V.A., 2005)

Steam economy and with it specific heat consumption in multiple-effect evaporation varies in five to seven evaporator vessels (effects) and leads to evaporation preparation adapted to consumption and as a result to a decrease in steam consumption (E.V.A., 2005).

The estimated savings on heat demand given by the Austrian Energy Agency aggregate 0.5 GJ/tonne product (E.V.A., 2005). The resulting reduction efficiency amounts to 5.4% and the reduction potential comes to 0%.

The percentage composition of the applicability of measure IND_60 is equal to IND_59.

Implementation: Referring to E.V.A. all plants in Austria have already implemented multi-stage evaporation including six stages. Although seven stages are feasible, further CO_2 mitigation can not be expected by refitting because the additional electric energy demand compensates for the decreasing in steam consumption (2005).

IND_61: Falling film black liquor evaporation (E.V.A., 2005)

Falling film evaporation is similar to conventional rising film evaporation, but streaming the opposite way around and as a result, leads to decreasing in deposit. Usage of black liquor with higher solids content render possible and the concentrator is no longer useful (E.V.A., 2005).

Estimations of the reduction efficiency underlie the following input data: 0.8 GJ/tonne product (E.V.A., 2005). The reduction efficiency resulting from this accounts for 8.6%. Therefore, the reduction potential results in 1.3%.

The percentage composition of the applicability of measure IND_60 is equal to IND_59 and IND_60.

Implementation: Referring to the questionnaire conducted by the Austrian Energy Agency, three of 13 plants in Austria have falling film black liquor evaporation implemented (E.V.A., 2005).

IND_63: Improved brown stock washing (E.V.A., 2005)

There are several technological measures given to improve the brown stock washing and hence, to reduce the energy demand of this process. For instance, chemi-washers, CB filters or Drum Displacer® are mentioned by E.V.A. (2005).

A reduction of the heat demand of 0.01 GJ/tonne product is declared by the Austrian Energy Agency. The reduction efficiency resulting from this accounts for 0.1% and the reduction potential reaches the total of 0.02% (E.V.A., 2005).

Applicability: IND_63 is counted among pulp production with 60% of energy demand in pulp and paper industry and among chemical pulp with 31.2% of the pulp and paper production in Austria.

Implementation: Three of 13 plants in Austria have implemented any kind of improved brownstock washing (E.V.A., 2005).

IND_64: Washing presses (E.V.A., 2005)

Utilisation of presses during the washing process instead of filters reduces the amount of energy required as well as the chemical demand (E.V.A., 2005).

The estimated savings on the heat demand given in E.V.A. aggregate 0.39 GJ/tonne product (E.V.A., 2005). Hence, the reduction efficiency comes to 4.2% and the reduction potential results in 0.6%.

Applicability: The percentage composition of the applicability of measure IND_64 is equal to IND_63.

Implementation: Three of 13 plants in Austria have implemented washing presses (E.V.A., 2005).

IND_65: Optimisation refining process (E.V.A., 2005)

The following suggestions for improvement concerning the refining process are specified in E.V.A. (2005) and are expected to result in energy savings:

– Ideal refiner efficiency
– Twin disc refiner instead of conical refiner
– Reduction in rotation speed regulated by efficiency
– Optimisation of refiner filling as far as geometry and material is concerned
– Capacity should be adapted to freeness and dehydration

The estimated savings of electricity aggregate to 30 kWh/tonne product (E.V.A., 2005). Therefore, the reduction efficiency accounts for 4.8% then the reduction potential results in 1.0%.

Applicability: IND_65 rank among paper production with 40% of energy demand in pulp and paper production and has a production share of 100% of pulp and paper production in Austria.

Implementation: Six of 13 plants in Austria have implemented an optimisation of the refining processes (E.V.A., 2005).

Interaction: This set of measures partly coincides with IND_18: Refiner improvements in mechanical pulp.

IND_66: Heat recovery from dryer section (E.V.A., 2005)

Reduced air requirements by closing hoods or optimising ventilation entail reduction of energy demand (E.V.A., 2005).

The estimated savings on heat demand given in the study of the Austrian Energy Agency aggregate 0.92 GJ/tonne product (E.V.A., 2005). The reduction efficiency mounts up to 9.8% and the reduction potential comes to 1.1%.

Applicability: The percentage composition of the applicability of measure IND_66 is equal to IND_65.

Implementation: 10 of 14 plants in Austria have implemented a system for recovering heat from dryer section (E.V.A., 2005).

IND_67: Infrared profiling (E.V.A., 2005)

Reduction efficiency is achieved by the capability of profile correction by means of moisture profilers (E.V.A., 2005).

Energy savings are estimated to be on the order of 0.7 GJ/tonne of product and 0.08 kWh/tonne product (E.V.A., 2005). 7.5% is the reduction efficiency calculated from the underlying data; therefore, the reduction potential comes to 0.9%.

Applicability: IND_67 is allocated in the paper production with a percentage of 40% of energy demand in pulp and paper production and as far as production is concerned with 100% of the pulp and paper production in Austria.

Implementation: Two of 12 plants in Austria have implemented infrared profiling (E.V.A., 2005).

IND_16: Super pressurised ground wood (mechanical pulp) (de Beer et al., 2001)

"The energy demand for pressurised ground wood pulp can be halved by grinding under elevated pressure. […] As a result, higher temperature can be achieved without boiling, softening the lignin. […] Benefits are not only obtained from reduced electricity consumption, but also from a reduction in the use of chemical pulp. Less chemical pulp (10 - 20%) is required to have a pulp mix with equal qualities." (de Beer et al., 2001).

The resulting saving of this measure given by de Beer is on average 2.5 GJ/tonne product.

The reduction efficiency resulting from this accounts for 26.8% and the reduction potential comes to 1.4%.

Applicability: IND_16 rank among pulp production with 60% of energy demand in pulp and paper industry and among mechanical wood pulp with 8.9% of the pulp and paper production in Austria concerning the production data.

Implementation: 0 of 13 plants in Austria have implemented super pressurised ground wood (E.V.A., 2005).

IND_17: Heat recovery in thermo-mechanical pulping (de Beer et al., 2001)

"The heat produced in the process of thermo mechanical pulping can be recovered as low pressure steam in an evaporator reboiler system."(de Beer et al., 2001).

"Heat recovery systems can be expected to save 3.2 to 5.5 GJ/tonne of pulp." (de Beer et al., 2001). Hence, the reduction efficiency comes to 24.9% and the reduction potential results in 2.3%.

Applicability: IND_17 is allocated in pulp production with 60% of energy demand in pulp and paper production and in chemical pulp with a share of 31.2% of the pulp and paper production in Austria as far as production data is concerned.

Implementation: "This measure is already common; we assume an average penetration of 50% in 1990." (de Beer et al., 2001).

Costs: Investment costs are expected to amount to a total of € 4.1/GJ (de Beer et al., 2001).

IND_18: Refiner improvements in mechanical pulping (de Beer et al., 2001)

“The electricity demand for refining can be reduced by several options: refiner control strategies, conical instead of disk refiners and decreasing the consistency of pulping to 30% from 50%.” (de Beer et al., 2001).

Estimations of the reduction efficiency underlie the following data: 0.4 GJe/tonne (de Beer et al., 2001). Thus, the reduction efficiency is 15.5% and the reduction potential comes to 0.2%.

Applicability: IND_18 is counted among pulp production with 60% of energy demand in pulp and paper production and among mechanical wood pulp: 8.9% of the pulp and paper production in Austria.

Implementation: In de Beer it is assessed that in the EU the penetration of this measure is already high (estimate 75%), (2001).

Costs: Investment costs are assumed to be on the order of € 30.4/GJ.

Interaction: This set of measures partly coincides with IND_65: Optimisation refining process.

The data for applicability, implementation, reduction potential, costs and interaction of measures discussed in this chapter are summarized in the following table.

Table 18: Applicability, implementation, reduction potential as a fraction of the entity emissions, costs and interactions of measures in the pulp and paper industry

TECH ID	Applicability	Imple-mentation	Reduction Potential [%]	Costs [€/GJ]	Interactions
IND_1	0.400	0.667	1.896	20	-
IND_2	0.400	0.667	2.060	40	-
IND_5	0.400	0	3.211	675	IND_7 IND_5a
IND_5a	0.400	0	-	-	IND_7, IND_5
IND_7	0.400	0.420	2.607	25	IND_5, IND_5a
IND_8	0.400	0.450	0.706	36	-
IND_57	0.053	0.230	0.026	-	-
IND_58	0.186	-	0.100	-	-
IND_59	0.186	0.083	0.365	-	-
IND_60	0.186	1	0	-	-
IND_61	0.186	0.200	1.274	-	-
IND_63	0.186	0.230	0.015	-	-
IND_64	0.186	0.230	0.598	-	-

TECH ID	Applicability	Imple-mentation	Reduction Potential [%]	Costs [€/GJ]	Interactions
IND_65	0.400	0.460	1.036	-	IND_18
IND_66	0.400	0.710	1.142	-	-
IND_67	0.400	0.710	0.869	-	-
IND_16	0.053	0	1.429	-	-
IND_17	0.186	0.500	2.315	4.1	-
IND_18	0.053	0.750	0.207	30.4	IND_65

3.3.3 Cement Production

The greater part of CO_2 emission from cement production derives from transforming the raw material into clinker. Therefore, the identified measures aim at reducing the clinker in the cement or at improvements concerning the oven that entails energy savings. There is only one measure that explicitly suggests interfering to the level of activity of the cement industry, while maintaining the current standard of living (see IND_19).

According to WIFO data (Kratena & Wüger, 2005), we assume that the typical energy carrier used in the case of cement industry is fuel oil. Carbon content and energy content have been selected accordingly to assess CO_2 reduction from energy savings.

Applicability in Cement Production:

Applicability is derived in a similar way as described in section “Applicability in pulp and paper production”. Specific data for cement production are listed below.

Emissions (Hackl & Mauschitz 2003):

– Decarbonating: 64.6%

– Pyrogenic CO_2: 35.4%

Austrian plants (energy data) (Hackl & Mauschitz 2003):

Hackl and Mauschitz (2003) report energy consumption for heat production of 10.627 TJ/a in the Austrian cement industry, and electric power consumption of 1.596 TJ/a for the year 2000. We assume that heat production is mostly used for clinker production, whereas electric power is spent for winning and grinding the material. Therefore, three fractions can be differentiated:

– Energy consumption for clinker production: 86.9% (in line with Wopfinger, 2007, who assume CO_2 savings of 73-90% when clinker production can be avoided),

– Electric power consumption for cement production: 13.1% and

– Energy consumption for cement production: 100% if a measure applies to all cement production (including heat energy and electric power consumption)

IND_19: Housing: wood construction instead of concrete

Measure IND_19 suggests an augmentation in using wood construction for housing instead of concrete. This abatement measure is definitely interfering to the activity of the cement industry, but in our view would not have a negative effect on the standard of living. Unfortunately, this measure has so far not been quantified.

Apparently, the reduction potential in Austria is not clear at the time. However, we regard this measure worth to be mentioned.

As far as applicability is concerned, finally, all aspects of the cement industry are affected. Reduction of CO_2 results from avoiding kilned clinker, amounting to 100% reduction in cement production.

Data for implementation in Austria and costs will be investigated soon.

Interaction: The Interactions with the sector: “Soils and Landfill” and the entity: “Pulp and Paper” is due to the availability of wood in Austria.

IND_20: Electricity savings: roller mills instead of ball mills; high-pressure mills; high-efficiency classifiers; high-efficiency motors; (de Beer et al., 2001)

This set of measures given by de Beer (2001) can reduce the demand for electricity and thus, result in a total potential saving expressed as reduction potential.

The estimations of the reduction efficiency underlie the following input data: 10 kWh/tonne product (de Beer et al., 2001). The reduction efficiency resulting from this account for 0.93% and the reduction potential is 0.33%.

That implies an applicability factor of 0.046, because IND_20 reduces pyrogenic CO_2 emissions with its share of 35.4% and electric power with 13.057%.

Costs: Average costs are € 35/GJ saved annually (de Beer et al., 2001).

IND_22: Reduce clinker content of cement (de Beer et al., 2001)

Reducing the clinker content of cement by substitution of clinker for coal ash, blast furnace slag or/and pozzolanic material e.g. volcanic material leads to energy savings due to the high energy demand of clinker production (de Beer et al., 2001).

The calculated reduction efficiency is 6.3%, therefore, the reduction potential results in 3.1%.

Applicability: IND_22 reduces CO_2 emissions from decarbonating with a share of 64.6% and could be adopted in the clinker production with an energy consumption of 86.9%.

Implementation: In de Beer´s report it is assumed that the average clinker/cement ratio can be reduced to 75% from 80% (EU) in 2010. In Austria the clinker-factor (clinker/cement) is already at 0.75 in 2000.

Costs: “Costs for shipping of the blending materials are balanced by the avoided costs for clinker production”. (de Beer et al., 2001).

Interaction: This measure depends on availability of slag in the Austrian iron and steel industry, because import is not a feasible option. The quality standard in Austria, “Ö-Norm”, restricts the possible spectrum of this measure.

IND_23: Improving wet process kilns; Replacement of wet kilns by dry kilns (de Beer et al., 2001)

“Wet kilns use about twice as much fuel as dry kilns. Replacement of wet kilns by dry kilns therefore has the potential of improving the energy efficiency of cement production considerably.” (de Beer et al, 2001).

The calculated reduction efficiency is 16%; therefore, the reduction potential is 0.15%.

Applicability: IND_23 reduces pyrogenic CO_2 emissions with a share of 35.4% and could be adopted in the clinker production with an energy consumption of 86.9%.

Implementation: There are only 6% of wet process kilns implemented within the EU, a further decrement to 3% should be aspired in Austria (de Beer et al., 2001).

Costs are expected at € 55 - 100/tonne annual capacity (de Beer et al., 2001), here we decide to use € 75/tonne as a typical value.

IND_24: Use of waste derived fuels; The use of waste as replacement for fossil fuels (de Beer et al., 2001)

The use of waste as replacement for fossil fuels is current practice in Austria. Waste as used tyres, rubber, paper waste, waste oils, waste wood, paper sludge, sewage sludge, plastics as well as spent solvent is frequently used for this purpose and may reduce CO_2 emissions (de Beer et al., 2001).

De Beer estimated that waste may reduce CO_2 emissions by 0.1 - 0.5 kg/kg cement produced compared to current used production techniques using fossil fuels (2001).

Applicability: IND_24 reduces pyrogenic CO_2 emissions with a share of 35.4% and could be adopted in the clinker production with an energy consumption of 86.9%.

Implementation: In Austria, measure IND_24 is already implemented, but there is further potential (VÖZ, 2007). Accordingly, we estimated the implementation of this measure in Austria to 0.9.

Costs: There are more or less complex systems available and the prize also depends on the type of waste. Average investment costs are estimated at € 0.5/GJ of fossil fuel use avoided per year (de Beer et al., 2001).

Interaction: “The use of waste generates no additional emissions, although care should be taken for high volatile elements as mercury, thallium, cadmium, chlorine. Some of the materials e.g. certain types of plastic waste burned as fuel in cement kilns could be recycled. The corresponding CO_2 emissions would be lower if materials were recycled.” (de Beer et al., 2001); Sector “Soils and Landfill.”

IND_25: Optimisation of heat recovery of clinker cooler; (de Beer et al., 2001)

Rotary or planetary cooler versus grate cooler "do not need cooler fans and use little excess air, resulting in relatively lower heat losses." (de Beer et al., 2001).

Reported fuel savings are 0.1 GJ/tonne (de Beer et al., 2001). 0.434% is the reduction efficiency calculated from the underlying data; therefore, the reduction potential comes to 0.035%.

Applicability: IND_25 reduces pyrogenic CO_2 emissions with a share of 35.4% and could be adopted in the clinker production with an energy consumption of 86.9%.

Implementation: De Beer declares that there was a technical penetration of 50% in 1990 and they assume 100% for 2010 (de Beer et al., 2001). We use this estimation, although we are aware that the situation within the EU and in Austria is not equal.

Costs: Investment costs were estimated at € 2/GJ saved annually (de Beer et al., 2001).

IND_26: Application of multi-stage preheaters and precalciners; (de Beer et al., 2001)

"An existing preheater kiln may be converted to a multi-stage preheater precalciner kiln by adding a precalciner and, when possible an extra cyclone.[…] For new plants the specific fuel consumption can be lowered; this is not automatically the case in retrofit situations." (de Beer et al. , 2001

The estimated savings on energy use given in de Beer's report are from 3.56 to 3.19 GJ/tonne product. The reduction efficiency results in 3.77% and the reduction potential is 0.05%.

Applicability: IND_26 reduces pyrogenic CO_2 emissions with a share of 35.4% and could be adopted in the clinker production with an energy consumption of 86.9%.

Implementation: The full potential is not tapped at the moment in Austria (Wiesenberger, 2006, personal information). Whereas de Beer published: "Since this measure can only be applied to new plants, we assume only a small future penetration of 5% up to 2010." (de Beer et al., 2001), regarding that we estimated the implementation in Austria at 95%.

Costs: Average Costs were assumed to be € 18.5/tonne clinker or € 46/GJ saved annually, O & M costs decrease by € 2.5/GJ saved annually (de Beer et al., 2001).

IND_68: Alternative binder to replace concrete – Slagstar® (Wopfinger, 2007)

Similar to IND_22: "Reduce clinker content of cement" this measure allows to replace clinker by blast furnace slag. It has been proven that an alternate binder without any clinker is able to fully replace cement (Schmid, personal information). Since clinker production is not only the most energy intensive process in cement production, but also responsible for release of process CO_2, this measure is expected to reduce emissions considerably.

The applicability of this measure is defined by the fraction of energy consumption in clinker production to total cement production, about 86.9%.

Implementation: The cement industry utilise slag already entirely in Austria (Wiesenberger, 2006, personal information), thus no further use of this measure is possible.

Interaction: This measure depends on availability of slag in the Austrian iron and steel industry, because import is not a feasible option. The quality standard in Austria, “Ö-Norm”, restricts the possible spectrum of this measure.

The data for applicability, implementation, reduction potential, costs and interaction of measures discussed in this chapter are summarized in the following table.

Table 19: Applicability, implementation, reduction potential as a fraction of the entity emissions, costs and interactions of measures in cement and lime production

TECH ID	Applicability	Imple-mentation	Reduction Potential [%]	Costs [€/GJ]	Interactions
IND_19	1.000	-	-	-	Sector: “Soils and Landfill”, Entity: Pulp and Paper
IND_20	0.046	-	0.043	35	-
IND_22	0.561	1.000	0.000	0	Entity: Iron and Steel
IND_23	0.308	0.970	0.148	75	-
IND_24	0.308	0.9	1.063	0.5	Sector “Soils and Landfill”
IND_25	0.308	0.700	0.040	2	-
IND_26	0.308	0.950	0.058	48.5	-
IND_68	0.869	1.000	0	-	Entity: Iron and Steel

3.3.4 Iron and Steel Production

The CO_2 emissions of iron and steel industry are half from fuels and half from the used reducing agent, which is coke in general. The measures available are on the one hand measures to increase the energy efficiency and on the other hand alternative processes to reduce or avoid the usage of coke. For all calculations we assume that the energy carrier is coal in the case of iron and steel industry, according to WIFO data (Kratena & Wüger, 2005).

Applicability in Iron and Steel Production:

Applicability is derived as described in section “Applicability in pulp and paper production”. Results for iron and steel production are listed below.

Processes: (CO_2 emissions) (UNFCCC, 2006)

- Pyrogenic CO_2: 55.8%
- Pig iron: 37.5%
- Steel: 6.4%
- Electric Steel: 0.3%

Austrian plants (production data) (UNFCCC, 2006)

- Pig iron production: 75.5%
- Steel production: 90.5%
- Electric steel production: 9.5%

IND_32: Alternative process – COREX® (Gara, 1993), (VAI, 2001a, 2001b)

"COREX® is a revolutionary smelting-reduction process developed by VAI Group which allows for the production of hot metal in blast furnace quality without the need for coking plants. All metallurgical work carried out in two separate process reactors - the reduction shaft and the melter gasifier." (VAI, 2001).

A reduction of the heat demand of 3.0 GJ/tonne product has been estimated by Gara (1993). Therefore, the reduction efficiency is 15.89% and the reduction potential is 11.16%.

Applicability: IND_32 reduces pyrogenic CO_2 emissions with a share of 55.8%, process CO_2 emissions with 37.5% and could be adopted in pig iron production with a share of 75.5%.

Implementation: Blast furnaces were recently expanded in Austria's plants and the operating period in this sector is about 30 years. As a consequence such alternative processes as COREX® or MITREX® or FINMET® can not be implemented in Austria before 2030 or 2040 without significant incurring of stranded costs due to investments taken.

Interaction: Coking plants would not be needed, if COREX® was implemented. Coking plants are allocated in the sector "Energy" in this project.

IND_33: Application of continuous casting (de Beer et al., 2001)

Continuous casting is far less energy intensive than ingot casting. According to de Beer ingot casting requires about 1.5 - 3.0 GJ/tonne steel in addition (2001).

The estimated savings on heat demand given in de Beer are 1.5 - 3.0 GJ/tonne product (2001).The calculated reduction efficiency is 11.92% and the reduction potential results in 0.02%.

Applicability: IND_33 reduces process CO_2 emissions in steel production. Steel production demands a share of 6.4% of energy in iron and steel industry. IND_33 could be adopted in steel production with a production share of 90.5% in iron and steel production.

Implementation: In de Beer it is assumed that in 1998 the penetration was world wide 83.3%, in Europe even higher and in Austria at 97% (de Beer et al., 2001).

Costs: “Investment costs are € 69/tonne cast steel (€ 31/GJ saved annually). Operation costs can be reduced significantly compared to ingot casting: -€ 31/tonne cast steel (- € 14/GJ saved annually).

Interaction: This measure competes with IND_44: thin slab casting, albeit continuous casting is the more mature technology.

IND_34: Injection of pulverised coal and plastics waste in blast furnaces (plastic waste as reducing agent instead of coal) (de Beer et al., 2001)

“Coal injections result in energy savings at coke making.” (de Beer et al., 2001).

The resulting saving of this measure given by de Beer is on average 3.5 GJ/t product. The reduction efficiency resulting from this accounts for 2.65% and the reduction potential comes to 1.04%.

Applicability: IND_34 reduces pyrogenic CO_2 emissions with a share of 55.8% of iron and steel industry as well as process CO_2 emissions with 37.5% and could be adopted in pig iron production with a production share of 75.5% in iron and steel production.

Implementation: In 1990 the injection rate in Austria was at 9%, the maximal penetration is estimated at about 75% (de Beer et al., 2001).

Costs: For coal grinding equipment costs are estimated at € 50 - 55/tonne coal injected and € 10 - 11/GJ saved annually (de Beer et al., 2001).

Interaction: Coal injection results in energy savings at coke making, whereas there is no coke production needed during the COREX process (IND_32).

IND_36: End of pipe: CO_2 separation

Measures are being discussed that would allow collecting CO_2 from the flux gas of blast furnaces. The CO_2 recovered then would be injected into geological storage. At this stage no further information is available. The measure remains here as a placeholder.

IND_38: Efficient recovery of low-temperature heat (de Beer et al., 2001)

In this category, options like coke dry quenching, heat recovery from hot stove waste gas, heat recovery from blast furnace slag, recuperative burners at the reheating furnace, heat recovery from sinter cooler air, blast furnace dry cleaning top gas recovery and suppressed combustion of basic oxygen furnace gas are aggregated (de Beer et al., 2001).

In de Beer’s report it is estimated that the total saving of low-temperature heat recovery is at 0.5 - 1.0 GJ/tonne crude steel. The reduction efficiency resulting from this comes to 2.39% and the reduction potential is 1.98%. Because IND_38 deals with low temperature processes, we suppose that gas is the reduced energy carrier instead of coal as usually used in the calculations for iron and steel industry.

Applicability: IND_38 reduces pyrogenic CO_2 emissions with a share of 55.8% and process CO_2 emissions with 37.5% in iron and steel industry and could be adopted in pig iron production with a production share of 75.5% in iron and steel production.

Implementation: “Implementation is very site specific and is estimated at 50% at maximum (de Beer et al., 2001).

Costs: Investment costs are set at € 70/tonne steel, € 93/GJ saved annually (de Beer et al., 2001).

Interaction: This measure results in energy improvements in coke production and consequently competes with the COREX® process.

IND_39: Heat recovery from sinter cooler air (de Beer et al., 2001)

“The recovered heat can be used to preheat raw material or combustion air or to produce steam” (de Beer et al., 2001) which results in energy savings.

Estimations of the reduction efficiency underlie the following data: 0.55 GJ/tonne sinter (de Beer et al., 2001). Thus, the reduction efficiency is 2.043% and the reduction potential comes to 0.14%. According to IND_38, we suppose that gas is the reduced energy carrier instead of coal as usually used in the calculations for iron and steel industry.

Applicability: IND_39 reduces pyrogenic CO_2 emissions with a share of 55.8%, process CO_2 emissions with 37.5% in iron and steel industry and could be adopted in pig iron production with a production share of 75.5% in Austria’s iron and steel production.

IND_40: Recovery from energy in process gases from the blast furnace and the basic oxygen furnace (de Beer et al., 2001)

Process gas contains energy in form of heat, chemicals and pressure. Various options to save these forms of energy are given in de Beer.

Recovery from energy in process gases can be expected to save 0.9 - 1.4 GJ/tonne liquid steel. Hence, the reduction efficiency accounts for 6.09% and the reduction potential results in 4.28%.

Applicability: IND_40 reduces pyrogenic CO_2 emissions with a share of 55.8%, process CO_2 emissions with 37.5% in iron and steel industry and could be adopted in pig iron production with a production share of 75.5%.

Implementation: This measure is to a large extent implemented in Austria (Wiesenberger, 2006, personal information). Thus, we estimated the implementation at 90%.

The investment costs of the measure with the largest saving is € 2/t steel and € 9/GJ saved annually, O & M costs are estimated at 10% of the investment costs.

Interaction: This measure results in energy improvements in coke production and consequently competes with the COREX® process.

IND_41: Scrap preheating in electric arc furnaces (de Beer et al., 2001)

“Preheating of the scrap before being charged into the furnace by use of the hot off-gases of the furnace is a way to save on the power demand for melting.” (de Beer et al., 2001).

The total amount of energy that can be recovered is 80 kWh/tonne liquid steel. The reduction efficiency is 2.76% and the reduction potential is reduced because of the small contribution of electric steel production in Austria.

Applicability: IND_41 reduces process CO_2 emissions from electric steel production with a share of 0.3%, and could adopt in electric steel production with a production share of 9.5%.

Costs: Extra investment costs are estimated at € 4.5 – 5.5/tonne liquid steel or € 50/GJ saved annually. The annual costs savings due to increasing productivity reduced electrode costs and increased yield: € 1.9/tonne liquid steel (€ 19/GJ saved annually) (de Beer et al., 2001).

IND_42: Oxygen and fuel injection in the electric arc furnaces (de Beer et al., 2001)

“Injection of oxygen and fuel can improve the energy efficiency of an electric arc furnace in the following ways: post combustion […], foamy slag practice […] and oxy-fuel burners.” (de Beer et al., 2001).

Saving of about 50 kWh/tonne liquid steel can be achieved (de Beer et al., 2001). Thus, the reduction efficiency is 2.54% and due to the small share of electric steel production in iron and steel industry the reduction potential results in 0.00074%.

Applicability: IND_42 reduces process CO_2 emissions from electric steel production with a share of 0.3%, and could be adopted in electric steel production with a production share of 9.5% in Austria.

Implementation: Penetration in 1990 was 60% in all EU member states, a maximum of 80% is feasible (de Beer et al., 2001).

Costs: Investment costs are evaluated at € 3.5/tonne liquid steel or € 70/GJ saved annually, O & M costs are -€ 25/tonne liquid steel or -€ 5/GJ saved annually (de Beer et al., 2001).

IND_43: Improved process control in mini mills (de Beer et al., 2001)

“Artificial intelligence techniques, e.g. fuzzy logic or neural networks, can be applied to optimize the energy input” (de Beer et a., 2001) and therefore, lead to savings in electricity.

In line with de Beer, we assume that savings of 30 kWh/t crude steel are possible on average (2001). Reduction efficiency comes to 1.43% and reduction potential is 0.4%.

Applicability: IND_43 reduces process CO_2 emissions from processing pig iron with 37.5% and could adopt in pig iron production with a production share of 75.5%.

Implementation: According to de Beer a zero penetration is assumed in 1990 (de Beer et al., 2001).

Costs: Capital costs are € 0.95/t steel or € 9/ GJ saved annually (de Beer et al., 2001).

IND_44: Thin slab casting (de Beer et al., 2001)

According to de Beer thin slab casting allows casting of thinner slabs than with continuous casting and consequently less energy is required to reheat the slabs before rolling (2001). The savings assumed by de Beer amount to 1.5 GJ of fuel and 0.15 GJ of electricity per tonne steel (de Beer et al., 2001). The reduction efficiency is 6.854% and the reduction potential reaches the total of 0.4% including applicability and implementation.

Applicability: IND_44 reduces process CO_2 emissions from processing steel with 6.4% and could be adopted in steel production with a production share of 90.5%.

Implementation: The penetration is estimated at a maximum of 7% of crude steel production in 2010 (de Beer et al., 2001). Average reductions in O & M costs at € 0.1/GJ saved annually are assumed in the same study (de Beer et al., 2001).

Interaction: Measure IND_44 competes with IND_33: continuous casting.

IND_45a: Miscellaneous measures: low cost range (de Beer et al., 2001)

IND_45a is a set of measures to be taken in iron and steel industry to reduce the energy demand. The distinction here was made along costs. IND_45a includes measures at less than € 25/GJ. "The fuel savings in the low cost range (average costs € 15/GJ saved annually) total to 1.0 GJ/tonne steel and the electricity savings to 0.1 GJ/tonne steel." (de Beer et al., 2001). 6.62% is the reduction efficiency calculated from the underlying data; therefore, the reduction potential is 3.7%.

Applicability: IND_45a reduces pyrogenic CO_2 emissions with 55.8% and could be adopted all over iron and steel industry.

Costs: Measures in IND_45a cost less than € 25 /GJ saved annually which is on average € 15/GJ (de Beer et al., 2001).

IND_45b: Miscellaneous measures: high cost rage (de Beer et al., 2001)

Grouped according to their investment costs, this set of measures is meant to represent more costly energy savings. "In the high cost range (average costs € 50/GJ saved annually) the potential saving on electricity demand is 0.05 GJ/t steel. The saving on fuel demand in this range amounts to 1.0 GJ/tonne steel." (de Beer et al., 2001). The reduction efficiency starting from that data results in 6.04% and the reduction potential comes to 3.37%.

Applicability: IND_45b reduces pyrogenic CO_2 emissions with 55.8% and could be adopted all over iron and steel industry.

Costs: Measures in IND_45b cost more than € 25 /GJ saved annually, on average € 50/GJ saved annually (de Beer et al., 2001).

The data for applicability, implementation, reduction potential, costs and interaction of measures discussed in this chapter are summarized in the following table.

Table 20: Applicability, implementation, reduction potential as a fraction of the entity emissions, costs and interactions of measures in iron and steel industry

TECH ID	Applicability	Imple-mentation	Reduction Potential [%]	Costs [€/GJ]	Interactions
IND_32	0.702	0	11.159		Sector: “Energy”, IND_34, IND_38, IND_40
IND_33	0.058	0.970	0.021	14	IND_44
IND_34	0.702	0.440	1.042	10	IND_32
IND_36	0.058	-	0.046	-	Sector “Energy”
IND_38	0.702	0.500	1.681	93	IND_32
IND_39	0.702	-	0.143	-	-
IND_40	0.702	0.900	4.278	9	IND_32
IND_41	0.0003	-	0.0002	19	-
IND_46	0.0003	0.800	0.0007	65	-
IND_43	0.283	0	0.405	9	
IND_44	0.058	-	0.397	48	IND_33
IND_45a	0.558	-	3.695	15	-
IND_45b	0.558	-	3.370	50	-

The measures specified in the following sections have so far not been quantified.

3.3.5 Fertilizer Production

– N_2O SCR technology (nitric acid)

3.3.6 Further Measures

– Fuel switch
– Increase heat efficiency
– Power heat coupling in industrial plant

4 Agriculture

4.1 Introduction/ Scenario-development basics

In 2002, agriculture had a share of 8 % of the total national GHG emissions in Austria. 42 % of agricultural GHG emissions came from enteric fermentation, 36 % from agricultural soils (Umweltbundesamt, 2005). 51 % of Austrian CH_4 emissions, and 61 % of N_2O emissions result from agricultural activities. Agricultural GHG emissions are composed of 46 % CH_4, and 54 % N_2O (Umweltbundesamt, 2005).

N_2O and CH_4 formation

Agricultural emissions of N_2O and CH_4 are influenced by a multitude of different factors. Complex interactions exist between different emitting sources (Duxbury, 1994; Jarvis and Pain, 1994; Kaiser et al., 1996). The control of the emission of one compound might enhance the emission of another compound or of the same compound but at another stage of management. This requires a whole system approach when proposing mitigation measures.

Microbiology of N_2O formation is fairly well understood and described in the work by e.g. Hutchinson and Davidson (1993), Beese (1994), Bronson and Mosier (1993), Hellmann (1993), Papke-Rothkamp 1994), Simarmata (1993) and Haider & Heinemeyer (1990). N_2O and NO are formed during nitrification and denitrification. Firestone and Davidson (1989) developed the “hole in the pipe model”. According to their findings, NO and N_2O leak during nitrification of ammonium to nitrate and during denitrification of nitrate to N_2.

Nitrification is a strictly aerobic process mainly carried out by autotrophic micro-organisms (nitrosomonas, nitrospira, nitrobacter). The intensity of nitrification is mainly governed by ammonium availability. Optimum temperatures for nitrification lie between 30 and 35 °C. No nitrification can be observed below 5 °C. N_2O-N emissions are estimated to be below 1 % of nitrified ammonium.

Denitrification is an anaerobic process where nitrate is reduced to N_2 via NO and N_2O. NO and N_2O are emitted if denitrification is incomplete. NO_3^-, NO and N_2O act as electron acceptors when oxygen is lacking. Denitrification is a function of oxygen supply, carbon availability, temperature, pH, water content and concentration of NO_3^-, NO and N_2O. Denitrification needs an oxygen concentration below 5 vol. %. High concentration of available organic carbon, pH between 6 and 8, temperature above 10 °C and volumetric water content of more than 80 % support denitrification. Denitrifying micro-organisms are facultative anaerobe and heterotroph. They comprise a wide variety of species and are wide spread. Complex interactions exist between the influences on the degree of denitrification and it is difficult to predict, which influence will be dominant under real life conditions. Measurements reveal considerable variability in N_2O emissions from agricultural sources and emission estimates comprise a considerable range of uncertainty. E.g. Brumme and Beese (1992) found daily variations in N_2O emissions of 10 – 100 % and Bronson and Mosier (1993) measured spatial variations of 30 – 270 %.

Estimations of N_2O emissions from manure management are based on the assumption that a certain percentage of N excreted by domestic livestock is released as N_2O during manure storage. The emission of N_2O during storage depends on the nitrogen and carbon content of manure, on the duration of the storage and on the type of treatment. There are large uncertainties associated with the default emission factors. Accurate and well-designed emission measurements can help to reduce these uncertainties (IPCC, 2001).

Fundamentals of methane formation have been intensively researched and explained e.g. by Knowles (1993), Heyer (1994), Schimel et al. (1993), Sedmidubsky (1992), Heyer (1990), Hauer (1993), Enquete-Kommission (1994) and Hellman (1995). Methane formation is a strictly anaerobic process and is the final step of anaerobic degradation of organic matter. Intensity of methane formation increases with temperature.

Methane emissions from enteric fermentation depend on the composition and amount of feed, on the animal weight and on the milk yield. Intensive research has been carried out and regression equations derived that estimate methane formation during enteric fermentation (e.g. Kirchgessner et al. 1991, 1993).

Estimations of CH_4 emissions from manure management are based on the assumption that manure has a specific maximum methane producing capacity (Casada and Safley, 1990; Umweltbundesamt, 1993; Steed and Hashimoto, 1995). The maximum methane producing capacity is called ''B_0'' and has been investigated by incubation of manure in laboratory experiments. B_0 values are taken from a study by Safley et al. (1992). This study summarises several B_0 values from different experiments, which show considerable variability. This means that IPCC default B_0 values include a range of uncertainty.

Starting from B_0 values, CH_4 produced from manure stores is estimated with the help of ''methane conversion factors (MCF)''. MCF give the percentage of the maximum methane producing capacity (B_0) that is formed and released from manure stores. Methane conversion factors are based on expert judgement, not on experimental research. Default MCF values are provided by IPCC/OECD (1997) for different manure management systems and climate zones. These default values may not, however, encompass the potentially wide variation within the defined categories of management systems. Therefore, IPCC (2001) encourages countries to develop country-specific MCFs that reflect their specific management systems. Field measurements should be conducted to replace the laboratory based default MCF values.

Mitigation of agricultural greenhouse gas emissions

Countries must meet reduction targets to meet international requirements on reduction of greenhouse gases (GHGs) as well as ammonia (NH_3), which is considered an air pollutant, by applying efficient and cost effective mitigation measures. The agricultural part of reclip:tom assessed emissions, trends, mitigation options and their effects and costs.

To come up with a baseline scenario we used the following literature:

- IPCC/OECD 1997. Revised 1996 IPCC guidelines for national greenhouse gas inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm
- CAFE national scenario: RAINS online: http://www.iiasa.ac.at/web-apps/apd/RainsWeb/ alternatively GAINS online: http://gains.iiasa.ac.at/
- Amon, B., Hopfner-Sixt K., Amon, T. (2002) Emission Inventory for the Agricultural Sector in Austria, Manure Management. Final Report. On behalf of Umweltbundesamt GmbH, Institut für Land-, Umwelt- und Energietechnik
- Gebetsroither, E., Strebl, F., Orthofer, R. (2002). CH_4 Emissions from Enteric Fermentation in Austria, ARC—S-175, ARC Seibersdorf research GmbH.

The CAFE national programme provides an estimation of livestock numbers in 2020. CAFE (Clean Air For Europe) is a programme of the European Commission, which was installed in the course of the 6^{th} environmental action plan (European Commission, 2001a; 2001b). CAFE has the general aim of developing a long-term, strategic and integrated policy to protect against the effects of air pollution on human health and the environment. As required by the Treaty, policy will aim at a high level of environmental protection based on the precautionary principle, taking account of the best available scientific and technical data and the costs of benefits of action or lack of action.

Under the CAFE programme, different scenarios for the future development of livestock numbers have been created. The "CAFE baseline scenario" gives the expected evolution in EU-25 pollutant emissions up to 2020 assuming that current legislation to reduce air pollution is implemented. The baseline – or "Business-as-usual" or "Current Legislation" – is based upon forecasts of economic growth and changes in energy production, transport and other polluting activities (European Commission, 2005). The CAFE national scenario includes national projections of activity data up to 2030. Livestock numbers for the reclip:tom database for 2050 were extrapolated from the CAFE national scenario trend between 2020 and 2030.

The RAINS model has been chosen by the European Community for providing the scientific and technical basis for the CAFE integrated policy advice. It has been developed at IIASA (International Institute for Applied Systems Analysis) and combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion and environmental sensitivities towards air pollution (Schöpp et al., 1999)

Agricultural activities considered in the RAINS model include two major categories, i.e., livestock production and application of mineral N fertilizers. Projections of animal numbers are based on results of a number of European and global models. Historical data for livestock production and application of mineral N fertilizers from 1990 to 2000 originate from international statistics, national submissions to the NEC Directive and to the UNECE LRTAP Convention as well as discussions with national experts during the consultations carried out within the CAFE program (Klimont and Brink, 2004). With the online version of the RAINS model (http://www.iiasa.ac.at/web-apps/apd/RainsWeb/) it is possible to explore the environmental impacts of alternative emission control strategies and their economic implications for the various economic sectors in the 43 European countries. The RAINS model follows, for a given pathway of economic development, air pollutants from their sources (energy combustion, industrial production, agriculture) over their transformation and transport in the atmosphere to their impacts on human health and ecosystems.

For the agricultural sector, the RAINS model covers modules to describe emissions and emission control costs for ammonia (NH_3), sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and particulate matter (PM). Greenhouse gases are not included in the RAINS model. Further information about RAINS can be found at http://www.iiasa.ac.at/rains/.

The GAINS (GHG-Air pollution Interaction and Synergies)[8] model was developed as an extension of RAINS and will allow the assessment of emission control costs for the six greenhouse gases covered under the Kyoto Protocol (CO_2, CH_4, N_2O and the three F-gases) together with the emissions of air pollutants SO_2, NO_x, VOC, NH_3 and PM.

The "Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories" (IPCC, 1997) require emissions from the following categories to be quantified:

– CH_4 emissions from enteric fermentation,
– CH_4 and N_2O emissions from manure management,
– Direct N_2O emissions from agricultural soils, and
– Indirect N_2O emissions from N use in agriculture.

8 http://gains.iiasa.ac.at/ - scenario used is NEC_NAT_CLEV4

The Austrian emission inventory estimates include the animal categories “cattle” (dairy cows > 2 years, mother, and suckling cows > 2 years, young cattle < 1 year, young cattle 1 – 2 years, cattle > 2 years), “swine” (fattening pigs > 50 kg, swine for breeding > 50 kg, young pigs < 50 kg), “sheep and goats”, and “poultry” (chicken, other poultry).

The category soils is split into direct and indirect emissions from soils: Direct emissions are broken down in the categories: N from fertilizer, N from N-fixation, N from crop residues, N from sewage sludge, N from grazing and N from animal manure. Indirect emissions are broken down in indirect emissions from animal manure and indirect emissions from fertilizer and indirect emissions from leaching.

4.2 Entities, Activities and Emissions

4.2.1 Entities

Agricultural activities contribute to emissions of greenhouse gases through a variety of processes. Entities in the sector agriculture have been calculated from:

– CH_4 emissions from enteric fermentation
– CH_4 emissions from manure management
– N_2O emissions from manure management
– Direct N_2O emissions from agricultural soils
– Indirect N_2O emissions from N use in agriculture

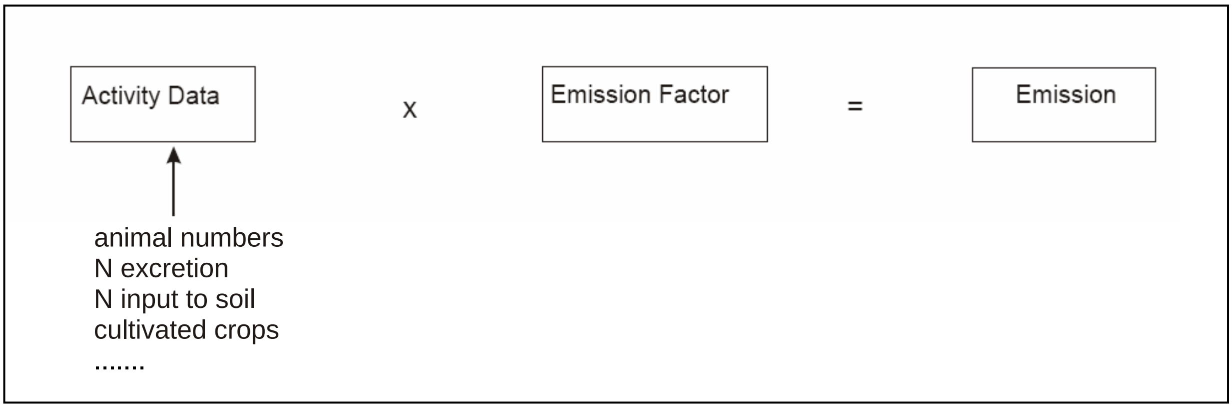

Figure 37: Estimation of emissions

Emissions are estimated by multiplying activity data with emission factors (Figure 37). Compiling the national inventory therefore comprises two main steps: Assessment of national activity data and assessment of emission factors – either default or country specific emission factors.

Table 21 provides an overview of entities used for agriculture in the reclip:tom database.

Table 21: Agricultural entities of the reclip:tom database

Activity type	Process causing emissions
Dairy cattle	CH_4 enteric fermentation
solid	CH_4 manure management
liquid	CH_4 manure management
solid	N_2O manure management
liquid	N_2O manure management
Suckling cows	CH_4 enteric fermentation
solid	CH_4 manure management
liquid	CH_4 manure management
solid	N_2O manure management
liquid	N_2O manure management
Cattle > 1 year	CH_4 enteric fermentation
solid	CH_4 manure management
liquid	CH_4 manure management
solid	N_2O manure management
liquid	N_2O manure management
Cattle 1 – 2 years	CH_4 enteric fermentation
solid	CH_4 manure management
liquid	CH_4 manure management
solid	N_2O manure management
liquid	N_2O manure management
Cattle >2 years	CH_4 enteric fermentation
solid	CH_4 manure management
liquid	CH_4 manure management
solid	N_2O manure management
liquid	N_2O manure management
Breeding sows	CH_4 enteric fermentation
solid	CH_4 manure management
liquid	CH_4 manure management
solid	N_2O manure management
liquid	N_2O manure management
Fattening pigs	CH_4 enteric fermentation
solid	CH_4 manure management
liquid	CH_4 manure management
solid	N_2O manure management
liquid	N_2O manure management
Sheep	CH_4 enteric fermentation
	CH_4 manure management
	N_2O manure management
Goats	CH_4 enteric fermentation
	CH_4 manure management
	N_2O manure management
Soliped	CH_4 enteric fermentation
	CH_4 manure management
	N_2O manure management
Poultry	CH_4 enteric fermentation
	CH_4 manure management
	N_2O manure management
Soils	N fertilizer
Direct emissions	N animal manure
	N fixation
	N grazing
	N crop residues
	N sewage sludge
Indirect emissions	N fertilizer (Atmospheric deposition)
	N animal manure (Atmospheric deposition)
	N Leaching

4.2.2 Livestock numbers

Since 1990, a general reduction in livestock numbers was observed in Europe as a reaction to the common agricultural policy (CAP) (European Commission, 2000).

Basic livestock population characterisation is needed for the estimation of GHG emissions from the Agricultural Sector and for proposing mitigation measures. Livestock population characterisation comprises information on livestock species and categories, annual population, milk production, and climate. It is of vital importance to use a consistent livestock characterisation across all categories of animal-related emission sources. For the reclip:tom data base, livestock numbers for the year 2000 were taken from “Methane Emissions from Enteric Fermentation in Austria” (Gebetsroither et al. 2002, Table 4)

A comparison of animal population data given in “Methane Emissions from Enteric Fermentation in Austria” (Gebetsroither et al., 2002) and in the “CAFE national scenario” shows a consistency of the data. Slight differences can be explained through rounding errors (Tables 2 and 3). For consistency reasons, livestock classification for reclip:tom was adopted from Gebetsroither et al. (2002).

Table 22 provides livestock numbers for 2000 (Gebetsroither et al., 2002) and 2020 (CAFE national scenario). CAFE differentiates less livestock categories than required by the IPCC 1996 guidelines (IPCC/OECD 1997). Gebetsroither et al. (2002) differentiate more livestock categories. In order to meet IPCC requirements, CAFE numbers were broken down into more livestock categories assuming the percentage contribution of each sub-category to be the same as presented by Gebetsroither et al. (2002).

Table 22: Livestock numbers in 2000 (Gebetsroither et al. 2002) and in 2020 (CAFE national scenario assuming the percentage contribution of livestock sub-categories as given by Gebetsroither et al. 2002)

		2000	2020
	(%)	Number of animals (head)	Number of animals (head)
Pigs	**100.0**	**3,347,931**	**4,119,000**
breeding sows	10.0	334,278	411,900
fattening pigs	36.2	1,211,988	1,491,078
young pigs	53.8	1,801,665	2,216,022
Dairy cattle	**100.0**	**621,002**	**487,000**
Other cattle	**100.0**	**1,534,445**	**1,360,000**
suckling cows	16.5	252,792	224,400
cattle < 1 yr	42.7	655,368	580,720
cattle 1 - 2 yr	30.4	466,484	413,440
cattle > 2 yr	10.4	159,801	141,440

Table 23: Livestock numbers in 2000 and in 2020 (CAFE national scenario)

	2000	2020
	Number of animals (head)	Number of animals (head)
Pigs	3,348,000	4,119,000
Dairy Cattle	621,000	487,000
Other cattle	1,535,000	1,360,000
Poultry	11,894,000	15,875,000
Laying hens	5,141,000	6,239,000
Other poultry	6,753,000	9,636,000
Sheep	395,000	389,000

Table 24: Livestock numbers of the reclip:tom database for the years 2000, 2020 und 2050

	2000	2020	2050
	Number of animals [head]	Number of animals [head]	Number of animals [head]
Dairy cattle*	621,002	569,000	569,000
Other cattle	1,534,445	1,360,000	1,360,000
suckling cows	252,792	224,400	224,400
cattle < 1 year	655,368	580,720	580,720
cattle 1 – 2 years	466,484	413,440	413,440
non dairy cattle > 2 years	159,801	141,440	141,440
Swine	3,347,931	4,119,000	4,110,000
Breeding sows	334,278	411,900	411,000
Fattening pigs	1,211,988	1,491,078	1,487,820
Sheep	339,238	333,762	326,040
Goats	56,105	55,238	53,960
Soliped	83,000	83,000	83,000
Poultry	11,786,670	15,875,000	17,090,000

*) Figures for 2020 and 2050 extrapolated based on constant milk yield – see text

Table 24 provides livestock population data as fed into the reclip:tom database for the years 2000, 2020 and 2050. Data for the year 2000 were taken from Gebetsroither et al. (2002). Data for the year 2020 were taken from the CAFE national scenario. 2050 data result from an extrapolation of the trend in animal numbers from 2020 to 2030 as given in the CAFE national scenario.

The same table also shows a declining trend of cattle and dairy cattle number until 2020. The 2020 level is assumed to stabilize until 2050, as the CAFE national programme assumes a stabilization between 2020 and 2030 which was extrapolated to 2050 for reclip:tom. Pig and poultry numbers show a slight increase. Numbers of sheep, goats and soliped continue to decrease until 2020 and 2050. As the CAFE figure for dairy cows already considers an increased milk yield, which is taken care of here in the model, we corrected the number assuming constant (year 2000) milk yields. With increasing milk yields, as also implemented in the model, the actual numbers of cows will become smaller (487000 in 2020, and 460000 in 2050).

4.2.3 Nitrogen excretion

Methane emissions from enteric fermentation are estimated per animal. This means that these emissions can directly be quantified by multiplying animal numbers given in section 4.2.2 with the respective emission factor. N_2O emissions from manure management however require not only animal numbers, but in addition the amount of nitrogen excretion needs to be known. Excretion rates by animal category for Austria are presented in Table 25; the differentiation by year for dairy cattle reflects expectations on an increased metabolism connected with higher future milk yields (see below). N excretion rates were taken from the Austrian nitrogen excretion data as submitted under the Nitrates Directive[9].

Table 25: Austrian N excretion rates

animal category	N excretion [kg N per animal and year]
Dairy cattle 2000 (default milk yield)	89.39
suckling cows	69.50
Cattle < 1 yr	25.70
Cattle 1 – 2 yr	53.60
Cattle > 2 yr	68.40
Breeding sows	24.96
Fattening pigs	9.00
Sheep	0.19

Table 26 lists total N excretion per animal category for the years 2000, 2020 and 2050. Livestock numbers in 2000, 2020 and 2050 (see Table 24) were multiplied with the nitrogen excretion rates for the different livestock categories. Nitrogen excretion of piglets is considered in the N excretion rate of breeding sows, thus need not be calculated separately. N_2O emissions from manure management differentiate between emissions from solid systems and emissions from liquid systems, while N excreted during grazing needs no consideration for manure management emissions. Fractions of N excretion in solid and liquid systems was adopted from Amon et al. (2002) and compiled into this table (grazing emissions were omitted).

9 http://ec.europa.eu/environment/water/water-nitrates/directiv.html

Table 26: Nitrogen excretion for livestock categories and manure management systems for the years 2000, 2020 and 2050

	2000	2020	2050
dairy cattle solid system*	39,080,004	35,807,489	35,807,489
dairy cattle liquid system*	10,547,160	9,663,953	9,663,953
suckling cows solid system	12,368,607	10,979,443	10,979,443
suckling cows liquid system	3,338,118	2,963,202	2,963,202
cattle < 1 years solid system	12,000,607	10,633,709	10,633,709
cattle < 1 years liquid system	4,842,350	4,290,795	4,290,795
cattle 1 - 2 years solid system	15,452,189	13,695,117	13,695,117
cattle 1 - 2 years liquid system	3,000,425	2,659,246	2,659,246
cattle > 2 years solid system	5,312,169	4,701,805	4,701,805
cattle > 2 years liquid system	5,618,220	4,972,691	4,972,691
All cattle (excl. dairy cattle):			
cattle solid system	32,764,965	29,030,631	29,030,631
cattle liquid system	13,460,995	11,922,732	11,922,732
breeding sows solid system	2,918,247	3,595,887	3,588,030
breeding sows liquid system	6,809,243	8,390,403	8,372,070
fattening pigs solid system	3,507,857	4,315,627	4,306,197
fattening pigs liquid system	8,975,620	11,042,476	11,018,349
All pigs:			
pigs solid system	6,426,104	7,911,514	7,894,227
pigs liquid system	15,784,862	19,432,879	19,390,419
Sheep & Goats solid system	5,178,993	5,095,900	4,978,000
Soliped solid system	4,150,000	4,150,000	4,150,000
Poultry solid system	10,010,464	13,843,880	14,903,427

*) In analogy to animal numbers, data for 2020 and 2050 extrapolated based on constant milk yield and are adapted to expected milk yields in the model

In this context dairy cattle deserve closer attention. Nitrogen excretion of dairy cattle depends on the milk production per cow and year. The number of dairy cows is assumed to decline (see Table 24) which would result in a decline in nitrogen excretion. However, with the decrease in dairy cow numbers, the annual milk production per cow increases which partly counteracts the decrease in nitrogen excretion that would have been expected from the decreasing animal numbers.

Table 27 shows annual milk production per dairy cow and its development until 2050. For the years 2000 and 2020 data were taken from the GAINS model. Milk production in the year 2050 was extrapolated from the trend between 2015 and 2020. The corresponding nitrogen excretion was taken from the Austrian nitrogen excretion rates for 2000 and extrapolated using an increase rate of 14.5 kg N / ton milk yield as also used in GAINS. The increase in nitrogen excretion per cow is presented in Table 27.

Table 27: Trend of milk yield per cow and year and corresponding nitrogen excretion

	2000	2020	2050
milk yield [kg $cow^{-1}yr^{-1}$]	5,210	6,685	7,129
nitrogen excretion [kg cow^{-1} yr^{-1}]	89.39	110.78	117.22

4.2.4 Agricultural soils

For the calculation of emissions from soils we extrapolated data from CAFE national programme for direct emissions from fertilizer input, and N input from grazing and animal manure until 2050. For the sources N input through N fixation, crop residues and sewage sludge we used data from Umweltbundesamt (2006a). Table 28 shows the amount of nitrogen added to soil by the respective pathway.

Data was taken from Austria's national inventory report (Umweltbundesamt, 2006a) and CAFE national programme. Input of fertilizers and the extrapolation into the future was taken from the GAINS database. For estimating the extent of N fixation we used data from Umweltbundesamt (2005b). The years 2020 and 2050 were extrapolated through harvest data of N fixing crops: soy bean, horse bean, peas and clover from 1990 - 2005 The calculation method is based on the calculation method in Umweltbundesamt (2005b).

Table 28: Input of nitrogen to agricultural soils (Umweltbundesamt 2005, CAFE national)

Source	2000	2020	2050
	[kg N/yr]	[kg N/yr]	[kg N/yr]
N_fertilizer	118,000,000	117,800,000	124,100,000
N_fixation	19,035,000	22,941,000	28,641,000
N_crop residues	33,340,000	33,340,000	33,340,000
N_sewage sludge	1,686,000	1,686,000	1,686,000
N_grazing	23,602,000	21,484,000	21,948,000
N_animal manure	103,606,618	103,454,099	103,788,419

As mentioned before we extrapolated data for N input through fertilizers, N-fixation, grazing and animal manure. Data for the sources grazing and animal manure result of the development of livestock numbers given in section 4.2.2. Following the IPCC methodology on emission calculations, losses of N to the atmosphere (20% of N in animal manure) here have been subtracted already.

We expect a constant trend of application of sewage sludge and crop residues, because of the expected only slight increase of Austrian population (see Table 29).

Table 29: Development of population 2006 – 2050 in Austria

		population and age structure		
year	**total**	**up to 15 yr**	**15 to 60 yr**	**60 yr and more**
2006	8,281,948	1,303,907	5,161,048	1,816,993
2020	8,689,447	1,213,914	5,195,195	2,280,338
2050	9,514,363	1,257,884	5,000,405	3,256,074

4.2.5 Emission Factors

Methane and nitrous oxide emissions are estimated by multiplication of activity data with emission factors. Activity data may be livestock numbers or nitrogen excretion rates as given in section 4.2.2 and 4.2.3, respectively. In addition to methane and nitrous oxide emissions from livestock, direct N_2O emissions from agricultural soils and indirect N_2O emissions have to be included into the estimation of greenhouse gas emissions from agricultural activities. Table 30 shows activity categories included in the reclip:tom database with their corresponding emission factors and source of information.

Table 30: Emission factors for livestock categories and source of information.

Livestock Category	**Emission Factor**	**Source**
CH_4 emissions from enteric fermentation [kg CH_4 head^{-1}]		
Dairy Cattle	100	Amon et al. (2002) IPCC Guidelines: Methodology
Suckling cows	75	Amon et al. (2002) IPCC Guidelines: Methodology
Cattle < 1 year	33	Amon et al. (2002) IPCC Guidelines: Methodology
Cattle 1-2 years	66	Amon et al. (2002) IPCC Guidelines: Methodology
Cattle > 2 years	64	Amon et al. (2002) IPCC Guidelines: Methodology
Swine	1.5	IPCC Guidelines: default factor
Sheep	8	IPCC Guidelines: default factor
Goats	5	IPCC Guidelines: default factor
Soliped		IPCC Guidelines: default factor
CH_4 emissions manure management [kg CH_4 head^{-1}]		
Dairy Cattle	18.58	Amon et al. (2002) IPCC Guidelines: Methodology
Suckling cows	11.28	Amon et al. (2002) IPCC Guidelines: Methodology
Cattle < 1 year	4.79	Amon et al. (2002) IPCC Guidelines: Methodology
Cattle 1-2 years	4.98	Amon et al. (2002) IPCC Guidelines: Methodology
Cattle > 2 years	17.23	Amon et al. (2002) IPCC Guidelines: Methodology

Livestock Category	Emission Factor	Source
Breeding sows	24.96	Amon et al. (2002) IPCC Guidelines: Methodology
Fattening pigs	9	Amon et al. (2002) IPCC Guidelines: Methodology
Sheep	8	IPCC Guidelines: default factor
Goats	5	IPCC Guidelines: default factor
Soliped	1.39	IPCC Guidelines: default factor
Poultry	0.078	IPCC Guidelines: default factor
N_2O emissions from manure management [kg N_2O-N (kg N excr.)$^{-1}$]		
Dairy cattle liquid system	0.001	IPCC Guidelines: default factor
Dairy cattle solid system	0.02	IPCC Guidelines: default factor
Suckling cows liquid system	0.001	IPCC Guidelines: default factor
Suckling cows solid system	0.02	IPCC Guidelines: default factor
Cattle < 1 year liquid system	0.001	IPCC Guidelines: default factor
Cattle < 1 year solid system	0.02	IPCC Guidelines: default factor
Cattle 1-2 years liquid system	0.001	IPCC Guidelines: default factor
Cattle 1-2 years solid system	0.02	IPCC Guidelines: default factor
Cattle > 2 years liquid system	0.001	IPCC Guidelines: default factor
Cattle > 2 years solid system	0.02	IPCC Guidelines: default factor
Breeding sows liquid system	0.001	IPCC Guidelines: default factor
Breeding sows solid system	0.02	IPCC Guidelines: default factor
Fattening pigs liquid system	0.001	IPCC Guidelines: default factor
Fattening pigs solid system	0.02	IPCC Guidelines: default factor
Soliped	0.005	IPCC Guidelines: default factor
Direct N_2O emissions from agricultural soils [kg N_2O-N (kg N input)$^{-1}$]		
Fertilizer use	0.0125	IPCC Guidelines: default factor
N input from animal manures	0.0125	IPCC Guidelines: default factor
Biological N-fixation	0.0125	IPCC Guidelines: default factor
N from crop residues	0.0125	IPCC Guidelines: default factor
N from sewage sludge application	0.0125	IPCC Guidelines: default factor
N input from grazing	0.02	IPCC Guidelines: default factor

4.2.6 Emissions baseline

CH_4 emissions from enteric fermentation

Methane emissions from enteric fermentation of ruminant animals are estimated according to the “Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories” (IPCC, 1997). Methane emissions from enteric fermentation depend on:

– Livestock population
– Annual milk production of dairy cattle
– Feed intake, gross energy intake

Calculation is based on multiplication of livestock (Table 24) by corresponding emission factor given in Table 30. For the calculation of the emission factors, influencing factors have been considered.

Table 31 provides an overview of methane emissions from enteric fermentation in a business-as-usual scenario for the years 2000, 2020 and 2050.

Table 31: CH_4 emissions from enteric fermentation (business-as-usual scenario)

CH_4 emissions Enteric fermentation	**2000**	**2020**	**2050**
	[kg CH4]	[kg CH4]	[kg CH4]
Dairy cattle	62,100,200	48,723,470	45,997,960
Suckling cows	18,959,400	16,830,000	16,830,000
Cattle < 1 yr	21,627,144	19,163,760	19,163,760
Cattle 1 – 2 yr	30,787,944	27,287,040	27,287,040
Cattle > 2 yr	10,227,264	9,052,160	9,052,160
Breeding sows	501,417	617,850	616,500
Fattening pigs	1,817,982	2,236,617	2,231,730
Sheep	2,713,904	2,670,096	2,608,320

CH_4 emissions from manure management

Estimations of CH_4 emissions from manure management require the following input data:

– Livestock population
– Volatile solids excretion
– Maximum methane production potential (B0)
– Methane conversion factors (MCF)
– Manure management system distribution

Data on distribution of manure management systems in each livestock category are important for accurate emission estimates. There are considerable differences in emission factors between contrasting manure management systems. Manure management offers promising options for mitigation of greenhouse gas emissions.

Table 32 provides an overview of methane emissions from manure management in a business-as-usual scenario for the years 2000, 2020 and 2050

Table 32: CH_4 emissions from manure management (business-as-usual scenario).

CH_4 emissions Manure management	2000	2020	2050
	[kg CH_4]	[kg CH_4]	[kg CH_4]
Dairy cattle	11,538,217	9,639,443	9,284,832
Suckling cows	2,851,494	2,531,232	2,531,232
Cattle < 1 yr	3,139,213	2,781,649	2,781,649
Cattle 1 – 2 yr	2,323,090	2,058,931	2,058,931
Cattle > 2 yr	2,753,371	2,437,011	2,437,011
Breeding sows	8,343,579	10,281,024	10,258,560
Fattening pigs	10,907,892	13,419,702	13,390,380
Sheep	64,455	63,415	61,948
Goats	6,733	6,629	6,475
Soliped	115,370	115,370	115,370
Poultry	919,360	1,238,250	1,333,020

N_2O emissions from manure management

Estimations of N_2O emissions from manure management require the following input data:

- Livestock population
- Nitrogen excretion
- N_2O emission factors
- Manure management system distribution

All emissions of N_2O taking place before the manure is added to soils are to be reported under "Manure Management". Estimations of N_2O emissions from manure management are based on the assumption that a certain percentage of N excreted by domestic livestock is released as N_2O during manure storage. The emission of N_2O during storage depends on the nitrogen and carbon content of manure, on the duration of the storage and on the type of treatment. Table 33 gives an overview of N_2O emissions in a business-as-usual scenario scenario.

Table 33: N_2O-N emissions from manure management (business-as-usual scenario).

N_2O-N emissions Manure management	2000	2020	2050
	[kg N2O-N]	[kg N2O-N]	[kg N2O-N]
Dairy cattle solid	781,600	651,934	631,016
Dairy cattle liquid	10,547	8,797	8,515
Suckling cows solid	247,372	219,589	219,589
Suckling cows liquid	3,338	2,963	2,963
Cattle < 1 y solid	240,012	212,674	212,674

N_2O-N emissions Manure management	2000	2020	2050
Cattle < 1 y liquid	4,842	4,291	4,291
Cattle 1 - 2 solid	309,044	273,902	273,902
Cattle 1 – 2 liquid	3,000	2,659	2,659
Cattle > 2 solid	106,243	94,036	94,036
Cattle > 2 liquid	5,618	4,973	4,973
Breeding sows solid	58,365	71,918	71,761
Breeding sows liquid	6,809	8,390	8,372
Fattening pigs solid	70,157	86,313	86,124
Fattening pigs liquid	8,976	11,042	11,018
Sheep&Goats	5,179	5,096	4,978
Soliped	20,750	20,750	20,750
Poultry	10,010	13,844	14,903

Direct N_2O emissions from agricultural soils

Estimations of direct N_2O emissions from agricultural soils require the following input data:

- Plant production
- Fertilizer use
- N input from manure
- N from grazing animals
- Biological N fixation
- N from crop residues
- N from sewage sludge application

The IPCC method for calculating direct N_2O emissions from soils is based on the assumption that 1.25 % of all nitrogen inputs to agricultural soils are emitted in the form of N_2O-N. Total direct N_2O emissions are estimated with the emission factor of 1.25 % irrespective on type of soils, land use, vegetation, nitrogen compounds, and climatic conditions. Table 34 gives an overview of direct emissions from soils in a business-as-usual scenario.

Table 34: Direct N_2O-N emissions from soils (business-as-usual scenario).

N_2O-N emissions	2000	2020	2050
	[kg N_2O-N]	[kg N_2O-N]	[kg N_2O-N]
N_fertilizer	1,475,000	1,472,500	1,551,250
N_fixation	237,937	286,769	358,007
N_crop residues	416,750	416,750	416,750
N_sewage sludge	21,075	21,075	21,075
N_grazing	472,040	429,680	438,960
N_animal manure	1,871,421	1,812,611	1,842,036

Indirect N_2O emissions from N use in agriculture

Estimations of direct N_2O emissions from agricultural soils require the following input data:

– Atmospheric nitrogen deposition

– Nitrogen leaching losses

N surplus in Agriculture not only leads to direct N_2O and NH_3 emissions, but as well induces indirect N_2O emissions through atmospheric deposition of nitrogen and through nitrogen leaching from soils. Indirect N_2O emissions through atmospheric deposition of nitrogen are estimated to be 1 % of total NO_x-N and NH_3-N losses. Following IPCC default values, leaching losses from nitrogen fertilizers are estimated to be about 30 % of the nitrogen inputs from synthetic fertilizer use, animal manure, and sewage sludge application. N_2O emissions are then estimated to be 2.5 % of the leaching losses.

Table 35 gives an overview of indirect emissions from soils in a business as usual scenario.

Table 35: Indirect N_2O-N emissions (business-as-usual scenario).

N_2O-N emissions	2000	2020	2050
	[kg N_2O-N]	[kg N_2O-N]	[kg N_2O-N]
from N volatiled	377,017	376,435	383,571
from N leached	2,121,827	2,102,862	2,161,451

4.3 Measures, mitigation potential and costs

4.3.1 Increase milk yield per cow

An increased milk yield per cow can mitigate CH_4 emissions (Müller, 2002) and causes a reduction in dairy cow numbers. The reduction in CH_4 emissions per kg of produced milk is due to two reasons: 1) the percentage of energy needed for the cows´ maintenance is reduced and 2) the diet of higher yielding cows contains more concentrate and less roughage which results in lower CH_4 emissions per kg of food intake.

Müller (2002) and Vabitsch (2006) showed that dairy cattle farms can reduce enteric CH_4 emissions by increasing the milk yield per cow. Limitations to this measure result from the limited production potential of arable land and grassland and from the minimum amount of roughage required by dairy cattle to maintain their health and animal welfare. Ecological side effects of this measure – especially in Alpine regions – must be considered, as well. More concentrate intake means that less grass is consumed and more concentrate must be imported onto the farms. In countries with an already intensive dairy cattle husbandry the additional reduction in CH_4 emissions by a further increase in milk yield per cow is expected to be small (Vabitsch 2006).

Figure 38 shows the development of the total average milk yield in 1000 t and the milk yield per cow and year in kg, as well as the development of numbers of dairy cattle from 1960 until 2006 in Austria in 1000 heads. The milk production per cow and year shows a significant increase, while the number of dairy cows decrease. The total average milk yield is nearly constant.

Data from 1960 until 1999 were taken from “Grüner Bericht 2000”. From 2000 on data were taken from “Grüner Bericht 2007”.

From 1960 to 2006 the average milk yield per cow more than doubled from 2,512 kg to 5,902 kg. While the productivity per cow increased, the number of cows was constantly reduced from 1,131,000 in 1960 to 533,000 in 2006. Total milk production only increased slightly from 2,841,100 t in 1960 to 3,146,700 t in 2006.

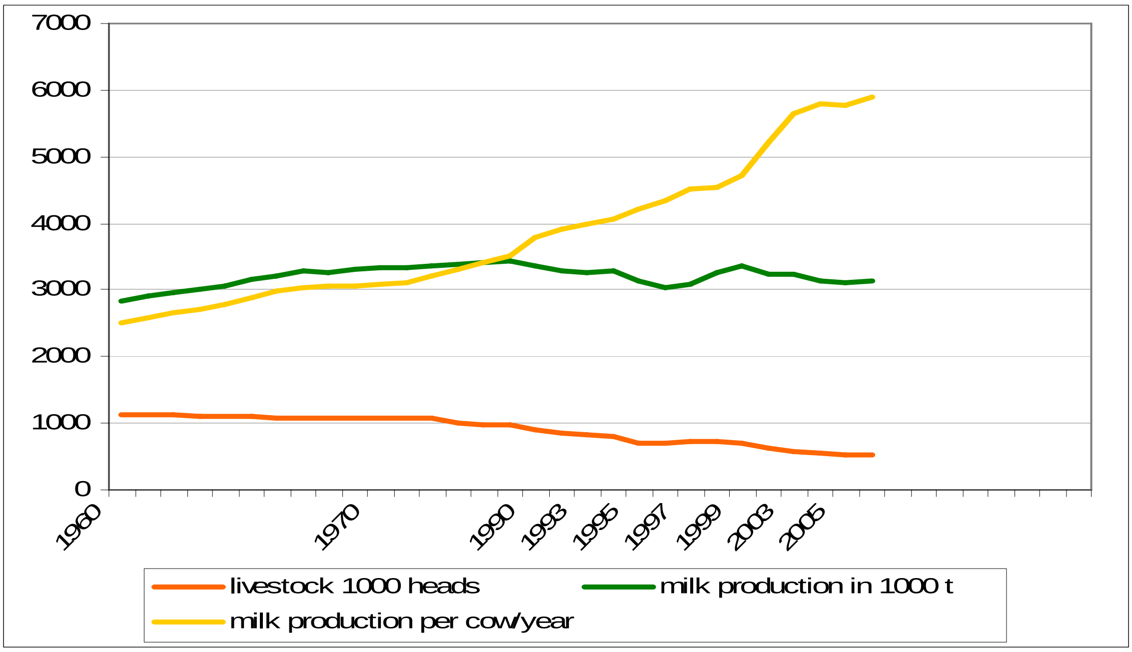

Figure 38: Average milk yield in kg per cow and year and total milk production in 1000 t from 1960 to 2006 in Austria compared to development of livestock in 1000 heads (Grüner Bericht, 2001; Grüner Bericht, 2007)

There is still potential for further increase in the productivity per cow through the use of different cattle breeds, different feeding, progress in breeding, and optimized use of livestock.

Assuming a milk yield of 10,000 kg per cow and year and a constant distribution of solid and liquid systems, the reduction potential is 37 % (CH_4) of total CH_4 emissions from enteric fermentation of dairy cattle and 23 % (N_2O) of total N_2O emissions from manure management of dairy cattle when this measure is fully implemented (Table 36). This decrease occurs even as CH_4 emissions from enteric fermentation per cow and year increase about 21 %, but a higher milk yield leads to smaller numbers of dairy cows and thus overall reductions in emissions.

Table 36: Mitigation potential and costs of the measure: Increase milk yield per cow

Measure: Increase milk yield 10,000 kg	**Reduction potential compared to base year [%]**		**costs [€]**
	CH_4	N_2O	
Dairy cattle	36.60	22.77	0

As presented in section 4.2.3 (Table 27), an increased milk yield of 7129 kg per cow and year until 2050 without further measures is expected. Table 37 gives the mitigation potential of the GHG CH_4 and N_2O of the base year 2000 compared to 2050 in a business as usual scenario.

Table 37: GHG Mitigation and costs in the business as usual scenario for the year 2050

Measure: Increase milk yield 7129 kg	**Reduction potential compared to base year [%]**		**costs [€]**
	CH_4	N_2O	
Dairy cattle	12.85	21.85	0

Without additional measures, total emissions decrease in a business as usual scenario in the year 2050 with an expected milk yield of 7129 kg compared to the year 2000 with a milk yield of 5210 kg, by 12.85 % CH_4 of total CH_4 emissions from enteric fermentation of dairy cattle and 21.85 % N_2O of total N_2O emissions from manure management of dairy cattle.

4.3.2 Feeding measures

The close connection between cattle diet and enteric CH_4 emissions was already discovered in the 1960s. A detailed research was made and formulas were developed that estimated CH_4 loss in dependency of feed composition (e.g. Blaxter and Clapperton, 1965, Moe and Tyrell, 1979)

Recent studies on the effect of animal diets on CH_4 emissions from enteric fermentation name three approaches to mitigate direct CH_4 emissions: more starch, more concentrate, and more maize silage instead of grass silage. The combination of these measures can significantly reduce emissions. At present a proof of their applicability is still outstanding (Vabitsch, 2006).

For the reclip:tom project a range of potential rations have been calculated. Table 38 to Table 41 present the CH_4 emissions (in g per ration), of the different rations.

Table 38: CH_4 emissions in g per ration for “maize silage I”

Animal category	Ration: maize silage I composition	[kg]	DM [%]	DM [kg]	roughage [%]	CH_4 [g / ration]
cattle < 1 yr LW 150 kg	maize silage	8	30.00	2.4	18.60	
	wheat	1	88.00	0.88	2.50	
	soyabean oil meal	1.1	89.00	0.968	6.70	
	Total			**4.248**	**12.55**	**60.90**
cattle 1 - 2 yr LW 450 kg	maize silage	16	30.00	4.8	18.60	
	wheat	1	88.00	0.88	2.50	
	soyabean oil meal	1.1	89.00	0.968	6.70	
	Total			**6.65**	**14.74**	**126.50**
cattle > 2 yr LW 550 kg	maize silage	20	30.00	6	18.60	
	wheat	1	88.00	0.88	2.50	
	soyabean oil meal	1.1	89.00	0.968	6.70	
	Total			**7.85**	**15.33**	**157.30**

Table 39: CH_4 emissions in g per ration for “maize silage II”

Animal category	Ration: maize silage II composition	[kg]	DM [%]	DM [kg]	roughage [%]	CH_4 [g / ration]
cattle < 1 yr LW 150 kg	maize silage	8	35.00	2.8	20.10	
	wheat	1	88.00	0.88	2.50	
	soyabean oil meal	1.1	89.00	0.968	6.70	
	Total			**4.648**	**13.98**	**66.20**
cattle 1 - 2 yr LW 450 kg	maize silage	16	35.00	5.6	20.10	
	wheat	1	88.00	0.88	2.50	
	soyabean oil meal	1.1	89.00	0.968	6.70	
	Total			**7.45**	**16.28**	**139.20**
cattle > 2 yr LW 550 kg	maize silage	20	35.00	7	20.10	
	wheat	1	88.00	0.88	2.50	
	soyabean oil meal	1.1	89.00	0.968	6.70	
	Total			**8.85**	**16.88**	**173.30**

Table 40: CH_4 emissions in g per ration for "grass silage"

Animal category	Ration: grass silage composition	[kg]	DM [%]	DM [kg]	roughage [%]	CH4 [g / ration]
cattle < 1 yr	grass silage	8	35.00	2.8	29.90	
LW 150 kg	wheat	1	88.00	0.88	2.50	
	chips	0.5	90.00	0.45	20.50	
	Total			**4.13**	**23.04**	**64.80**
cattle 1 - 2 yr	grass silage	15	35.00	5.25	29.90	
LW 450 kg	wheat	1	88.00	0.88	2.50	
	chips	1.5	90.00	1.35	20.50	
	Total			**7.48**	**24.98**	**147.50**
cattle > 2 yr	grass silage	17	35.00	5.95	29.90	
LW 550 kg	wheat	1	88.00	0.88	2.50	
	chips	2	90.00	1.8	20.50	
	Total			**8.63**	**25.15**	**178.90**

Table 41: CH_4 emissions in g per ration for "maize pulp"

Animal category	Ration: maize pulp composition	[kg]	DM [%]	DM [kg]	roughage [%]	CH_4 [g / ration]
cattle < 1 yr	maize mash	15	7.00	1.05	8.50	
LW 150 kg	maize silage	5	35.00	1.75	20.10	
	hay	1	44.00	0.44	32.10	
	wheat	1	88.00	0.88	2.50	
	Total			**4.12**	**14.67**	**60.50**
cattle 1 - 2 yr	maize mash	40	7.00	2.8	8.50	
LW 450 kg	maize silage	11	35.00	3.85	20.10	
	hay	1	44.00	0.44	32.10	
	wheat	1	88.00	0.88	2.50	
	Total			**7.97**	**14.74**	**144.80**
cattle > 2 yr	maize mash	55	7.00	3.85	8.50	
LW 550 kg	maize silage	12	35.00	4.2	20.10	
	hay	1	44.00	0.44	32.10	
	wheat	1	88.00	0.88	2.50	
	Total			**9.37**	**14.24**	**177.40**

Feeding plans for Table 38 to Table 41 have been taken from Kirchgessner 2004. For calculation of the different feeding rations DLG Futterwerttabellen 1997 (German feed composition table 1997) have been used.

Basically there is a potential to mitigate methane emissions from cattle through less roughage in the feeding. As ruminants are the only production animals that can obtain energy from roughage (Kirchgessner et. al. 1993), this measure puts them into food competition with all other animals and roughage out of use. Also the measure can only be applied to a certain extent: ruminant animals a minimum amount of roughage for adequate gastroesphageal vestibule function.

Table 42 gives the comparison of ration maize silage I to ration maize silage II, the reduction potential and costs.

Table 42: Mitigation potential and costs of the measure: Less roughage in the feeding (cattle)

Measure: Less roughage in the feeding (cattle)	CH_4 Reduction potential [%]	costs [€]
Cattle <1	8.05	0
Cattle 1 - 2	9.16	0
Cattle > 2	9.22	0

For reclip:tom data base we used ration maize silage I compared to maize silage II to show the potential of a decrease of roughage feeding. The reduction potential if the measure is fully implemented is 8.05 % (cattle < 1) to 9.22 % (cattle >2) of total CH_4 emissions from enteric fermentation. The costs are assumed as 0 €, because the production steps are the same.

4.3.3 Solid system instead of liquid system

For CH_4 emissions from manure management, a shift from liquid systems to solid systems would result in a decrease in emissions as the methane conversion factor is 39 % for liquid systems and only 1 % for solid systems (IPCC 1997). On the other hand, the N_2O emission factor is higher for solid systems than for liquid systems, which counteracts the reduction in CH_4 emissions. Table 43. gives the reduction potential and the costs of the mitigation measure solid systems instead of liquid systems.

Table 43: Mitigation potential and costs of the measure: Solid system instead of liquid system

Measure: Solid system instead of liquid system	CH_4 Reduction potential [%]	Related N_2O increase [%]	GHG Reduction potential [%]	costs [€]
Dairy cattle	87.80%	20.20%	30.88%	0
Suckling cows	87.80%	20.20%	23.92%	0
Cattle > 2 yr	94.90%	48.83%	23.44%	0
Cattle 1-2 yr	82.00%	15.50%	15.34%	0
Cattle < 1 yr	91.60%	25.60%	23.52%	0
Breeding sows	96.40%	66.50%	65.90%	0
Fattening pigs	96.50%	68.30%	66.28%	0

A very promising mitigation measure for new buildings is a switch from liquid to solid systems. A reduction potential from 87 to 96 % of total CH_4 emissions from manure management depending on the animal category is estimated. The reduction results in the different methane conversion factors (MCF) that are applied to estimate methane emissions from manure management. The MCF for liquid manure is 39 whereas it is only 1 for solid manure.

As Table 43 shows, a switch from liquid systems to solid systems would result in higher N_2O emissions from manure management. For cattle and suckling cows the total N_2O emissions from manure management increase by 20.20 %, for cattle > 2 yr to cattle < 1 yr the total N_2O emissions from manure management increase from 15.50% to 48.83 % depending on the animal category. The highest increase of 66.50% and 68.30 % of total N_2O emissions from manure management is estimated for the animal categories breeding sows and fattening pigs, because here, the share of liquid systems is high in the baseline scenario.

Despite of the higher N_2O emissions, total GHG emissions from manure management decrease from 15.34% to 66.28%. GHG emissions from manure management are more dependent on the amount of CH_4 emissions than on the amount of N_2O emissions. So even if solid systems have higher N_20 emissions, their reduction in CH_4 emissions leads to lower GHG emissions. The highest mitigation potentials are given for the animal categories breeding sows and fattening pigs.

This measure is mainly interesting for new buildings, it is unlikely that existing houses would switch because of the high investment costs and new machinery for manure management and manure handling.

4.3.4 Biogas production

Biogas production is a very effective means to reduce CH_4 emissions from manure management (IPCC 2001, Clemens et al. 2006). Biogas production reduces the organic carbon content of animal manures and increased their NH_4-N content. Both measures should not only reduce CH_4 emissions from manure management, but as well N_2O emissions during manure storage and after manure application. For N_2O emissions, the trend is not as clear as for CH_4 emissions due to the generally high variability of N_2O emission. Total GHG emissions however are always lower with biogas slurry than with untreated slurry (Wulf et al. 2001, 2002a, 2002b).

Table 44: Mitigation potential and costs of the measure: Biogas production

Measure: Biogas production	CH_4 Reduction potential [%]	Related N_2O increase [%]	GHG Reduction potential [%]	costs per livestock unit [€]
pigs	74.90 %	37.50 %	19.90 %	1.50
cattle	66.80 %	30.30 %	59.00 %	1.50

Biogas production is mainly implemented for energy production reasons. As Table 44 shows the reduction potential for methane if the measure is fully implemented is 66 – 74 % of total CH_4 emissions from manure management depending on the animal category. Although biogas production results in increased emissions of nitrous oxide of 37.5 % (pigs) (Amon et al., 2004) and 30.30 % (cattle) (Amon et al., 2006) of total N_2O emissions from manure management, total GHG emissions decline of 19.90 % (pigs) (Amon et al., 2004) and 59.00 % (cattle) (Amon et al., 2006). The costs given as 1.50 € per livestock unit do not include the additional income from electricity and heat production, as well as the higher fertilizer value of the digestate.

The price fixed for electricity generation from biogas plants with agricultural raw materials amounts between 16.5 and 10.3 Cent per kWh. (Walla und Schneeberger, 2007)

4.3.5 Separation of solids

Slurry based systems offer the possibility of separating solids from the slurry. This manure treatment option results in a solid fraction that may be stored and composted and a liquid fraction with a lower organic carbon content. Amon et al. (2004; 2006) could show in extensive research trials that slurry separation results in a reduction of GHG emissions from manure management.

Table 45: Mitigation potential and costs of the measure: Separation

Measure: Separation	CH_4 Reduction potential [%]	N_2O Reduction potential [%]	GHG Reduction potential [%]	costs per livestock unit [€]
pigs	71.30%	26.50%	49.40%	2.04
cattle	41.60%	-19.70%*	36.70%	2.04

*) negative reduction potential = related increase in emissions

As Table 45 shows the reduction potential for methane is 41.6 – 71.3 % of total CH_4 emissions from manure management depending on the animal category. Separation of pig leads to lower N2O emissions. With cattle slurry, higher N_2O emissions were measured after slurry separation. The increase in emissions mainly results from the storage of the solids separated from cattle slurry. Total GHG emissions in this category decline by 49.4 % (pigs) (Amon et al., 2004) and 36.70 % (cattle) (Amon et. al., 2006). The costs are given as 1.50 € per livestock unit (Boxberger und Amon, 1998).

4.3.6 Match N input in the diet to the pigs requirements

Especially with pig husbandry, it should be an aim to adjust N in the diet to the pigs´ requirements. For fattening pigs, this means the introduction of phase feeding with a higher diet N content in the first half of the fattening period and a lower N content in the second half. Phase feeding is common in many European countries and has been proven to be applicable on commercial farms. In Austria, phase feeding has so far not been implemented on many farms and so the potential for mitigation of GHG emissions through this measure is high.

Table 46: Mitigation potential and costs of the measure: Match N input in the diet to the pigs requirements

Measure: Match N-input in the pigs' diet – IV Phase feeding	N_2O Reduction potential [%]	costs [€]
pigs	12.00%	0

If the measure is fully implemented it would result in a reduction of 12.00 % N_2O of total N_2O emissions from manure management. (Kirchgessner et al. 1993) (Table 46). The costs are given as 0 €.

4.3.7 Reduce mineral fertilizer input

N input must meet crop demand, N must be readily available to the plants, technologies must be available that apply N during the vegetation period (this is sometimes difficult for animal manures). Farmers sometimes do not rely on their crops to grow on animal manures alone, but fertilize additional N. Lower N input leads to lower direct N_2O emissions from agricultural soils and to lower indirect N_2O emissions from agricultural activities. At the same time, GHG emissions from mineral fertilizer production are reduced.

Focusing on mitigation options the reduction of nitrogen input is not only be the most straightforward strategy with discernable effects (Kuikman et al., 2004), but it is also fully compatible with current emission reporting (Winiwarter, 2005).

Table 47 gives the mitigation potential and costs of decreased fertilizer input.

Table 47: Mitigation potential and costs of the measure: Reduce mineral fertilizer input

Measure: Reduce mineral fertilizer input	N_2O Reduction potential [%]	costs per t N_2O [€]
	6.00%	1500

A reduction in N fertilization might not only be achieved through avoidance of N surplus, but as well through a better utilization of fertilized N. This may be achieved through an optimized timing of fertilizer application, through application of slow-release fertilizers, through the growing of crops to shorten the fallow period, through an increased frequency of slurry application and through the application of nitrification inhibitors (Winiwarter, 2005).

GAINS estimates the potential of decreased fertilizer input and lower emissions at about 6 % N_2O of total N_2O emissions from manure management. The costs are given with 1500 € per t N_2O. (Winiwarter, 2005).

4.3.8 All mitigation measures and their mitigation potential

Table 48 gives an overview of all calculated measures and their mitigation potential when the measure is fully implemented.

Table 48: Calculated measures and their mitigation potential in %.

Measure	Livestock category	Reduction potential [%]	
		CH_4	N_2O
Increase milk yield per cow (10000 kg)	Dairy cattle	36.6	7.4
Less roughage in the feeding	Cattle <1 yr	8.05	
	Cattle 1 – 2 yr	9.16	
	Cattle > 2 yr	9.22	
Solid system instead of liquid system	Dairy cattle	87.80	-20.19*
	Suckling cows	87.80	-20.19*
	Non dairy cattle > 2 yr	94.90	-25.57*
	Cattle 1-2 yr	82.00	-15.45*
	Cattle < 1 yr	91.60	-48.83*
	Breeding sows	96.40	-66.50*
	Fattening pigs	96.50	-68.31*
Biogas production	Pigs	74.90	-37.50*
	Cattle	66.80	-30.30*
Separation	Pigs	71.30	26.50
	Cattle	41.60	-19.70*
Match N input to the pigs requirements	Pigs		12.00
Reduce mineral fertilizer input			6.00

*) negative reduction potential = related increase in emissions

4.3.9 Further promising mitigation measures

Reduce meat consumption

This mitigation option does not form a central part in the reclip:tom database as it requires a change in consumer habits. Reclip:tom by definition is restricted to technical mitigation measures. For the sake of completeness, however, the reduction in meat consumption is mentioned here.

Weik (2005) analysed the influence of human nutrition on greenhouse gas emissions. Weik (2005) distinguishes food from conventional production and food from organic production as well as a "state-of-the-art nutrition" and a nutrition that follows recommendation of nutrition science.

The state of the art nutrition with conventionally produced food results in an emission of 1230 kg CO_2-eq. per head and year. Considering recommendation of nutrition science – which means among others a reduction in meat consumption – reduces emissions to 1031 kg CO_2-eq. per head and year. If food is produced following the guidelines of organic farming, 856 kg CO_2-eq. per head and year are emitted. The combination of organic food and recommendation of nutrition science results in the lowest emissions: 742 kg CO_2-eq. per head and year (Weik, 2005).

Increase percentage of grazing

More grazing will lead to a lower N excretion in the house and to more excreta being directly applied to grassland instead of being stored on the farm. Less manure storage reduces both CH_4 and N_2O emissions from manure management. An increase in the percentage of grazing can be achieved at no additional costs. But the applicability is limited, because an increase of grazing is only possible during the vegetation period and only for farms where the infrastructure allows grazing. This measure has no or less potential for Austria.

Match N input in the diet to the cattle's requirements

If the N content in the diet better matches the cattle's requirements, then less N will be excreted. A lower N excretion results in lower N_2O emissions from manure management and in lower direct N_2O emissions from agricultural soils after manure application. It is an ideal "beginning of the pipe measure" with no additional costs for the farmer.

Decrease growing of N fixing crops

Sustainable crop rotations contain N fixing crops and would be less sustainable without them. Even though less N fixation results in lower N_2O emissions from N fixation, it is likely that this N would be replaced by an additional input of mineral fertilizers and would so not result in an overall decrease in GHG emissions. However, one should bear in mind that N fixation should not exceed crop demand.

4.4 Note on interactions

Interactions might occur between the sectors "agriculture" and "soils". Interactions will be expressed on basis of the unit [ha]. It is important to consider that a multiple use of soils must not in every case be additive but might be possible without having consequences on the net total agricultural area. A region specific examination is required.

Interaction "grassland – soils": When the sector agriculture increased the percentage of grazing as an option to mitigate GHG emissions than it is important for the sector "soils" to know that this does not go in line with an increase in total grassland area, but merely with in increase in the time the animals spend outside. The sector "soils" differentiates mountain pasture and meadows whereas the sector "agriculture" only considers the category "pasture".

Interaction "mountain pasture – soils": The area of mountain pasture is likely to shrink in the future due to an expansion of skiing resorts and an increase in forest area. This might have consequences on roughage production in the sector "agriculture". Livestock numbers, however, are estimated to decline in the next years and thus the area required for roughage production will be reduced as well. It is therefore not assumed that interactions between the area of mountain pasture and the sector "agriculture" will have to be considered.

Interaction biogas production: agriculture – soils – energy: The sector "agriculture" proposes an increase in biogas production as an efficient means to mitigate GHG emissions. This measure influences the sectors "soils" and "energy". Biogas production does not require additional agricultural area, but crop production may change. Biogas production removes carbon from animal manures and energy crops and the digestate contains less carbon than without biogas production. This means that less carbon is brought back onto the field which must be considered in the sector "soils". The carbon remaining in the digestate is not easily degradable and forms thus an ideal basis for humus production on the soils. The digestate is a valuable and highly efficient fertilizer and its application might reduce mineral fertilizer input.

Interaction biogas production: agriculture – industrial processes: The digestate (residue of the biogas process) is a valuable and highly efficient fertilizer and its application might reduce mineral fertilizer input. In consequence, this leads to less mineral fertilizer production in the sector “industry”.

Interaction biogas production: agriculture – energy: Biogas is a renewable energy source and can replace fossil fuels. This effect must be considered in the sector “energy”.

Interaction N fertilization: agriculture – industrial processes: Less input of mineral fertilizer nitrogen – as suggested as a mitigation option in the sector “agriculture” – leads to a reduction in the production of mineral fertilizers in the sector “industrial processes”.

Interaction N fertilization: agriculture – soils: Less N input might change the soil N: C ratio which in consequence would alter degradation processes in the soil. It is however questionable if nameable changes in soil processes will be induced through a slight reduction in N input. The same applies to a slight change in soil pH that might occur if fertilization practices change.

Interaction: land use competition: While none of the measures presented aims at extending or changing the use of agricultural area, agriculture necessarily is linked to utilize large extents of land. Options in other sectors (biofuel production in section 25.2) possibly interfere with land use assumptions outlined for agriculture.

5 Soils & Landfill

5.1 Introduction

Carbon fluxes in soil have a decisive part in any greenhouse gas balance. In contrast to most other sectors, soils are able to store carbon, and thus in effect can act as sinks for CO_2. While also dealing with carbon in the ground, landfills play a quite different role, releasing CH_4 and CO_2. Thus the work package was divided into two quite independent tasks, one for the soil-related emissions, including agricultural soils, forest soils and other soils (but not those related to the agricultural nitrogen cycle, specifically N_2O) and the other for the CO_2 emissions from landfills. This section explains which entities and measures for mitigation have been selected, and quantitatively assesses their related properties. Methods for cost calculation as well as first costs estimates are presented. For the fruitful discussion to this section we have to thank Dr. Elisabeth Schachermayer, Dr. Christian Neubauer, Dipl.Ing. Alex Storch (all Umweltbundesamt Vienna), Prof. Peter Lechner and colleagues (BOKU Vienna),

5.2 Soils

As already discussed in the 2005 report to reclip:tom (Winiwarter et al., 2005) we focus on the soil carbon change over the time between land use categories. Carbon content of the soil has a high uncertainty, but as Table 49 demonstrates differences of the measured mean soil carbon contents between land use categories are very high. Therefore it is supposed that significant changes over time after a land use change will occur.

Table 49: organic carbon contents for different land use categories

Land use	Soil carbon [t C/ha] 0-20cm	Soil carbon [t C/ha] 20-50cm
Agriculture	41	18
Grassland intensive	60	21
Grassland extensive (alpine)	92	27
Vineyards	39	18
Sparse built up area	57	17
Orchards/ house garden	57	21
Tree nurseries	93	20

Source: Gerzabek et al. 2003

Based on the conceptual land use change (LUC) -model presented in the 2005 report (see Figure 40) enhancements were made and a parameterised computer model was developed. During the development of the LUC-model it became obvious that changes within the entities and measures, developed 2005, had to be made. These changes were mainly caused due to the structure of the available data and the structure of the reclip:tom project database. The following chapter presents the new entities and measures. Compared to the previous report, new land use change categories have been added, as e.g. new grassland area from other land area or new grassland intensive area from arable land area. This has been done to increase the completeness of the model, whereas we know that still some seldom occurring land use changes are still missing. These missing LUC categories can be neglected within the framework of this project.

5.2.1 Entities and Measures

Compared to the entities presented in the annual report 2005, where flows as entities e.g. *Land use change to forest* (in ha/yr) have been used, we now use stocks as entities (in ha). This was necessary to calculate the emissions of the different stocks with their relevant emission factors. Entities have changed slightly, only some new categories for new arable land have been added.

Table 50: Entities used for the sector "Soils"

name of entity	ID	activity unit	emission factor unit	Comments
Forest soils	SOIL_76	ha	t CO_2/ha,yr	Total forest areas
New forest areas from alpine areas	SOIL_76a	ha	t CO_2/ha,yr	Changes in the timberline
New forest areas from grassland intensive	SOIL_76b	ha	t CO_2/ha,yr	Abandonment of intensive managed grassland
New forest areas from grassland extensive	SOIL_76c	ha	t CO_2/ha,yr	Abandonment of extensive managed grassland
New forest areas from arable land	SOIL_76d	ha	t CO_2/ha,yr	Abandonment of arable land
Grassland soils intensive	SOIL_77	ha	t CO_2/ha,yr	Total grassland area intensive managed
New grassland int. area from forest	SOIL_77a	ha	t CO_2/ha,yr	Deforestation of forest land
New grassland int. area from grassland ext. area	SOIL_77b	ha	t CO_2/ha,yr	Change in grassland management-- intensification
New grassland int. area from arable land area	SOIL_77c	ha	t CO_2/ha,yr	Change in agricultural management
New grassland int. area from other land area	SOIL_77d	ha	t CO_2/ha,yr	Recultivation of other land area
Grassland soils extensive	SOIL_78	ha	t CO_2/ha,yr	Total grassland area extensive managed
New grassland ext. area from forest	SOIL_78a	ha	t CO_2/ha,yr	Deforestation of forest area
New grassland ext. area from grassland int. area	SOIL_78b	ha	t CO_2/ha,yr	Change in grassland management -to extensive managed grassland
New grassland ext. area from arable land area	SOIL_78c	ha	t CO_2/ha,yr	Change in agricultural management
New grassland ext. area from other land area	SOIL_78d	ha	t CO_2/ha,yr	Recultivation of other land area
Arable land	SOIL_79	ha	t CO_2/ha,yr	Total arable land area
New arable land from other land area	SOIL_79a	ha	t CO_2/ha,yr	New arable land from other land area

name of entity	**ID**	**activity unit**	**emission factor unit**	**Comments**
New arable land ext from arable land int	SOIL_79b	ha	t CO_2/ha,yr	Extensivation of intensiv agricaltural areas
New arable land abandoned	SOIL_79c	ha	t CO_2/ha,yr	Abandonment of arable land
New arable tilled former untilled land	SOIL_79d	ha	t CO_2/ha,yr	Increasement of tilled arable land area
New arable land from other land area	SOIL_79a	ha	t CO_2/ha,yr	Afforestation of other land area
Other soils	SOIL_80	ha	t CO_2/ha,yr	Total other soil areas
New other land area from forest area	SOIL_80a	ha	t CO_2/ha,yr	Deforestation of forest area to other land area
Open agricultural land area	SOIL_81	ha	t CO_2/ha,yr	Uncovered agricultural area
Revitalization of brownfields	SOIL_82	ha	t CO_2/ha,yr	Abandoned industrial and commercial areas where expansion or redevelopment is complicated by real or perceived environmental contamination

In Table 51 the measures and the reference to their entities are listed. Measures can change the emission factor for one entity or also change the amount of an entity. As an example the measure “*extensivation of grassland from intensive production”* increases the entity (the stock) of “*new grassland ext. area from grassland int. area”.* The measure *“decreased removals from arable land”* decreases the emission factor from arable land.

Table 51: Measures applied to soil entities

ID of entity	Abatement measure	Abated EF/ EF[10] [t CO_2/ha,yr][11]	Description
SOIL_76	Decreased removal from forests	n.a.[12]	Former management led to decrease of carbon which is regained
SOIL_76	Change to potential natural vegetation	n.a.	Regain of lost carbon due to a use of more appropriate tree species
SOIL_76a	Alpine areas changes to forest land by natural “rejuvenation”	-3.7	Regain of lost carbon in the **soil** and **aboveground** biomass (assumption 2.5 t CO_2/ha[13], yr over 30 years according to Umweltbundesamt 2000-M106 and ACBM)
SOIL_76c	Extensive grassland changes to forest land by natural “rejuvenation”	-2.8	Regain of lost carbon in the **soil** and **aboveground** biomass (assumption 2.5 t CO_2/ha, yr over 30 years according to Umweltbundesamt 2000-M106 and ACBM)
SOIL_76c	Extensive grassland changes to forest land by reforestation	-2.8	Regain of lost carbon in the **soil** and **aboveground** biomass (assumption 2.5 t CO_2/ha, yr over 30 years according to Umweltbundesamt 2000-M106 and ACBM)
SOIL_76d	Arable land area changes to forest area	-10.1	Regain of lost carbon in the **soil** and **aboveground** biomass (assumption 2.5 t CO_2/ha, yr over 30 years according to Umweltbundesamt 2000-M106 and ACBM)
SOIL_77c	Arable land area changes to new grassland int. area	-2.7	Regain of lost carbon in the soil due to changed agricultural management
SOIL_77d	Other land area changes to new grassland int. area	-0.12	Regain of lost carbon
SOIL_78b	Extensivation of grassland from intensive production	-4.6	Regain of lost carbon in soils due to agr. practice
SOIL_78c	Abandonment of agricultural land[14]	-7.3	Regain of lost carbon in the soil
SOIL_78d	New grassland ext. area from other land area	-4.8	Regain of lost carbon in the soil
SOIL_79	Changed fertilizer to arable soils	n.a.	Changes in soil pH and C/N ratio increases amount of stored carbon

10 In some cases there are not abated emission factor available because the reduction is due to the change of the activity!

11 Negative numbers indicate a sink of CO_2

12 Currently not available (n.a.): estimates will be performed within the next project period.

13 The figure of 2.5 t CO_2/ha, yr have to be discussed with experts within the next project period because of the high uncertainty!

14 Arable land changes to grassland extensive

ID of entity	Abatement measure	Abated EF/ EF[10] [t CO_2/ha,yr][11]	Description
SOIL_79	Decreased removals from arable land	n.a.	More residues are left on the fields this increases the stored carbon in soils
SOIL_79	Extensivation of arable production	n.a.	Regain of lost carbon in soils due to arable practice
SOIL_81	Reduction of ploughed untilled land	n.a.	Reduction of losses due to distur-bance of soil structure
SOIL_82	Use of old brownfields for new industrial land	-4.8[15]	Decrease of reduction of carbon losses because no grassland areas have to be used for industry areas
SOIL_82	Use of old brownfields for infrastructural land	-4.8[11]	Decrease of reduction of carbon losses because no grassland areas have to be used for infrastructure areas

5.2.2 LUC-Model

– LUC according to historical trends

Data input used to develop the LUC-Model has been taken from a number of different sources. Figure 39 shows the rate of change between the different land use categories in Austria according to Jonas and Nilsson (2001). These changes are net changes, and as already discussed in the 2005 report, the net changes are more important to calculate the emissions than the gross changes.

15 The change of carbon from extensive grassland areas to other land areas would be a loss of about 4.8 t CO_2/ha, yr

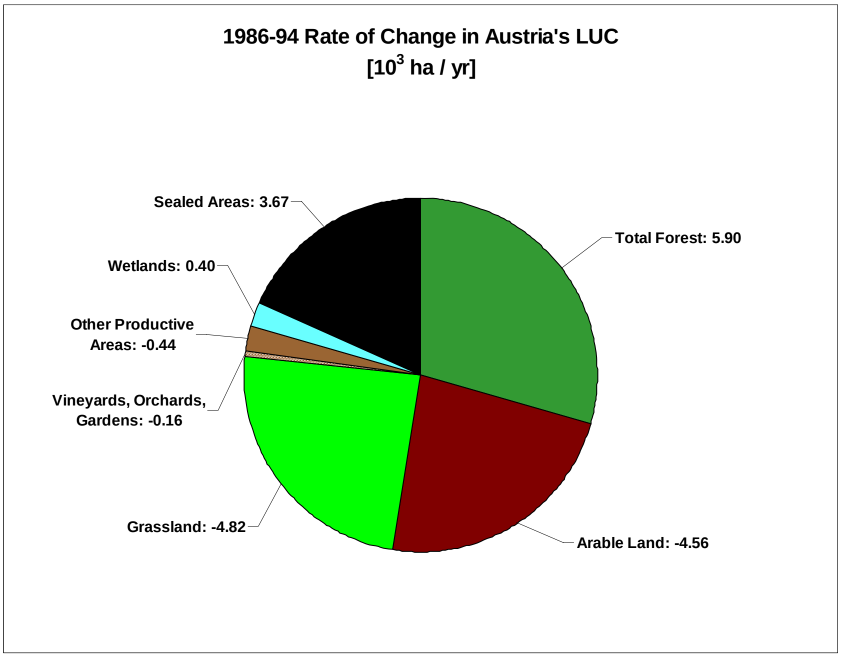

Figure 39: Av. rate of net land use change between 1986 and 1994

Source: Jonas and Nilsson, 2001

Following additional data has been used to develop and parameterise the LUC-Model:

– Forestry data – „Waldinventuren“ (86/90 – 92/96 – 00/02), BFW (2006)
– Agricultural data – „Grüne Berichte“, BMLFUW (2006)

The LUC-model was built with stocks and flows. Main stocks represent the forest area, arable land areas, unused alpine land, grassland intensive, and grassland extensive and other land areas. Additional stocks had to be introduced into the model to calculate the emissions or removals from land use change, as for example “*new forest area from alpine area”*, “*new forest area from grassland extensive area”* or “*new grassland extensive area from grassland intensive area”*. These stocks are necessary because it is essential to know from which former land use category the new forest area or other land types result. For the calculation of the emissions or removals for each of these stocks an emission factor (EF) was derived (see Figure 42).

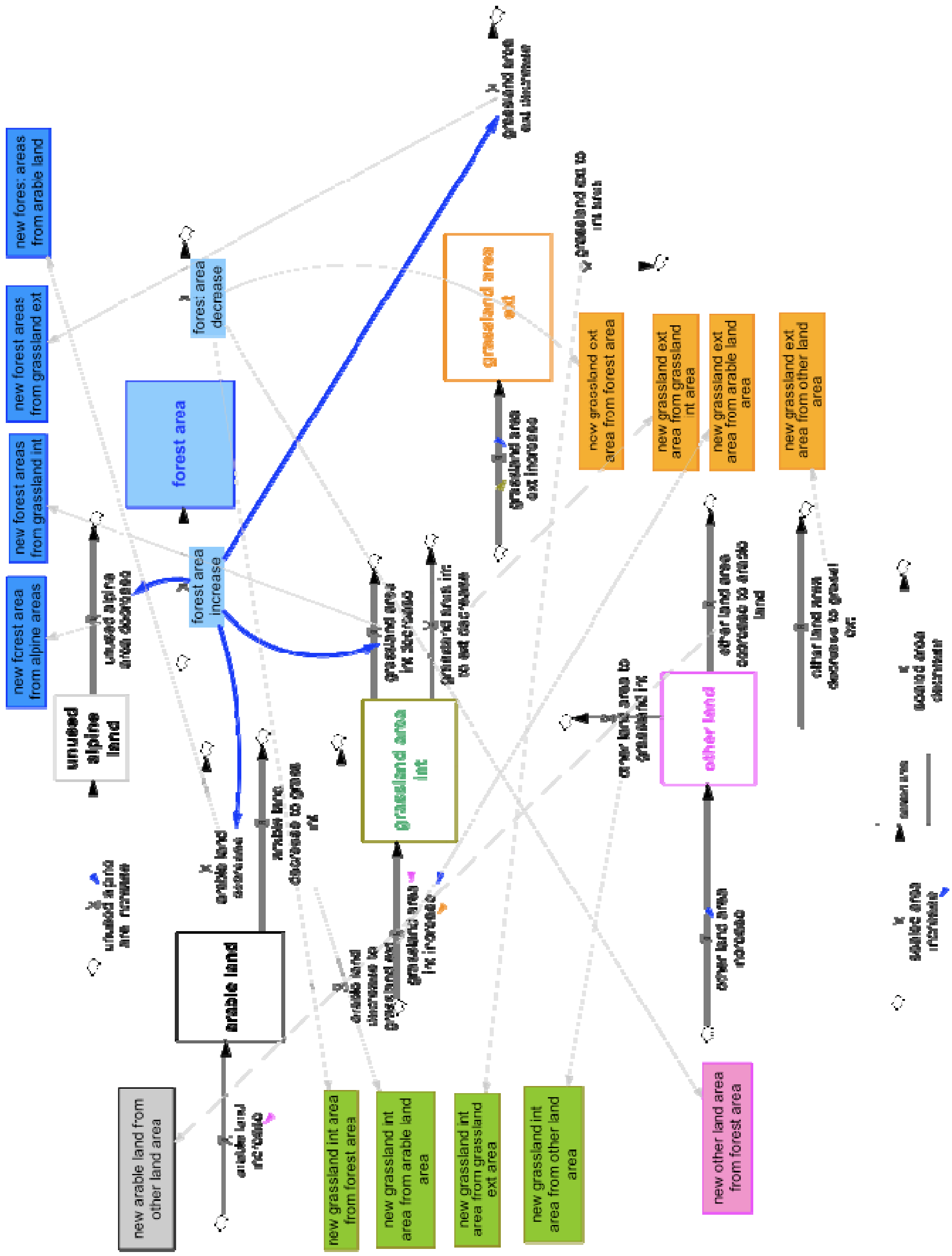

Figure 40: LUC-Model (the boxes are the stocks and the arrows are the flows)

5.2.3 Baseline Scenario

For the baseline scenario the historical development extracted from the literature (Umweltbundesamt 2000; BFW, 2006) was projected into the future. Figure 41 shows the result of this projection. Until the year 2020 the results are considered reliable, but for the future until 2050 the uncertainties are very high. In the future changes to these projection can be made without a great effort if new data is available to make it more accurate.

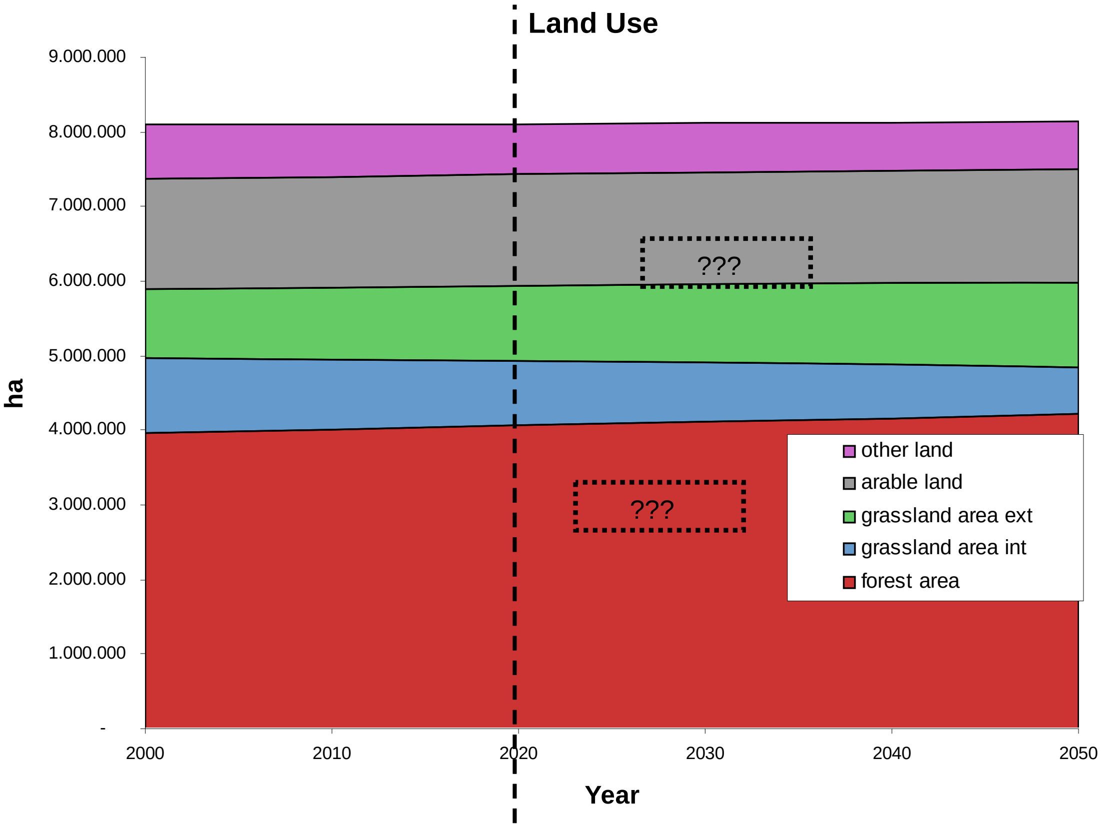

Figure 41: Projected LUC from historical trends into the future. Question marks indicate high uncertainty after year 2020.

The following emission factor calculation has been made to calculate the emissions or removals:

– The soil carbon content within the upper 50 cm for each land use category was taken from literature (Gerzabek et al., 2003).

– Differences between the origin and target land use categories have been calculated.

– The EF per ha and year have been calculated with the assumption that 2/3 of the difference will be balanced within 20-30 years. The last third needs 80-4000 years to balance and therefore we did not count this for our projections till 2050 (Umweltbundesamt, 2000).

– The derived EF have been taken to calculate the emissions without considering that the areas increased 2000 would have a slightly different EF after 20-30 years. We assume that this small uncertainty can be neglected compared to the high general uncertainty.

EF	Soil C from 0-50cm in tC/ha	Soil C to 0-50cm in tC/ha	EF pro ha in t CO2 pro ha/yr	EF pro ha icluding above ground changes in t CO2 pro ha/yr	Comments
EF forest dec	121		-3.12		
EF new forest former alpine	90	100	-1.22	-3.7	
EF new forest former grassland int	81	121	-4.89	-7.4	
EF new forest former grassland ext	119	121	-0.24	-2.7	
EF new forest former arable land	59	121	-7.58	-10.1	
EF grassland int area	81		0.37		70% compared to arable land
EF new grassland int former forest	121	81	4.89		
EF new grassland int former grassland e	119	81	4.64		
EF new grassland int former arable land	59	81	-2.69		
EF new grassland int former other land	80	81	-0.12		
EF grassland ext area	119		0.16		30% compared to arable land
EF new grassland ext fomer forest area	121	119	0.24		
EF new grassland ext former grassland i	81	119	-4.64		
EF new grassland ext former arable land	59	119	-7.33		
EF new grassland ext former other land	80	119	-4.77		
EF arable land	59		0.52		
EF new arable land former other land	80	59	2.57		
EF other land	80				
EF new other land from forest area	121	80	5.01		
EF new other land grassland areas	119	80	4.77		
EF alpine area	90		0		input is equal to output

Figure 42: Emission factors calculation

Figure 42 presents the parameters used for the calculation of the EF. The following Figure 43 shows the resulting emissions and removals for the soil. Removals are seen for the formation of extensively cultivated grassland, based on considerable shift from intensively cultivated grassland. Also new forest formation leads to removals, even at a smaller scale. Forest becomes more important in terms of removals, when also considering aboveground biomass formation (see Figure 44). We have not previously taken into account this gain of biomass by changing grassland into forest land, as it does not occur in soils. But aboveground biomass increase is not covered elsewhere, so it makes sense to include it. The result indicates that aboveground biomass is almost as important as CO_2 sink as the soil component.

Also visible from these Figures is the largest CO_2 source from soils (changes to intensive grassland) and the total soil emissions from Austria. If LUC follows the extrapolated historical trend, soil will continue to be a net sink for CO_2.

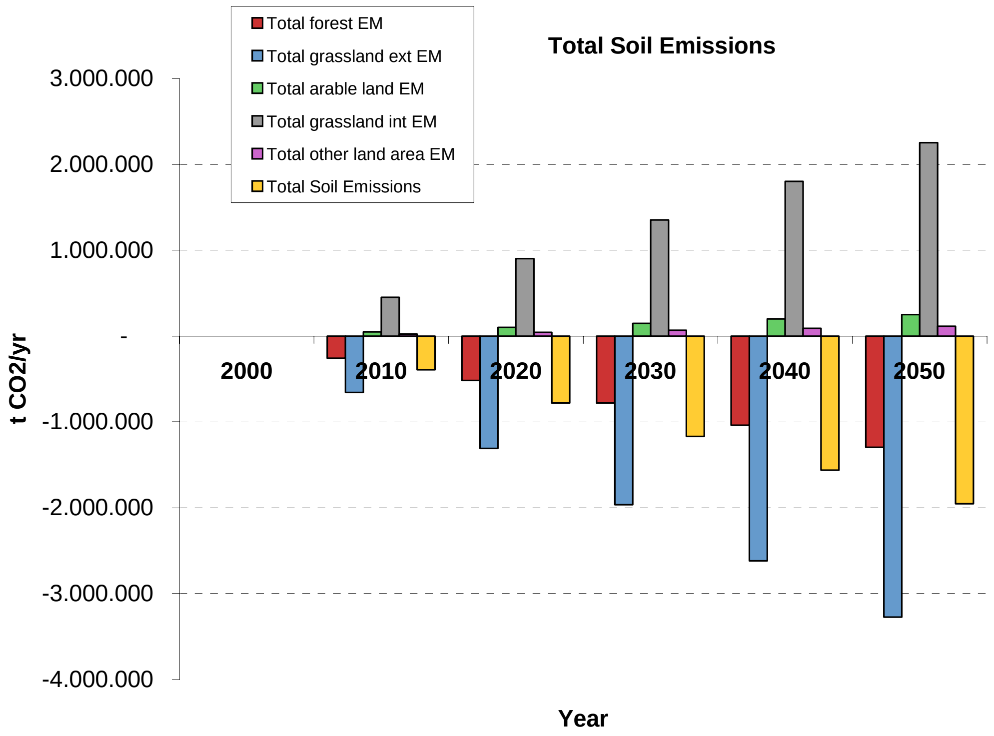

Figure 43: Projected LUC emissions and removals from historical trends

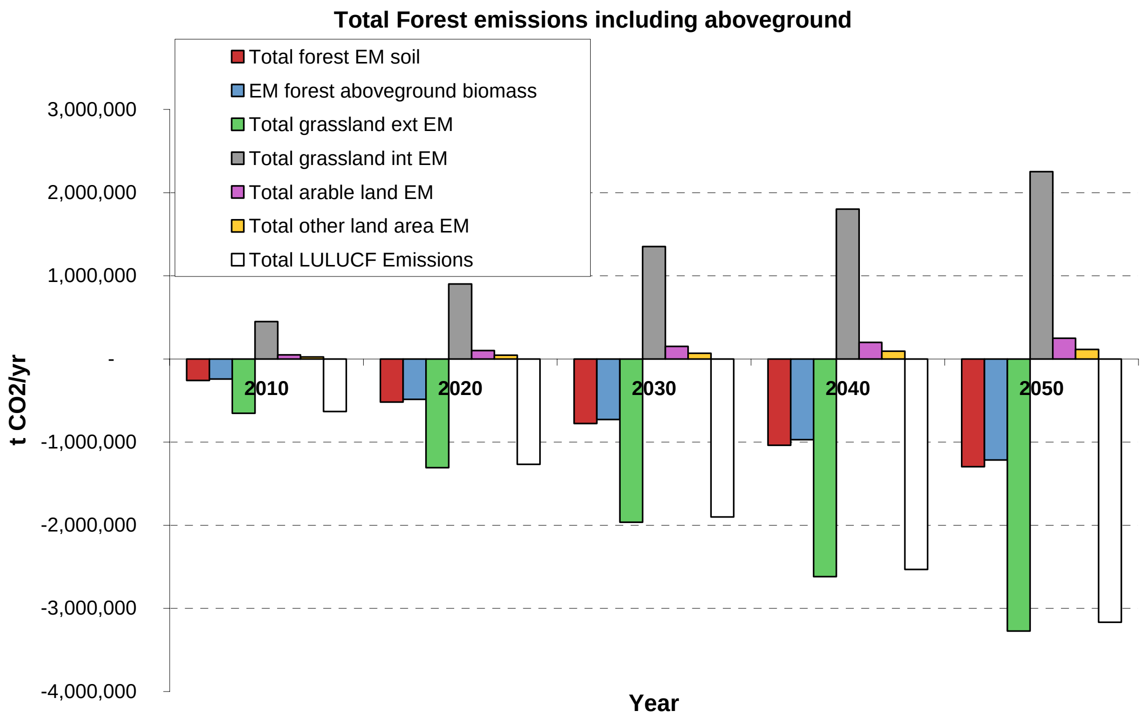

Figure 44: Projected LUC emissions and removals from historical trends including aboveground

5.2.4 Validation and Verification – Uncertainty

Our results, the removal of about 0.5 Mt CO_2/yr for the year 2010, fits quiet well to the results announced from the Federal Environmental Agency (Umweltbundesamt, 2000). They report about 450-650[16] Mt CO_2/yr as annual average for the period 2008-2012. The uncertainty for these results is very high because different definitions are used for deforestation, afforestation and reforestation as well as the definition for forests within the different methods.

The total carbon pool in Austria within the soil and aboveground are estimated for the year 1990 at 783 MtC and the uncertainty for this is +/- 190 MtC (see Umweltbundesamt, 2000). This means that the uncertainty is much higher than the total anthropogenic emissions according to Emission Inventory of Austria (Ritter, 1999).

5.2.5 Scenario "with measures"

The measures presented in Table 21 e.g. increase the amount of new forest areas from grassland extensive area of the baseline scenario. To calculate how far this amount could be increased is very difficult. Theoretically there are very high potentials as only very few economic restrictions exist. But there are other uses for land to be considered, e.g. area needed for the production of food or animal feed, tourism depends on certain land use types and patterns etc. etc. We calculated our estimations for the "with measures" scenario based on the baseline development. For example the development within the baseline scenario for new forest land area from grassland extensive cultivated, of about 250,000 ha until the year 2050, was increased by 150,000 ha to 400,000 ha in total. Furthermore we have assumed that about 300,000 ha of currently used arable land converts to intensive grassland area until 2050. This is about 20% of the currently used arable land area. For the year 2020, we have assumed that only about 7% of the currently used arable land is used for new intensive grassland areas. We think that these small changes will not significantly affect the agricultural production. Further details of the changes assumed for the measures scenario can be found in the project database.

5.2.6 Cost calculations

The cost for the different measures can be estimated mainly with two different methods:

- Under the use of aggregated marginal income data ("Aggregierte Deckungsbeiträge") for the different land uses
- with the ÖPUL-Subsidies for different agricultural measures.

The aggregated marginal income is used for agricultural planning, to estimate which farm management results in which mean income. For example, one ha of arable land used for feed production for fattening pigs will yield revenue of about 600 -1000 Euro. Would this same area be converted into forest area, about 7.6 t CO_2/yr could be removed from the atmosphere due to the increase of the soil carbon content. In addition we assume that 2.5 t CO_2/yr could be stored in the aboveground biomass. Therefore one t CO_2/yr removal would cost between 60 and 100 Euro. The forest can only be used after longer period of time economically and therefore it is difficult to consider this as income for the farmer, within the considered period of time.

The second method is to use the currently paid subsidies for changing agricultural management (e.g. for the measure shift from intensive to extensive cultivate grassland) to estimate how much cost would occur. For example, if a farmer does not use harvest increasing production facilities for grass-

16 depending on the calculation method—FAO activity based or IPCC activity based

land he would get about 160 Euro/ha, yr. With the above calculated 4.6 t CO_2/ha, yr removal for the shift from intensive to extensive cultivated grassland (see Table 50) would the costs for one ton CO_2 removal be at about 35 Euros (cf. Table 52).

Cost calculated with these two methods shows that the measure *Extensivation of grassland from intensive production* is much cheaper as to shift arable land to forest area.

Table 52 shows the first rough estimates of calculated costs for the different measures.

Table 52: Measures and costs (first estimates)

ID of entity	Abatement measure	Costs, best estimates [Euro/ t CO_2 removal]	Calculation description
SOIL_76	Decreased removal from forests	n.a. [17]	e.g. loss of income for additional products from forest
SOIL_76	Change to potential natural vegetation	n.a.	non additional costs
SOIL_76a	Alpine areas changes to forest land by natural "re-juvenation"	47	ÖPUL subsidies for "Mahd von Steilflächen" (145-290 €)
SOIL_76c	Extensive grassland changes to forest land by natural "rejuvenation"	214[18]	marginal income grassland average yield without income from forest, reduced by fix costs for buildings (about 500 €/yr)
SOIL_76c	Extensive grassland changes to forest land by reforestation	357	marginal income grassland average yield, without income from forest and, reduced by fix cost for buildings (about 500 €), increased by reforestation costs (assumed 400 € /ha)
SOIL_76d	Arable land area changes to forest area	73	marginal income for arable land is lost, without income from forest MI=1650€-500€=1150 for the buildings; and: "Kulturplanzen-Flächenzahlung" (KPF) abandonment of arable land 332 €/ha (2002)
SOIL_77c	Arable land area changes to new grassland int. area	204	Difference between marginal income of grassland int. and arable land fix costs for building are assumed not to be significant

17 Currently not available (n.a.): estimates will be performed as data becomes available.

18 The high costs are mainly due to the low reduction potential between the two land use categories

ID of entity	Abatement measure	Costs, best estimates [Euro/ t CO_2 removal]	Calculation description
			different
SOIL_77d	Other land area changes to new grassland int. area	n.a.	no costs available
SOIL_78b	Extensivation of grassland from intensive production	35	ÖPUL subsidies for “Verzicht auf Betriebsmittel im Grünland”
SOIL_78c	Abandonment of agricultural land	45	marginal income for arable land is lost; Source: "Kulturplanzen-Flächenzahlungv(KPF) abandonment of arable land 332 €/ha (2002)
SOIL_78d	New grassland ext. area from other land area	n.a.	former fruit plantations or wine plantations are changed to grassland extensive. Difference in marginal costs
SOIL_79	Changed fertilizer to arable soils	n.a.	no additonal costs
SOIL_79	Decreased removals from arable land	n.a.	e.g. additional costs for straw in stables
SOIL_79	Extensivation of arable production	n.a.	ÖPUL subsidies for “Verzicht auf Betriebsmittel im Ackerbau” 217 € 2003
SOIL_81	Reduction of ploughed untilled land	n.a.	ÖPUL subsidies for "Begrünung von Ackerflächen" 94 € 2003
SOIL_82	Use of old brownfields for new industrial land	n.a.	Costs for the revitalization of old brown fields
SOIL_82	Use of old brownfields for infrastructural land	n.a.	Costs for the revitalization of old brown fields

5.3 Landfills

In principle the concepts for the mitigation of CO_2 emissions from landfill are similar to the one in soils. Depending on the internal state of the system increases in a carbon input leads to an increase of carbon (CO_2) output of the system except if it can be stored – due to a slower decay and an increase of biomass within the system – over a longer period of time. But there are greater differences as landfills are man-made, with different reaction rates than in natural systems and many artificial compounds, which do not at all exist in natural soils, or only in minute amounts. Landfills can be understood as manmade chemical reactors which are often under anaerobic conditions. This factor leads to a higher conversion ratio of the carbon input to CH_4 output, which has a considerably higher global warming potential (GWP) than the CO_2 emissions. For example, one ton of household waste stored on a landfill produces about 100-250m³/yr of landfill gas which contains about 55 Vol% CH_4.

The actual amount is strongly dependent of the carbon content of the household waste and the individual conditions of the landfill itself.

Entities and measures as developed for the 2005 report (Winiwarter et al., 2005) have been discussed with experts and some changes have been made. The following chapter lists all entities and measures as the result of this discussion process.

5.3.1 Entities and Measures

Table 53: Entity table landfills

name of entity	ID	activity unit	emission factor	Comments
Production of waste for landfills	SOIL_83	t C/yr	kg CO_2 /t C	Amount of waste stored on landfills
Conversion of carbon input to CO_2 or CH_4 output	SOIL_84	t C/yr	kg CO_2/t C or kg CH_4/t C	Reduction of conversion ratio

The first entity --*Production of waste for landfill*-- is important, however it is not an activity which can be changed on the landfill itself. But we have decided to include it and also to try to find data for some measures for this entity.

Measures:

Table 54 shows a list of measures which belong to the entities.

Table 54: Extraction form the Measures table landfills²

ID of entity	Abatement measure	Abated emission factor	Description
SOIL_83	Reduction of the waste production	kg C/yr[19]	Reduction of packing materials; Increase of material efficiency in production
SOIL_83	Reduction of waste amount which is stored in landfills by material recycling	kg C/yr	Because of recycling less material new material is necessary
SOIL_83	Reduction of waste amount which is stored in landfills by incineration	kg C/yr	Increase of the currently existing incineration volume
SOIL_84	Sanitation of old landfills	kg CO_2/ton C	The sanitation changes the reactions within the landfill, less CH_4 is produced

19 The activity amount of carbon stored in landfills per year is reduced.

ID of entity	Abatement measure	Abated emission factor	Description
SOIL_84	Change in management of landfills	kg CO_2/ton C	Because of the changed management of new landfills different reactions within the landfills occur, therefore less CH_4 and CO_2 is produced
SOIL_84	Produced CH_4 is converted into CO_2	kg CO_2 equiv. /ton C	Collection and incineration of CH_4 on the landfill increase CO_2 , but reduces GWP
SOIL_84	Produced CH_4 is converted into CO_2	kg CO_2 equiv. /ton C	Collection and incineration of CH_4 in energy production increase CO_2 in energy sector, but reduces GWP
SOIL_84	Conversion of CH_4 by bio-methane-oxidation through compost	kg CO_2/kg CH_4	Landfill cover with compost increases the methane-oxidation.
SOIL_84	Increased methane-oxidation through forced ventilation of landfills	kg CO_2/kg CH_4	An artificial ventilation system in the landfill increases the methane-oxidation.

5.3.2 Baseline Scenario

For the baseline scenario the following reduction can be assumed (“Evaluierung der Klimastrategie”, Umweltbundesamt, 2006b):

– Due to garbage incineration from domestic waster, after waste separation, a reduction between 2003 and 2010 of 220 000 t CO_2 equivalents is assumed.

– Due to forced mechanical biological waste treatment (MBA) between 2003 and 2010 emissions are reduced by 200 000 t CO_2 equivalents.

5.3.3 Measures

The discussion with different experts showed that additional measures as presented in the measure table can not be quantified with the currently available data.

Suggested measures from the “Evaluierung der Klimastrategie” (Umweltbundesamt, 2006b) report are:

– Optimizing of the compost production process (“Rotteführung” and “Abluftreinigung”).

– Forced waste incineration

– Reduction of methane production potential

The discussion with the experts showed that beyond the baseline scenario the reduction potential seems almost negligible. For example more then 90% of CH_4 from landfills is currently already collected and converted to CO_2. Also for the baseline scenario the “Evaluierung der Klimastrategie” lists “no additional effect” from landfill gas collection.

Furthermore the discussion with experts showed that it is currently not possible to estimate the potential of the measure *Optimizing of the compost production process,* mainly because of lack of data.

5.3.4 Cost Calculation

As we only calculate costs for the measures and because it is currently not possible to quantify the measures, a cost calculation for the measures is also currently not possible. It can be assumed, according to other experience, that the reduction of the last percentages are very cost intensive.

5.4 Influences to other entities and interactions

There are only very few interactions and relations to other work packages. As already mentioned for the land use change model (LUC-model), some boundary conditions need consideration.

These conditions are for example:

- The shift from extensive cultivated grassland area to forest area is restricted by the need of animal husbandry for pastures and meadows for cattle.
- Cultivated grassland required for feed production must not be converted.

The discussion within the project team has shown that our assumed changes as described above in section 5.2.5 will not violate the boundary conditions.

For landfills no such interactions can be seen, as no measures could be quantified.

6 Tools for data handling

6.1 Motivation

The major task in reclip:tom consists in collecting information from different sectors, from the individual work packages, and compiling data into a common system. A common data platform had been agreed upon already in the first project phase (Winiwarter et al., 2005). This platform has been established in the form of a database. Entry of information (entity, measure) into the database ensures that it is compatible to the common structure. The database is able to handle all links as described in section 1.3. At the same time it allows to calculate emissions under certain scenarios, and the costs of such scenarios. Applicability of measures, and influences towards other measures are implemented as well.

For each source sector, there are specific ways to enter information and display results. In order to allow for such sector-specific approaches, special views may be created which access the main tables of the database but mimic a sectoral practice. It is obvious that such a feature can be implemented only to a limited extent, as long as the focus of the project refers to collection of data rather than towards an operative computer program. Further extension beyond the current possibilities may prove useful.

The data interface has been prepared to allow a structured collection of data. It was not designed as a self-explanatory and user friendly software tool. Thus its application beyond the project team could prove quite difficult.

6.2 Database structure

For the current purpose, a system that is easy to operate and widely available was most important. Therefore MS Access® was chosen as the basic application for the data handling tool. Adhering to a database structure, the required input information is contained in tables, while all calculations required are performed in views or queries. In the current application, there is no requirement of a data initialization. Calculations are sufficiently fast and simple, such that no tables of interim results are needed. Currently, database and the associated queries are available as version 1.3.

The key input information related to reclip:tom obviously is contained in the tables “entity”, containing information on all emitting sectors, and in the table “technology”, reflecting those abatement measures that have been dealt with so far. The only pre-defined relationship within the database is to relate each measure to one specific entity, according to the entity_ID code. These two and all other tables are presented in Table 55.

Table 55: Tables within database

Table name	Purpose	Comment
ACT	Contains activity numbers (quantity for a specific year) of entities	
APPL	Describes for each control measure, which fraction of its entity can be covered as a maximum (in percent).	Applicability is less than 100 when • only part of emissions of an entity are affected by the measure • some of the entities/installations for (technical) reasons can not be equipped with a device described in the measure
COMP	Chemical compound considered and its global warming potential	Currently contains CO_2, CH_4, N_2O plus NH_3 as a reminder for potential interferences of measures with air pollution
CONTROL	Indicates for each measure which fraction (share in percent) of an entity is expected to be affected by a certain year (=scenario)	Share of control is necessarily smaller than applicability – i.e., maximum control is achieved when share=applicability
CONVER-SION	Common conversion factors between energy contents and other, more popular units typically used to describe the activity numbers (year dependent, to cover efficiency changes)	For display only
COSTS	Additional costs due to implementation of an abatement measure, calculated per activity unit of the entity applied to (e.g., €/TJ)	Investments as well as running costs have been converted into annual costs, assuming a 6% interest rate
DESCRIPTOR	Allow to define limitations between different abatement measures	For display only
ENTITY	Describes emission source (or sector), includes the activity unit and default emission factors per unit for each compound	
INFLUENCE	Influence describes the effect of an abatement measure towards the activity of an entity (refers both to the entity affected by the measure, and any other entity). Either relative influences (in percent of activity number) or absolute influences (in activity units) need to be quantified and presented assuming a measure is fully implemented	If measures exhibit “influences” towards several entities, such influences need to be defined separately

Table name	Purpose	Comment
SOURCES	Reference to literature or other data sources.	Entries either consist of a full citation, or a set of abbreviated citations (multiple reference to sources is not possible from other tables, as that would lead to an n:m relationship which is extremely difficult to cover)
TECHNO-LOGY	Defines abatement measure and a "reduction efficiency" in percent for each compound, allowing to calculate an emission factor after introduction of a measure.	A measure is always assigned to a specific entity. Measures that have a reduction efficiency of zero only may be useful when addressing the activity only, which needs to be defined as "influence".
YEAR	Defines the specific years to be considered	Currently 2000=base year, 2020=target year, and 2050=projection

Entry of data into tables is performed via specific interfaces (see section 6.4). Batch loading of data may also be performed directly into the respective tables, even if links (e.g. to references) need to be set manually at a later point.

6.3 Queries

The calculation of results is performed inside queries, which are formulated as cascades of SQL commands. The query generator built into MS Access allows also to display a graphical view of the respective relationships, at least for most of the queries.

The following query cascades have been established:

- c*ontrol_technology*: assesses the share a control technology is implemented for a specific year, and calculates the rest as "no control" case, for which the unabated emission factor applies.
- *activity_influenced*: calculates the activity associated to an entity <u>after</u> all influencing measures have been considered. In order to minimize the chance in ending up at negative activities due to multiple influences, additive influences are considered first, and multiplicative (percentages) afterwards.
- *emissions*: calculates emissions (by entity or by abatement measure) using the above query cascades
- *implied_EF*: using emissions by entity, an implied emission factor is derived
- *costs*: on a parallel cascade of queries, costs of the individual measures taken (influencing controls or activities) are compiled. Comparing emissions against costs allows to identify cost-efficient measures.

The queries are meant to allow a user to perform data checks, and to calculate results in terms of emissions. This includes calculation of a difference between an "expected" scenario (like the *default* scenario or other scenarios *with measures*) and an extreme scenario (*maximum feasible reductions* or *with additional measures*).

6.4 Interface

As guidance to users, tables (for input) and queries (results of calculations) are accessible via user interfaces. When opening the database, a menu pops up, leading a user towards the individual input data forms as well as to the calculation sheet (Figure 45). The design of the menus is meant to be self-explaining, but as the current project does not focus on usability of computer programs, it may not fully serve this purpose. Thus use outside the project is not recommended, also as no user instructions are available.

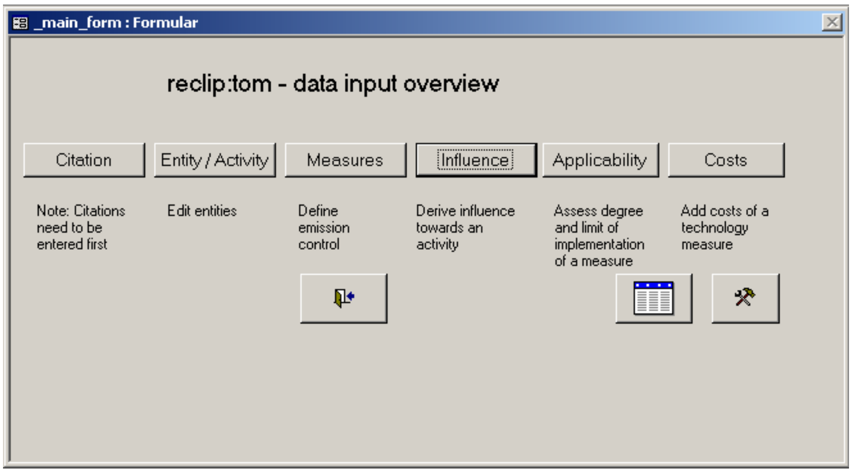

Figure 45: Main user menu

Each of the data forms for input again allows, via a series of pull-down menus and inter-linkages, for a consistent way of data input. An example for input (of implementation and applicability) is presented in Figure 46. Note that this form links to several tables. Some of the data fields (text in grey font) can not be accessed by the user, but are filled from the system only.

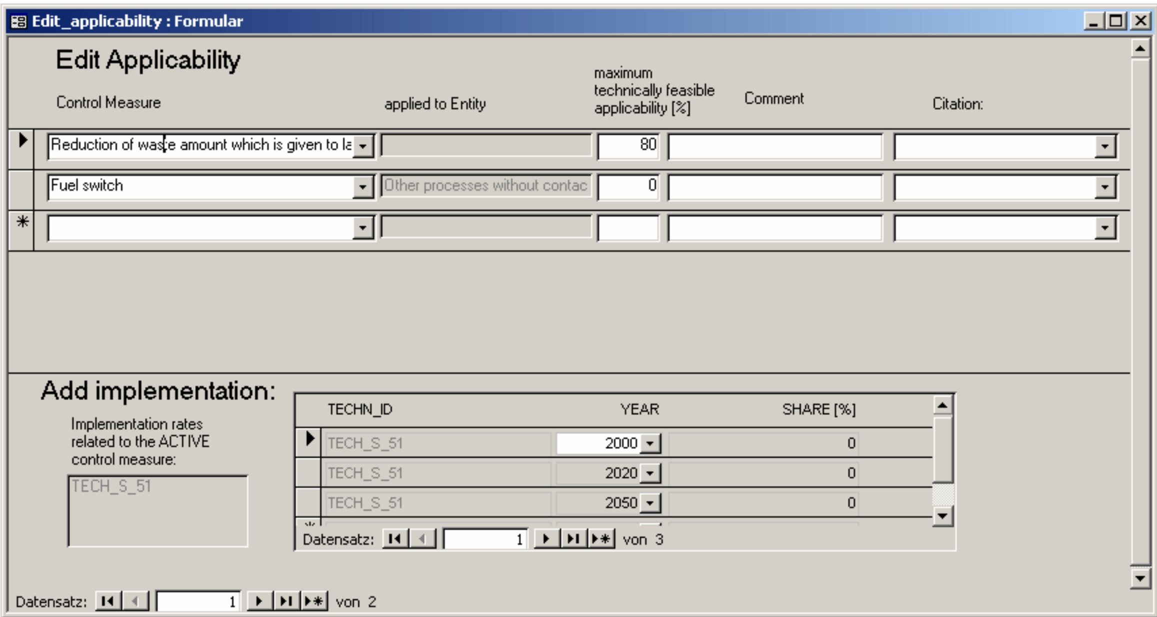

Figure 46: Example for data forms

Not only the input, but also the output is governed by a user interface. Accessible from the main menu an additional “calculation sheet” menu is accessible (Figure 47). The queries providing respective evaluation are called directly from this menu.

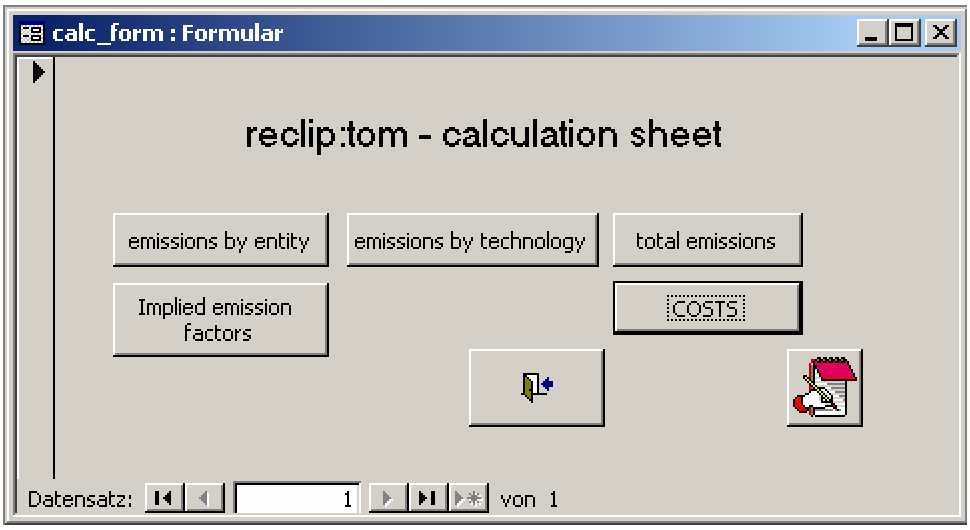

Figure 47: Calculation sheet menu

Results are available in all years for which activity data are presented and which are elements of the table “YEAR”. The simpler queries (emissions by entity; total emissions) provide direct access to results for all years. Only the very detailed queries (Implied emission factors; emissions by technology) request a year to be specified, for which then results are presented.

An option to calculate the costs of measures has been added as the final step (current version is 1.3) and have not been available previously. Obviously, additional costs in the base year are zero (as no additional measures can be defined in any scenario). Costs are thus presented, in the current setup, for the target year 2020 as well as the projection to 2050.

Scenarios, i.e. changes in the options beyond a mere variation of the activity path, may be defined by adjusting the appropriate extent of implementation in the table “CONTROL”. In practice it has been useful to define (outside of the menu structure) additional tables CONTROL_bau (business as usual, no measures taken beyond energy efficiency improvements that are considered autonomous development), CONTROL_default (default pathway, covers the most realistic pathway that includes significant emission reductions) and CONTROL_mfr (maximum feasible reduction, i.e. set all options to maximum). These tables allow the respective scenario information, the contents only need to be copied into the table CONTROL to allow specific results to be created. Scenarios affect any of the calculation algorithms offered.

7 Results

7.1 Year 2000 emissions

The setup of the entities was optimized to describe the respective activity changes and the options applied within the respective sectors. Thus the entities were not harmonized with guidelines normally used for emissions reporting. Still, for the purpose of effectively applying control measures on Austrian greenhouse gas emissions, it was essential to match the emission situation described by reclip:tom to that of the Austrian Umweltbundesamt (Umweltbundesamt, 2006a). Such a comparison should safeguard the appropriateness of measures to the respective source sectors, and their effect on a future emission situation.

As national emission data are available for historic periods only, and very few and unspecified information on emission projections can be obtained, a meaningful comparison can be made on the situation of the year 2000 only, among the three years that are currently implemented. Depending on a future exploitation, it may be useful to extend that comparison to 2005 and/or even 2010. This extension should be limited to an ex-post evaluation, i.e. after detailed historical data on the respective year have become available.

The comparison is presented in Table 56. It is obvious that the reclip:tom emissions, essentially, cover all important emission sources in Austria. In the case of CH_4 and N_2O, some sectors are missing, but CO_2 can be considered complete. Agreement by individual source sectors is within 20% when focusing on the larger sources which dominate the overall situation. In the case of metal industry, reclip:tom assigns all emissions to the “industrial processes” while the national inventory splits between process and fuel-related emissions. The inventory approach, in line with IPCC requirements, provides a very good fit to national statistics, while making it difficult to appropriately assign emissions to an individual company. The comparison proves that it is possible to reconcile the two approaches.

A larger discrepancy occurs for CO_2 in land use change, where the national inventory assesses considerably larger CO_2 uptake rates for the year 2000 already.

Despite of the attempts to provide complete coverage of sources, some minor sources had to be left out. This concerns, specifically, sources relevant for CH_4 and N_2O emissions. As a consequence, emissions of these gases in reclip:tom are lower than those of the national inventory. Sources not included are, i.a., fugitive emissions from fuel production (CH_4), product use (N_2O) or wastewater handling (both CH_4 and N_2O).

Assuming that these minor sources would not undergo a major emission shift in the future or that such a shift would hardly affect the overall results, and also assuming that any control is either inefficient or data will not become available, these sources may be lumped into a common, constant source category. We call this category “other” (available separately for CO_2, CH_4 and N_2O). Emissions not assignable elsewhere are added into this category. In practice, we use the difference between the national inventory total and the reclip:tom estimate for each gas to establish the category. Thus, using the category will yield exactly the same emissions in the reclip:tom estimate and the national total (see also Höglund-Isakssen et al., 2008, who apply the identical approach). This approach allows covering all emission sources, even if we do not explicitely mention them. Obviously, we will lack the possibility to apply measures upon such sources.

The fraction of total emissions which fall into the “other” category also indicates how comprehensive the approach is. If the fraction is small, then only minor emissions are missing and also trends or abatement measures will likely not strongly affect results. As shown in Table 56, together with all other results, there are negative “other” emissions associated with CO_2. This is a consequence of the different accounting for Land Use Change already mentioned. For CH_4, the category amounts to 10%, and for N_2O, the least important of the three gases, the relative difference is largest at 13%.

But specifying these emissions shows that indeed the differences can be traced separately to sources that behave like this “other” sector is expected to do: neither “product use” nor “waste treatment” is expected to change drastically, nor should we expect large mitigation potential. While it may be possible in the future to single out source sectors individually, we should not expect this to affect the results strongly.

In consequence, the comparison exercise proves that reclip:tom entities can be matched successfully to the base year emission inventories established by the Austrian Umweltbundesamt, which represent the Austrian position also with regard to international agreements.

Table 56: Comparing reclip:tom emissions and national (Umweltbundesamt, 2007) emissions for 2000

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Inventory 2000 Submission 2007 v1.2 AUSTRIA	Net CO_2 emissions/removals (Gg)	CH_4 (Gg)	N_2O (Gg)	CO_2	CH_4	N_2O
Total National Emissions and Removals		**49,605.05**	**362.14**	**20.19**	55,004.14	324.67	17.57
1. Energy		**58,000.73**	**41.25**	**2.62**			
A. Fuel Combustion	Reference Approach (2)	61,751.14					
	Sectoral Approach (2)	57,836.20	14.32	2.62			
1. Energy Industries		12,290.43	0.16	0.18	11,113.93	0.49	0.11
2. Manufacturing Industries and Construction		14,311.93	0.46	0.57	10,279.23	5.90	0.18
3. Transport		17,734.48	1.28	0.94	16,925.95	0.81	0.67
4. Other Sectors		13,454.41	12.42	0.93	13,098.16	13.27	0.46
5. Other		44.95	0.00	0.00			
B. Fugitive Emissions from Fuels		164.53	26.93	IE,NA			
1. Solid Fuels		IE,NA,NO	0.27	IE,NA			
2. Oil and Natural Gas		164.53	26.66	IE,NA			
2. Industrial Processes		**7,766.11**	**0.70**	**3.07**			
A. Mineral Products		2,958.13	IE,NA	IE,NA	3.,141.56	0.00	0.00
B. Chemical Industry		587.27	0.70	3.07	490.72	0.00	3.09
C. Metal Production		4,220.70	0.00	NA	9,730.80	0.00	0.00
3. Solvent and Other Product Use		**181.02**		**0.75**			
4. Agriculture			**206.62**	**12.88**			
A. Enteric Fermentation			161.87			151.72	
B. Manure Management			44.23	2.98		42.96	2.97
C. Rice Cultivation			NO				
D. Agricultural Soils(4)			0.45	9.90			10.08
E. Prescribed Burning of Savannas			NO	NO			
F. Field Burning of Agricultural Residues			0.06	0.00			
G. Other			NA	NA			

5. Land Use, Land-Use Change and Forestry	(5)	**-16,355.08**	**0.00**	**0.04**			
A. Forest Land	(5)	-17,028.48	0.00	0.00	-12,355.20	0.00	0.00
B. Cropland	(5)	-187.46	NA,NO	0.04	764.40	0.00	0.00
C. Grassland	(5)	384.84	NO	NO	521.93	0.00	0.00
D. Wetlands	(5)	208.24	NO	NO			
E. Settlements	(5)	156.79	NA,NO	NA,NO			
F. Other Land	(5)	110.99	NA,NO	NA,NO			
G. Other	(5)	NE	NA	NA			
6. Waste		**12.26**	**113.58**	**0.83**			
A. Solid Waste Disposal on Land	(6)	NA,NO	109.68			109.52	
B. Waste-water Handling			2.68	0.66			
C. Waste Incineration	(6)	12.26	0.00	0.00			
D. Other		NA	1.22	0.18			
7. Other ***(please specify)***[7]		**NA**	**NA**	**NA**			
International Bunkers		**1,674.93**	**0.03**	**0.06**			
Aviation		1,674.93	0.03	0.06	1,292.67	0.00	0.00
Total		51,279.97	362.17	20.25			
				Other emissions	-3,811.95	36.29	2.65
					-7%	10%	13%

7.2 Austrian GHG emissions in the “default” scenario (2020 and 2050)

The “default” scenario starts with the status-quo of the year 2000. For this year and subsequent years, activities for the respective entities have been derived as a part of the respective sectoral contributions in reclip:tom. Moreover, the expected activity changes for 2020 and 2050 have been derived. Activity rates in reclip:tom are considered external information, which is determined from outside sources.

Scenarios in reclip:tom describe sets of technology change aimed to influence emission patterns. As shown in section 1.3, such a change may influence either the emission factor (rate of release per activity unit) or more directly the effective activity itself, both related to the sector the change is applied to, and to other sectors. While activity rates are external, it is still possible to influence the “effective” activity rates, e.g. measures on increasing the energy efficiency will effect the real energy consumption and thus the associated emissions.

It is important to understand this concept to differentiate between externalities and the extent of technology change to be introduced, especially in the context of efficiency improvements. Both in the agricultural and in the energy sector, such efficiency improvements are already expected as autonomous development, i.e. technological improvement driven by market advantage will to some extent allow for an emission reduction.

Moreover, in the default scenario, a set of measures is included as described in the respective sections of this report. No claim on a full coverage of all possible or even only all realistic measures is made, and by definition measures are limited to the “technological” options. A realistic estimate for the respective implementation rates in 2020 and 2050 completes the set of information required for the emission projections.

Figure 48 presents the projections derived in reclip:tom by sector. A strong overall decrease in emissions between 2000 and 2050 becomes evident, with 2050 emissions only 56% of those in 2000. Reductions are clearly carried by the energy sector, the decrease of the total emissions being almost parallel to the energy-related emissions. This reflects mostly the multitude of options that allow for energy savings. A slight decrease in agricultural emissions also becomes evident, due to increased milk yields (at a constant rate of milk production, the number of methane-generating cows will go down) and improved efficiency of nitrogen application on fields. This scenario does not consider a strong shift into biofuel production (which in turn could increase fertilizer consumption and N_2O release).

At the same time, the industrial emissions are expected to increase. Especially, an increase of steel production still is part of the concept of the Austrian steel industry. While, at this time, also other scenarios seem possible, for us the activity number will remain an external factor. Emission reductions per unit of steel produced are possible, but significant improvements can only be achieved using iron scrap as input (e.g. electric arc process) due to stoichiometric limitations: the chemical transformation as such requires the release of CO_2. Likewise, potential for reductions in other sectors is limited to a material shift only, e.g. in the construction industry, replacing cement by wood. Limitations in applicability had to be considered as well, resulting in an overall emission increase in industry.

This increase is matched by the increase in carbon sequestration by soils. As a consequence of increased afforestation, the amount of CO_2 fixed by trees and in soil is still expected to increase significantly. Carbon sequestration is considered “negative emission” and its increase compensates the industrial increase.

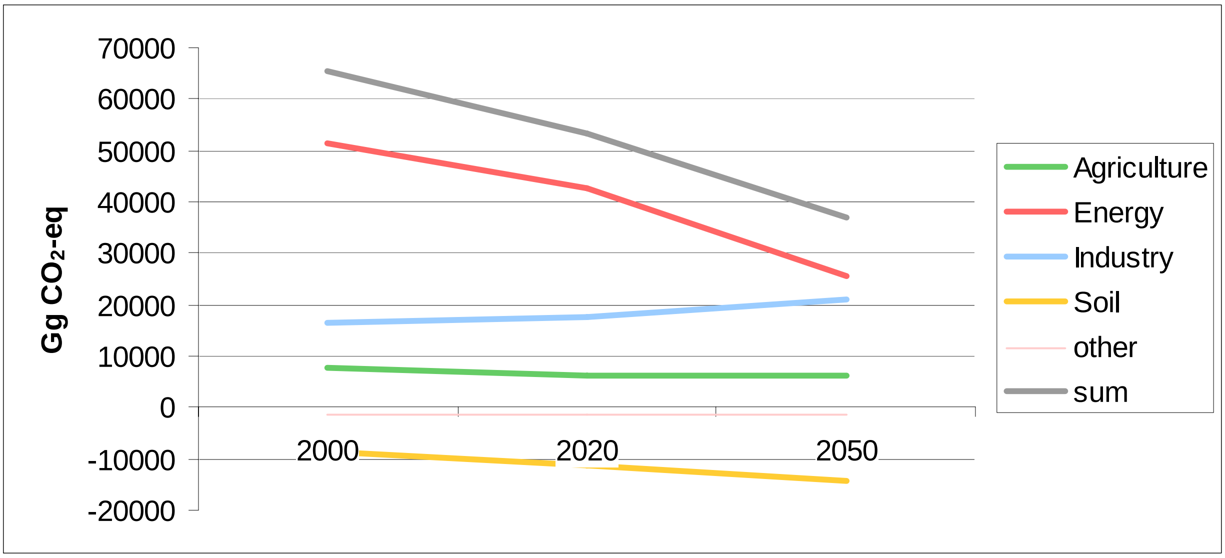

Figure 48: emission trends in the "default" scenario

7.3 Emission abatement and abatement costs (cost curves) for 2020 and 2050

In addition to the default scenario, two other scenarios have been investigated. One is a business-as-usual scenario, comprising no emission technology changes beyond autonomous development, and the other is a "maximum feasible reduction" scenario, maximizing the application of each measure towards its full potential. Figure 49 presents the resulting emissions in 2000, 2020 and 2050.

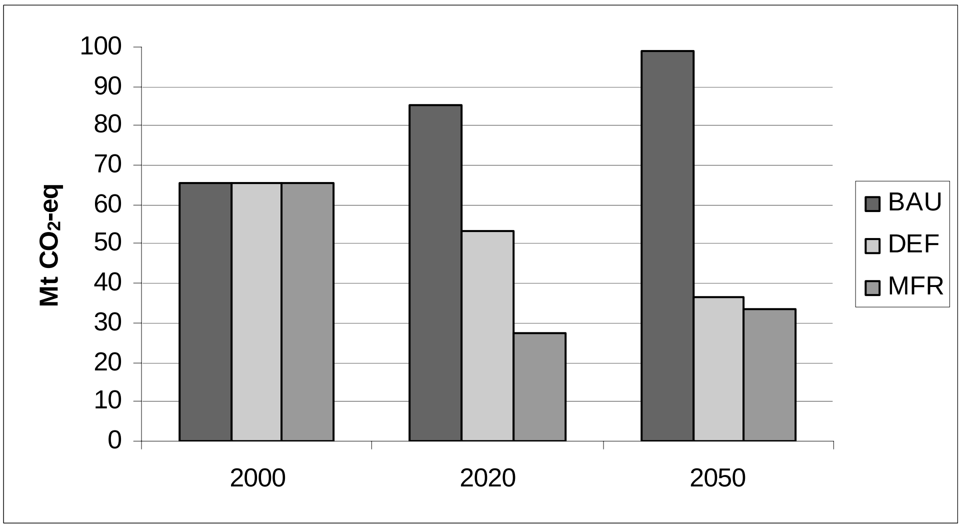

Figure 49: emission trends in the "default" scenario
(BAU … business as usual; DEF … default; MFR … maximum feasible reduction)

The comparison makes clear that the “default” scenario already covers significant emission reductions compared to “business-as-usual”. While in the default scenario emissions in 2050 will be reduced by a third compared to 2000, emissions will be less than half with respect to “business as usual” in 2050. This means that a considerable extension in activity is expected, which is compensated and its emissions largely abated by the measures considered. The maximum feasible reduction scenario shows impact for 2020, but not for 2050. The reason is that measures included for these scenarios are optimized for 2050. This means they are considered to be mostly in place in 2050 and only partly in 2020. What MFR does is to take the maximum as early as 2020 – it does not consider taking additional measures. As activities increase between 2020 and 2050, also MFR emissions will increase, as there are no more measures considered in the set currently used for reclip:tom.

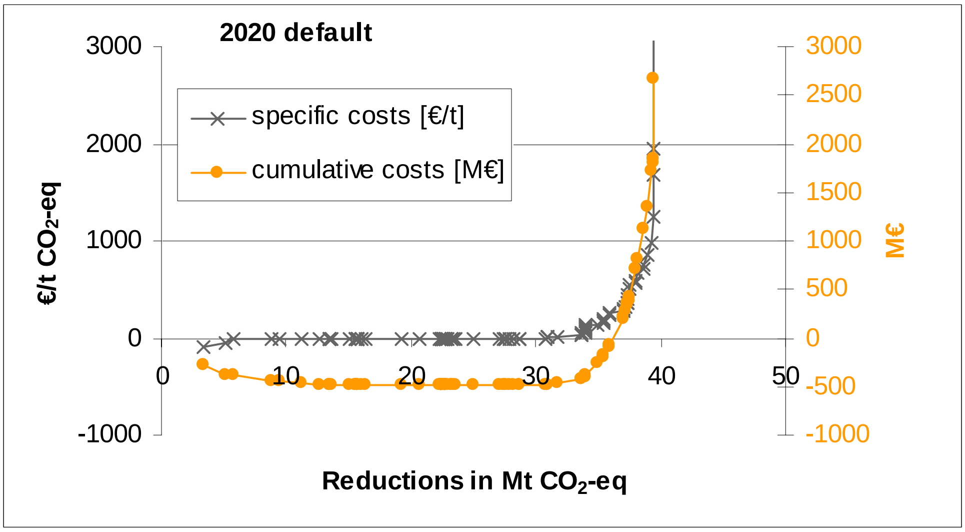

Figure 50: Cost curve for 2020 (default scenario)

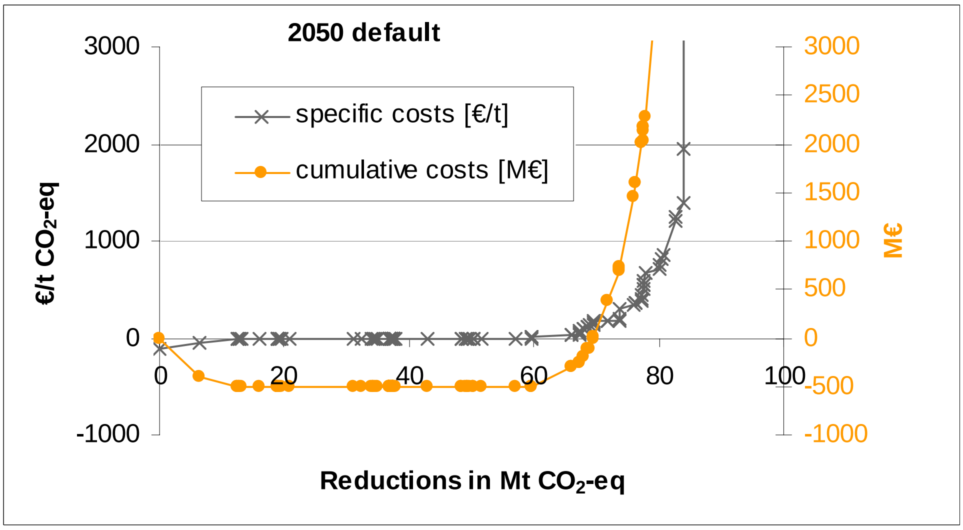

Figure 51: Cost curve for 2050 (default scenario)

The model also allows for an evaluation regarding the costs of measures taken. Typically, such costs are evaluated against emission reductions in so-called cost curves, assuming that the first options implemented are the cheapest options. In contrast to economic theory we assume here that options exist that have “negative costs”, i.e. cost savings will occur when those options are taken. As overall costs here regard to a national economy, it may well be that a negative cost option consists of an investment to be taken by another player than the one harvesting the benefits – thus the benefit remains invisible to the prospective investor, and investment will not be taken. A typical example is that of a landlord, who might not be willing to invest into energy efficiency measures when the saved energy costs would benefit his tenant only.

Results shown for 2020 (Figure 50) and 2050 (Figure 51) show exactly such a behaviour. The specific costs of individual measures (in € per ton CO_2-eq abated) are presented as the black lines. In both the 2020 as well as the 2050 case a handful of options exists which allows considerable emission reductions at negative costs already. These negative cost options are followed by a significant number of zero cost or low cost options, until only at the very end of the cost curves the most expensive options pop up, quickly bringing costs beyond 100€/ton CO_2-eq. At this point it should be noted, that even 100€/ton CO_2 equate about an additional 25 cents per l diesel oil, a quantity within recent market fluctuations. The cost curves are presented only for the measures applied in the “default” scenario, as (due to the lack in completeness of measures) the MFR scenario is far from “maximum feasible” anyway.

The fact that many options are very cheap also affects the overall costs of the measures (shown in orange, the line representing the cumulative costs of all measures up to that point in reductions). Significant emission reductions in the order of two third of the total achieved in the default scenario are available for free, when balancing savings against costs of the cheaper options. Only the very final measures on the cost curve will drive also cumulative costs.

It should be noted that the overall reduction potential presented (maximum value in reductions) is somewhat larger than the difference between BAU and DEF scenarios. This is as the autonomous development reductions are also part of the cost curve, adding to a potential but being considered already in the BAU scenario.

The respective measures leading to these costs can also be analyzed in detail (Table 57), again showing specific costs for each measure, the cumulative reduction in Mt and the cumulative costs. In the energy sector, both household and industry offer considerable savings, the larger part of which occurs in households: measures like heat insulation provide considerable energy savings which both reduce costs and CO_2 emissions.

A large number of measures are considered not to inflict additional costs, while at the same time reducing greenhouse gas emissions. Such measures can be seen in all sectors, and more than 80% of the overall savings consists of cost-free or cost saving options. Note that a number of options appear more than once in the table; these have been applied with the same name to different entities, and thus may be available at different costs.

Applying the “low-cost” range of measures, again from all sectors, brings the cumulative costs back to zero into actual costs instead of savings, but at that point more than 80% of the total reduction potential has been acquired. Further savings, under measures presented here, quickly become very expensive and may be difficult to achieve economically. But at this point most of the reductions have already been harvested, such that the overall annual costs will still remain only a tiny fraction of the annual GDP (less than 1% of the GDP of the year 2000 for all but the final measure on the cost curve).

Table 57: Abatement measures ranked by costs (2020)

TECHNOLOGY	specific costs [€/t]	cumulative reduction [Mt]	cumulative costs [M€]
Households: simple efficiency measures [main]	-87	3.30	-286
Households: extended efficiency measures [stage 1]	-49	5.17	-378
Increased electricity efficiency: extended [stage 1]	-16	5.76	-388
Increased electricity efficiency: extended [stage 2]	-15	8.83	-434
Increased electricity efficiency: extended [stage 3]	-14	9.42	-443
Households: extended efficiency measures [stage 2]	-13	11.30	-466
Increased electricity efficiency: extended [stage 4]	-12	12.71	-483
Road, freight transport: efficiency increase	0	13.48	-483
Railways, freight: efficiency increase	0	13.50	-483
Railways and other electrical, passengers: efficiency increase	0	13.51	-483
Busses: efficiency increase	0	13.63	-483
Individual passenger transport: efficiency increase	0	15.04	-483
Heat&electricity prod., fossil: efficiency increase	0	15.47	-483
Heat&electricity prod., renewables: efficiency increase	0	15.61	-483
Reduce mineral fertiliser input	0	15.63	-483
Match N input in the diet to the pig's requirements => phase feeding	0	15.63	-483
Match N input in the diet to the pig's requirements => phase feeding	0	15.63	-483
Match N input in the diet to the pig's requirements => phase feeding	0	15.63	-483
Increase milk yield per cow	0	15.68	-483
Reduction of emissions due to pre-treatment (mechanical biological waste treatment, MBA)	0	15.93	-483
Produced CH_4 is converted to CO_2	0	16.34	-483
Increase electricity production from renewables and additional CHP (2020: 50%, 2050:70%) [main]	0	19.28	-483
Households: fuel switch to gas [main]	0	20.72	-483
Commercial & public services: efficiency increase	0	23.26	-483
Industry: efficiency increase	0	23.38	-483
Agriculture: efficiency increase	0	23.55	-483
Multiple dwellings: efficiency increase	0	23.19	-483
Single dwellings: efficiency increase	0	22.26	-483
Separation of solids	0	22.37	-483
Solid system instead of liquid system	0	22.37	-483
Solid system instead of liquid system	0	22.37	-483
Solid system instead of liquid system	0	22.37	-483

TECHNOLOGY	specific costs [€/t]	cumulative reduction [Mt]	cumulative costs [M€]
Solid system instead of liquid system	0	22.37	-483
Solid system instead of liquid system	0	22.37	-483
Match N input in the diet to the pig's requirements => phase feeding	0	22.37	-483
Solid system instead of liquid system	0	22.38	-483
Change animal diet	0	22.38	-483
Change animal diet	0	22.38	-483
Change animal diet	0	22.38	-483
Increase milk yield per cow	0	22.73	-483
Increase milk yield per cow	0	22.73	-483
Separation of solids	0	22.81	-483
Separation of solids	0	22.82	-483
Separation of solids	0	22.83	-483
Separation of solids	0	22.84	-483
Separation of solids	0	22.85	-483
Biogas production	0	22.97	-483
Solid system instead of liquid system	0	22.97	-483
Biogas production	0	23.06	-483
Biogas production	0	23.07	-483
Biogas production	0	23.08	-483
Biogas production	0	23.09	-483
Biogas production	0	23.11	-483
Use of waste derived fuels; The use of waste as replacement for fossil fuels	0	23.18	-483
Change in transport mode [stage 1]	0	25.30	-483
Change in transport mode [stage 2]	0	27.42	-483
Agricultural land abandoned	0	27.73	-483
Housing: wood construction instead of concrete	0	27.78	-483
Optimisation of heat recovery of clinker cooler;	0	27.79	-483
Reduction of waste amount which is stored to land-fills by incineration	0	28.09	-483
N_2O SCR Technology (nitric acid)	0	28.51	-483
Reduce clinker content of cement;	0	28.94	-483
Reduction of ploughed untilled land	0	28.98	-483
Transport: simple efficiency measures [main]	0	31.13	-483
Biogas production	5	31.20	-483
Separation of solids	10	31.24	-483
Arable land areas changes to forest areas	18	31.33	-481

TECHNOLOGY	specific costs [€/t]	cumulative reduction [Mt]	cumulative costs [M€]
Extensivation of grassland from intensive production	19	32.04	-468
Households: extended efficiency measures [stage 3]	24	33.92	-423
Heat recovery from sinter cooler air	35	33.92	-422
Improved process control in mini mills	46	33.93	-422
Arable land areas changes to new grassland int areas	57	34.24	-404
Alpine areas change to forest land by natural "rejuvenation"	70	34.28	-401
Oxygen and fuel injection in the electric arc furnaces: post combustion, foamy slag practice,	89	34.29	-401
Recovery from energy in process gases from the blast furnace and the basic oxygen furnace	120	34.30	-399
Injection of pulverised coal and plastics waste in blast furnaces	131	34.36	-391
Transport: fuel switch to biogenics [stage 1]	137	35.33	-258
Transport: extended efficiency measures [stage 1]	146	35.71	-203
Electricity savings: roller mills instead of ball mills; high-pressure mills; high-efficiency classifiers; high-efficiency motors;	165	35.72	-202
Heat recovery in thermo-mechanical pulping	175	35.72	-201
Miscellaneous measures-Low cost range	191	35.81	-185
Extensivation of arable production	236	36.18	-97
Extensive grassland changes to forest land by natural "rejuvenation"	251	36.30	-67
Transport: fuel switch to biogenics [stage 2]	275	37.27	200
Miscellaneous measures-Low cost range: better dimensioning refiners, more efficient steam distribution, Energy Management, Optimisation of process control, Use less steam in stock preparation	299	37.30	210
Transport: extended efficiency measures [stage 2]	311	37.53	280
Industry: replace Oil by Gas, increase Biomass and introduce Solarthermal [main]	360	37.71	347
Refiner improvements in mechanical pulping	369	37.71	347
Application of continuous casting	408	37.72	351
Application of multi-stage preheaters and precalciners;	450	37.73	352
Pressing to higher consistency, e.g. by extended nip press (paper making);	511	37.77	375
Miscellaneous measures-High cost tranche: Energy efficient motor drives, Direct drive motors, Waste heat recovery, Matching componentss pumping system	556	37.84	413
Transport: extended efficiency measures [stage 3]	562	38.37	710
Improving wet process kilns; Replacement of wet kilns by dry kilns	586	38.37	713

TECHNOLOGY	specific costs [€/t]	cumulative reduction [Mt]	cumulative costs [M€]
Miscellaneous measures-High cost range	670	38.52	811
Transport: fuel switch to gas [main]	712	38.96	1123
Reduced air requirements, e.g. by huminity control in paper machine drying hoods;	758	38.97	1132
Thin slab casting	853	39.22	1349
Transport: extended efficiency measures [stage 4]	973	39.60	1716
Efficient recovery of low- temperature heat: coke dry quenching, recuperative burners,	1241	39.67	1797
Extensive grassland changes to forest land by refor-estation	1675	39.70	1848
Super pressurised ground wood (mechanical pulp)	1947	39.70	1853
Improved pressing techniques, e.g. condensing belt drying	15202	39.75	2676

Above we have focussed on the costs of abatement measures; another important consideration refers to their potentials. The reduction in greenhouse gas emissions achievable by a specific measure indicates beyond the costs alone, how much it needs to be considered. In order to achieve the reductions as indicated, those measures that contribute most to the overall potential definitely have priority.

Table 58 ranks the same mitigation measures already discussed above by their potential, here for the year 2050. It becomes obvious that clearly the most and most important options are in the energy sector. The most important bundle of options covers the efficiency increases in household energy (both space heating and hot water). Here also cost advantages are to be harvested. A further increase in hydroelectric power generation (here lumped with electricity production in combined heat and power plants) also shows very considerable potential. Industrial efficiency increases (improved electrical motors) also are on top of the list. The measures also cover infrastructural changes, as increasing settlement density will affect both space heating and transport mode change towards public transport. CO_2 sequestration by soils also provides substantial potential, through extensification of agriculture (albeit at considerable costs). Further reductions in agriculture are possible by increasing milk yields to 10000 kg per head and year, which will reduce the number of animals and likewise emissions of methane and nitrous oxide. In industry, largest potential is shown in further reducing the clinker content of cement – an option for which the replacing additive still has to be identified, as iron ore slag, a very useful additive, is already now completely in use for this purpose.

This list makes also clear that there are options that are cheap and have high potentials, which can be taken without regret. But for several other options, despite of showing no economic barrier, conflicting interests exist that need to be resolved before measures can be implemented. Hydroelectricity potential already now has been used quite extensively; free-flowing river stretches may be limited to sensitive areas of some kind. Increasing density of living means moving away from the current trend of sinle houses to multi-apartment houses to an extent of population density which also would allow efficient public transport to be provided. Any intervention into agriculture will strongly affect productivity and may also touch on animal welfare issues, potentially supporting large agricultural facilities at the expense of the small-scale single farmer enterprise.

Such trade-offs clearly need to be tackled or even accepted, if overall emission decrease is to be really achieved. These conflicts will be a much larger barrier to implementing measures than the costs ever can be, as our analyses shows costs to remain in an acceptable range.

Table 58: Abatement measures ranked by potential (2050); table cuts less important options

TECHNOLOGY	specific costs [€/t]	CO2-eq reduction [Mt]
Increase electricity production from renewables and additional CHP (2020: 50%, 2050:70%) [main]	0	10.50
Households: extended efficiency measures [stage 1]	-62	6.25
Households: extended efficiency measures [stage 2]	-16	6.25
Households: extended efficiency measures [stage 3]	30	6.25
Increased electricity efficiency: extended [stage 2]	0	5.69
Change in transport mode [stage 1]	0	5.33
Change in transport mode [stage 2]	0	5.33
Commercial & public services: efficiency increase	0	3.10
Individual passenger transport: efficiency increase	0	2.69
Increased electricity efficiency: extended [stage 4]	0	2.59
Transport: extended efficiency measures [stage 3]	701	2.41
Transport: fuel switch to biogenics [stage 1]	166	2.21
Transport: fuel switch to biogenics [stage 2]	333	2.21
Single dwellings: efficiency increase	0	1.83
Transport: extended efficiency measures [stage 1]	182	1.72
Transport: extended efficiency measures [stage 4]	1216	1.72
Road, freight transport: efficiency increase	0	1.49
Extensivation of grassland from intensive production	40	1.28
Households: fuel switch to gas [main]	0	1.17
Transport: fuel switch to gas [main]	1387	1.15
Increased electricity efficiency: extended [stage 1]	0	1.03
Increased electricity efficiency: extended [stage 3]	0	1.03
Transport: extended efficiency measures [stage 2]	389	1.03
Arable land areas changes to new grassland int areas	137	0.77
Arable land areas changes to forest areas	84	0.74
Increase milk yield per cow	0	0.71
Reduce clinker content of cement;	0	0.70
Extensivation of arable production	112	0.65
List not complete		

7.4 Discussion and limitations of results

Very different approaches have been taken for individual economic sectors to determine greenhouse gas emissions and to assess their abatement. Harmonizing these approaches is difficult, but the effort taken in this study shows that it is possible. Abatement options can be introduced, their costs adapted, and interferences to the use of resources (activity) of a specific entity or any other entity may be expressed in a consistent manner.

A comparison of the greenhouse gas emissions for the year 2000 presented in reclip:tom on the level of individual entities with those of the official Austrian estimate by Umweltbundesamt shows good agreement. In general, entities can be successfully allocated to specific sectors.

There are two instances which require further explanation: Sequestering CO_2 by soils is considered to be much higher in the national inventory. This is an issue that clearly requires more investigation, but also clearly can be singled out. Furthermore, some smaller source sectors relevant for CH_4 or N_2O emissions have not been covered by the entities defined. This refers to fugitive emissions from fuel production, to sewage treatment, or to direct product use. Lumping these activities into an “other” entity provides a valid and consistent solution, as long as no specific abatement options need to be applied to these activities, and as long as no strong dynamics until 2050 need to be expected. In order to support these assumptions, we simply have to keep the “other” entity constant.

The reclip:tom database is able to collect all the input information from the individual sectors, its calculation algorithm can calculate emissions according to the activity trends and the scenarios of abatement measures introduced. Furthermore, also costs of these abatement measures can be assessed. The measures selected (not necessarily a complete set of all that might be possible) indicate that significant decrease of greenhouse gas emissions until 2050, using technological options for mitigation, is possible, which would cut emissions by a third from their 2000 level.

Looking at the costs of these mitigation measures, one may wish to differentiate between three categories: negative-cost options, which for economical reasons should be implemented anyway as cost-effective, energy efficient and saving greenhouse gas emissions compared to the status-quo. For these measures (primarily heat insulation of houses, but also energy savings and increased gas use in industry) first of all it is essential to identify the reasons why they do not occur autonomously. Resistance may derive from initial cost, initial effort, or lack of knowledge.

Next is a set of options which are either available at (assumed) no cost or require modest cost contributions. Such options are available in all sectors, and they comprise most (about 75%) of the total abatement potential. Also for these options, obstacles should be identified that would prevent their implementation, in case general policy changes like introduction of carbon trade change them into profitable.

Only the third set of options should be regarded as those actually adding costs of abatement to the economy. According to current understanding, measures taken beyond a certain point quickly may become very expensive. Still, half of the remaining potential for this group could be covered at costs similar to fluctuation of diesel prices observed over the year 2008.

Some of the options that offer large abatement potential are in conflict with other expectations for future objectives. It is likely that such conflicting interests, be it nature protection, animal protection or agricultural objectives will provide much larger barriers to implementing greenhouse gas abatement than costs alone will do. These barriers need to be resolved, however, in order to efficiently tackle climate change.

Obviously, more options are possible than those currently included in reclip:tom. It is well conceivable that further low cost options can be found, or that technology will become available in the future that provides such low cost options. Thus we consider the results presented here a cautious, conservative estimate of what actually can be achieved.

There exists need to reduce GHG emissions far beyond the point offered in the abatements suggested by reclip:tom. A target of the EU's council of ministers for the environment requests reductions of 60-80% by 2050, in order to arrive at a stabilization of greenhouse gas concentrations in the atmosphere. This is merely a response to IPCC demands. While further reductions to those expressed here are possible, it may become difficult to find reductions purely based on technological change.

The reclip:tom approach per se is not limited to technological options. It is open to all options that provide the necessary information – emission reductions, influences on activities of entities and across entities, and costs. While it will definitely be worthwhile to improve the data already available in the current set of abatement options, it may also be worthwhile starting a program providing reliable data on other options, including those describing behavioural changes. In all cases, an important challenge will be to define and redefine entities and abatement options in a way that prevents double counting and maintains consistency of the results.

8 Conclusions and Outlook

Information on the emissions of greenhouse gases in Austria has been structured in as way that allows consistent emission projections and consistent modelling of the application of abatement measures. The sources of greenhouse gases have been grouped into so-called entities, which comprise sources of similar characteristics. The most important similarity is in terms of possible (abatement) measures: Each entity can be influenced in its emission behaviour by one or more measures. Each measure can affect the entity it belongs to, but at the same time can influence other entities.

This concept of entities and measures has been used consistently throughout all sectors covered here by the individual expert groups (energy, agriculture, industry, soils). While the approach required to fully cover the whole range of emitting activities by entities, including exogenous information on projections, measures are only included to an extent that was readily available in the literature or in current studies of the expert groups involved. Great care was taken to include costs of measures and to cover interaction to other entities, specifically also to those in a different sector, if relevant. Nevertheless it was not the aim of this study to cover all potential measures.

The diversity of sectors contributing to greenhouse gas emissions and thus included in this project is also reflected by the difference in approaches (and structure) presented in the previous chapters. Harmonization of the information provided has proven a difficult task, facilitated here by a common data platform implemented in form of a database.

The most striking example of interaction between sectors was the competition for land. Land is used for agriculture and as a feedstock for animal husbandry, but also for biofuel production or for regrowth of forests. Any measure in terms of agricultural extensification may create conflicts with measures to foster biofuel or carbon sequestration in standing forests and soils. Important interactions are also seen with energy in general, as energy is both a cross-cutting issue of considerable importance for each sector, and a sector of its own.

In basic industry, where energy costs are a key element of total costs, considerable efforts to increase fuel efficiency have been taken. Energy demand as a key driver of CO_2 emissions can still be reduced, but many of the cheap and readily available options have already been considered in Austria (except for fuel switching which might still reduce CO_2 emissions). Also the level of interaction between different industry sectors is remarkable: Waste from one sector (specifically: iron ore slag) is already now used in a different sector (additive to clinker in cement industry). Thus an option to produce clinker-free cement substitute – and saving both fuel and process derived CO_2 from the combustion process – is not available any more.

A different situation occurs for private households and especially in office buildings, where energy costs seem small compared to overall maintenance costs. Considerable savings especially in terms of heating (cooling) energy are possible, when modern technology is taken advantage of. Costs wasted due to lack of insulation seem to be small to the investor – in other words, only strong increase in energy prices could make investments for energy savings profitable. On the other hand, this also means that there is considerable potential still available for energy savings for this entity, while other entities will hardly allow further energy savings under the boundary conditions of this project.

In the discussions with experts it has been remarkable to see that measures which point towards energy savings (or energy switch) are generally considered acceptable. Measures that address savings of other raw materials (fertilizer consumption, replacement of cement by wood as construction material) raise considerable objection. Industries producing such goods defend their right of production. This has not been seen with energy industry, which obviously finds it difficult to advertise wasting energy.

The results obtained so far may be seen as a good foundation for further work. A detailed analysis of the sectors, together with specification of additional measures, will provide new information needed to render the system presented operational.

9 References

Amon, B., Amon T., Boxberger, J., Wagner-Alt, C. (2001)
Emissions of NH_3, N_2O and CH_4 from dairy cows housed in a farmyard manure tying stall (housing, manure storage, manure spreading). Nutrient Cycling in Agro-Ecosystems 60: p. 103-113.

Amon, B., Hopfner-Sixt K., Amon, T. (2002)
Emission Inventory for the Agricultural Sector in Austria, Manure Management. Final Report. On behalf of Umweltbundesamt GmbH, Institut für Land-, Umwelt- und Energietechnik

Amon, B., Kryvoruchko, V., Moitzi, G., Amon, T., Zechmeister-Boltenstern, S. (2004)
Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle and pig slurry and influence of slurry treatment. In: AgEng2004, Engineering the Future, EurAgEng (Hrsg.), 12 - 16 September, Leuven, Belgium.

Amon, B., Kryvoruchko, V., Amon, T., Zechmeister-Boltenstern, S. (2006)
Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. Agriculture, Ecosystems & Environment, Special Issue "Mitigation of Greenhouse Gas Emissions from Livestock Production", 112, 2 - 3, 153-162.

Andritz AG (2002)
Drum Displacer® - the Ideal Washer for Pulp Production, Andritz Oy, Finland, 2002

Austropapier (2006)
Statistical data: www.austropapier.at > Service > Statistik > 5_Energie.pdf, (last access: 10.01.2007)

Bartenstein M., Windtner L. (2008)
Masterplan Wasserkraft. Press conference,5. 5. 2008.,VEÖ,
http://www.veoe.at/fileadmin/allgemein/Presse/050508_PA_Bartenstein_Windtner_Wasserkraft.doc
(last access: 15.5.2008)

Beckmann (2007)
Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland, Study by „BDI initiativ – Wirtschaft für Klimaschutz", www.wirtschaftfuerklimaschutz.de

Beese, F. (1994)
Gasförmige Stickstoffverbindungen. Studienprogramm Landwirtschaft. Kapitel D; 1 – 94, Economica Verlag GmbH, Bonn

BFW (2006)
Forest Inventory data– „Waldinventuren" (86/90 – 92/96 – 00/02): http://bfw.ac.at/

Blaxter, K.L. and J.L. Clapperton (1965)
Prediction of the amount of methane produced by ruminants. British Journal of Nutrition, 19: 511-522.

Blok, K., de Jager, D. and Hendriks, C. (2001)
Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change – Summary Report for Policy Makers, ECOFYS Energy and Environment – Netherlands, AEA Technology Environment - United Kingdom, National Technical University of Athens – Greece, Utrecht, 2001

BMLFUW (2006)
Grüne Berichte. http://www.gruener-bericht.at/

Boxberger, J., und Amon, T. (1998)
Verfahren zur Flüssigmistbehandlung, Teil V, in Kooperation mit dem LTV-Arbeitskreis Flüssigmistverwertung).

Bronson, K.F. and Mosier, A.R. (1993)
Nitrous oxide emissions and methane consumption in wheat and corn-cropped systems in northeastern Colorado. Agricultural ecosystem effects on trace gases and global climate change. ASA Special Publication Nr. 55. 133-144, Wisconsin.

Brumme, R. and Beese, F. (1992)
Effects of nitrogen fertilization and liming on emissions of CO2 and N2O from a temperate forest. Journal of Geophysical Research, Volume 97, 12851-12858.

Casada, M.E. and Safley, L.M. (1990)
Global methane emissions from livestock and poultry manure. Biological and Agricultural Engineering Departement. North Carolina State University

Clemens, J., Trimborn, M., Weiland, P., Amon, B. (2006)
Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry. Agriculture, Ecosystems & Environment, Special Issue "Mitigation of Greenhouse Gas Emissions from Livestock Production", 112, 2-3, 171-177.

Capros, P. (2006)
EUSUSTEL 2006 New PRIMES Baseline Scenario. Available at www.eusustel.be

Cremer, C., Kleemann, M. et al. (2001)
Systematisierung der Potenziale und Optionen. Final report to the Enquête-commission „Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und der Liberalisierung", Karlsruhe/Jülich: Fraunhofer ISI, research centre Jülich, 2001.

de Beer, J., Phylipsen, D. and Bates, J. (2001)
Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Economic Evaluation of Carbon Dioxide and Nitrous Oxide Emission Reduction in Industry in the EU. Bottom-up Analysis, Final Report. Contribution to a Study for DG Environment, European Commission by Ecofys Energy and Environment, AEA Technology Environment and National Technical University of Athens, Brussels, 2001,
http://europa.eu.int/comm/environment/enveco/climate_change/sectoral_objectives.htm

DLG-Futterwerttabellen (1991)
DLG Futterwerttabellen für Wiederkäuer. 6. Auflage, Frankfurt am Main.

Döhler et al. (2002)
Anpassung der deutschen Methodik zur rechnerischen Emissionsermittlung an internationale Richtlinien und Prognose der Ammoniak-Emissionen der deutschen Landwirtschaft und Szenarien zu deren Minderung bis zum Jahre 2010. Final Report.

Duxbury, J.M. (1994)
The significance of agricultural sources of greenhouse gases. Fertil. Res. 38, 151 – 163.

EEA (2006)
How much bioenergy can Europe produce without harming the environment?, EEA Report 7/2006, ISBN: 92-9167-849-X.

Energieversorgung Österreichs – Jahresheft 1996
Österreichisches Statistisches Zentralamt, Wien.

Enquete-Kommission (1994)
Enquete-Kommission „Schutz der Erdatmosphäre" des Deutschen Bundestages: Schutz der grünen Erde. Klimaschutz durch umweltgerechte Landwirtschaft und Erhalt der Wälder. Economica Verlag GmbH, Bonn.

European Commission (2000)
The environmental impact of dairy production in the EU: Practical options for the improvement of the environmental impact. Final report for the European Commission prepared by CEAS Consultants Ltd, Centre for European Agricultural Studies, and the European Forum on Nature Conservation and Pastoralism.
http://europa.eu.int/comm/environment/agriculture/pdf/dairy.pdf

European Commission (2001a)
Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions on the Sixth Environment Action Programme of the European Community 'Environment 2010: Our future, Our choice' - The Sixth Environment Action Programme, Brussels (COM (2001) 31)

European Commission (2001b)
The Clean Air for Europe (CAFE) Programme: Towards a Thematic Strategy for Air Quality, Brussels (COM(2001) 245).

European Commission (2005)
Annex to: The Communication on Thematic Strategy on Air Pollution and The Directive on “Ambient Air Quality and Cleaner Air for Europe”, Brussels, SEC (2005) 1133.

E.V.A. (2005)
J. Brand, H. Pinter, M. Sattler, M. Schweighofer, O. Starzer (Projektleitung), H. Tretter, F. Unterpertinger

Chancen der Papierindustrie im Rahmen der Klimastrategie, Energieeffizienz und CO_2-Emissionen der österreichischen Papierindustrie – Entwicklungen und Potenziale, im Auftrag von Austropapier, herausgegeben von Energieverwertungsagentur – the Austrian Energy Agency E.V.A.), Wien, 2005

E.V.A. (2006)
Energiesparendes, umweltschonendes Dünnbandgießverfahren zur Flachstahlherstellung , EU- Musterprojekte JOULE, Nicht-Nukleare Energie Bereich rationelle Energienutzung in der Indstrie, Österreichische Energieagentur- Austrian Energy Agency, Wien, 2006

Ferguson K.H. (1998)
Weyenhaeuser modernizes Flint River with continuous digester overhaul, Journal: Pulp and Paper (Pulp pap.) ISSN 0033-4081, 1998, vol.72, n°6, pp.43-47 http://www.findarticles.com/p/articles/mi_qa3636/is_199806/ai_n8783809

Firestone, M.K. and Davidson, E.A. (1989)
Microbiological basis of NO and NO2 production and consumption in soil. Exchange of trace gases between terrestrial ecosystems and the atmosphere, 7-2,John Wiley and Sons, Dahlem Workshop Report, Chichester.

GAINS 2006
GAINS online: http://www.iiasa.ac.at/web-apps/apd/RainsWeb/

Gara, S. (1993)
Environmental Life- Cycle Assessment. Demonstration der LCA- Methodik anhand der Hochofen- und COREX-Route zur Stahlerzeugung, Vorstudie im Auftrag von VAI, Center for Impact Assessment, August 1993

Gebetsroither, E., Strebl, F., Schwaiger, H., Jäkel, U., Jungmeier, G., Canella L., Spitzer, J., Hintermeier, G., Windsperger, G., Schneider, F., (2001)
The Austrian Carbon Balance Model (ACBM), Final Project Report Annex, Seibersdorf Research Report OEFZS-S--0112, BV, 216 pp., Jan. 2001

Gebetsroither, E., Strebl, F., Orthofer, R. (2002)
CH_4 Emissions from Enteric Fermentation in Austria, ARC—S-175, ARC Seibersdorf research GmbH..

Gerzabek, M. H., F. Strebl, M. Tulipan and S. Schwarz (2003)
Quantification of carbon pools in agriculturally used soils of Austria by use of a soil information system as basis for the Austrian carbon balance model. OECD Expert Meeting: Soil Organic Carbon and Agriculture: Developing Indicators for Policy Analyses., C. A. S. Smith (ed., 14-18 October 2002, Ottawa, Canada, Agriculture and Agri-Food Canada, Ottawa, CA & Organisation of Economic Co-operation and Development, Paris, FR.

Götz (1998)
Stickstoffbilanz der österreichischen Landwirtschaft nach den Vorgaben der OECD. Aktualisierte und erweiterte Fassung. Umweltbundesamt, Wien.

Gruber & Steinwidder (1996)
Einfluss der Fütterung auf die Stickstoff- und Phosphorausscheidung landwirtschaftlicher Nutztiere - Modellkalkulationen auf Basis einer Literaturübersicht. In: Die Bodenkultur - Austrian Journal of Agricultural Research.

Grüner Bericht 2000 (2001)
Bericht über die Lage der österreichischen Landwirtschaft 2000. Bundesministerium für Land und Forstwirtschaft. Lebensministerium. www.gruenerbericht.at, Wien.

Grüner Bericht 2007 (2007)
Bericht über die Lage der österreichischen Landwirtschaft 2007. Bundesministerium für Land und Forstwirtschaft. Lebensministerium. www.gruenerbericht.at, Wien.

Haas R., Berger M., Kranzl L. (2001)
Strategien zur weiteren Forcierung erneuerbarer Energieträger in Österreich unter besonderer Berücksichtigung des EU Weißbuches für erneuerbare Energien und der Campaign for take-off, Institut f. elektr. Anlagen und Energiewirtschaft, TU Wien.

Haas R., Ajanovic A., Kloess M., Nakicenovic N., Könighofer K., Jungmeier P., Canella L., Prenninger P., Rechberger J. (2008)
Szenarien der (volks) wirtschaftlichen Machbarkeit alternativer Antriebssysteme und Kraftstoffe im Bereich des individuellen Verkehrs bis 2050, funded within the Austrian research program " Austrian Advanced Automotive Technology", Energy Economics Group, Vienna University of Technology, Vienna, Austria. (German language)

Hackl, A.und Mauschitz, G. (2003).
Emissionen aus Anlagen der österreichischen Zementindustrie IV,Jahresreihe 2000 - 2002, Zement + Beton Handels- und Werbeges.m.b.H, Wien, 2003

Haider, K. and Heinemeyer, O. (1990)
Distickstoffoxid (N_2O). Landbauforschung Völkenrode, 47-56.

Hauer, Ina. (1993)
Biogas-, Klärgas- und Deponiegasanlagen im Praxisbetrieb. Österreichisches Kuratorium für Landtechnik, Landtechnische Schriftenreihe 192, Wien.

Heinemann Z., (2004)
CO_2 Sinks in Oil/Gas Fields & Aquifers. Workshop: CO_2 Capture and Sequestration (CCS) in Future International R&D Programmes, 17 November 2004, Vienna, Austria.

Hellmann, Bettina. (1993)
N2O Emissionen aus unterschiedlich behandelnten Fichtenstandorten im Höglwald. Fraunhofer Institut für atmosphärische Umweltforschung; IFU-Schrifenreihe 19-93, Garmisch-Partenkirchen.

Hellmann, Bettina. (1995)
Freisetzung klimarelevanter Spurengase in Bereichen mit hoher Akkumulation von Biomassen. Abschlußbericht am GSF-Forschungszentrum für Umwelt und Gesundheit GmbH, Oberschleißheim.

Heyer, Jürgen. (1990)
Der Kreislauf des Methans. Mikrobiologie/Ökologie/Nutzung, Akademie-Verlag. Berlin.

Heyer, Jürgen. (1994)
Methan. Studienprogramm Landwirtschaft. Chapter C, 1- 91, Economica Verlag GmbH, Bonn.

Hiebler M., Gamsjäger H., God C. (as cited by Statistics Austria, 2008)
Vergleich von metallurgisch und thermisch bedingten CO_2 Emissionen. Montanuniversität Leoben.

Hofer, R. (1994)
Analyse der Potenziale industrieller Kraft-Wärme-Kopplung. IfE Schriftenreihe, Nr. 28, TU München, 1994.

Höglund-Isaksson, L., Mechler, R. (2005).
IIASA Interim Report IR-05-54: The GAINS Model for Greenhouse Gases – Version 1.0: Methane (CH_4). IIASA, Laxenburg, Austria

Höglund-Isaksson, L., Winiwarter, W., Tohka, A. (2008).
GAINS – Potentials and costs for mitigation of non-CO2 greenhouse gases in Annex 1 countries. Methodology. International Institute for Applied` Systems Analysis, Laxenburg, Austria.

Hutchinson, G.L. and Davidson, E.A. (1993)
Processes for production and consumption of gaseous nitrogen oxides in soil in Agricultural ecosystem effects on trace gases and global climate change; ASA Special Publication Number 55, (79-93), Wisconsin.

IEA (2006)
Energy technology perspectives 2006, Scenarios & Strategies to 2050. IEA (Hrsg.), Paris, France, 2006, ISBN: 92-64-10982-X.

IIASA (2006).
GAINS database – scenario NEC_NAT_CLEV4: http://www.iiasa.ac.at/rains/gains-online.html?sb=9 (last access: 21.11.2006)

IKARUS (2003)
Instrumente für Klimagasreduktionsstrategien. Datenbank Version 2.1. Karlsruhe/Jülich: Fraunhofer ISI, Forschungszentrum Jülich, 2003.

IPCC/OECD (1997)
Revised 1996 IPCC guidelines for national greenhouse gas inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm

IPCC (2001a)
Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC Good Practice Report). Edited by J. Penman, D. Kruger, I. Galbally, T. Hiraishi, B. Nyenzi, S. Emmanuel, L. Buendia, R. Hoppaus, T. Martinsen, J. Meijer, K. Miwa and K. Tanabe, IPCC national greenhouse gas inventories programme, Technical Support Unit, Hayama, Japan.

IPCC (2001b)
Climate Change 2001: Mitigation. Edited by Metz, B., Davidson, O., Swart, R., Pan, J., Cambridge University Press, Cambridge.

IPCC (2005)
IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

IPCC (2006)
2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds)., Published: IGES, Japan.

Jarvis, S.C., Pain, B.F. (1994)
Greenhouse gas emissions from intensive livestock systems: their estimation and technologies for reduction. Clim. Chang. 27, 27 – 38.

JRC (2007)
Well-to-Wheels analysis of future automotive fuels and powertrains in the European context. Joint Research Centre, Ispra, Italy, March 2007.

Jonas, M. and Nilsson, S. (2001)
The Austrian Carbon Database (ACDb) Study- Overview. Interim Report IR-01-064, IIASA, Dezember 2001

Kaiser, E.A., Eiland, F., Germon, J.C., Heinemeyer, O., Henault, C., Lind, A.M., Maag, M., Saguer, E. (1996).
What predicts nitrous oxide emissions and denitrification N-loss from European soils? Z. Pflanzenernähr. Bodenk. 159, 541 – 547.

Kirchgessner, M., Windisch, W., Müller, H.L., Kreuzer, M. (1991)
Release of methane and of carbon dioxide by dairy cattle. Agribiological Research. 91-102.

Kirchgessner, M., Roth, F. X., Windisch, W. (1993)
Verminderung der Stickstoff- und Methanausscheidung von Schwein und Rind durch die Fütterung, Übersichten zur Tierernährung, 89-120.

Kirchgessner, M. (2004)
Tierernährung, DLG VerlagsGmbH, Frankfurt am Main.

Kletzan-Slamanig D., Köppl A., Artner H., Karner A., Pfeffer T. (2008)
Energieeffiziente Gebäude, Potentiale und Effekte von emissionsreduzierenden Maßnahmen, Austrian Institute of Economic Research, Vienna.

Klimont, Z. and Brink, C. (2004).
Modelling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe. IR-04-048. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Knowles, R. (1993)
Methane: Process of production and consumption. Agricultural ecosystem effects on trace gases and global climate change, ASA Special Publication Nr. 55, 145-156, Madison, Wisconsin.

Kollmann (2009).
Regionalökonomische Effekte der Sanierung von Einfamilienhäuser - Analyse mit dem makroökonomischen Simulationsmodell MOVE, Proceedings of the 7. Internationale Energiewirtschaftstagung an der TU Wien, Februar 11-13. 2009

Konrad (1995).
Die Rinder-, Schweine- und Legehennenhaltung in Österreich aus ethologischer Sicht, WUV Universitätsverlag, Wien.

Kratena, K., Wüger, M. (2005).
Energieszenarien für Österreich bis 2020, Austrian Institute of Economic Research, Vienna.

Kranzl L., Haas R., Kalt G., Diesenreiter F., Eltrop L., König A., Makkonen P. (2008)
Strategies for reaching an optimal use of biomass potentials in Austria until 2050 with respect to GHG emission reduction, mid term report, final project report funded within the Austrian research program "Energy systems of tomorrow", Energy Economics Group, Vienna University of Technology, Vienna, Austria. (German language)

Kuikman, P.J., Velthof, G.L., Oenema, O. (2004).
Controlling nitrous oxide emissions from agriculture: experience from The Netherlands. In: D.J. Hatch, D.R. Chadwick, S.C. Jarvis, J.A. Roker (Eds.) Controlling nitrogen flows and losses, p. 333 – 4, Wageningen Academic Publishers, Wageningen, the Netherlands.

L-B-Systemtechnik (2006)
GM Well-to-wheel analysis of energy use and greenhouse gas emissios of advanced fuel/vehicle systems- a european study, 2002.
http://www.lbst.de/publications/studies__d/2002/TheReport_Euro-WTW_27092002.pdf

Mährenbach (2006)
Analyse des technischen Effizienzsteigerungspotentials österreichischer Kraftwerke, Master thesis at the FH Kapfenberg, department of infrastructure and urban technologies.

Mantzos L., Capros. P. (2006)
European Energy and Transport, Scenarios on energy efficiency and renewables. European Commission, Luxembourg, 2006. ISBN 92-79-02652-6

Moe, P.W. and H.F. Tyrell (1979)
Methane production in dairy cows. Journal of Dairy Science, 62: 1583-1586.

Müller, A., Haas, R., Kranzl, L. (2008)
Scenario assessment for the economic market potential of renewable energy technologies, final project report funded within the Austrian research program "Energy systems of tomorrow", Energy Economics Group, Vienna University of Technology, Vienna, Austria. (German language)

Müller, H.-U. (2002)
Strategien zur Verminderung von Gasemissionen aus der Milchviehhaltung in einer intensiven Grünlandregion. Dissertation an der Universität Hohenheim. Shaker Verlag, Aachen. ISBN: 978-3-8265-9734-3

Nowak S., Gutschner M., Toggweiler P., Rouss D. (2000)
Potential for building integrated Photovoltaics. activity 3.2 „BIPV potential“ within the frame of the IEA PVPS programme Task 7, Summary.

ÖSTAT (1997).
Energieversorgung Österreichs – Jahresheft 1996. Österreichisches Statistisches Zentralamt, Wien.

Papke-Rothkamp, Hannelore (1994)
Einfluss saurer Beregnung und kompensatorischer Kalkung auf die Emissionen gasförmiger Stickstoffverbindungen aus Böden eines Fichtenbestandes. Fraunhofer Institut für atmosphärische Umweltforschung. Nr. 25 – 94. Garmisch-Partenkirchen.

Pehnt M. (2001)
Bedeutung alternativer Antriebe und Kraftstoffe für den Ressourcen- und Klimaschutz. Energiewirtschaftliche Tagesfragen November 2001, S. 732-737.

Pöyry (2008)
Wasserkraftpotentialstudie Österreich, Final report. Study by Pöyry Energy GmbH for the Austrian association of electricity producers (VEÖ).

Ritter M. (1999).
Bestandsaufnahme der Emissionen an Treibhausgasen in Österreich von 1980 bis 1998. IB-618, Umweltbundesamt, Wien.

Scharf C. (2004)
CO_2 zurück in die Erde!. Energy, Issue 3, 2004, Wien, Austria. ISSN: 1026-339X

Schimel, J.P. and others. (1993)
Controls on methane flux from terrestrial ecosystems. Agricultural ecosystem effects on trace gases and global climate change, ASA Special Publication Nr. 55, 167-182, Madison, Wisconsin.

Schmid, Ch.; Layer, G.; Brakhage, A.; Radgen, P.; Arndt, U.; Carter, J.; Duschl, A.; Lilleike, J.; Nebelung, O. (2003)
Möglichkeiten, Potenziale, Hemmnisse und Instrumente zur Senkung des Energieverbrauchs branchenübergreifender Techniken in den Bereichen Industrie und Kleinverbrauch, Endbericht an das Umweltbundesamt, Karlsruhe/München: Fraunhofer-Institut für Systemtechnik und Innovationsforschung, Forschungsstelle für Energiewirtschaft, 2003. http://www.isi.fraunhofer.de/e/projekte/091s.htm

Schriefl, E., Haas R. (2006)
Assessment of the potentials for greenhouse gas emissions reductions and renewable energy technology application in the Austrian residential buildings sector with a special focus on policy issues. World Renewable Energy Congress 2006, Florence, Italy, 21st-25th August, 2006.

Schöpp, W., Amann, M., Cofala, J., Heyes, C. and Klimont, Z. (1999).
Integrated Assessment of European Air Pollution Emission Control Strategies. Environmental Modelling and Software 14(1), 1-9.

Sedmidubsky, Alice. (1992)
Die Umweltwirkung des Methans: Entstehung.- Auswirkungen - Lösungsstrategien, Universität für Bodenkultur, Wien

Simarmata, Tualar (1993)
Einfluss erhöhter Mineralisierungsaktivität (Grünlandumbruch, Stroh- oder Kompostdüngung) auf die Kinetik der Denitrifikationsverluste, das N_2/N_2O Verhältnis und die Zuverlässigkeit N_2O Reduktaseblockierung durch Acetylen in Böden. Justus-Liebig-Universität Giessen.

Sinabell, F., Schmid, E. (2005)
Austrian Agriculture 2005–2020: Consequences of Measures to Mitigate Greenhouse Gas Emission, WIFO, Austria.

Stanzel W., G. Jungmeier, J. Spitzer (1995)
Emissionsfaktoren und energietechnische Parameter für die Erstellung von Energie- und Emissionsbilanzen im Bereich Raumwärmeversorgung. Joanneum Research, IEF-B-02/95, Graz

Statistik Austria (2001)
Statistisches Jahrbuch 2001, Chapter 19, Animal Production, Vienna.

Statistik Austria (2007)
Bevölkerungsprognose 2007.
www.statistik.gv.at/web_de/statistiken/bevoelkrung/demographische_prognosen/bevoelkerungsprognosen

Steed, John and Hashimoto, Andrew G. (1995)
Methane emissions from typical manure management systems; Bioresource Technology. Volume 50.

Stigler (2005)
Energiewirtschaftliche und ökonomische Bewertung potenzieller Auswirkungen der Umsetzung der EU-Wasserrahmenrichtlinie auf die Wasserkraft.

Thomas S., Barthel C., Bunse M., Irrek W. (2006)
Optionen und Potenziale für Endenergieeffizienz und Energiedienstleistungen. Endbericht im Auftrag der E.ON AG, Wuppertal Institut für Klima, Umwelt Energie GmbH, Wuppertal.

TU München (2006)
Energetischer Vergleich verschiedener Arten der Drehzahlregelung. Vorlesungsunterlagen, 2006.

UITP (2004)
Die Rolle des ÖPNV bei der Reduzierung von Treibhausgas-Emissionen und der Verbesserung der Energieeffizienz. Belgium, 2004.
http://www.uitp.com/eupolicy/positions/2006/03/Climate_Change_DE.pdf.

Umweltbundesamt (2000)
Peter Weiss, Karl Schieler, Klemens Schadauer, Klaus Radunsky und Michael Englisch: Die Kohlenstoffbilanz des Österreichischen Waldes und Betrachtungen zum Kyoto-Protokoll. UBA Wien Monographien M106. Wien 2000NGEN ZUM KYOTO-PROTOKOLL

Umweltbundesamt (2001).
Sechster Umweltkontrollbericht. Umweltbundesamt (Hrsg.), Wien 2001

Umweltbundesamt (2002)
M. Gangl, A. Hrabal, G. Lichtblau, S. Poupa, K. Radunsky, M. Ritter, E. Waitz, P. Weiss, M. Wieser, A. Winkler: Austria’s National Inventory Report 2002. Submission under the United Nations Framework. Convention on Climate Change 2002. Umweltbundesamt (UBA), BE-206, 2002, Wien

Umweltbundesamt (2004)
Erfassung von Deponiegas - Statusbericht von Österreichischen Deponien. Christian Rolland Judith Oliva, UBA-Bericht BE-238, Wien 2004.

Umweltbundesamt (2005a).

Austria's annual national greenhouse gas inventory 1990 – 2003. Submission under Decision 280/2004/EC series. Umweltbundesamt GmbH (Ed.), UBA-Bericht 262, Wien.

Umweltbundesamt (2005b)
Austria’s National Inventory Report 2005 - Submission under the United Nations Framework Convention on Climate Change. Report BE-268, Vienna, 2005.

Umweltbundesamt (2006a)
Austria’s National Inventory Report 2006, Submission under the United Nations Framework Convention on Climate Change, Resubmission October 2006, Umweltbundesamt, REP-0016, Vienna 2006

Umweltbundesamt (2006b).
Evaluierungsbericht zur Klimastrategie 2002, Endbericht. UBA-REPORT: Rep-0021. Wien, 2006

Umweltbundesamt (2007)
Austria’s National Inventory Report 2007, Submission under the United Nations Framework, Convention on Climate Change, Umweltbundesamt, REP-0084, Vienna 2007

Umweltbundesamt (2009)
GHG Projections and Assessment of Policies and Measures in Austria, Reporting under Decision 280/2004/EC, Umweltbundesamt, REP-0227, Vienna 2009

UNFCCC (2006)
National Inventory Submissions 2006, Austria, Common Reporting Format (CRF): http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/3734.php (last access: 30.11.2006)

Vabitsch, A. (2006).
Qualitativer Vergleich von Modellen zur Bewertung von Klimaschutzmaßnahmen in Europa unter besonderer Berücksichtigung der Landwirtschaft. Dissertation, Universität Hohenheim.

VAI (2001a).
VAI Ironmaking technology: The Victory March of COREX®, VOEST-ALPINE Industrieanlagenbau GmbH &Co, Linz, 2001

VAI (2001b)
VAI Reduction Technology: Start-up of world's first combined COREX®-DR Plant. Saldanha Steel, Republic South Africa, VOEST-ALPINE Industrieanlagenbau, Linz, September 2001

VÖZ (2007).
www.voez.at, (last access: 17.02.2007)

Walla, C. und Scheeberger, W. (2007)
Die Bodenkultur, Austrian Journal of Agricultural Research, 57. Band/ Heft 1-4/ISSN 0006-5471.

WBCSD (2004)
Mobility 2030: Meeting the challenges to sustainability. WBCSD, England, 2004, ISBN: 2-940240-57-4.
http://www.wbcsd.org/web/mobilitypubs.htm

Weik, S. (2005).
Die Umweltauswirkungen der österreichischen Ernährung am Beispiel Treibhausgasemissionen, Analyse, ökonomische Auswirkungen und Optimierungspotentiale unterschiedlicher Ernährungsweisen und Produktionsverfahren. Master Thesis, Universität für Bodenkultur, Wien.

Wiesenberger H., A. Windsperger, Hrsg. (2004)
CO_2 Emissionen von Anlagen und Branchen als fachliche Grundlage für den Emissionshandel. Endbericht; im Auftrag von BMLFUW, WKÖ, VEÖ; durchgeführt von: UBA, IIÖ, Wien/ St. Pölten, 2004

Winiwarter, W. und Orthofer, R. (2000)
Unsicherheit der Emissionsinventur für Treibhausgase in Österreich, Seibersdorf Research Report, OEFZS--S-0072, Wien, 2000

Winiwarter, W., Amon, B., Fröhlich, M., Gebetsroither, E., Müller, A. and Nakicenovic, N. (2005)
Reclip:tom – Research for climate protection: technological options for mitigation, Annual Report 2005, Hrg.: ARC systems research, ARC-sys-0074, Wien, 2005

Winiwarter, W. (2005).
IIASA Interim Report IR-05-055: The GAINS Model for Greenhouse Gases – Version 1.0: Nitrous Oxide (N_2O)

Wopfinger Baustoffindustrie (2007).
www.slagstar.at, (last access: 19.02.2007)

Wulf, S., Maeting, M., Bergmann, S., Clemens, J. (2001).
Simultaneous measurement of NH_3, N_2O and CH_4 to assess efficiency of trace gas emission abatement after slurry application. Phyton (Austria), Special Issue: "Nitrogen emissions", 41(3), 131-142.

Wulf, S., Maeting, M., Clemens, J. (2002a).
Effect of application technique on the emission of trace gases (NH_3, CH_4, N_2O) after spreading co-fermented slurry on arable and grassland; Part I: Ammonia volatilization. J. Environ. Qual. 31, 1789-1794.

Wulf, S., Maeting, M., Clemens, J. (2002b).
Effect of application technique on the emission of trace gases (NH_3, N_2O, CH_4) after spreading co-fermented slurry on arable and grassland; Part II: Greenhouse gas emissions. J. Environ. Qual. 31, 1795-1

Impressum

AIT-F&PD-Report
ISSN 2075-5694

Herausgeber, Verleger, Redaktion, Hersteller:
AIT Austrian Institute of Technology GmbH
Foresight & Policy Development Department
1220 Wien, Donau-City-Straße 1
T: +43(0)50550-4500, F: +43 (0)50550-4599
f&pd@ait.ac.at, http://www.ait.ac.at/foresight_and_policy_development